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Soil Characterization and Soil Amendment Use on Coal Surface Mine Lands: An Annotated Bibliography

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ILLUSTRATION

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

at pct	atomic percent	gal	gallon
Btu	British thermal unit	gal $acre^{-1}$	gallon per acre
Btu $acre^{-1}$	British thermal unit per acre	h	hour
Btu $cord^{-1}$	British thermal unit per cord	ha	hectare
Btu ha^{-1}	British thermal unit per hectare	in	inch
Btu lb^{-1}	British thermal unit per pound	in h^{-1}	inch per hour
bu $acre^{-1}$	bushel per acre	in yr^{-1}	inch per year
°C	degree Celsius	K	kelvin
cm	centimeter	kg	kilogram
cm^3	cubic centimeter	kg ha^{-1}	kilogram per hectare
cm d^{-1}	centimeter per day	kg ha^{-1} yr^{-1}	kilogram per hectare per year
cm h^{-1}	centimeter per hour	kg m^{-3}	kilogram per cubic meter
cm yr^{-1}	centimeter per year	kg Mg^{-1}	kilogram per megagram
cmol kg^{-1}	centimole per kilogram	km	kilometer
cmol L^{-1}	centimole per liter	kPa	kilopascal
dS m^{-1}	decisiemens per meter	L	liter
dS m^{-2}	decisiemens per square meter	L m^{-1}	liter per meter
ft	foot	L m^{-2}	liter per square meter
ft^2	square foot	lb	pound
g	gram	lb $acre^{-1}$	pound per acre
g cm^{-3}	gram per cubic centimeter	*M*	molar
g g^{-1}	gram per gram	m	meter
g ha^{-1}	gram per hectare	m^2	square meter
g kg^{-1}	gram per kilogram	m^3	cubic meter
g m^{-2}	gram per square meter	m^2 g^{-1}	square meter per gram
g m^{-3}	gram per cubic meter	m^2 ha^{-1}	square meter per hectare

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT—Continued

MBtu ha^{-1}	million British thermal units per hectare	mmho cm^{-1}	millimho per centimeter
meq	milliequivalent	mmol	millimole
meq L^{-1}	milliequivalent per liter	mmol kg^{-1}	millimole per kilogram
Mg	megagram	mmol m^{-3}	millimole per cubic meter
Mg ha^{-1}	megagram per hectare	mol	mole
Mg ha^{-1} yr^{-1}	megagram per hectare per year	mol L^{-1}	mole per liter
Mg kg^{-1}	megagram per kilogram	MPa	megapascal
Mg m^{-3}	megagram per cubic meter	mt	metric ton
mg	milligram	mt $acre^{-1}$	metric ton per acre
mg cm^{-3}	milligram per cubic centimeter	mt ha^{-1}	metric ton per hectare
mg d^{-1}	milligram per day	mt ha^{-1} mo^{-1}	metric ton per hectare per month
mg g^{-1}	milligram per gram	μg	microgram
mg ha^{-1}	milligram per hectare	μg g^{-1}	microgram per gram
mg ha^{-1} yr^{-1}	milligram per hectare per year	μg mL^{-1}	microgram per milliliter
mg kg^{-1}	milligram per kilogram	μM	micromolar
mg L^{-1}	milligram per liter	μm	micrometer
min	minute	μmho cm^{-1}	micromho per centimeter
mL	milliliter	*N*	normal
mL g^{-1}	milliliter per gram	pct	percent
m *M*	millimolar	ppm	part per million
mm	millimeter	s	second
mm d^{-1}	millimeter per day	W	watt
mm h^{-1}	millimeter per hour	yd^3	cubic yard
mm yr^{-1}	millimeter per year	yd^3 $acre^{-1}$	cubic yard per acre

NOTE.—In this report, "ton" is used to indicate short ton (2,000 pounds).

OTHER ABBREVIATIONS AND ACRONYMS USED IN THIS REPORT

AMD	acid mine drainage
AML	abandoned mine land(s)
ASA	American Society of Agronomy
ATP	adenosine triphosphate
AWC	available water capacity
BCR	British Columbia Research
BLM	Bureau of Land Management
CEC	cation-exchange capacity
CFR	Code of Federal Regulations
CHN	carbon-hydrogen-nitrogen
CSSA	Crop Science Society of America
CT	computed tomography
D	diameter
DAP	diammonium phosphate
D_b	bulk density
DBH	diameter at breast height
D^2H	diameter squared times height (seedling volume index)
DTPA	diethylenetriamine pentaacetic acid
EC	electrical conductivity
EDDHA	ethylenediamine di-o-hydroxy-phenylacetic acid
EDTA	ethylenediamine tetraacetic acid
Eh	redox potential
EIS	environmental impact statement
EMRIA	Energy Mineral Rehabilitation Inventory and Analysis
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Administration (now part of the Department of Energy)
ESP	exchangeable sodium percent
ESR	exchangeable sodium ratio
FDA	Food and Drug Administration
H	height
HC	hydraulic conductivity
ICP	inductively coupled plasmas
IVDMD	in vitro dry matter digestibility
K	USLE soil erodibility factor
K_m	kinetic constant
K_{sat}	saturated hydraulic conductivity
MPN	most probable number
N-P-K	nitrogen-phosphorus-potassium (fertilizer)
NRC	Nuclear Regulatory Commission
OSMRE	Office of Surface Mining Reclamation and Enforcement
p	probability
PCB	polychlorinated biphenyl
PI	productivity index
PLS	pure live seed
Pt	*Pisolithus tinctorius*
PVC	polyvinyl chloride
PVI	plot volume index
R^2	coefficient of multiple determination
r	correlation coefficient

OTHER ABBREVIATIONS AND ACRONYMS USED IN THIS REPORT—Continued

r^2	coefficient of simple determination
SAR	sodium adsorption ratio
SMCRA	Surface Mining Control and Reclamation Act (1977)
SMP	Shoemaker-McLean-Pratt
SSSA	Soil Science Society of America
TEM	transmission electron microscopy
Tt	*Thelephora terrestris*
TVA	Tennessee Valley Authority
UF	urea-formaldehyde
USDA	U.S. Department of Agriculture
USLE	Universal Soil Loss Equation
VA	vesicular-arbuscular
VAM	vesicular-arbuscular mycorrhizae
V_{max}	kinetic constant
v/v	volume per volume

SOIL CHARACTERIZATION AND SOIL AMENDMENT USE ON COAL SURFACE MINE LANDS: AN ANNOTATED BIBLIOGRAPHY

By Michael R. Norland[1] and David L. Veith[2]

ABSTRACT

This U.S. Bureau of Mines report on U.S. and Canadian literature pertaining to soil characterization and the use of soil amendments as a part of the reclamation process of coal surface-mined lands contains 1,280 references. The references were published during the 1977 to 1988 period. Each reference is evaluated by keywords, providing the reader with a means of rapidly sorting through the references to locate those articles with the coal mining region and subjects of interest. All references are annotated.

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INTRODUCTION

The Surface Mining Control and Reclamation Act of 1977 (SMCRA), Public Law 95-87, was signed into law on August 3, 1977. The act provides, through the Office of Surface Mining Reclamation and Enforcement (OSMRE), that any coal surface mining operation must restore all affected areas to conditions capable of supporting the uses that the areas were capable of supporting prior to any mining, or to higher or better uses that are compatible with surrounding areas. Additionally, the uses must be feasible and proposed uses must not present actual or probable hazards to public health or safety; the reclamation must not be impractical or unreasonable (*1*).[1]

In many instances, to achieve these performance standards, soil amendments such as fertilizers and sludges must be applied. The permanent program standards (subchapter K 816.25 and 816.114) (*1-2*) state that nutrients and soil amendments in the amounts determined by soil tests should be applied to the redistributed surface soil layers, so that they support the approved postmining land use and meet the revegetation requirements of sections 816.111 and 816.116. Additionally, suitable mulch and other soil-stabilizing practices shall be used on all areas that have been regraded and covered by topsoil or topsoil substitutes (soil amendments) if soil stabilization and erosion control are necessary as determined by the regulatory authority (*2*).

Soil amendments are necessary in the reclamation process when the replaced soils or soil substitutes alter the soil physical characteristics such that conditions for plant growth and development are unfavorable (poor soil texture or structure). Soil amendments are also necessary when the soils used in reclamation do not supply the essential plant nutrients in balanced proportions or in adequate quantities for optimum plant nutrition, growth, or development.

Amendments are used to cause immediate changes in the physical and chemical properties of mine soils. Soil amendments to alter unfavorable physical characteristics are needed to optimize plant growth responses. Some of the soil physical characteristics that can be altered favorably by soil amendments are soil texture and structure, moisture, temperature, bulk density, pore size and distribution, and aeration.

There is a large amount of information available on the use of soil amendments in coal mine reclamation and the characterization of coal mine soils. This information, however, is widely disseminated throughout various professional and scientific journals, State and Federal documents, proceedings of conferences, theses, and other technical writings. Unless the reclamation inspectors, researchers, and others involved in reclaiming mined lands have ready access to these numerous publications, a critical need exists for a comprehensive and up-to-date publication containing the "state-of-the-art" uses, methodologies, and types of soil amendments that are necessary for reclamation success.

There is a need to consolidate this information into a single comprehensive document for the regulatory agencies and mining industry. The purpose of this U.S. Bureau of Mines research was to produce such a document in the form of an annotated bibliography. The bibliography will provide those involved in surface coal mine reclamation a single source or reference guide to the current literature available on the use of soil amendments.

This report contains bibliographic listings and summaries, as annotations, of various studies and articles that have appeared in the literature between 1977 and 1988. The studies and articles concern soil amendments, mine soil characterization techniques, Federal, State, and local regulatory policies, short- and long-term additive impacts, and the techniques of application of soil amendments.

SOIL CHARACTERIZATION AND SOIL AMENDMENT USE

SOIL CHARACTERIZATION

Every site requiring revegetation is unique (*3*). Site-specific factors that influence species selection, growth, and development must be considered. Concerns about land use, regulations, soil and overburden characteristics, and the availability of soil amendments are important factors in developing a reclamation plan.

Since the soil and overburden that existed prior to mining are often used as the growth medium, the characteristics of that material must be known prior to developing a reclamation plan (*3*). Once those characteristics are determined, soil amendments can be selected that would ameliorate the soil characteristics that may limit subsequent plant growth and development. A discussion of soil characterization and soil amendment use follows.

Soil is a fundamental resource (*4*). Soil characteristics determine the ability of a particular soil to support and sustain plant growth and productivity. The various aspects of soil characterization of interest are the chemical, physical, biological, and mineralogical properties of soil.

The characteristics of the medium to be used for plant growth—whether it is soil, overburden, or a substitute material—must be determined prior to mining. Vogel (*5*) states that a detailed examination of the soils and geologic strata above the coal seams must occur prior to mining for

[1]Italic numbers in parentheses refer to items in the list of references preceding appendixes.

use in (1) the development of a soil reconstruction plan, (2) the evaluation of the success of soil reconstruction, and (3) the determination of soil amendments and plant species for use in revegetation.

Soil reconstruction is mandated by SMCRA. All overburden or spoil material of a coal mined area must be transported, backfilled, and graded to its approximate original contour prior to the redistribution of subsoil and topsoil materials. The redistribution of topsoil and subsoil (if replaced) must be accomplished in a manner that achieves an approximate uniform thickness consistent with approved postmining land uses, contours, and surface water drainage patterns.

The goal of soil reconstruction during surface-mined land reclamation is the replacement and restoration of a plant growth medium. The medium is to have characteristics similar to, and be at least equally suited for plant growth and production as, the soils that were in place prior to mining (*5*). In some instances, where certain overburden materials are more fertile than the original topsoil, they may be used to supplement or replace topsoil as the plant growth medium. They may only be used if they are equal to, or more suitable for sustaining the planted vegetation than, the available topsoil of a particular region. Soil characterization will assist in the identification of those materials most suited for replacement as plant growth media and in the identification of materials with properties that may limit or prevent plant growth (*5*).

Chemical Properties

Soil chemical parameters that are of concern prior to and during surface coal mined land reclamation are soil reaction, electrical conductivity, and the concentration of elements in the soil. Element concentration concerns both the deficiency of plant-essential elements or nutrients and the toxicity of certain elements.

Soil Reaction

Soil reaction is the degree of soil acidity or alkalinity as measured by pH. Soil pH is the negative logarithm of hydrogen ion (H^+) activity of a soil. By specifying activity rather than concentration it is recognized that there are other hydrogen ions in the soil system, such as in organic matter and the mineral structure. Soil pH is a measure of the hydrogen ion activity in the soil solution (*6*). The degree of acidity or alkalinity is expressed in terms of the pH scale, 0 (extremely acid) to 14 (extremely basic or alkaline), while a pH of 7.0 is neutral. Lower pH values are an indication of various degrees or intensities of acidity, while higher pH values indicate varying intensities of alkalinity. Because the pH scale is logarithmic, the intensity of acidity or alkalinity changes tenfold for each unit change in pH.

The determination of soil pH is one of the most common and important chemical measurements that can be made in soil or overburden materials. It is useful for predicting and defining many of the problems associated with the revegetation of surface-mined land, as plant species vary in their tolerance of acid or alkaline conditions (*5*). Additionally, based on soil reaction, the concentration of plant-essential mineral elements and other mineral elements (such as aluminum, cadmium, chromium, nickel, lead, selenium) may be toxic, or sufficient or deficient (limiting) for the mineral nutrients. A relationship exists between the pH of the soil solution and nutrient availability. The soil pH may influence nutrient absorption and plant growth in two ways: (1) through the direct effect of the hydrogen ion or (2) indirectly, through its influence on nutrient availability and the presence of toxic ions (*7*). The indirect effect is of greater significance; for example, as the pH is raised from 5.0 to 8.0, iron, manganese, and zinc become less available, while molybdenum availability increases. At pH values below 5.0, aluminum, iron, and manganese are soluble in sufficient quantities to be phytotoxic.

Soil pH measurements can also provide information as to which soil amendments are needed to neutralize acidity (lime) or to correct problems of alkalinity (sulfur), thus improving nutrient availability and plant responses to fertilizer amendments.

Electrical Conductivity

In the semiarid or arid regions of the United States, soil salinity is a major problem. Salinity is associated with climates in which annual evaporation-transpiration exceeds annual rainfall. Consequently, there is no net movement or percolation of water through the soil profile and the result is an accumulation of salts in the soil.

Salinity or salt concentration of the soil solution is quantified by electrical conductivity of a saturation extract. Electrical conductivity is the reciprocal of electrical resistance, and its unit of measure is decisiemens per meter, which is equivalent to its better known unit of measure, millimhos per centimeter. Electrical conductivity is a measure of dissociated electrolytes in the soil solution, charged ions that carry an electrical current. As a result, as the ionic concentration increases so too does the electrical conductivity (*8*). Soil with conductivity of 4 dS m^{-1} and greater at 25° C is considered a saline soil (*9*).

The major influence of soil salinity on plant growth is the reduction of water availability to plants. The presence of salt reduces soil water potential. As the plant makes an osmotic adjustment toward maintaining a constant water potential gradient between the plant and soil solution, there is a corresponding decrease in plant growth and productivity (*8*).

Electrical conductivity levels also affect soil physical properties. Of particular interest is the interaction among salinity, exchangeable sodium percentage (sodium adsorption ratio), hydraulic conductivity, and infiltration rate (*8*).

Element Concentration

Sixteen mineral elements have been recognized as essential nutrients for plant growth. Three criteria of essentiality (*10*) must be met for an element to be considered essential: (1) a given plant must be unable to complete its life cycle in the absence of the mineral element, (2) the function of the element must not be replaceable by another mineral element, and (3) the element must be directly involved in the plant metabolism as a component of an essential plant constituent, such as an enzyme, or it must be required for a distinct metabolic step, such as an enzyme reaction. Of the 16 essential nutrients, 9 are used in relatively high concentrations and are referred to as "macronutrients." These are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. The sources of carbon, hydrogen and oxygen are mainly air and water, while the source of the other six macronutrients is the soil solids.

The remaining essential mineral nutrients are referred to as "micronutrients" because they are essential only in very low concentrations in plants; however, they are not any less essential than the macronutrients. The micronutrients are iron, manganese, zinc, copper, boron, molybdenum, and chloride. The source of all micronutrients is the soil solids.

Macronutrients are generally constituents of organic compounds found in plants, such as proteins and nucleic acids, while micronutrients are predominantly constituents of enzyme molecules.

When mineral elements, including the essential nutrient elements, are present in either deficient or toxic concentrations, plant growth and productivity can be adversely effected. In general, the common growth-production versus nutrient supply curve has three well-defined regions: deficient, sufficient, and toxic. In the first region, growth rate increases with increasing nutrient supply. In the second, the growth rate or productivity reaches a maximum and remains unaffected by nutrient supply as there is a sufficient supply of nutrients for normal plant growth and development. In the third region, the growth rate falls with increasing nutrient supply. Toxicity response involves both the essential and nonessential mineral elements.

Essential nutrients, particularly nitrogen, phosphorus, and potassium, are often deficient in reconstructed mine soils. In situations where topsoil and its associated organic matter are not replaced, nitrogen is almost always deficient for plant growth (*5*). Soil chemical and plant tissue analyses are necessary to provide a basis for making fertilizer recommendations. Deficiencies of other macronutrients and micronutrients do exist on mine soils, but in most instances these deficiencies are site specific and have not been well defined (*5*). Toxicity occurs when mineral elements, including essential nutrient elements, are present in concentrations that are abnormally high. Elements that have been found in mine soils at concentrations considered toxic to plants include selenium, boron, aluminum, manganese, iron, sulfur, arsenic, barium, nickel, copper, zinc, and lead (*5*).

Physical Properties

Soil physical properties that are known to affect plant growth on reclaimed mine lands include soil texture and structure, bulk density, pore space, and soil color.

Soil Texture and Structure

Soil texture is a measurement of the size of the mineral particles and refers to the relative proportion of particles of various sizes in a given soil (*7*). Particle size analysis is used to measure the percentages of the primary separates: sand, silt, and clay. The diameter limits of these classes are sand, 2 to 0.05 mm; silt, 50 to 2 μm; and clay, less than 2 μm.

Soil textural classes (sands, silts, clays) are names used to identify the textural makeup of soils and give an indication of some of their physical properties (*7*). Physical features of the soil affected by soil texture include water movement and retention, water availability to plants, bulk density, soil erodibility, and soil consistence. Soil texture also affects the soil cation-exchange capacity, a chemical parameter (*5*).

Soil structure refers to the overall aggregation or arrangement of the primary separates (*7*). A soil profile may be dominated by a single structural pattern, or a number of types of aggregates can be found within a soil profile from horizon to horizon. Individual aggregates are known as peds. Soils that do not have aggregates with naturally preserved boundaries (peds) are considered structureless (*6*) and are characterized by one of two forms, either single grain or massive. There are four primary types of structure that refer to the shape of the peds: platelike, prismlike, blocklike, and spheroidal. Ped shape, together with size, is used to define soil structure. Soil structure can influence water movement, heat transfer, aeration, bulk density, and pore space (*7*).

Soil Bulk Density and Pore Space

Bulk density is defined as the mass of dry soil per unit bulk volume, which includes both soil solids and pore space (*11*). Vogel (*5*) states that high bulk density is the

most troublesome soil feature of reconstructed soils on surface-mined land. Soils that are loose and porous will have lower bulk density values, while those that are more compact (less pore space) will have higher bulk density values and a resulting loss of soil structure.

Compaction is a result of soil-handling operations (topsoil removal, topsoil stockpiling, overburden regrading, and topsoil replacement) by heavy equipment under the wrong conditions (high soil moisture values, for example). Compaction causes a reduction in pore space, which inhibits or restricts the movement of air into the soil and the movement and storage of water within the soil. High bulk density values may also restrict plant root expansion and penetration into the soil.

The pore space of a soil is that portion of the soil bulk volume that is occupied by pores, air, and water (*11*). The amount of pore space is determined by the arrangement of solid soil particles. If the particles lie close together as in sands or compacted soils, the total porosity is low; however, if they are arranged in porous aggregates (such as soils high in organic matter) the porosity will be high (*7*). In general, one-half the volume of soil is thought of as pore space, and the size, shape, and continuity of these voids will affect the movement of air and water in the soil.

Soil structure has a great influence over soil pore space. Soil horizons with structure defined as granular, blocky, prismatic, or columnar will have much less resistance to soil air and water movement and root extension than will soil horizons with structure that is massive or platy.

Two types of soil pores are generally recognized, macropores and micropores. Although pore types are not clearly separated, macropores characteristically allow the ready movement of air and percolating water, while in micropores air movement is greatly impeded and water movement is restricted to capillary movement (*7*).

Soil Color

Soil color is probably the most easily recognizable physical feature of a soil. It may also be related to specific chemical and biological properties of a soil. Soil color affects the temperature of the surface layers of a soil. Black or dark-colored soil absorbs more heat from the sun, resulting in elevated soil surface temperatures that can be lethal to plant seedlings. These higher temperatures can also lead to soil drying. A black soil color is also an indication of the presence of organic matter. Lighter colored soils are not as warm, nor do they dry as quickly. Red-colored soil may contain elevated levels of free iron oxides common in well-oxidized soils. Under reducing conditions, the removal of free iron generally results in a gray or bluish-gray color.

Biological Properties

The biological components of soil contribute to soil development and to the development and maintenance of a vegetative cover. The presence of soil flora and fauna is essential for the long-term survival and growth of most plant species and for the reestablishment of natural ecosystems (*5*). The biological component of soil consists of diverse groups of organisms that range in size from the larger rodents, worms, and insects to microscopic bacteria and fungi. These organisms, either individually or in complex interactions, are an integral part of numerous physiological activities associated with plants and in soil processes (*5*).

The activities of soil organisms range from physical disintegration of plant residues by insects and earthworms to the complete decomposition of these residues by micro-organisms, including bacteria, fungi, and actinomycetes. Organic matter alteration and decomposition of plant residues release nutrients that are available for plant uptake, including but not limited to nitrogen, phosphorus, and sulfur. Micro-organisms are also obligatory for nitrogen fixation (bacteria), nitrogen and sulfur cycling (bacteria), fermentation of manure and compost piles (actinomycetes), root nodulation of nonleguminous plants (actinomycetes), and development of mycorrhizal associations (fungi).

The establishment, rate of development, density, and community composition of micro-organisms in reconstructed soils will be influenced by the physical and chemical characteristics of the material used in soil reconstruction and the availability of organic matter. The environmental factors that influence the density and composition of bacteria, actinomycetes, and fungi are discussed below.

Bacteria

Moisture, aeration, temperature, organic matter, acidity, and inorganic nutrient supply are the primary environmental factors that affect soil bacteria. Moisture affects microbial activity in two ways: (1) it must be available for microbial development and (2) where it is excessive the bacterial flora decreases because of waterlogging, which limits gaseous exchange and lowers the available oxygen supply, creating anaerobic conditions (*12*). Alexander (*12*) states that maximum bacterial density is found in regions of fairly high moisture content with the optimum level for aerobic bacteria activity occurring where soil moisture is between 50 and 75 pct of the soil's water-holding capacity. Under anaerobic conditions only those bacteria tolerant of low oxygen levels or complete anaerobiosis are capable of surviving.

All biological processes are governed by temperature, including microbial activity. Most soil bacteria are mesophilic; their optimum temperature for growth and proliferation ranges from 25° to 35° C (*12*).

The largest bacterial numbers are found in soils with high organic matter content (*12*). Additions of carbonaceous materials, green manures, and crop residues stimulate bacterial numbers. This effect, however, is most

pronounced during the first months of decomposition, disappearing after a period of 1 year (*12*).

Many soil bacteria are inhibited by highly acidic or alkaline conditions. The optimum pH for most species is near neutrality. The lower the pH, the smaller the size of the bacterial community (*12*).

Inorganic nutrients are required by bacteria even though organic carbon is the major constituent of their energy supply. Applications of inorganic nutrients serve a dual function since they supply both the plant and the bacteria (*12*).

Actinomycetes

For actinomycetes, the stage of the life cycle that predominates, the size of the community, its biochemical transformations, and the genera and species found are determined by the ecological factors acting within the ecosystem (*12*). The primary ecological influences acting on actinomycetes are the status of organic matter, pH, moisture, and temperature.

The availability of carbon directly affects the community size of actinomycetes. As the organic matter content increases, so does the concentration of actinomycetes. When organic amendments are added to the soil, bacterial and fungus flora usually proliferate initially, but actinomycetes populations generally do not respond until the later stages of decomposition (*12*). This suggested to Alexander (*12*) that the greater growth rates and biochemical versatility of bacteria and fungi make them initial agents of decomposition, while actinomycetes appear only after more readily available compounds have been metabolized and competition has been reduced.

Actinomycetes are not tolerant of low soil pH values, with the limiting pH for most strains at approximately 5.0. Actinomycetes are most abundant in soils with pH values ranging from 6.5 to 8.0 (*12*).

Under conditions of waterlogging or where soil moisture is 85 to 100 pct of water-holding capacity, actinomycetes occur only on occasion. All common soil actinomycetes require aerobic conditions for metabolism; under conditions of anaerobiosis, actinomycetes do not develop or spread. Additionally, actinomycetes are not as greatly influenced by dry soil conditions as are the bacteria. The number of actinomycetes remains high as soils dry out; however, their relative incidence decreases because of their lack of tolerance to arid conditions (*12*). The optimum temperature range for the growth and development of actinomycetes is from 28° to 37° C.

Fungi

Fungi (mushrooms, molds, mildews, and yeasts) vary in abundance, physiological activity, and biochemical activities with time on any single site (*12*). Organic matter status of the soil, pH, organic and inorganic fertilizers, moisture, aeration, temperature, position in the profile, season of the year, and vegetative composition are all environmental factors that influence the fungi community.

The numbers of filamentous fungi in the soil will vary directly with the content of utilizable organic matter (*12*). Incorporation of crop residues, green manures, and other carbonaceous materials into the soil not only improves the nutrient content of the soil, but also increases the size of the fungi community. There is a succession of fungal species following the additions of a carbon source, through its decomposition.

Many fungal species are adapted to a wide range of soil pH values, from highly acidic conditions to highly alkaline conditions. Since both bacteria and actinomycetes are not commonly found in acidic conditions, fungi dominate the microbial communities in areas of low pH (*12*). The presence of fungi in acidic soils is not the result of these areas' providing optimum conditions for their existence, but a consequence of the lack of microbial competition for food reserves. Fungi are the dominant micro-organisms in acid soils because of their tolerance to low soil pH values and the narrow range of pH values in which most bacteria and actinomycetes can function (*12*). Fungi are responsible for a large portion of the biochemical transformations that occur in acid soil habitats.

Soil water has a direct effect on the abundance and functions of fungi (*12*). When the water supply or water-holding capacity of the soil is low, the capacity of fungi for catalyzing chemical transformations may be lacking. When moisture is excessive, the diffusion of oxygen that is necessary for aerobic metabolism is inadequate to meet microbiological demands, and fungal populations decrease.

In general, filamentous fungi are strict aerobes. This dependency on oxygen helps to explain the high concentrations of fungi in the upper few centimeters of soil and the absence of fungi in the lower levels of undrained peat and from swamps and bogs (*12*). Like bacteria and actinomycetes, most species of fungi are mesophilic in their temperature relationships. The effects of moisture and temperature on fungal composition and density can be shown through seasonal changes. Spring warmth and moisture are usually beneficial to fungal populations, but periods of summer drought or cold winters significantly reduce the activity of fungal populations in the soil (*12*).

Mineralogical Properties

Soils are characterized mineralogically by separating soil minerals into two groups: (1) skeletal minerals that are composed of primary minerals, grains, microcrystalline aggregates, and fragments, and (2) clay minerals and amorphous or fine-grained (clay size) compounds (*6*). Buol,

Hole, and McCracken (*6*) state that skeletal minerals make up the sand and silt fractions of the soil, while clay minerals and amorphous fine-grained compounds are found in the clay fraction of soils. Primary minerals may, however, be found in the clay fractions of some soils, and the clay minerals may be found in the silt and sand fractions of certain soils (*6*).

The primary minerals in the skeletal groups consist of sand and silt-size grains, each of which is a single mineral. The microcrystalline aggregates consist of volcanic ash and chert. Fragments are small chips of rock that contain various minerals found in sand and silt sizes (*6*).

The majority of the clay fraction in most soils consists of aluminosilicate clays. Also present in certain soils are significant amounts of hydrous iron oxides and gibbsite in the more highly weathered soils, and allophane (amorphous aluminosilicate), which is abundant in soils formed from volcanic ash in humid regions (*6*).

SOIL AMENDMENT USE

A soil amendment is any material that is worked into the soil or applied on the surface to enhance plant growth (*11*). Common examples are lime, gypsum, sawdust, compost, animal manure, crop residue, or synthetic soil conditioners. Additionally, amendments may contain important fertilizer elements, but the term "amendment" commonly refers to added materials other than those used primarily as fertilizers (*11*). Follet, Murphy, and Donahue (*13*) listed four factors that are essential for the optimum biological efficiency of plants: (1) favorable air and soil temperature, (2) optimum available soil water and soil air, (3) adequate light as a source of energy for green plants to carry on photosynthesis, and (4) essential elements for adequate nutrition of plants available when needed and supplied in balanced proportions. When any of these chemical or physical parameters are low or not in balance, resulting plant growth, development, and production will not be optimum. Soil amendments are necessary to enhance the plant's physiological condition and production.

Soil amendments may be grouped into six categories: (1) fertility management (inorganic and organic fertilizers), (2) pH modifiers, (3) organic materials, including sludges and composts, (4) biological materials, including soil-dwelling micro-organisms, (5) mulches, including crop residues (straw and hay), bark, and wood chips, and (6) topsoil as an amendment that contains nutrients, organic matter, and soil-dwelling micro-organisms. Mulches, although not considered a soil amendment by many people, were included as a category because (1) they are applied to the soil surface to enhance plant growth, (2) they alter the physical condition of the soil by reducing evaporative water losses, conserving soil moisture, improving water infiltration by lessening the sealing over and crusting of the soil surface, modifying the extremes of soil temperature in the upper soil depth sections, and restricting air movement over the soil surface, (3) they provide an energy source for soil microbial populations, and (4) through their decomposition nutrients may be released, although in some circumstances nitrogen deficiency can develop. The carbon-to-nitrogen ratio must be monitored.

The application of mulches that are high in cellulose may result in nitrogen deficiencies because of microbial immobilization of soil nitrogen during the decomposition process. When micro-organisms cannot assimilate enough nitrogen from the material they are decomposing, they must obtain nitrogen from the soil, which is then immobilized in microbial cells or hyphae. As long as the carbon-nitrogen ratio is not greater than between 20:1 and 30:1, immobilization should not occur. If the ratio is less than 20:1, mineralization, or the conversion of organic nitrogen (plant residues) to the inorganic state, should occur. The net consequence of mineralization is the generation of ammonium and with nitrification, nitrate-nitrogen.

Topsoil can be considered a soil amendment if, during the removal, stockpiling, and replacement during soil reconstruction, the chemical, physical, and biological parameters of the topsoil are not adversely affected by the soil-moving processes. The quality of the soils used as amendments should be maintained. Soils that are reconstructed should have the same or a higher capacity for production as those soils found in the surrounding area. To achieve this goal, the reconstructed soil should have density, texture, thickness, pH, available water-holding capacity, cation-exchange capacity, and porosity values that are similar to those of undisturbed soils found in the immediate surrounding area. Vogel (*5*) states that success in revegetating mine soils may be more dependent on the proper use and application of cultural practices and soil amendments than on the selection of plant species.

The remaining four categories of soil amendments are not discussed here since their use as soil amendments is well documented. They are, however, defined in detail in the "Reference Categories" section of this publication and discussed in appendix B, the annotated bibliographies of soil amendment and soil characterization research.

REFERENCE SELECTION FOR ANNOTATED BIBLIOGRAPHY

There is a substantial amount of information available on coal mine reclamation and revegetation, particularly on the use of soil amendments to ameliorate site conditions and aid vegetation establishment, growth, development,

and productivity. Additionally, site characterizations based on soil chemical, physical, and mineralogical properties have been widely researched. The InfoMaster System,[4] a collection of on-line data bases available through Western Union Telegraph Co., was selected as a starting point for retrieving surface mine literature on mine-soil characterization and soil amendment use. Because of the large number of data bases within the InfoMaster System, four data bases were selected for preview prior to selecting the appropriate data base for retrieving the surface mine literature. The four data bases selected for preview, based on their probability of listing appropriate surface coal mine literature, were Biological and Agricultural Abstracts, Biosis Previews, Enviroline, and Environmental Bibliography. Each data base was previewed based on the key search phrases "surface mine/ and soil" and "strip mine/ and soil" (the / being any suffix associated with "mine"—such as mining). Based on the preview of the data bases, the Biosis Previews data base was selected to obtain an initial bibliographic listing. Biosis Previews is a bibliographic data base consisting of a collection of articles from over 9,000 periodicals and other published sources covering all aspects of the biological sciences, beginning with January 1969 publications and continuing through the present. Biosis Previews is updated twice monthly. Biosis Previews was accessed through InfoMaster, and by utilizing the two search phrases, 186 bibliographic headings were retrieved.

Since two search phrases were used, the 186 headings were reviewed to remove any duplicate headings, but none were found. Additionally, all 186 headings from the Biosis Previews data base were cross referenced against Bureau of Mines Information Circular (IC) 9048 (*3*) and duplicate headings were canceled from the current Biosis Previews bibliographic listing. All 186 headings retrieved through Biosis Previews were obtained through the University of Minnesota library system.

In addition to the literature obtained through the Biosis Previews data base, appropriate (suitable) literature on surface mine soil characterization and soil amendments was obtained by reviewing recent symposia proceedings such as the 1988 Mine Drainage and Surface Mine Reclamation Conference held in Pittsburgh, PA, and the proceedings of the 1984 through 1987 symposiums on Mining, Hydrology, Sedimentology, and Reclamation sponsored by the University of Kentucky. Articles in these and other proceedings that pertained to the characterization of surface-mined soils or to the additions of soil amendments to mined lands were reviewed. The literature citation section of each article was also reviewed. Any reference material that was not included in the Biosis Previews headings or in IC 9048 (*3*), or already acquired was noted for additional acquisition. Additionally, any literature published from 1987 to 1988 that dealt with soil amendment use or soil characterization of lands other than coal or hard-rock mined lands was obtained and reviewed. The basis for review was the technical information that the paper contained or whether the information presented was pertinent to the status of the current technology. Most of these articles were obtained through the University of Minnesota library system. Those journals, articles, theses, or books that could not be located at the University of Minnesota were obtained through interlibrary loans.

Finally, any reference material that was not reviewed or evaluated in IC 9048, but was obtained for that publication, was included in this review process. Additionally, references annotated in IC 9048 that dealt with soil characterization or soil amendments were included as reference material for this current annotated bibliography.

Prior to evaluating the articles based on keywords, each listing was reviewed to determine if it contained information on soils or soil amendment use on coal or hard-rock mined lands. Additionally, other noncoal papers that discussed these subjects in detail were included in the review process.

The Bureau compiled approximately 1,600 popular and scientific papers and books published between 1977 and 1988 dealing with the subjects of soil amendment technology and soil characterization of mined lands. Of these articles, 535 were previously referenced and annotated in IC 9048 (*3*). These articles were published between 1977 and 1983. Approximately 1,065 articles dealing with soil characterization and soil amendment use on mined lands, dating from 1984 to 1988, were new and not previously reviewed or annotated. Additionally, approximately 300 relevant noncoal articles dating from 1987 to 1988 were included based on their technical content. The number of references available for review and inclusion in the annotated bibliography was approximately 1,900.

Beginning with the most recently published information, all articles were read and a decision was made as to whether enough information or data were presented that dealt with the topics of soil characterization or soil amendment technology. Those articles selected for inclusion were given an evaluation rating based on preestablished keywords or phrases. All articles that have been included were reviewed, evaluated, and annotated, and bibliographic information was noted and entered into a computer database utilizing Pro/Tem Software's Notebook II and WordPerfect software packages. Notebook II was written specifically for information storage and retrieval of research notes (annotations in this case) and bibliographies.

A total of 1,280 references were evaluated within the timeframe of this project and are annotated in this bibliography. Almost all of the references date from 1977 to 1988, with a majority dating from 1984 to 1988.

[4]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

REFERENCE CATEGORIES FOR ANNOTATED BIBLIOGRAPHY

Each of the articles selected for review, beginning with those published in 1988, were evaluated utilizing eight broad categorical phrases: (1) coal region, (2) intended or current land use, (3) regulatory policy, (4) soil characterization, (5) soil amendments, (6) economic considerations, (7) short- and long-term additive impacts, and (8) techniques for application and/or rates of application. Of the phrases listed, the first was used to define the coal region where the research was conducted. The remaining seven categories contain the keywords used to evaluate each article. An evaluation code was developed to rate each of the articles on the keywords or subjects that a particular article may contain.

In order to evaluate each article, 24 keywords were developed based on the intended or current land usage, regulatory policy, soil characterization, and the various soil amendments that have been used in the reclamation of surface coal mined lands. Additionally, keywords were developed so that the economic considerations, short- and long-term additive impacts, and the techniques for application or rates of application of soil amendments could be evaluated for each article. A discussion of this list and the coal region designations follows.

The keywords and regional designations are used in appendix A to evaluate and identify each article so that the reader can identify the articles of particular interest. The keywords were chosen to deal with all aspects of soil characterization and soil amendment use and to allow the reader to obtain information on particular aspects of soil amendment use on and soil characterization of coal surface-mined lands.

The following discussion defines the keywords and evaluation codes and identifies the coal mining regions. The domestic mining regions were designated based on adaptations of three previously published maps of coal mining regions in the United States (*3, 14-15*). For the purpose of this publication, there are eight coal mining regions within the United States (fig. 1). Additionally,

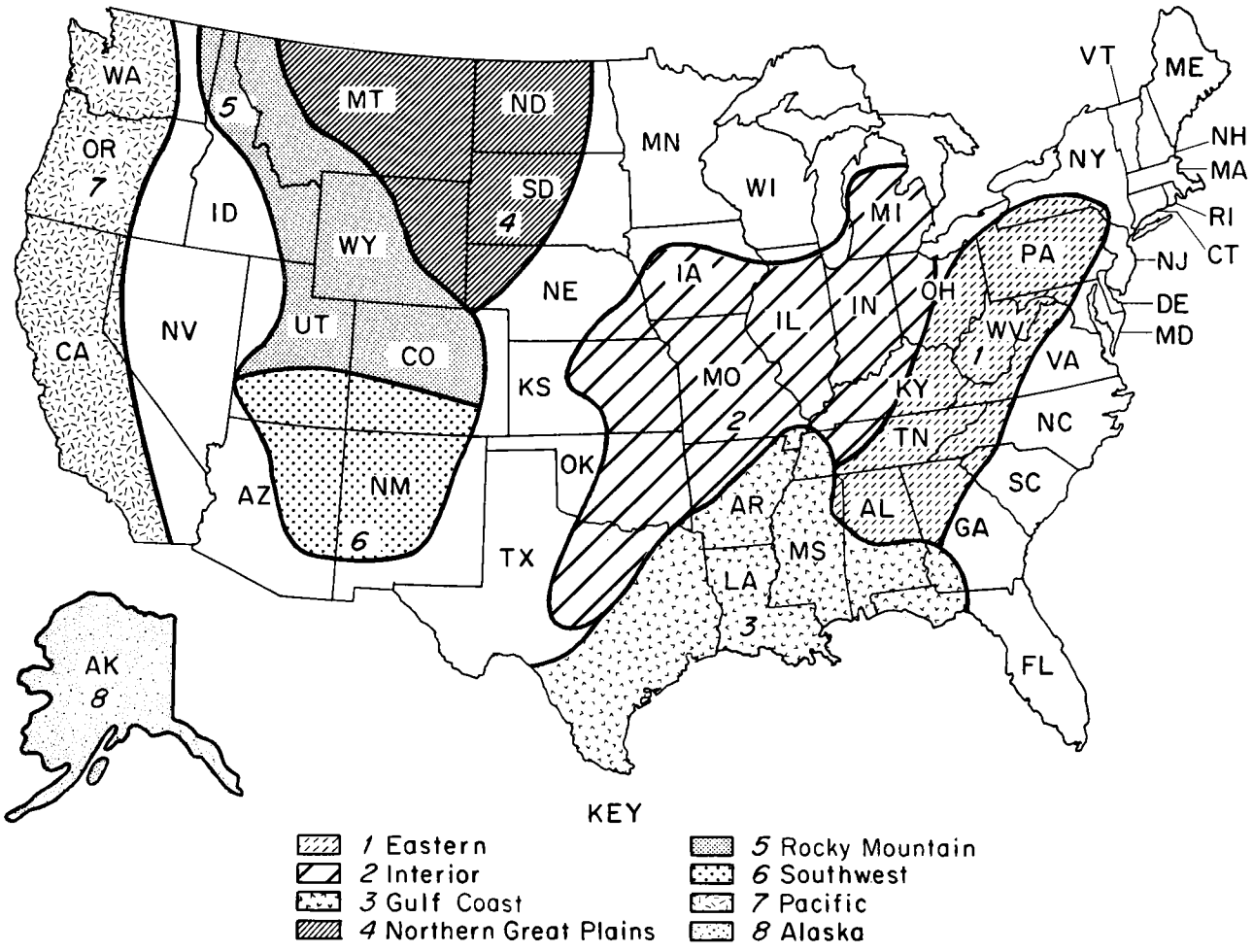


Figure 1.—Coal mining regions of the United States.

three designations are used to define literature that is applicable to coal mine revegetation throughout the entire United States or in Canada, or information that does not deal directly with coal surface mine reclamation, but can be applied to areas that have been surface mined. The regional designations are E—Eastern, I—Interior, G—Gulf Coast, N—Northern Great Plains, R—Rocky Mountains, S—Southwest, P—Pacific, A—Alaska, O—Entire United States, C—Canada, and X—Noncoal.

An evaluation code was developed to provide consistency when rating each article based on the keywords or phrases. Definitions of the designations E for excellent, G for good, and S for satisfactory follow.

E—Excellent reference for that keyword; keyword has direct, practical application or specific information on the use of soil amendments and/or the characterization of mine soil.

G—Good reference for that keyword; keyword has direct application, but has less specific information; the reference contains good background information.

S—Satisfactory reference for that keyword; keyword has little practical application because of generalities or limited information.

The regional coal mining designations and the evaluation code were applied to the 24 keywords or key phrases for each article. These keywords or phrases, shown in italic, are defined as follows.

Intended or current land use.—Specifies the intended land use or current management-related activities rather than the vegetative cover of the land. Land use may be identified in combination when joint or seasonal uses occur. Within this category the following seven subcategories (keywords) of intended or current land uses have been defined.

Cropland.—Land used for the production of adapted crops for harvest, alone or in rotation with grasses and legumes; includes row crops, small grain crops, hay crops, nursery crops, orchard crops, and other similar specialty crops.

Grazing land or rangeland.—Both grasslands and forest lands where the indigenous vegetation is actively managed for grazing, browsing, or occasional hay production.

Pastureland.—Land used primarily for the long-term production of adapted domesticated forage plants to be grazed by livestock or occasionally cut and cured for livestock feed.

Reforestation or afforestation.—Land used or managed for the long-term production of wood, wood fiber, or wood-derived products.

Wildlife.—Land dedicated wholly or partly to the production, protection, or management of species of fish or wildlife.

Recreational.—Land used for public or private leisure-time use, including developed recreation facilities such as parks, camps, and amusement areas, as well as areas for less intensive uses such as hiking, canoeing, and other undeveloped recreational uses.

Miscellaneous.—Other land uses as defined in 30 CFR 701.5 (*16*). These include residential, industrial-commercial, and undeveloped land.

Regulatory policy.—Refers to the laws or policies pertaining to the use of soil amendments in the reclamation of surface coal mined lands and the characterization of these soil types. Within this category there are three subcategories that deal with regulations at three levels of government.

Local.—City or county regulations and the policies of individual companies.

State.—Regulations of a particular State.

Federal.—Regulations of the Federal Government, such as the Office of Surface Mining Reclamation and Enforcement.

Soil characterization.—Refers to information presented on the soil characteristics (chemical and physical properties and mineralogical composition) of mine soils that are to be revegetated, either prior to mining, during soil storage, or after soil replacement. In this category, three subcategories that deal with soil characterization have been defined.

Soil chemical characteristics.—Chemical constitution, chemical properties, or chemical reactions of soils. Soil chemical properties of interest include: (1) soil pH, (2) exchange acidity, (3) exchangeable cations, (4) cation-exchange capacity, (5) percent base saturation, (6) free (extractable) iron, (7) saturation extract conductivity, (8) organic matter and its components (organic carbon, total nitrogen, carbon-nitrogen ratio), and (9) total chemical analysis (oxides of silicon, titanium, aluminum, iron, maganese, calcium, sodium, potassium, and phosphorus).

Soil physical characteristics.—Physical properties of soils, with emphasis on the state and transport of matter (especially water) and energy in the soil. Soil physical properties of interest include (1) soil texture-particle size analysis (percent of primary separates, sand, silt, and clay), (2) soil structure, (3) bulk density, (4) soil temperature, (5) soil moisture parameters (including defining the field moisture regimes—moisture content of each horizon, moisture retention, and hydraulic conductivity), and (6) shrink-swell capacity or linear extensibility.

Soil mineralogical composition.—Mineralogy of the soil, the homogeneous inorganic materials found in the Earth's crust to depth of weathering or sedimentation. Mineralogical considerations include (1) skeletal mineralogy (sand and silt-size grains of single minerals) and (2) clay minerals and amorphous clays.

Soil amendments.—Refers to organic or inorganic additions to soils to modify the physical, chemical, or biological characteristics or composition of soil to facilitate revegetation. Soil amendments are used to ameliorate soil properties that limit revegetation efforts. They are necessary or required when soil chemical, physical, or biological parameters essential for efficient plant nutrition and economic production are low in availability or not in balance. Within this category there are eight subcategories, each concerned with a different type of soil amendment.

pH modifiers.—Materials or procedures whose primary purpose is to maintain, raise, or lower soil pH values. Soil pH modifiers include (1) soil buffer, (2) organic materials, (3) liming materials (the oxides, hydroxides, carbonates, and silicates of calcium or calcium and magnesium, and wood ashes), (4) recarbonation (a carbon dioxide pressure system), (5) acidulating the soil with inorganic additions (sulfur, sulfuric acid, aluminum sulfate, iron sulfate, ammonium polysulfide), all capable of increasing soil acidity, and (6) acidulating the soil with organic additions (leaf mold, pine needles, tanbark, sawdust, or peat moss).

The liming of acid soils increases the uptake of essential nutrient elements, resulting in enhanced growth. Lime additions can also aid symbiotic and nonsymbiotic fixation of atmospheric nitrogen, help to speed up the release of essential nutrients from organic matter and clay colloids, and help to improve soil structure. Acidulation may be necessary where the soil is inherently high in carbonates, where excess liming has occurred, where dust from limestone roads has been deposited, or where plant species need acidification for growth (potatoes, for example).

Mulches.—Any suitable protective layer of organic or inorganic material applied or left on or near the soil surface as a temporary aid in stabilizing the surface and improving soil microclimatic conditions for establishing vegetation. Mulches are used at the soil surface to (1) prevent the loss of water by increasing infiltration, increasing the total and available water-holding capacity of the soil, and increasing surface wetness, (2) aid in soil stabilization by reducing surface erosion by wind, water, and raindrop impact, (3) increase soil organic matter or humus, (4) reduce soil surface temperature extremes, (5) decrease surface crust formation by decreasing the soil dispersing action of raindrops, (6) increase structural stability, tilth, and permeability of soil, (7) or reduce the germination and growth of weeds, resulting in improved microclimatic conditions for the growth of desired species. Additionally, mulches may serve as a substrate for beneficial soil organisms such as earthworms and the microflora. Materials used as mulch include (1) organic mulches (sawdust, paper, manure, hay and straw, bark, leaves, and other litter), (2) inorganic mulches (plastics, rocks, stones), (3) chemical stabilizers, and (4) preparatory crops.

Fertilizers.—Any materials of natural or synthetic origin that are applied to a soil to supply certain nutrient elements essential to the growth of plant species used in revegetation. Fertilizers used include (1) organic nutrient carriers (animal and green manures, plant residues, cottonseed meal, fish meal, and peat) and (2) inorganic nutrient carriers (ammonium nitrate, phosphate, and potash, for example).

Sludges.—Any liquid or solid waste from municipal or industrial processes applied to disturbed lands to aid reclamation and revegetation. Sludges may adversely or beneficially affect soil chemical, physical, and biological properties, depending on the sludge composition.

Biological.—The addition of soil-dwelling microorganisms to aid the establishment, growth, and development of plant species used in the revegetation of coal mined land through symbiotic interactions, decomposition processes, and oxidation reactions. Soil micro-organisms that may be added to the soil include (1) algae, (2) fungi, (3) bacteria, (4) actinomycetes, and (5) various soil microfauna.

Topsoil.—Additions of topsoil or topsoil substitutes as an aid in plant establishment, growth, and development on abandoned or disturbed mine lands that are to be reclaimed. May be used to reestablish soil organisms on lands that are to be reclaimed.

Compost.—Additions of compost as an aid in plant establishment, growth, and development on mined lands that are to be reclaimed. Composting is accomplished through aerobic mesophilic and thermophilic decomposition of organic residues to a relatively stable humuslike material. Composting aerobically is essential for encouraging specific microbial proliferation of bacteria, actinomycetes, and fungi for rapid decomposition. Compost is considered a separate keyword since it is both a mulch and a fertilizer. Materials that have been used for composting include (1) sewage sludge, (2) garbage, (3) alfalfa hay, (4) fresh grass clippings, (5) leaves that have freshly fallen, (6) peat moss, (7) newspaper, (8) sawdust, (9) wheat straw, and (10) manure.

Other.—This subcategory contains materials used as soil amendments that do not fit neatly into any of the preceding subcategories. These materials include (1) sand, used to improve the physical condition of mine soils, (2) gypsum, added to facilitate exchange with sodium to encourage flocculation and water penetration, and to

discourage surface crust formation, (3) dredged material, sediments from lake and river bottoms, (4) bactericides, reduction of acid formation and acid mine drainage through the inhibition or destruction of bacteria responsible for catalyzing pyrite oxidation, (5) soil conditioners, materials that improve the physical characteristics of the soil as a plant growth medium, including such materials as sawdust, peat, compost, and various inert materials, and (6) superabsorbents, materials that are capable of absorbing hundreds to thousands of times their weight in liquid, usually water (also called hydrogels). These are considered water management tools, as the material acts as a sponge and swells as it absorbs water. Superabsorbents also act to promote aeration and the retention of water and nutrients. They are typically effective for 6 months to 1 year.

The final three key phrases are—

Economic considerations.—Any information that pertains to the cost or cost benefit of adding soil amendments to facilitate the reclamation of surface-mined lands.

Short- and long-term additive impacts.—Information on the effects that the additions of soil amendments have, either short or long term, on soil physical, chemical, or biological characteristics and the various effects of soil amendments on plant species nutrient relationships, growth, biomass, or productivity.

Techniques for application and/or rates of application.—Any information on the techniques or equipment used to apply the soil amendments utilized, or any information on the rates of application of soil amendments.

There was no problem with personal interpretation of the keywords or evaluation code when an article was reviewed since the principal author developed all the keywords used, and reviewed, evaluated, and annotated each of the articles dating from 1984 to 1988, and most of those dating from 1977 to 1983. The keyword system utilized in this publication provides a single, rapid, and effective method of screening references so the reader can quickly determine which reference to obtain.

Once familiar with the keyword, coal region, and evaluation criteria definitions, the reader can select those articles of interest by using the table in appendix A to locate article reference numbers (1 through 1280). The reader can then turn to the numbered annotated bibliographical listing in appendix B for more information. The reference article can be obtained or rejected based on the annotation.

SUMMARY

The technical literature pertaining to soil characterization and soil amendments used on coal mined lands, published in the United States and Canada from 1977 to 1988, was reviewed.

From almost 1,900 references considered for inclusion in this bibliography, 1,280 were chosen for detailed assessment and annotation. Each reference was evaluated for various keywords, and a means was developed for rapidly sorting through the references. This report describes the rationale for selecting references, developing keywords, and evaluating the references.

REFERENCES

1. Federal Register. Office of Surface Mining Reclamation and Enforcement (Dep. Interior). Surface Coal Mining and Reclamation Operations Permanent Regulatory Program. V. 44, No. 50, Mar. 13, 1979, pp. 15311-15463.

2. _____. Office of Surface Mining Reclamation and Enforcement (Dep. Interior). Revegetation of Regraded Areas and Other Lands Disturbed by Surface Coal Mining Operations, Final Rule. V. 48, No. 172, Sept. 2, 1983, pp. 40140-40162.

3. Veith, D. L., K. L. Bickel, R. W. E. Hopper, and M. R. Norland. Literature on the Revegetation of Coal-Mined Lands: An Annotated Bibliography. BuMines IC 9048, 1985, 296 pp.

4. Jenny, H. Soil Resource Origin and Behavior (Ecological Studies: V. 37). Springer, 1980, 377 pp.

5. Vogel, W. G. A Manual for Training Reclamation Inspectors in the Fundamentals of Soils and Revegetation (prepared for OSMRE by U.S. Dep. Agric. For. Serv.). Soil and Water Conserv. Soc. Am., Sept. 1987, 178 pp.

6. Buol, S. W., F. D. Hole, R. J. McCracken. Soil Genesis and Classification. IA State Univ. Press, 2d ed., 1980, 406 pp.

7. Brady, N. C. The Nature and Properties of Soils. Macmillan, 1974, 639 pp.

8. Jurinak, J. J., J. Bowden, F. Samson, and T. Portal. Electrical Conductivity. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 27-34.

9. U.S. Salinity Laboratory (Dep. Agriculture). Diagnosis and Improvement of Saline and Alkali Soils. Handbook 60, 1954, 160 pp.

10. Arnon, D. I., and P. R. Stout. The Essentiality of Certain Elements in Minute Quantity for Plants With Special Reference to Copper. Plant Physiol., v. 14, 1939, pp. 371-375.

11. Soil Science Society of America. Glossary of Soil Science Terms. July 1987, 44 pp.

12. Alexander, M. Introduction to Soil Microbiology. Wiley, 1977, 467 pp.

13. Follet, R. H., L. S. Murphy, and R. L. Donahue. Fertilizers and Soil Amendments. Prentice-Hall, 1981, 557 pp.

14. National Research Council (Natl. Acad. Sci.). Energy in Transition 1985-2010: Final Report on the Committee on Nuclear and Alternative Systems. Freeman, 1979, 213 pp.

15. Trumbull, J. V. A. Coal Fields of the United States. U.S. Geol. Surv., 1960, Sheet 1, 1:500,000 scale.

16. U.S. Code of Federal Regulations. Title 30—Mineral Resources; Chapter VII—Office of Surface Mining Reclamation and Enforcement, Department of the Interior; Oct. 1, 1983.

APPENDIX A.—REFERENCE EVALUATIONS

Bibliographic entry	0001	0002	0003	0004	0005	0006	0007	0008	0009	0010	0011	0012	0013	0014	0015	0016
Coal region	C	N	E	P	E	X	E	X	X	X	N, R	X, N	X	G	G	X
Intended or current land use:																
Cropland																
Grazing land																
Pastureland							S									
Reforestation or afforestation	G						S	G								
Wildlife	G			E												
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal					G											
Soil characterization:																
Soil chemical	E	E					E	G				G	G	E	E	
Soil physical	E	E	S				E	G				G	G	G	E	E
Mineralogical composition														S		
Soil amendments:																
pH modifiers	G					S	E									
Mulches											S					
Fertilizers	G						G	G			S		S			
Sludges						S	E		G	G						
Biological			S													
Topsoil	G															
Compost																
Other																
Economic considerations	G				G											
Short- and long-term additive impacts	G		S			S	E	G	G	G	S					
Techniques for application and/or rates of application	G					S		S	G				S			

	0017	0018	0019	0020	0021	0022	0023	0024	0025	0026	0027	0028	0029	0030	0031	0032
Coal region	X, E	I	X, A	E	E	S	S	S	S	S	S	X, O	N, R	R	X, R	R
Intended or current land use:																
Cropland		E														
Grazing land									S		G					
Pastureland				S	S											
Reforestation or afforestation			G													
Wildlife																
Recreational																
Miscellaneous														S		
Regulations:																
Local																
State		E														
Federal		E														
Soil characterization:																
Soil chemical		E	S	G	G		G	S	S	S	G	G		S	G	
Soil physical	E	E	S	S	S		E	S	S	S	G				G	
Mineralogical composition																
Soil amendments:																
pH modifiers															G	
Mulches				E	E		S	G			G				G	S
Fertilizers				E	E			G							G	S
Sludges				E	E		S									
Biological		G				G	S						E	E	G	G
Topsoil				G	G		S							G		G
Compost		G														
Other																
Economic considerations																
Short- and long-term additive impacts		S		E	E	G		G			G		E	E	G	
Techniques for application and/or rates of application		S		E	E	S		G			G		E	G		

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

Evaluation code: **E**—Excellent, keyword has direct, practical application or specific information on the use of soil amendments and/or the characterization of mine soils; **G**—Good, keyword has direct application, but has less specific information; reference contains good background information; **S**—Satisfactory, keyword has little practical application because of generalities or limited information.

Bibliographic entry	0033	0034	0035	0036	0037	0038	0039	0040	0041	0042	0043	0044	0045	0046	0047	0048
Coal region	R	N	X	E, I	E, I	E	X	I	I	I	X, R	X, O	E	N	X	O
Intended or current land use:																
Cropland				G				S								G
Grazing land		G														G
Pastureland				G												G
Reforestation or afforestation		G							S	G						
Wildlife		S														G
Recreational													E			
Miscellaneous					E								E			
Regulation:																
Local																
State																
Federal								S						S		
Soil characterization:																
Soil chemical	E	S		E	E	E	G		E	E	G		G	S	G	G
Soil physical	G	S		E	E	E	G	S	E	E						G
Mineralogical composition																
Soil amendments:																
pH modifiers									G				G			G
Mulches		G														
Fertilizers									G		S		G	G		G
Sludges																G
Biological	E		G										G			
Topsoil	G					G					G					
Compost																
Other														G		
Economic considerations													G			
Short- and long-term additive impacts	E	S	G						E		G		G	G		G
Techniques for application and/or rates of application	S	G	G						E		G		G	G		G

	0049	0050	0051	0052	0053	0054	0055	0056	0057	0058	0059	0060	0061	0062	0063	0064
Coal region	X, N	G	N, R	N, R	I	E, I	O	I	I	E, I	E, I	G	X, E	X	O	X
Intended or current land use:																
Cropland											G	S				S
Grazing land	G		S	S												
Pastureland									G		G					S
Reforestation or afforestation					S	G		G		G			G			
Wildlife	S															
Recreational																
Miscellaneous																
Regulations:																
Local																
State															S	
Federal						E			S		S					
Soil characterization:																
Soil chemical	S	E	S	S	S			S	S	S	G	G		G	E	G
Soil physical	S				S	G		S	S	S	G					E
Mineralogical composition																G
Soil amendments:																
pH modifiers		S													S	
Mulches														G		
Fertilizers	S								G		S	E		S	S	
Sludges															G	
Biological	G						G									
Topsoil																
Compost																
Other																
Economic considerations																
Short- and long-term additive impacts	G	S						G		G		E		G		
Techniques for application and/or rates of application	G	S						S	G	G		G				

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	0065	0066	0067	0068	0069	0070	0071	0072	0073	0074	0075	0076	0077	0078	0079	0080
Coal region	O	G, E	E	E	I	I	I	I	I	I	I	I	O	N	X	N
Intended or current land use:																
Cropland						S		E	S	G						
Grazing land							S									
Pastureland		S		S	S		G			G						S
Reforestation or afforestation		G	G	S												
Wildlife			S	S												
Recreational				S												
Miscellaneous																
Regulation:																
Local																
State																
Federal								G								
Soil characterization:																
Soil chemical	E			G	E		G	G			E	G	E	S	S	E
Soil physical		S			E	S		E	S				E	S	S	E
Mineralogical composition	E															
Soil amendments:																
pH modifiers				E	E	S	E	E		G	E	G				
Mulches														S		G
Fertilizers		G	S	G	E		E	G		G	G			S		G
Sludges												G				
Biological			E													
Topsoil								E		G						E
Compost																
Other																
Economic considerations		S														
Short- and long-term additive impacts		G	E	G	E	S	E	E		G	E	G		S		E
Techniques for application and/or rates of application			E	E	E		E	E		G	E	G		S		E

	0081	0082	0083	0084	0085	0086	0087	0088	0089	0090	0091	0092	0093	0094	0095	0096
Coal region	N	N, R	X	X, C	X	E	E	E	X, E	X, S	X	E	N, R	N, R	R, X	X, E
Intended or current land use:																
Cropland												S		S		
Grazing land	S									S		S	S	S		
Pastureland												S		S		
Reforestation or afforestation			S			G			S			S		S		S
Wildlife										S		S		S		
Recreational														S		
Miscellaneous							S							S		
Regulations:																
Local																
State																
Federal								G				G				
Soil characterization:																
Soil chemical	E	E				G			G			S	E	G		
Soil physical	E						E	E				S		G		
Mineralogical composition	E															
Soil amendments:																
pH modifiers		G										S				S
Mulches										G		S	G		E	
Fertilizers	G		G	G	G					G	G	S	E		E	E
Sludges										G		S			E	E
Biological						E										E
Topsoil	E	G								G					E	
Compost												S				
Other																
Economic considerations										G	G					
Short- and long-term additive impacts	E	G	G	G	G	E				G		S	E		E	E
Techniques for application and/or rates of application	E	G		G	G	E					E	S	E		E	E

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Bibliographic entry	0097	0098	0099	0100	0101	0102	0103	0104	0105	0106	0107	0108	0109	0110	0111	0112
Coal region	X	X, E	E, X	X	X, E	X, E	X, E	X, E	I	X	E	E	E	E	E	X
Intended or current land use:																
Cropland												S	S		S	
Grazing land																
Pastureland															S	
Reforestation or afforestation		S	S			G	S	S								G
Wildlife											G					
Recreational																
Miscellaneous																
Regulation:																
Local																
State											S					
Federal											S					
Soil characterization:																
Soil chemical	S	E	E			G		E	E						G	G
Soil physical															G	
Mineralogical composition																
Soil amendments:																
pH modifiers				G	E	G		E			G	S		G	G	G
Mulches						G		E		G						
Fertilizers	G	E	E	G	E	G		E			S	S	S		E	
Sludges	G	E	E	G	E	E		E		G		S	S		E	
Biological				G	S	G	E	G	G	E						
Topsoil										G						
Compost																G
Other										G						
Economic considerations											S					
Short- and long-term additive impacts	G	E	E	G	E	E	E	E		E		S	S	G	E	G
Techniques for application and/or rates of application	G	E	E	G	E	E	E	E		E	S	S	S		G	G

	0113	0114	0115	0116	0117	0118	0119	0120	0121	0122	0123	0124	0125	0126	0127	0128
Coal region	X	I	X, R	X, R	O	X	X, N	N	N	O	E	X, C	X, C	N	I, E	I
Intended or current land use:																
Cropland																
Grazing land								G			G			G		
Pastureland																
Reforestation or afforestation							G	G			S					
Wildlife								S						G		
Recreational																
Miscellaneous											S					G
Regulations:																
Local					S											
State					S					G						
Federal					E					E						
Soil characterization:																
Soil chemical							S	G	S		G	G				E
Soil physical	E						S	G	S		G	G				E
Mineralogical composition																
Soil amendments:																
pH modifiers												G				G
Mulches		E												S		
Fertilizers			G	E		G					G	S	G			G
Sludges	G									S						
Biological			G			G						G		G		
Topsoil			G	E												
Compost																
Other																
Economic considerations					E					S						
Short- and long-term additive impacts	G	E	G	E		G					G	G	G	G		G
Techniques for application and/or rates of application		G	S	G		G					G	G	G	S		G

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Bibliographic entry	0129	0130	0131	0132	0133	0134	0135	0136	0137	0138	0139	0140	0141	0142	0143	0144
Coal region	I	G, N	N, X	X	X, E	O	I	X	X	X	E, I	O	E	E	X, G	E
Intended or current land use:																
Cropland												G				
Grazing land							S					G				
Pastureland							S					G	G			
Reforestation or afforestation												G	G	G		
Wildlife			S								G	G	G			
Recreational																
Miscellaneous	S															
Regulation:																
Local																
State		G										S				
Federal												G				
Soil characterization:																
Soil chemical	G	E		E									E		E	
Soil physical	G			E									E		E	
Mineralogical composition		G		E											E	
Soil amendments:																
pH modifiers					S											
Mulches	G															
Fertilizers	S			E			E		G	G		S				
Sludges					S			S								E
Biological													G		E	
Topsoil				E												
Compost					S											
Other			G	E												
Economic considerations												G				
Short- and long-term additive impacts			G	E	S		E	G	G	G					E	G
Techniques for application and/or rates of application	G		G	E			E	S	G	G						E

	0145	0146	0147	0148	0149	0150	0151	0152	0153	0154	0155	0156	0157	0158	0159	0160
Coal region	X	X	X	E	E	E	E	E	I, E	G	G	O	X, N	X	X	E
Intended or current land use:																
Cropland																
Grazing land	S						S				S		S			
Pastureland						G		S				S				
Reforestation or afforestation	S		S		G		S		G							
Wildlife	S				G		S		S							
Recreational	S												S			
Miscellaneous				G												
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	S				S			G	S	E	G					E
Soil physical	S				S			G	S	E	G					G
Mineralogical composition									S							
Soil amendments:																
pH modifiers											G		G		S	G
Mulches					G	E	E		S				G			G
Fertilizers		G		S	G	S	S	G	S		G	G	G	G	G	G
Sludges			S												S	E
Biological					S							E				
Topsoil																
Compost																
Other							E									
Economic considerations				G			E									E
Short- and long-term additive impacts		G	S		G	E	E	E	G		E	G	S	G	S	E
Techniques for application and/or rates of application		G	S	S	G	E	E	G	S		G	E	G		S	E

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Bibliographic entry	0161	0162	0163	0164	0165	0166	0167	0168	0169	0170	0171	0172	0173	0174	0175	0176
Coal region	E	X, R	X	E	X	X	O	O	X	X	G	I	X	E	I	I
Intended or current land use:																
Cropland								G		S						
Grazing land																
Pastureland	S															
Reforestation or afforestation				G							S	S			S	S
Wildlife													G			
Recreational																
Miscellaneous													G			
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	E							G	G		E	E	E		E	G
Soil physical	E						G	G			G	E	E		E	G
Mineralogical composition																
Soil amendments:																
pH modifiers	G								G		G		E	S		G
Mulches	G												G			
Fertilizers	G		G	E		G			G		G		G	S		G
Sludges	E	E	E													
Biological				E	G	G										G
Topsoil	G	G									E				G	
Compost																
Other																
Economic considerations	E															
Short- and long-term additive impacts	E	G	G	G	G	G			G	S	E		E	S		E
Techniques for application and/or rates of application	E	G	G	E	G				S	S	E		G	S	G	G

	0177	0178	0179	0180	0181	0182	0183	0184	0185	0186	0187	0188	0189	0190	0191	0192
Coal region	X	X	E, I	I	X, R	N, R	E	N, R	E	E, I	E	E	E	I	I	N
Intended or current land use:																
Cropland		S		S										G	G	
Grazing land						G										S
Pastureland							S							G	G	
Reforestation or afforestation			G													
Wildlife																
Recreational																
Miscellaneous																
Regulations:																
Local																
State			G													
Federal			G													
Soil characterization:																
Soil chemical	G	S			G	G		E	G			S	G	S	S	G
Soil physical		S			G	S			E			S	E	S	S	E
Mineralogical composition								G								
Soil amendments:																
pH modifiers						G	E									
Mulches							E	S			E	G	S			
Fertilizers						G	G		G	S	G	G	G			
Sludges							E									
Biological			G		G	E										
Topsoil				S				E								
Compost																
Other								E								
Economic considerations			G													
Short- and long-term additive impacts				S	E	E	E	G	E	G	E	G	E			
Techniques for application and/or rates of application			G			G	E	G	G	S	E	G	G			

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Bibliographic entry	0193	0194	0195	0196	0197	0198	0199	0200	0201	0202	0203	0204	0205	0206	0207	0208
Coal region	O	X, O	X	E	X, I	X	X	X	X	G, I	G	O	I	I	X	E
Intended or current land use:																
Cropland	G															
Grazing land	G									S	G					
Pastureland	G									S						
Reforestation or afforestation																
Wildlife																
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal										S						
Soil characterization:																
Soil chemical	S	E		S		G	E	G		E	E	S		S	G	E
Soil physical	S					G	E	S		E	E	S		E		E
Mineralogical composition							S								G	S
Soil amendments:																
pH modifiers	G						G		G	E	E					
Mulches			G			G	G				E					
Fertilizers	G		G			G	G			E	E		S		G	
Sludges						G			G							
Biological	G				G											
Topsoil														E		
Compost																
Other																
Economic considerations																
Short- and long-term additive impacts	G		G			G	G	G		E	E		S	G	G	
Techniques for application and/or rates of application	G		G			G	G			E	E		S	G	S	

	0209	0210	0211	0212	0213	0214	0215	0216	0217	0218	0219	0220	0221	0222	0223	0224
Coal region	X	X, P	X	E, G	A	O	G	S	G	A	X	N, R	O	E, G	X	X
Intended or current land use:																
Cropland					S				S	S						
Grazing land		S			S					S		S				
Pastureland						G			G							
Reforestation or afforestation					S				S				G	G		
Wildlife									S	G						
Recreational																
Miscellaneous																
Regulations:																
Local																
State																
Federal										S						
Soil characterization:																
Soil chemical		S				E	G	G	S		E	S				
Soil physical		S				E	G	G	S			S				
Mineralogical composition																
Soil amendments:																
pH modifiers				G			G									
Mulches		G		G			G									
Fertilizers	G	G		G	S	E	E			S						
Sludges				S			E							S	S	S
Biological	S		G					G					G	E		
Topsoil								G								
Compost																
Other		G														
Economic considerations	S												G	E		
Short- and long-term additive impacts	G	G		G	S	E	E	G		S			G	G	S	S
Techniques for application and/or rates of application	G	G		G	S	E	E	G		S			G	E	S	

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Bibliographic entry	0225	0226	0227	0228	0229	0230	0231	0232	0233	0234	0235	0236	0237	0238	0239	0240
Coal region	E	X	X, N	E, G	E	E	E	X, C	X, N	E	X	E	X	I	I	I
Intended or current land use:																
Cropland									S						E	
Grazing land			G						S				G			
Pastureland																
Reforestation or afforestation	G				S	S	G			G						
Wildlife			G									G				
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal														G		
Soil characterization:																
Soil chemical	G		G	G		G	G	G	G	G			S	G	E	G
Soil physical	G		G	G		G	G		G	E			S	G	E	G
Mineralogical composition																
Soil amendments:																
pH modifiers				S				S						G		G
Mulches	G		G		G				S	E		G	G			
Fertilizers	G	S	G	E	E			S		E	S	G	S	G	G	G
Sludges		S							S							S
Biological				G		E			G		G					
Topsoil							E							G		
Compost										S						
Other																
Economic considerations																
Short- and long-term additive impacts	E	S	G	E	E	E	E	G	G	E	G	G		G	E	G
Techniques for application and/or rates of application	E	S	G	G	G	G		S	S	G	G	G		G	G	G

	0241	0242	0243	0244	0245	0246	0247	0248	0249	0250	0251	0252	0253	0254	0255	0256
Coal region	I	E	E	E	E	E	E	O, C	C	I	E	N	N	X	I	X
Intended or current land use:																
Cropland	E									S					S	
Grazing land									G	S		G				
Pastureland					S	S			G	S						
Reforestation or afforestation						S				S	S				S	
Wildlife									G	S						
Recreational										S						
Miscellaneous										S						
Regulations:																
Local																
State											G					
Federal		G	G													
Soil characterization:																
Soil chemical	E	E	E	E	E	E	E			E	S					
Soil physical				E	E					E	S					
Mineralogical composition		E	E	E		E										
Soil amendments:																
pH modifiers	G	G			G	E				S	S					S
Mulches						E	G					E	E			
Fertilizers	G	G	S		G	E	G	S	E		G					
Sludges		G	S			E	G		E					G		G
Biological	G				E			E	E							
Topsoil	E		E		E	E		G	G				G			
Compost																
Other																G
Economic considerations								G								
Short- and long-term additive impacts	E	G	G		E	E	E	E	E	S	G	E				G
Techniques for application and/or rates of application	G	G	S		E	E	G	G	E	S	G	G	E			

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Bibliographic entry	0257	0258	0259	0260	0261	0262	0263	0264	0265	0266	0267	0268	0269	0270	0271	0272
Coal region	X, C	X, O	E, I	E	E	E	E	E, I	E	E	E, I	E, G	E	E, I	E	E, I
Intended or current land use:																
Cropland																
Grazing land																
Pastureland				S						S			G			
Reforestation or afforestation			G	G	S	G	G	G	S			E		G	G	G
Wildlife																
Recreational																
Miscellaneous																
Regulation:																
Local																
State												G	S	S		
Federal												G		G		
Soil characterization:																
Soil chemical	G		S	S	S	G			G	G	E		G	S		S
Soil physical	G	G		S	S	G			G					S		S
Mineralogical composition	G															
Soil amendments:																
pH modifiers										E				S		
Mulches								S						S		
Fertilizers					S			G		E				S	E	
Sludges																
Biological								G								
Topsoil										G				S		
Compost																
Other																
Economic considerations								S				G				
Short- and long-term additive impacts					S					E					E	
Techniques for application and/or rates of application					S					G					E	

	0273	0274	0275	0276	0277	0278	0279	0280	0281	0282	0283	0284	0285	0286	0287	0288
Coal region	X, S	X, S	X, S	X	S	S	O	G	X	E	N	N	N	N	P, S	X
Intended or current land use:																
Cropland			S										S			
Grazing land	G	G			E						G	S	S	S		
Pastureland										S	S		S			
Reforestation or afforestation													S			G
Wildlife	S	S									S				S	
Recreational																
Miscellaneous																
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical					G		S									G
Soil physical					G		S									G
Mineralogical composition							S									
Soil amendments:																
pH modifiers							G			E						
Mulches	S	S	G			E	G						G	G	S	
Fertilizers	S	S	G				G	S	G	E	G	G	E	G	G	E
Sludges				S			G	S		E						
Biological							G			S			S			
Topsoil	G	G	S				G									
Compost							G			E						
Other							G							G		
Economic considerations				S			G									
Short- and long-term additive impacts	G	G	E			E	G	S	G	E	S	G	E	G	G	E
Techniques for application and/or rates of application	G	G	G			G	G	S		E	G	S	E	G	G	E

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	0289	0290	0291	0292	0293	0294	0295	0296	0297	0298	0299	0300	0301	0302	0303	0304
Coal region	X	E	X	X, E	G, I	G	X	X	X, R	N	N	N	N	N	N	N
Intended or current land use:																
Cropland					S					G		G				S
Grazing land									S	G				S		S
Pastureland				S	S											S
Reforestation or afforestation	S						S									
Wildlife					E											
Recreational																
Miscellaneous																
Regulation:																
Local																
State											G					
Federal																
Soil characterization:																
Soil chemical	G	E	G		S	E			G	E	E	G	E	E	G	E
Soil physical	G		G		S	E			G	E	E	G		E	G	
Mineralogical composition						E								E		
Soil amendments:																
pH modifiers		S		S				G								E
Mulches		S		G					G	G						
Fertilizers	E	S		G	S	G		S	E	G						
Sludges							G									
Biological							G									
Topsoil		S								E		G				
Compost																
Other										G				E		
Economic considerations																
Short- and long-term additive impacts	E			S	S	G	G	G	E	E		G		E		E
Techniques for application and/or rates of application	E			G	S	S		G	E	E		G		E		

	0305	0306	0307	0308	0309	0310	0311	0312	0313	0314	0315	0316	0317	0318	0319	0320
Coal region	X	I	I	I	E	X	X	I	I	X	C, X	C	X, C	E, I	E	I
Intended or current land use:																
Cropland				E				G	G				G			
Grazing land																
Pastureland		G												G		
Reforestation or afforestation			G													
Wildlife					G											
Recreational																
Miscellaneous																
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical		S		E				G			E	E		E	E	G
Soil physical		S						G		G	G	G	G	E	G	
Mineralogical composition																
Soil amendments:																
pH modifiers				G	S									G		E
Mulches														E	E	
Fertilizers				G	S			G						E	G	E
Sludges	S				E	G	G									
Biological			E													
Topsoil								E	E							
Compost																
Other																
Economic considerations				E												
Short- and long-term additive impacts	S		E	G	E	G	G	G	G					E	E	E
Techniques for application and/or rates of application			S	G	G	G		G	E					E	E	E

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	0321	0322	0323	0324	0325	0326	0327	0328	0329	0330	0331	0332	0333	0334	0335	0336
Coal region	N	N	S	X	X, E	S	O	N	E	N, R	I	G, N	X	X	E	E
Intended or current land use:																
Cropland											E			S		
Grazing land	E	E	G					E		E		S				
Pastureland									S							
Reforestation or afforestation									S							
Wildlife			G					G	S	E						
Recreational																
Miscellaneous																
Regulation:																
Local																
State			G													
Federal																
Soil characterization:																
Soil chemical	S	S			G	G		E	G		G	S			E	G
Soil physical	S	S			G	G		E	G		G	S				
Mineralogical composition																
Soil amendments:																
pH modifiers											G					
Mulches						E		E		S						
Fertilizers								E	G		G				S	
Sludges				S			G							G	S	
Biological						E									S	
Topsoil						E									S	
Compost																
Other													G			
Economic considerations							G									
Short- and long-term additive impacts				S		E	G	E		G	G		G	G		
Techniques for application and/or rates of application				S		G	G	E	S	S	S		G	G		

	0337	0338	0339	0340	0341	0342	0343	0344	0345	0346	0347	0348	0349	0350	0351	0352
Coal region	E	E	S	O	O	E, I	I	X, I	E	E	X	E	I, E	X	X	X
Intended or current land use:																
Cropland				S				S		S					S	S
Grazing land			S	S						S			E			
Pastureland				S						S			E			
Reforestation or afforestation				S						S						
Wildlife			S	S												
Recreational				S												
Miscellaneous				S												
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical		E		E	G	G	E	E	E	E		E	S	S	S	G
Soil physical		E	S	E			E			E		S		S	G	
Mineralogical composition												E				
Soil amendments:																
pH modifiers						G	E						G		G	G
Mulches						S										
Fertilizers											S		S		S	
Sludges											S			G		
Biological																
Topsoil																
Compost											S					
Other	E							G								
Economic considerations															S	G
Short- and long-term additive impacts	E						E	G			S		E	G	G	G
Techniques for application and/or rates of application	G						G	G			S		G	S	G	G

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	0353	0354	0355	0356	0357	0358	0359	0360	0361	0362	0363	0364	0365	0366	0367	0368
Coal region	X, R	X	E	X, A	C, X	C, X	I	X	X	S	X, R	X	S	N, R	N,R	X
Intended or current land use:																
Cropland							S							S		
Grazing land										G	S			S		
Pastureland														S		
Reforestation or afforestation			S	S	S	S				G			G			
Wildlife					S								G			
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal		G														
Soil characterization:																
Soil chemical	G	G	G	S			G	G	S	E				E	E	
Soil physical	S	G	G	S			E	S	S	E						G
Mineralogical composition															G	
Soil amendments:																
pH modifiers	G		S							E						
Mulches		S									E		G			
Fertilizers	G		G		S	E	S		G	E			G			
Sludges												S				
Biological													E			
Topsoil	G	G	E							E	E					
Compost										E						
Other		G			S	E										
Economic considerations																
Short- and long-term additive impacts	G	G	E		S	E	S	G	G	E	E	S	E			
Techniques for application and/or rates of application	G	S	E		S	E	S	G		E	E	S	G			

	0369	0370	0371	0372	0373	0374	0375	0376	0377	0378	0379	0380	0381	0382	0383	0384
Coal region	X, O	X, A	E	E	X, C	E	R	R	S	X, S	S	S	S	S	S	S
Intended or current land use:																
Cropland	G															
Grazing land	S									G						
Pastureland	S															
Reforestation or afforestation		S				G										
Wildlife			G	E												
Recreational																
Miscellaneous																
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	G	G	G		G		S	G	G	S	E		E	E	E	E
Soil physical	G	G			G		S	G	G	G				G	G	G
Mineralogical composition					G			G								
Soil amendments:																
pH modifiers	E															
Mulches	G			S		G	S			G	G	G	S	G	G	
Fertilizers	E			S						G	G	G	S	G	G	
Sludges																
Biological									G		E	G		E	E	
Topsoil									E		G	E	E	E	G	E
Compost	G									G						
Other																
Economic considerations	E															
Short- and long-term additive impacts	E			S		E	S			G	E	E	E	E	E	
Techniques for application and/or rates of application	E			S		G				G		E		E		

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Bibliographic entry	0385	0386	0387	0388	0389	0390	0391	0392	0393	0394	0395	0396	0397	0398	0399	0400
Coal region	S	S	S	S	X	X, P	X, C	E	E	X	X	X	X	G	E, I	X, R
Intended or current land use:																
Cropland				S									S			
Grazing land																
Pastureland																
Reforestation or afforestation															S	
Wildlife																
Recreational																
Miscellaneous																
Regulation:																
Local																
State															S	
Federal																
Soil characterization:																
Soil chemical	G	E	E	E	G	E	G	G	G	G		G	G	E		G
Soil physical		G	G			E	G	G	G	S			G	E		S
Mineralogical composition																
Soil amendments:																
pH modifiers				S				G	G					S	S	
Mulches	G	S														
Fertilizers			G	S	G	S		G	G		S	G	G	G	S	G
Sludges	G		G													
Biological	G		G													
Topsoil																G
Compost																
Other																
Economic considerations																
Short- and long-term additive impacts	E	S	E		G	S		G	E			G	G	G	S	G
Techniques for application and/or rates of application	G	S	G			S		G	G		S	S		G	S	G

	0401	0402	0403	0404	0405	0406	0407	0408	0409	0410	0411	0412	0413	0414	0415	0416
Coal region	E	X, A	E	I	R, S	E	N	N	E	E	N	X	I	X	X	E
Intended or current land use:																
Cropland				S												
Grazing land							G				S		G			
Pastureland													G			
Reforestation or afforestation		S				E										
Wildlife																
Recreational																
Miscellaneous	G			S					E	S						
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical		G	G	G							E		S	G		
Soil physical		G	S	G												
Mineralogical composition																
Soil amendments:																
pH modifiers			G						G		E	S				
Mulches											S			G		
Fertilizers			E			S			S		S					
Sludges			E									G			S	
Biological																E
Topsoil							E	E			E					
Compost																
Other																
Economic considerations									G							
Short- and long-term additive impacts			E				E	E	G		E	G		G		E
Techniques for application and/or rates of application			G			S	E	E	G		E	S				G

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Bibliographic entry	0417	0418	0419	0420	0421	0422	0423	0424	0425	0426	0427	0428	0429	0430	0431	0432
Coal region	E	E	X, S	N	E, I	I	I	I	E, I	X	E	E	I	S	O	N
Intended or current land use:																
Cropland					S	G	E	G	S				S			
Grazing land			S	G					S					G		
Pastureland						G	S		S							
Reforestation or afforestation	G				S				S		S	G				
Wildlife									S						E	
Recreational									S							
Miscellaneous		G							S							
Regulation:																
Local																
State							E	S					G			
Federal						G	E						G		S	
Soil characterization:																
Soil chemical			G	E	G	S	E	G	G					E	S	S
Soil physical					G	S	E	G	G				G	E	S	E
Mineralogical composition																
Soil amendments:																
pH modifiers	S				G				G						S	
Mulches	S		G						G		E	E			S	
Fertilizers	S				G	G	G	G	G	G	S	G			S	
Sludges											S					
Biological			G				G									
Topsoil							G	G	G					G		
Compost																
Other		G			G											
Economic considerations			E		E					S	S				S	
Short- and long-term additive impacts	S	G	E		G	G	E	E	G	G	E	E		G		
Techniques for application and/or rates of application	S	G	E		G	G	G	G	G	G	E	E				

	0433	0434	0435	0436	0437	0438	0439	0440	0441	0442	0443	0444	0445	0446	0447	0448
Coal region	S	O	X, R	I	I	I	X	X, E	I	X	R	X, E	X	E, I	N, R	E
Intended or current land use:																
Cropland								G	S	S						S
Grazing land	G							S								S
Pastureland								S	S							S
Reforestation or afforestation		G	G				S	S				E				S
Wildlife								S								S
Recreational								S	S							S
Miscellaneous								S	S							S
Regulations:																
Local																
State								G	G							
Federal																
Soil characterization:																
Soil chemical		G		G	G	S	S	G	G					S	E	E
Soil physical		G						G	G	G				S		E
Mineralogical composition																
Soil amendments:																
pH modifiers				G	G	E	S	S	S					S		
Mulches	G		G					S			S					
Fertilizers			G				G	S	S	G		G		S	S	
Sludges			G								S		S			
Biological		G	E				G					G				
Topsoil																
Compost										G						
Other				E												
Economic considerations																
Short- and long-term additive impacts	G	G	E	E	E	E	G	S	S	G	S	G	S	S	S	
Techniques for application and/or rates of application	G		E	E	G	G	G	S	S	S	S	G	S	S	S	

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Bibliographic entry	0449	0450	0451	0452	0453	0454	0455	0456	0457	0458	0459	0460	0461	0462	0463	0464
Coal region	I	N	N	N	N	N	N	N	X, E	N, R	E	C	E	N	X	X
Intended or current land use:																
Cropland					G		G	S								
Grazing land												S				
Pastureland													S			
Reforestation or afforestation	S											G				G
Wildlife	S															
Recreational	S															
Miscellaneous																
Regulation:																
Local																
State																
Federal										G						
Soil characterization:																
Soil chemical	S		S	S	G	G	G	G	E	G	E		E	E		S
Soil physical	S	E		S	G	G	G	E	E	G		E	E			
Mineralogical composition																
Soil amendments:																
pH modifiers									S		E		G	E		
Mulches						S										
Fertilizers					E		G	E	S	S					G	G
Sludges																S
Biological	S														G	G
Topsoil			S		E	E	E	E	G	G						
Compost																
Other						S							E			
Economic considerations										S						
Short- and long-term additive impacts	S		S		E	E	E	E	G	G	E		E	E	G	G
Techniques for application and/or rates of application	S				E	E	E	G	G	G			E	E		G

	0465	0466	0467	0468	0469	0470	0471	0472	0473	0474	0475	0476	0477	0478	0479	0480
Coal region	R	X, C	X	X	X	X	E	E	E	X	E	S	I	E, I	I	I
Intended or current land use:																
Cropland													E			
Grazing land																
Pastureland																
Reforestation or afforestation							S		E		G				G	G
Wildlife															G	
Recreational																
Miscellaneous	S							G								
Regulations:																
Local																
State								S								
Federal																
Soil characterization:																
Soil chemical							S		G		E	G	G	S		E
Soil physical		G											G	S		
Mineralogical composition																
Soil amendments:																
pH modifiers			G			G		S	S				G	S	E	E
Mulches														S		
Fertilizers			G			G		S	S				G	S		
Sludges				G	G					S						
Biological								S			E					
Topsoil	G			G				S				G				
Compost					G			S								
Other																
Economic considerations								S								
Short- and long-term additive impacts	G		G	G	G	G		G		S		G	G	G	E	E
Techniques for application and/or rates of application				G	S	G		S		S			G	S	E	E

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Bibliographic entry	0481	0482	0483	0484	0485	0486	0487	0488	0489	0490	0491	0492	0493	0494	0495	0496
Coal region	E	N, S	X, E	I	R, X	N	I	E	E	X	I	E	E, I	I	I, G	N, R
Intended or current land use:																
Cropland	S											G	G	G	G	G
Grazing land		G										G	G	G	G	G
Pastureland							S	S	G			G	G	G	G	G
Reforestation or afforestation							S	S				G	G	G	G	G
Wildlife				E			S	S				E	E	E	E	E
Recreational												G	G	G	G	G
Miscellaneous												G	G	G	G	G
Regulation:																
Local																
State							E					G	G	G	G	G
Federal												G	G	G	G	G
Soil characterization:																
Soil chemical			G		G	E			E		G	G	G	G	G	G
Soil physical					G					G	S	G	G	G	G	G
Mineralogical composition																
Soil amendments:																
pH modifiers			G	E				G	G		E					
Mulches		G														
Fertilizers	G			G			S	G	G		G					
Sludges									E							
Biological						G										
Topsoil				G			S	G			E					
Compost																
Other					E											
Economic considerations												S				
Short- and long-term additive impacts	G	G	G	G	E			E	E		E					
Techniques for application and/or rates of application	G	S		E	E			G	G		E					

	0497	0498	0499	0500	0501	0502	0503	0504	0505	0506	0507	0508	0509	0510	0511	0512
Coal region	X	I	X	R, S	N	N	N	N	N	E	X	X	R	R	X, O	G
Intended or current land use:																
Cropland		S								E				E		S
Grazing land				G	S	S	G	S	S	G				G		
Pastureland								S		G				G		S
Reforestation or afforestation										G				G		
Wildlife				G						G				G		
Recreational										G				G		
Miscellaneous										G		G	G	G		
Regulations:																
Local																
State																
Federal										E		G		E		
Soil characterization:																
Soil chemical		E		E				S	S	G		S		G		E
Soil physical				E						E				G		E
Mineralogical composition				E												
Soil amendments:																
pH modifiers		G														
Mulches				S						G				G		
Fertilizers		G	S	G	S	G	S	S	S	G				G		G
Sludges	S	E		G						G	G			G		
Biological																
Topsoil										E						
Compost																
Other										S				S		
Economic considerations												G	E			
Short- and long-term additive impacts	S	E	G	G	G	G	G	G	G	G	G			G		E
Techniques for application and/or rates of application	S	E		G	S	G	S	S	S	E				G		G

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	0513	0514	0515	0516	0517	0518	0519	0520	0521	0522	0523	0524	0525	0526	0527	0528
Coal region	G	G	I	I	X	I	N	X	X	E, G	N, R	X	I	E	X	A, C
Intended or current land use:																
Cropland				E							G				G	
Grazing land											G					S
Pastureland											G					
Reforestation or afforestation								S			G		S			
Wildlife											G					
Recreational											G					
Miscellaneous											G			S		
Regulation:																
Local																
State											G					
Federal											G					
Soil characterization:																
Soil chemical	E	G			G	G	S	G	G		S		G			E
Soil physical			E	G			S				S				G	
Mineralogical composition																
Soil amendments:																
pH modifiers						G							S			
Mulches										G						
Fertilizers	G	E			G		G						E		G	
Sludges							G		G							
Biological												G	E			
Topsoil						G	G									
Compost																
Other																
Economic considerations																
Short- and long-term additive impacts	E	E			G	G	G		G	G		G	E		G	
Techniques for application and/or rates of application	G	E			S	G	G			G		G	G		G	

	0529	0530	0531	0532	0533	0534	0535	0536	0537	0538	0539	0540	0541	0542	0543	0544
Coal region	E	E, G	I	I	N, R	N	I	X, R	G, N	X	N	I	O	I	X, C	I
Intended or current land use:																
Cropland									S			S	G	G		
Grazing land						G		S	S							
Pastureland																
Reforestation or afforestation	G							S	S							
Wildlife	S				E			S								E
Recreational																E
Miscellaneous																
Regulations:																
Local																
State																
Federal	S												G			
Soil characterization:																
Soil chemical	S	S	E	E	S	E	E	G	G				G		G	E
Soil physical	S		E	E	S		G	G	G			E	G	G		E
Mineralogical composition																
Soil amendments:																
pH modifiers	S						G									E
Mulches	S				G			G	G							
Fertilizers	S				G		G	G	G							G
Sludges							G	G		S						
Biological								S			G			E		E
Topsoil											G					
Compost																
Other							G									
Economic considerations									E							G
Short- and long-term additive impacts	S				G		G	G	G	S	G			E		E
Techniques for application and/or rates of application	S				G		G	G	G	G	S	S		E		E

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Bibliographic entry	0545	0546	0547	0548	0549	0550	0551	0552	0553	0554	0555	0556	0557	0558	0559	0560
Coal region	R	N	I	I	X	X	O	I	I	I	X	I	I	I	X	E
Intended or current land use:																
Cropland								G	S							
Grazing land										S						
Pastureland			G							S		S				
Reforestation or afforestation						G									G	
Wildlife			G												G	
Recreational																
Miscellaneous																
Regulation:																
Local																
State															G	
Federal			G													
Soil characterization:																
Soil chemical			E	E		G	G	E		G		G	S	E	G	
Soil physical			E					E		G		G	S	E	G	E
Mineralogical composition																
Soil amendments:																
pH modifiers			E	E						E		E	S	E		
Mulches		G	G											G		
Fertilizers			E	G		G		E	S			G		G		
Sludges			E	E	S					E		E	S	E		
Biological						G					G					
Topsoil	S	E	E	E				E	S							
Compost																
Other																
Economic considerations														S		
Short- and long-term additive impacts	S	E	E	E		G		E	S	E		E	S	E		
Techniques for application and/or rates of application		E	E	E		G		G	S	E		E	S	E		

	0561	0562	0563	0564	0565	0566	0567	0568	0569	0570	0571	0572	0573	0574	0575	0576
Coal region	I	N	O	N, P	N, R	E	X	E	E	X	X, S	E	E	X	X, S	N, R
Intended or current land use:																
Cropland		G										S	G			S
Grazing land		G													G	S
Pastureland								S				S				S
Reforestation or afforestation	G											S				S
Wildlife																S
Recreational																S
Miscellaneous																
Regulations:																
Local																
State		G														
Federal		G														
Soil characterization:																
Soil chemical		S	G	E	E			G		S		G	E	S	E	S
Soil physical	E	S	S							S		G	G	S	E	S
Mineralogical composition			G													S
Soil amendments:																
pH modifiers									S				G		G	
Mulches	S				S											S
Fertilizers	S				S			E		S			S	G		S
Sludges						S	S	E	S	G						
Biological																
Topsoil	E												G			S
Compost																
Other		S														
Economic considerations		G											E			S
Short- and long-term additive impacts	E	S			S		S	E	S	G			S	G	E	S
Techniques for application and/or rates of application	G	S						E	S	G			E		G	S

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Bibliographic entry	0577	0578	0579	0580	0581	0582	0583	0584	0585	0586	0587	0588	0589	0590	0591	0592
Coal region	E	E	E	E	E	E	X	R	X, R	X, R	X	X, R	O	O	N	E
Intended or current land use:																
Cropland																
Grazing land									S			G			S	
Pastureland																
Reforestation or afforestation				S	G	G										
Wildlife								G	S			S				
Recreational	G	G														
Miscellaneous																E
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical			S		E	S	S		G	G		E				
Soil physical																
Mineralogical composition																
Soil amendments:																
pH modifiers		S			G	G										
Mulches								S		S						
Fertilizers					G	S	G	G		S		S			S	
Sludges			E	E	G		G				S					
Biological													G	G		
Topsoil								G	E			G				
Compost		S														
Other																
Economic considerations																
Short- and long-term additive impacts		S	E	E	G	G	G	G	E	G	S	G		G	S	
Techniques for application and/or rates of application		S	G	G	S	G	G	S	E	G		G			S	

	0593	0594	0595	0596	0597	0598	0599	0600	0601	0602	0603	0604	0605	0606	0607	0608
Coal region	E	E	E	E	X	X	X	O	E, I	E, I	N	E	X, E	I	X	N
Intended or current land use:																
Cropland								S	S							
Grazing land								S	S		G					S
Pastureland								S	S			S				
Reforestation or afforestation			S	G	S			S	S	E			G			
Wildlife									S							
Recreational								S	S							
Miscellaneous		G						S	S							
Regulations:																
Local																
State									E	G						
Federal									E	G						
Soil characterization:																
Soil chemical			S		S			S	S	G	E		G			E
Soil physical	S		S		S			S	S	G	E					E
Mineralogical composition																
Soil amendments:																
pH modifiers		S							S							E
Mulches		S		G								E				
Fertilizers		S	S	E					S		E	G				E
Sludges						S	S						E			
Biological													G	G	G	
Topsoil										G	S					
Compost		S										G				
Other	E										G					E
Economic considerations																E
Short- and long-term additive impacts	E		S	E		S	S		S		E	E	E	G	G	E
Techniques for application and/or rates of application	G			E		S			S		E	E	E	S		G

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Bibliographic entry	0609	0610	0611	0612	0613	0614	0615	0616	0617	0618	0619	0620	0621	0622	0623	0624
Coal region	G	C	E	I	X	N, R	E	E	E	I	X, E	X, C	R	E	X, E	I
Intended or current land use:																
Cropland														S		G
Grazing land													E			
Pastureland															S	G
Reforestation or afforestation		S					E	G	E			S			S	
Wildlife		S		G									G		S	
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	E	S					G	S	S						G	G
Soil physical	E	S									G				G	G
Mineralogical composition																
Soil amendments:																
pH modifiers			E	E						G		G			E	
Mulches						G								G	G	G
Fertilizers		S		S				S		G		G		S	E	S
Sludges		S			S											
Biological																
Topsoil				E		G						S	G			
Compost																
Other																
Economic considerations												S				S
Short- and long-term additive impacts		S	E	E				S		E		S	G	S	E	
Techniques for application and/or rates of application		S	E	G		E		S		G		G	G	G	E	

	0625	0626	0627	0628	0629	0630	0631	0632	0633	0634	0635	0636	0637	0638	0639	0640
Coal region	X	I	I	I	X, R	C	E	I	E	X	X	R	I	X, E	X, C	X
Intended or current land use:																
Cropland		S						S								
Grazing land					G											
Pastureland																
Reforestation or afforestation									S						S	
Wildlife													S			
Recreational					G	G							S			
Miscellaneous					G	G										
Regulations:																
Local					G											
State					G											
Federal													S			
Soil characterization:																
Soil chemical	G	E	E	G	G		S	S			G	G	G	G		
Soil physical					G				G			G	G			
Mineralogical composition									S							
Soil amendments:																
pH modifiers		E	G	G		G										
Mulches												E				
Fertilizers			G	G		G						G				
Sludges										S	G	E			E	G
Biological								E				E		G		
Topsoil								E				G				
Compost															E	
Other																
Economic considerations																
Short- and long-term additive impacts		E	E	G		G		E			G	E		E	E	G
Techniques for application and/or rates of application		E	G	G		G		G		S	S	E		G	E	G

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Bibliographic entry	0641	0642	0643	0644	0645	0646	0647	0648	0649	0650	0651	0652	0653	0654	0655	0656
Coal region	X	I	X	S	X, C	X	E, G	E	O	E	E, G	X	X	E	X, R	C
Intended or current land use:																
Cropland		E							E							S
Grazing land				S			S		E		S					
Pastureland							S		E	S	S					
Reforestation or afforestation	S						G	G	E							G
Wildlife																S
Recreational																
Miscellaneous															G	
Regulation:																
Local																
State		G														
Federal		G					G									
Soil characterization:																
Soil chemical	G			E	G		S		E	G	G		E	G	G	G
Soil physical	G			E			S		E	G	E		E	G	G	G
Mineralogical composition																
Soil amendments:																
pH modifiers									E	G	G			G		
Mulches								G	E	G				G		
Fertilizers						G			E	G	G	S	G	G		G
Sludges									G			S	E	E		
Biological										S						
Topsoil			G													G
Compost														E		
Other																
Economic considerations									G							
Short- and long-term additive impacts			G			G		E	E	E	G	S	E	E		G
Techniques for application and/or rates of application			S			S		G	E	G	G	S	E	E		G

	0657	0658	0659	0660	0661	0662	0663	0664	0665	0666	0667	0668	0669	0670	0671	0672
Coal region	E, I	X	R, N	E	X	E	X, C	X	I, E	O	E	X	I	I	E	X
Intended or current land use:																
Cropland							S									
Grazing land			G				S									
Pastureland							S							S		
Reforestation or afforestation				E			S		E	S	E				G	
Wildlife							S		G		G			S		
Recreational				G			S						S			
Miscellaneous							S									
Regulations:																
Local				E												
State				S												
Federal				S												
Soil characterization:																
Soil chemical	S	S	G	E	S		S					S		G	G	S
Soil physical		S	G	E	S		S					S		S	G	S
Mineralogical composition							S									
Soil amendments:																
pH modifiers				G			S						S	S		G
Mulches				G			S						S	S		
Fertilizers	E			G	G		S				G	G		S	E	S
Sludges														S		G
Biological				G		G			E	G	E					
Topsoil			G		G											
Compost					G											
Other				S			S	S								S
Economic considerations				G												
Short- and long-term additive impacts	E			G	G		S		E	E	E	G	S	E	E	G
Techniques for application and/or rates of application	E		S	S			S		G	G	E			G	G	S

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Bibliographic entry	0673	0674	0675	0676	0677	0678	0679	0680	0681	0682	0683	0684	0685	0686	0687	0688
Coal region	N	X, E	E	O	X	C	I	R	R	X	R	I	E	X	X	X, E
Intended or current land use:																
Cropland				S			G									
Grazing land	S							S		G	S					
Pastureland							G									
Reforestation or afforestation		G				G	G									G
Wildlife		S	G													
Recreational																
Miscellaneous													S			
Regulation:																
Local																
State				G												
Federal				E												
Soil characterization:																
Soil chemical	E		S			S	E		E		E				S	
Soil physical			S			S	E		G		E				G	
Mineralogical composition																
Soil amendments:																
pH modifiers		G					G			S						
Mulches			E					E		G					G	
Fertilizers	G		E		G	S	G		E		G				G	G
Sludges					G		G									
Biological																
Topsoil									E		E					
Compost																
Other																
Economic considerations				S												
Short- and long-term additive impacts	E	E	E		G	S	E	E	E		E	E		S	G	G
Techniques for application and/or rates of application	G	S	E		G	S	G	E	E		E	G		S	G	G

	0689	0690	0691	0692	0693	0694	0695	0696	0697	0698	0699	0700	0701	0702	0703	0704
Coal region	O	R, S	R, S	R, S	R, S	E	N	I	I	X	X	X	X	X	X	N
Intended or current land use:																
Cropland								S								
Grazing land		E	S	S	S											
Pastureland																
Reforestation or afforestation						S										
Wildlife		G				S										
Recreational		G				S										
Miscellaneous																
Regulations:																
Local		G														
State		G														
Federal		G														
Soil characterization:																
Soil chemical		E			E		G		G	E	S	S			E	E
Soil physical					G			G	G	E					E	E
Mineralogical composition																
Soil amendments:																
pH modifiers	S					S					G	S				
Mulches	S	G													S	
Fertilizers	S	G	G	G		S						G			S	
Sludges																
Biological	S						G				G	G	E	G		
Topsoil							G		G							
Compost																
Other																
Economic considerations																
Short- and long-term additive impacts	S	G	E	E		G	G		G		G	G	E	G	S	
Techniques for application and/or rates of application	S	G	G	G		S			G		S	S	G	G	S	

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Bibliographic entry	0705	0706	0707	0708	0709	0710	0711	0712	0713	0714	0715	0716	0717	0718	0719	0720
Coal region	N, R	X, R	X, P	X	X	O	X, O	O	E	X, C	X	N	R	I	X, E	X
Intended or current land use:																
Cropland																G
Grazing land																
Pastureland														G		
Reforestation or afforestation			G	S							S					
Wildlife																
Recreational																
Miscellaneous																
Regulation:																
Local																
State						E										
Federal						E										
Soil characterization:																
Soil chemical		G	G									E	E	E		G
Soil physical	E		G				G			G	S	G	E	G		G
Mineralogical composition																
Soil amendments:																
pH modifiers																
Mulches				G								G				G
Fertilizers		S								G					G	G
Sludges				G				G	G							
Biological		G										E	E			
Topsoil		G										E	E			G
Compost									G							
Other																G
Economic considerations									G							
Short- and long-term additive impacts		G		G					S	G		E	E		G	G
Techniques for application and/or rates of application		S		S					G	G		G			S	G

	0721	0722	0723	0724	0725	0726	0727	0728	0729	0730	0731	0732	0733	0734	0735	0736
Coal region	X	O	X	X	A	I	I, E	S	E	N, R	G	X	N, R	I	I	E
Intended or current land use:																
Cropland	S					S										E
Grazing land					G					S						
Pastureland										S						
Reforestation or afforestation									S	S		S			S	
Wildlife					G		S			S			E			
Recreational																
Miscellaneous							G									
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical		G			G					S	E		G			S
Soil physical					G			G		S	E		G			S
Mineralogical composition																
Soil amendments:																
pH modifiers						G										S
Mulches	S				G								S			E
Fertilizers				S	G	G						G	S			S
Sludges		S												E	S	
Biological		G							E							
Topsoil	S	S	S	S												
Compost																
Other	S							G								
Economic considerations						S							S			
Short- and long-term additive impacts	S			S	G	G		E	E			G	S	E	E	E
Techniques for application and/or rates of application	S				G	G		G	E				S	G	G	G

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	0737	0738	0739	0740	0741	0742	0743	0744	0745	0746	0747	0748	0749	0750	0751	0752
Coal region	E	E	E	E	G	I	X	X	E, I	X, E	X, E	E	N, R	N	N	X, C
Intended or current land use:																
Cropland	G															
Grazing land														S		
Pastureland					G					G						
Reforestation or afforestation			S	S						G	S	S				G
Wildlife			S							G	S					
Recreational																
Miscellaneous																
Regulation:																
Local																
State					S								G			
Federal													G			
Soil characterization:																
Soil chemical	G	S			G		G				G	G	G	G	E	
Soil physical	G				S	E	G				G	G	E		E	G
Mineralogical composition																
Soil amendments:																
pH modifiers	S		G	G					G	G	G	G				
Mulches				E							G	G				
Fertilizers	E			G	S				G	G	G	G				G
Sludges				E			G	S								
Biological		G			G											
Topsoil			G	E								S				
Compost																
Other																
Economic considerations									E	G	G	G				
Short- and long-term additive impacts	E		G	E			G	S		S		S				G
Techniques for application and/or rates of application	E		G	E			S	S	E	G	G	G				G

	0753	0754	0755	0756	0757	0758	0759	0760	0761	0762	0763	0764	0765	0766	0767	0768
Coal region	X, C	X, C	X, E	X, C	O	A	O	I	I	I	I	I	I	I	I	I
Intended or current land use:																
Cropland	S					S	G									
Grazing land	S			S		S	G									
Pastureland	S					S	G						S			
Reforestation or afforestation	S			S	G	E				S	S			G		
Wildlife	S					G	G		G	S			S		S	
Recreational	S															
Miscellaneous	S								G						G	
Regulations:																
Local						S	S									
State						E	S						S		S	
Federal					G	E	S								S	
Soil characterization:																
Soil chemical	E	E	G	G	G	S	G	G	G	G	G	S	E	G	S	E
Soil physical	E		G	G	G	S	G	G	G	G	G	S	S	G	S	E
Mineralogical composition			G				G								S	
Soil amendments:																
pH modifiers	G	G	G						G		E		E	G	G	G
Mulches	S	G									S					
Fertilizers	S	G				S			G		G		S	G		G
Sludges																
Biological											S		G	G	G	
Topsoil																
Compost																
Other	G															
Economic considerations	S										G		S		S	
Short- and long-term additive impacts	G	E	G			S			G		E		E		S	S
Techniques for application and/or rates of application	G	G				S			G		E		E	S	G	G

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Bibliographic entry	0769	0770	0771	0772	0773	0774	0775	0776	0777	0778	0779	0780	0781	0782	0783	0784
Coal region	X	O	I, E	N, R	X	R, S	O	S	N	X	X	X, S	X, S	X	X, C	X
Intended or current land use:																
Cropland		S					G	S								S
Grazing land						S		S	G							
Pastureland		S														S
Reforestation or afforestation		S			S								S			
Wildlife		S	E													
Recreational		S														
Miscellaneous		S														
Regulation:																
Local																
State		S														
Federal		S														
Soil characterization:																
Soil chemical	G			E		S	S					E	G			
Soil physical						S	S			G						
Mineralogical composition	G															
Soil amendments:																
pH modifiers							S				G					
Mulches			S					S	G			E	S			
Fertilizers			S				S	S			S	G	G		G	G
Sludges	G				S									S		
Biological						G	S		S			E				
Topsoil																
Compost																
Other			S					S								
Economic considerations								S								
Short- and long-term additive impacts	G		S		S	G	G	S	G		G	E	E		G	G
Techniques for application and/or rates of application	G		S		S	G	S	S	S			E	G		G	G

	0785	0786	0787	0788	0789	0790	0791	0792	0793	0794	0795	0796	0797	0798	0799	0800
Coal region	X	X	N, R	E	E	E	X	O	I	I	I	X, A	N	X	X	N
Intended or current land use:																
Cropland									G	S	S			S		
Grazing land			S										G			G
Pastureland																
Reforestation or afforestation												S				
Wildlife					G	E						S	G			G
Recreational																
Miscellaneous																
Regulations:																
Local																
State						S							G			
Federal								S								
Soil characterization:																
Soil chemical	G		S			G			E			S			G	E
Soil physical			S			S			E			S			G	E
Mineralogical composition															G	
Soil amendments:																
pH modifiers			G	S		S		S								
Mulches						G							G			
Fertilizers	G					S			E	S	E		S			
Sludges	G	S					G	S						G	G	
Biological			G			S										
Topsoil			G			G			E	S			G			
Compost							G									
Other														G	G	
Economic considerations								S					S			
Short- and long-term additive impacts	G	S	G	S		G	G		E	S	E			G	G	
Techniques for application and/or rates of application	G	S	S	S		G	G		E	S	E		G	G		

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Bibliographic entry	0801	0802	0803	0804	0805	0806	0807	0808	0809	0810	0811	0812	0813	0814	0815	0816
Coal region	N	E	N	X, R	X	X, E	X, A	N, R	N, R	X	X	X	R	R	S	S
Intended or current land use:																
Cropland		E														
Grazing land	G		E	S				G								
Pastureland		E					S									
Reforestation or afforestation																
Wildlife	E		E													
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	G	E	S		S	G	S	E	G	S	G		G	G	G	
Soil physical	E	E	S	G			S	E	G				S	S	S	
Mineralogical composition								S	S							
Soil amendments:																
pH modifiers		G			S	G			S			S				
Mulches			G	G		G		G	S				G	G	E	G
Fertilizers		E	G		S	G		G	S	S					G	
Sludges					S	E				S		S				
Biological																
Topsoil				G											E	G
Compost																
Other																
Economic considerations						G							S	S		
Short- and long-term additive impacts		E	E	G	S	E		G	G	S		S	G	G	E	G
Techniques for application and/or rates of application		E	G	S	S	E		G	S	S		S	G	G	G	G

	0817	0818	0819	0820	0821	0822	0823	0824	0825	0826	0827	0828	0829	0830	0831	0832
Coal region	O	R	N, R	X	X	O	E	E	E	N, R	I	X	E, I	E, I	X, S	X
Intended or current land use:																
Cropland	S			S			S									
Grazing land	S		G					S		S					S	
Pastureland	S							S								
Reforestation or afforestation	S							S								
Wildlife			G								G		S		S	
Recreational																
Miscellaneous																
Regulations:																
Local						E										
State						E										
Federal																
Soil characterization:																
Soil chemical			G	S			E	E					E	G		
Soil physical			G	S			E	E	E				E			
Mineralogical composition			S				E	E								
Soil amendments:																
pH modifiers											G					
Mulches			G												E	
Fertilizers			G	G	S					S	G					
Sludges																S
Biological				G						S						
Topsoil		E													G	
Compost																
Other												S				
Economic considerations																
Short- and long-term additive impacts	E	E	G	G	S					S	G				E	S
Techniques for application and/or rates of application	G	S	G	S						S	G				G	S

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Bibliographic entry	0833	0834	0835	0836	0837	0838	0839	0840	0841	0842	0843	0844	0845	0846	0847	0848
Coal region	X	X	R	O	E	X	X, G	I	X	E	X	X	X	I	I	E
Intended or current land use:																
Cropland		S														
Grazing land						S										
Pastureland							S									
Reforestation or afforestation								S								
Wildlife																
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical			S	G			G							E		G
Soil physical			S		E		G	G								G
Mineralogical composition																
Soil amendments:																
pH modifiers				G			G				G	G			S	
Mulches																
Fertilizers	S					S	G				G	S				
Sludges	S									S	G	G	S	E	S	
Biological									G							
Topsoil			E		E					S						G
Compost		G								S						
Other		G													S	
Economic considerations																
Short- and long-term additive impacts	S	G	E	G	G	S	E		G	S	G	G	S	E	S	E
Techniques for application and/or rates of application			S		E	S	G		S		G	G	S	G	S	S

	0849	0850	0851	0852	0853	0854	0855	0856	0857	0858	0859	0860	0861	0862	0863	0864
Coal region	G	G	N	E	E	E	E	N	X, R	X, R	I, E	E	X	X	X	X
Intended or current land use:																
Cropland				S		S										
Grazing land			G	S												
Pastureland				S	S	S										
Reforestation or afforestation				S		S			G	S	G					
Wildlife																
Recreational																
Miscellaneous																
Regulations:																
Local																
State								E								
Federal								G								
Soil characterization:																
Soil chemical	S	E	S		G	S	S			S		G		G	G	
Soil physical			S			S				S		G		S	S	
Mineralogical composition																
Soil amendments:																
pH modifiers				S	G	G						G				
Mulches				S	G	G				S		G	G			
Fertilizers					G	G			S	G		G				
Sludges					G	S						E				S
Biological											G			G	G	
Topsoil						G		G				E	E			
Compost					G							E				
Other				S	G											
Economic considerations								E				E				
Short- and long-term additive impacts				S	E	S				S	G	E	E			S
Techniques for application and/or rates of application				S	G	G		G		S	G	G	G			S

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Bibliographic entry	0865	0866	0867	0868	0869	0870	0871	0872	0873	0874	0875	0876	0877	0878	0879	0880
Coal region	N	X	I	I	I	I	I	I	I	N	N	N	X	C	E	X
Intended or current land use:																
Cropland			S	E	G			E	E	S	S	S				
Grazing land				S	G					S	S	S				
Pastureland			S	E	G	G	G					S				
Reforestation or afforestation		S		S	S								G	G	G	
Wildlife			S	E	S						S			G		
Recreational				S	S						S					
Miscellaneous				S	S											
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	G		G	S	E	E	G		G	S	S	G	S	G	E	S
Soil physical	E	G	G	S	E	E	G	S	E	G	G	G		G	E	
Mineralogical composition																
Soil amendments:																
pH modifiers			E	E	E	E	E	S	E							S
Mulches			E	G												S
Fertilizers			E	E	E	E	E	G	G	S	S		G	G	E	S
Sludges									E							
Biological														G	E	
Topsoil												E				
Compost									E							S
Other										G	G					
Economic considerations																
Short- and long-term additive impacts			G	G	G	E	E		E	G	G	E	G		E	S
Techniques for application and/or rates of application			E	E	E	E	E		E	G	G	E			E	S

	0881	0882	0883	0884	0885	0886	0887	0888	0889	0890	0891	0892	0893	0894	0895	0896
Coal region	O	X	O	X, E	E	E	I	O	O	O	E	X	X	X	X	X
Intended or current land use:																
Cropland								G			S		G		G	
Grazing land						S					S					
Pastureland						S					S					
Reforestation or afforestation						S	E				S					
Wildlife					E	S	E				S					
Recreational											S					
Miscellaneous											S					
Regulations:																
Local																
State																
Federal								E	G	S	E					
Soil characterization:																
Soil chemical					S			G	S	S	S				G	
Soil physical					S			G	S	S	S				S	
Mineralogical composition										S					G	
Soil amendments:																
pH modifiers					G	G				S						
Mulches					G	G				S						
Fertilizers					G	G	G			S		S	S			
Sludges										S	S		G	S	G	G
Biological																
Topsoil										S						
Compost		S														
Other	E		E								S					
Economic considerations	E		G							S						
Short- and long-term additive impacts	G	S	E		G	G	G				S	S	G	S	G	G
Techniques for application and/or rates of application	E	S	E		G	G	S				S	S	G	S	G	

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Bibliographic entry	0897	0898	0899	0900	0901	0902	0903	0904	0905	0906	0907	0908	0909	0910	0911	0912
Coal region	X	E	O	E	X	X	N, R	X	X	X, R	X, R	X, R	X, N	X, R	R	R
Intended or current land use:																
Cropland					S											E
Grazing land														G	G	E
Pastureland																G
Reforestation or afforestation																
Wildlife															S	
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	G	E				S	S				G	G	S	G	E	E
Soil physical													S		E	E
Mineralogical composition								S	S	G	G	S	S	G		
Soil amendments:																
pH modifiers		S	G	S				S	G							
Mulches	G	S		S									S	E	G	
Fertilizers	G	S		S					S				S	E	E	G
Sludges					S											
Biological																
Topsoil		G	G	S					G				S	E	E	E
Compost																
Other		E	E	E												
Economic considerations		E	E	S												
Short- and long-term additive impacts	G	E	G	E	S			S	G				S	E		E
Techniques for application and/or rates of application	G	G	G	E	S				G				S	E	E	E

	0913	0914	0915	0916	0917	0918	0919	0920	0921	0922	0923	0924	0925	0926	0927	0928
Coal region	X, R	R	R, N	R	R	N, R	X, R	I	X	S	S	X, S	E, I	E	E, I	E
Intended or current land use:																
Cropland				S	S											
Grazing land	S			S	S		G		G			S				
Pastureland				S	S										G	
Reforestation or afforestation								G					S	G	G	
Wildlife							S		G						G	
Recreational																
Miscellaneous																
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical		E	G	S	S	E		E		E	E	E	G			
Soil physical		E	G					G		E	E	G	G			
Mineralogical composition																
Soil amendments:																
pH modifiers													G			
Mulches						G			G			G	G	E		G
Fertilizers	G	G	E	G	G		E	E	G				G	G	S	G
Sludges																
Biological						G	G	E					E			
Topsoil	E						E									
Compost																
Other																
Economic considerations															G	
Short- and long-term additive impacts		E		E	E	G	E	E					E	G		G
Techniques for application and/or rates of application		E		G	G	S	E	G					E	E		G

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	0929	0930	0931	0932	0933	0934	0935	0936	0937	0938	0939	0940	0941	0942	0943	0944
Coal region	E, I	N	N, R	A	X, R	X, P	X, P	N	N	E	E	E	E	E	E, I	I
Intended or current land use:																
Cropland				S		S			G							S
Grazing land		S	S		S	G		G	G							S
Pastureland						G		G						G		S
Reforestation or afforestation	S			S						S				G	S	S
Wildlife				S	S					S						S
Recreational																S
Miscellaneous																S
Regulation:																
Local																G
State																G
Federal				G												G
Soil characterization:																
Soil chemical		S			G	G			G							S
Soil physical						G	G		G							S
Mineralogical composition																
Soil amendments:																
pH modifiers			S													
Mulches	S	S	G									E	E	E	G	
Fertilizers	S	S	G	S	S			S	S			S		E		
Sludges																
Biological										G						
Topsoil			S			G			G		S					
Compost																
Other																
Economic considerations												E	E			
Short- and long-term additive impacts	G	S	G			G			G	G	S	E	G	E	E	
Techniques for application and/or rates of application	G	S	G			G			S			E	G	E	G	

	0945	0946	0947	0948	0949	0950	0951	0952	0953	0954	0955	0956	0957	0958	0959	0960
Coal region	E	E	E	E	E	X	O	E	I	I	E, I	I	E, I	E	E, I	E
Intended or current land use:																
Cropland																
Grazing land											G					
Pastureland	S		S	G					S	S	G			S	S	
Reforestation or afforestation					S									S	S	
Wildlife									S		E					
Recreational																
Miscellaneous																
Regulations:																
Local																
State				S												
Federal				S												
Soil characterization:																
Soil chemical	E	E	E	E			G	G	G	G		S				
Soil physical	E	E	E				E	G		G		G				
Mineralogical composition	E															
Soil amendments:																
pH modifiers	G	S		S						G		S			G	
Mulches	G	E	S	E					G					G		
Fertilizers	E	E	S	E	E	G			E	G	S	S				
Sludges	E	E		E		G										
Biological						G						E	G	G	G	E
Topsoil	E	E	E	E							S			G		
Compost																
Other																
Economic considerations									G							
Short- and long-term additive impacts	E	E	E	E	E	G			G	E	S	E	G	G	G	G
Techniques for application and/or rates of application	G	G	E		E				E	G						S

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	0961	0962	0963	0964	0965	0966	0967	0968	0969	0970	0971	0972	0973	0974	0975	0976
Coal region	X, C	X, C	X, C	X, E	X, N	E	X, C	N, R	X, R	N	O	N, R	N	X	I	O
Intended or current land use:																
Cropland											S					
Grazing land									G	S	S		S			
Pastureland	G	G	G							S	S		S			
Reforestation or afforestation				S							S				S	
Wildlife									S						S	
Recreational																
Miscellaneous																
Regulation:																
Local																
State															G	G
Federal																E
Soil characterization:																
Soil chemical	E	E	E		G		E		S	G	E	E				
Soil physical	G	G	G				E	E			G					
Mineralogical composition							S									
Soil amendments:																
pH modifiers	G	G	G	G			S						E		S	
Mulches																
Fertilizers	E	E	E	G			S		E		G	G	G	G	S	
Sludges				G					E			G				
Biological				E												
Topsoil	G	G	G	S	G											
Compost																
Other	E	E	E							G			E			
Economic considerations																
Short- and long-term additive impacts	E	E	E	E	G		G		E	G	G	G	E	G	S	
Techniques for application and/or rates of application	E	E	E	E	G				E	G	S		E	G		

	0977	0978	0979	0980	0981	0982	0983	0984	0985	0986	0987	0988	0989	0990	0991	0992
Coal region	N, P	N, P	N, P	X, E	N, R	O	N	N	N	N	N	N	N	N	X	X
Intended or current land use:																
Cropland	G	G	G		G	S		S	S							
Grazing land	G	G	G		G	S				S		S	S	S		
Pastureland	G		G		G	S										
Reforestation or afforestation				S	G	S										
Wildlife				S												
Recreational																
Miscellaneous																
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical					E	G	G	E	G	E		E	E	E	E	
Soil physical			G		E	G	G	E	G	E	E	E	E	E		
Mineralogical composition																
Soil amendments:																
pH modifiers																G
Mulches				S												G
Fertilizers	S		S	S												G
Sludges				E											S	E
Biological						S							S			
Topsoil	G	S	G		E	G	G						S			
Compost																
Other	G															
Economic considerations	S	S	G													
Short- and long-term additive impacts	S		G	E		S									S	G
Techniques for application and/or rates of application	S		S	S											S	G

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Bibliographic entry	0993	0994	0995	0996	0997	0998	0999	1000	1001	1002	1003	1004	1005	1006	1007	0008
Coal region	X	E, I	E	E	E	E	E	E	S	S	S	S	X	X	X	N
Intended or current land use:																
Cropland		S														
Grazing land		S							S							
Pastureland		S														
Reforestation or afforestation		S	S	G	G		G	G					S			
Wildlife																
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal		S														
Soil characterization:																
Soil chemical			G	G	E		G	G	G	G	E	E				G
Soil physical			S	G	E		G	G	G	G	G	E				E
Mineralogical composition																
Soil amendments:																
pH modifiers										G	E					
Mulches		S		G		S		G		G		E				
Fertilizers	G		E	E	E	S	E	G		G	E	E	S	S	S	
Sludges		S	E						E	G			S	S	S	
Biological				E	E		G	E								
Topsoil		S				S		G	E	G		E				
Compost																
Other										G	E					
Economic considerations																
Short- and long-term additive impacts	G		E	E	E	S	E	E	E	G	G	E	S	S	S	
Techniques for application and/or rates of application	G		E	E	E	S	E	E	G	G	G	E	S		S	

	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024
Coal region	N	N	N	N	I	X	X, N	N	N, X	X, N	X, N	X, N	E	E	N	X
Intended or current land use:																
Cropland			G	G				G							S	
Grazing land								G		G	S	G			S	
Pastureland															S	
Reforestation or afforestation													G	E	S	
Wildlife															S	
Recreational															S	
Miscellaneous															S	
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	G			S	E		G	S	S	E	S	G		E	G	
Soil physical	E		E	G			G	G	S	E	S	G		E	G	
Mineralogical composition														S		
Soil amendments:																
pH modifiers																
Mulches							G		G	E	E	E				
Fertilizers				G			G		G	G						S
Sludges																S
Biological																
Topsoil				E			G	G	G		G	E				
Compost						S										
Other							G									
Economic considerations																
Short- and long-term additive impacts				E			G	G		E	E	E				S
Techniques for application and/or rates of application				E			G	G	G	E	E	E				S

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Bibliographic entry	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040
Coal region	N	I	I	E	E	E	E	E	R, X	X	G	S	O	N, R	N, R	X
Intended or current land use:																
Cropland	G					S							S			
Grazing land	G												S		S	
Pastureland							G						S			
Reforestation or afforestation			G										S			
Wildlife	G															
Recreational	G															
Miscellaneous	G															
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical							E		G			E	E	E	E	
Soil physical							G									
Mineralogical composition											E					
Soil amendments:																
pH modifiers				S			G									
Mulches	G					G	G		S							
Fertilizers	G				S			S		S						
Sludges		S		S	S	E	E	S	G							S
Biological																
Topsoil			E													
Compost																
Other																
Economic considerations	G															
Short- and long-term additive impacts			E	S	S	E	E	S	G							S
Techniques for application and/or rates of application			G	S	S	E	E	S		S						

	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056
Coal region	X	O	E	N, R	X, C	X	N, R	X	X	G	X	X	I	X	N	N
Intended or current land use:																
Cropland					G											
Grazing land				S											G	S
Pastureland				S												
Reforestation or afforestation													S	G		
Wildlife				S												
Recreational																
Miscellaneous																
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	E			G			G	S							S	S
Soil physical				G	G		G	S				G	E	G	S	G
Mineralogical composition																
Soil amendments:																
pH modifiers	S		S							S	S					
Mulches									S			G				S
Fertilizers	S		S	S		G		G		S	G		S		S	S
Sludges											G	G				
Biological							G							G		
Topsoil	G		S						S							S
Compost																
Other		E	G													
Economic considerations																
Short- and long-term additive impacts	G	G	E			G		G	S	S	G	G		G		
Techniques for application and/or rates of application	S	G	G			G				S	G	G				

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Bibliographic entry	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072
Coal region	N	N	X	N	O	X	X, E	E	E	G	G	G	N	E, G	X, N	X, N
Intended or current land use:																
Cropland					S					S						
Grazing land	G	S		S	S				G	S			S			
Pastureland					S				G	S						
Reforestation or afforestation					S											
Wildlife					S					S						
Recreational					S					S						
Miscellaneous					S											
Regulation:																
Local																
State									G							
Federal					E				G					G		
Soil characterization:																
Soil chemical	S		S	E	G	S		S		G	G	G	G		G	E
Soil physical	G		G	E	G	S		S		G	G	G			G	G
Mineralogical composition																
Soil amendments:																
pH modifiers					S	S	S	S		S	S					
Mulches		S	S		S								E	E	E	E
Fertilizers		G	G		S	S	S	S		S	E		E	G	E	E
Sludges								E						G		
Biological																
Topsoil		S														
Compost																
Other																
Economic considerations														E		
Short- and long-term additive impacts		G	G			S	G	E			E		E	E	E	E
Techniques for application and/or rates of application		S			S	S	S	E			E		G	E	E	E

	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088
Coal region	X	I	E	R	O	N, R	X	I	X	I	O	N, R	X, C	X	X	E
Intended or current land use:																
Cropland								S								
Grazing land				S												
Pastureland																S
Reforestation or afforestation							G							G	G	S
Wildlife				S												
Recreational		G														
Miscellaneous																S
Regulations:																
Local																
State			E			S										
Federal						S										
Soil characterization:																
Soil chemical		G		S	E	E	S	E		E	G	E				
Soil physical		G		S	E			E		G						
Mineralogical composition								G								
Soil amendments:																
pH modifiers										S				G	G	
Mulches	G			G		G							G	G	G	
Fertilizers	G			G		G							G	G	G	
Sludges			E			G			G					E	E	E
Biological						G	G									
Topsoil						G				G						
Compost						G										
Other																
Economic considerations	S								S							
Short- and long-term additive impacts	G		E	G		G			G	G			G	E	E	E
Techniques for application and/or rates of application	S		G	G		G			G	G			G	E	E	E

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Bibliographic entry	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104
Coal region	E	E	E	E	S	X, R	X, R	X	X, R	X	N	N	X, R	N	N	E
Intended or current land use:																
Cropland				G						G						
Grazing land				G		G					G				S	
Pastureland	S			G						G						
Reforestation or afforestation				G										S		
Wildlife				S												
Recreational																
Miscellaneous	S															
Regulation:																
Local																
State			G	G												
Federal			G	G												
Soil characterization:																
Soil chemical	S	S		G	E	G	E			G		S	E	G	E	
Soil physical	S	S		G	S	G		G		S				G	E	
Mineralogical composition									S							
Soil amendments:																
pH modifiers	S	G		S			S									E
Mulches		G														
Fertilizers	G					G				S	S		S		G	E
Sludges	G	E	E	E												
Biological					G											
Topsoil					E	E						G	E			
Compost		E														
Other															G	
Economic considerations																
Short- and long-term additive impacts	G	E	E	E	G	E	G				G	G	E		E	E
Techniques for application and/or rates of application	G	E	G	E		G						G	G		S	E

	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120
Coal region	X	X	X, C	N	N, P	X	E	E	E	I	I	I	I	X, C	X, R	X, P
Intended or current land use:																
Cropland												S				
Grazing land																
Pastureland						G	S			S			S			
Reforestation or afforestation								G								S
Wildlife																
Recreational																
Miscellaneous																
Regulations:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical				G			G	S	G	G	G		G		S	
Soil physical	G			G		G	G	S			G	G		G		S
Mineralogical composition																
Soil amendments:																
pH modifiers							E		E		G	S				
Mulches		G			S		E									
Fertilizers		G		G		G	G		E		G	S		G		
Sludges							E		E	E			G			
Biological									G			S				
Topsoil				E							G					
Compost							E									
Other			G													
Economic considerations																
Short- and long-term additive impacts		G	G	E		G	E		E	E	G	G	G	G		
Techniques for application and/or rates of application		G		G			E		E	G	G	S	G	S		

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Bibliographic entry	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136
Coal region	E	E	E	E	O	E	X, C	O	N	N	E, G	X, E	X	X	X	X
Intended or current land use:																
Cropland	S															
Grazing land																
Pastureland							G									
Reforestation or afforestation			G	G												
Wildlife																
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical	G	S		G			E			E	S	G		G		
Soil physical	S			S						G		G				
Mineralogical composition														G		
Soil amendments:																
pH modifiers		S		E			E		S	G						
Mulches			E	G												
Fertilizers	G	S	G	E			E			G	S		S			
Sludges		S	G		G	E			S	G		E			S	S
Biological	G							G								
Topsoil		S					G			G		E				
Compost			G		G	E						E	S			
Other																
Economic considerations				E												
Short- and long-term additive impacts	E	S	E	G	G	E	E		S	G	S	E	S		S	S
Techniques for application and/or rates of application	E	S	E	E		G	E		S	G		G	S		S	S

	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152
Coal region	X	I	I	X	N, R	E, I	E	X, P	X	R	R	E	E	E	E	E
Intended or current land use:																
Cropland			S													
Grazing land					S											
Pastureland		S			S					S						
Reforestation or afforestation		S			S			S				G	G	E	E	G
Wildlife																
Recreational							G									
Miscellaneous							G									
Regulations:																
Local																
State														G		
Federal														G		
Soil characterization:																
Soil chemical		S		S		G	E					G	G	E	G	
Soil physical		E	E	S		E	E							E	G	
Mineralogical composition																
Soil amendments:																
pH modifiers				S								G		G		G
Mulches					G							E	G			
Fertilizers					S			E		E	S	E	G	G	G	E
Sludges	S									E	S	E				
Biological									G			E	E			
Topsoil					S	G						E	E			
Compost																
Other				S												
Economic considerations																
Short- and long-term additive impacts	S			S	G	E		E	G	E	S	E	E			E
Techniques for application and/or rates of application	S				S			G		G	S	E	E		G	G

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Bibliographic entry	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168
Coal region	E	E	E	N	X	X	N, R	E	E	X	X, P	N	N	N	E	G, I
Intended or current land use:																
Cropland			G										S			
Grazing land			G									G	G	S	S	S
Pastureland			G												S	
Reforestation or afforestation	S	E	G					G	G						S	S
Wildlife			G							G		G	S	S		
Recreational			G													
Miscellaneous			G													
Regulation:																
Local																
State												S			S	
Federal			G									S			S	
Soil characterization:																
Soil chemical	S	E	S	E	G		E	E	G		G	S	E	S	G	S
Soil physical	S	E	S	E	G	G		E				S	E	S	G	S
Mineralogical composition			S					G					E	S		S
Soil amendments:																
pH modifiers			G												S	
Mulches			G							S		S				
Fertilizers			G									S			S	
Sludges			G		G										S	
Biological																S
Topsoil			G									S				
Compost			G		G											
Other			G													
Economic considerations												S			G	
Short- and long-term additive impacts			S												G	
Techniques for application and/or rates of application			G									S			S	

	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184
Coal region	G	N, R	R	E	O	N, R	N, R	N	N	N	N	N	O	R, S	N	X
Intended or current land use:																
Cropland	S												G		E	
Grazing land		G	S			S		G	G	G	S	G	G	G	E	
Pastureland	S												G		G	
Reforestation or afforestation	S		S	G									G			
Wildlife			S	S	E	S		G	G	G		G	G	S	G	
Recreational			S			S							G	G		
Miscellaneous						S							G	G		
Regulations:																
Local																
State					S			S		S						
Federal			G		G	S		S		S			E	G	G	
Soil characterization:																
Soil chemical	S		G		S	S		G	G	S	S	G		G	E	G
Soil physical	S		G		S	S		G	G	S	S	G		G	E	
Mineralogical composition						S										
Soil amendments:																
pH modifiers			G													
Mulches		S	G			G	G	S				S				
Fertilizers			G			E		S		S		S			E	
Sludges						G										
Biological								S				S				
Topsoil		S	G		S	E	E	S	S	S	S	S		S	E	
Compost																
Other															E	
Economic considerations							S	S								
Short- and long-term additive impacts			G			E	G	S	S	S	S	S		S	E	
Techniques for application and/or rates of application		S	G			G	G	S	S	S	S	S		S	E	

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

Evaluation code: **E**—Excellent, keyword has direct, practical application or specific information on the use of soil amendments and/or the characterization of mine soils; **G**—Good, keyword has direct application, but has less specific information; reference contains good background information; **S**—Satisfactory, keyword has little practical application because of generalities or limited information.

Bibliographic entry	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200
Coal region	E	I	E	R, S	I	X, A	I	I	I	I	X, C	X	E	C	C	C
Intended or current land use:																
Cropland		S			E											
Grazing land				S												
Pastureland			S													
Reforestation or afforestation	G					S							G			G
Wildlife				S												
Recreational										G						
Miscellaneous										G						
Regulation:																
Local																
State																
Federal																
Soil characterization:																
Soil chemical				S					G	E			G	G	G	E
Soil physical		E		S	E	S			G	E	G	G	G	G		
Mineralogical composition																
Soil amendments:																
pH modifiers			E						E							
Mulches			G													S
Fertilizers	G		E	S										E		G
Sludges														E		G
Biological														E	E	E
Topsoil															E	E
Compost																
Other							G	G	E	E						
Economic considerations										G						
Short- and long-term additive impacts	E		E	S					E	E				E	E	E
Techniques for application and/or rates of application	G		G	S					E	G				G	G	G

	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216
Coal region	E, G	O	E	E, I	I	I	E	X, N	X, N	X, N	R	I	X	X	R	E
Intended or current land use:																
Cropland		G										G				
Grazing land	S	G														
Pastureland	S	G	S													
Reforestation or afforestation		G	G	S	G	G	G									E
Wildlife	G	G														
Recreational	G	G														
Miscellaneous	G	G														
Regulations:																
Local																
State												S				
Federal								G				S				
Soil characterization:																
Soil chemical	E	E	G		G	G	G	G		E	E		E		E	E
Soil physical	E	E	G		E	G	S	G			G		E	G	E	G
Mineralogical composition																
Soil amendments:																
pH modifiers	G	E	S	G	G		E									
Mulches	G	E	E	S		E	S	S	G	E						
Fertilizers	G	E	G	G	G	S	E	S	G	E						
Sludges	S	G					E				E					
Biological	S	E	S													
Topsoil	G	E	S	S							E				E	
Compost	S	G					E									
Other	S								G	E						
Economic considerations						S	E	S								
Short- and long-term additive impacts	S		G	E	E	E	E	S	G	E	G				E	
Techniques for application and/or rates of application	G	E	G	G	G	G	E	S	G	E						

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	1217	1218	1219	1220	1221	1222	1223	1224	1225	1226	1227	1228	1229	1230	1231	1232
Coal region	E	E	E	E	E	E	S	X	X	N, R	I	I	R, X	X, C	X	E
Intended or current land use:																
Cropland																
Grazing land							S			S			G			
Pastureland																
Reforestation or afforestation		E	E	G	G	G			S							
Wildlife		E					S									
Recreational																
Miscellaneous																
Regulation:																
Local										G						
State										G						
Federal											G					
Soil characterization:																
Soil chemical	E	G			S	E	G	G		G				G	G	
Soil physical	E				S		G			G		E			G	
Mineralogical composition																
Soil amendments:																
pH modifiers				S							E					
Mulches				S		G					S					
Fertilizers			G	G	G	E			E		G		G	G		G
Sludges														G		
Biological			E	G	E	E			E							
Topsoil										G	E	G	G			E
Compost																E
Other																E
Economic considerations											S					
Short- and long-term additive impacts			E	E	E	E			E	G	E	G	E	G		E
Techniques for application and/or rates of application			E	G	E	E			E	G	E	S	G	G		E

	1233	1234	1235	1236	1237	1238	1239	1240	1241	1242	1243	1244	1245	1246	1247	1248
Coal region	X, C	X, C	X	E	S	E	X, C	C	O	G	N, R	I	N, P	I	X, C	E
Intended or current land use:																
Cropland								S			G					
Grazing land					S			S			G					
Pastureland								S		S						
Reforestation or afforestation			S					S								G
Wildlife								S		S	G	S		G		
Recreational								S								
Miscellaneous								S				G				
Regulations:																
Local																
State																
Federal								E								
Soil characterization:																
Soil chemical	G		E	G	E	G	E			S	S	G	E	G	S	G
Soil physical			E	G	G	G	E			S	S	S				G
Mineralogical composition						E					S					
Soil amendments:																
pH modifiers							G	G				G			G	
Mulches								S			G					G
Fertilizers			G			G	S	G	G	S	S	G			G	G
Sludges	S	G														
Biological									E							
Topsoil									G	S	G					
Compost																
Other																
Economic considerations														S		
Short- and long-term additive impacts		G	G			E	G	G	G	S	S	G			G	E
Techniques for application and/or rates of application						G	G		G		S	G			G	G

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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Bibliographic entry	1249	1250	1251	1252	1253	1254	1255	1256	1257	1258	1259	1260	1261	1262	1263	1264
Coal region	E	E	E, I	X	E	X	X	E	O	E	X	X	N	O	N	X, R
Intended or current land use:																
Cropland																
Grazing land													S		S	
Pastureland		G														
Reforestation or afforestation	G	G	G							S						
Wildlife	S														S	
Recreational																
Miscellaneous																
Regulation:																
Local																
State																
Federal		G												E		G
Soil characterization:																
Soil chemical		G						E			G		S		E	E
Soil physical		G						E			S		S		E	E
Mineralogical composition								E								
Soil amendments:																
pH modifiers										S						S
Mulches	G				E					S						
Fertilizers	G	S		S						S						S
Sludges							S					S				
Biological			G			G			E	S						
Topsoil										S						
Compost																
Other																
Economic considerations		S	G		G											
Short- and long-term additive impacts	G	S	S	S	E	G	S		G	G		S				G
Techniques for application and/or rates of application	G	S	S	S	E		S		G	S		S				S

	1265	1266	1267	1268	1269	1270	1271	1272	1273	1274	1275	1276	1277	1278	1279	1280
Coal region	X, C	O	N	E	O	X	O	O	I	I	I	C	C	E	E	E
Intended or current land use:																
Cropland								G								S
Grazing land			S					G				S	S			
Pastureland								G								S
Reforestation or afforestation								G						S	G	S
Wildlife								G	G	G	E					
Recreational								G								S
Miscellaneous								G	G	G	E					S
Regulations:																
Local																
State		S						S							S	E
Federal		G						G							S	G
Soil characterization:																
Soil chemical	G		S					S		G		S	E			
Soil physical			S					S		G		S	E			
Mineralogical composition																
Soil amendments:																
pH modifiers		S						S	G	S	G					
Mulches								S								
Fertilizers	S	S	G				G	G	G		G	G	S	E	S	
Sludges				G			G	S								
Biological					G	S	E	S								
Topsoil		S					G	S	E	S	G					
Compost						S										
Other											S					
Economic considerations		E			G				G						S	
Short- and long-term additive impacts			G	E	G	S	E	S	E	G	E	G	S	E	S	
Techniques for application and/or rates of application			S	S	G		G	S	G	S	G	S	S	E	S	

Coal regions (see figure 1, main text): **A**—Alaska, **C**—Canada, **E**—Eastern, **G**—Gulf Coast, **I**—Interior, **N**—Northern Great Plains, **O**—Entire United States, **P**—Pacific, **R**—Rocky Mountain, **S**—Southwest, **X**—Noncoal.

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APPENDIX B.—ANNOTATED BIBLIOGRAPHY

1. Abbott, D., and G. B. Bacon. Reclamation of Coal Mine Wastes in New Brunswick. CIM Bull., v. 70, No. 781, 1977, pp. 112-119.

The authors' purpose was to describe a current reclamation program and the reclamation plan that is being developed for the future for the Minto Coalfield in New Brunswick, Canada. A good description of the soil's physical and chemical properties is presented. The initial reclamation program involved planting 3.84 million trees on 4,600 acres. Most of the plantings took place on ungraded spoil banks. These initial plantings provided the following information: (1) the afforestation program did not allow for a postmining land use, (2) the growth-limiting factors were high exchangeable acidity, low pH, high levels of salts, active aluminum, and heavy metals, (3) bare-root stock tree seedlings had better survival when planted in the spring, with local stock having the best survival, and (4) tree planting provides a relatively inexpensive cover for mine wastes. Future reclamation of the Minto Coalfield will aim at restoring the land to an aesthetically pleasing state, while allowing for maximum productivity. The authors conclude that an important key to the successful afforestation of the Minto Coalfield is soil improvement.

2. Abbott, R. D., D. J. Dollhopf, and A. M. Janney. Evaluation of Overburden Sampling Intensity in Mined Land Reclamation. Reclam. & Reveg. Res., v. 1, No. 3, 1982, pp. 255-269.

This paper examines drilling intensities to provide a better understanding of what accuracy can be expected when characterizing overburden material from a strip-mined area located near Colstrip, MT. Three physiochemical parameters—soluble salts, clay, and nickel—were used to assess the ability of a sample drill site to characterize the overburden at different distances. Assessments were based on a logistic model that represented the probability of an accurate inhibitory characterization of overburden as a function of distance between a predicting sample and the region to be characterized. This relationship was qualified by an additional analysis that was used to help select a threshold distance within which the accuracy of characterizing the overburden is significantly improved by decreasing the distance between the overburden and the drill site. Beyond this distance accurate characterization of overburden material occurs by chance alone and is not influenced by the location of the overburden. The chance of an accurate prediction of inhibitory status can exceed 0.70 for regions of overburden that are close to a sample drill site or be as low as 0.25 with increasing distance from the drill site.

The probabilities found for the strip-mined area near Colstrip reflected a degree of homogeneity in the physiochemical parameters of the overburden.

The probabilities found help to indicate what handling procedures are needed to properly redistribute overburden material found to be toxic in some physiochemical parameters. The threshold distance indicates how far away use of the special handling procedures should be considered. The information presented in this paper offers insight into what can be expected from predicting inhibitory characteristics of overburden based on the material sampled from a drill site.

3. Abell, M. S., and J. P. Vimmerstedt. White Oak (*Quercus alba*) Seedling Growth in Relation to Earthworm (*Lumbricus terrestris*) Activity in Ohio Surface Minesoil. OH J. Sci., v. 85, No. 2, 1985, p. 88.

Abstract of a paper presented at the Annual Meeting of the Ohio Academy of Science. A greenhouse study was conducted to test the effects of earthworms (*Lumbricus terrestris*) on soil compaction and the growth of white oak (*Quercus alba L.*) seedlings in Ohio surface mine soil. A silt loam subsoil and a loam topsoil were treated with and without earthworms, with high and low compaction, and planted with white oak seedlings. Earthworm treatments resulted in greater white oak root length, root diameter, and leaf dry weights than seedlings grown without earthworms. Earthworm additions did not affect soil compaction; however, compacted soils resulted in greater leaf dry weights, lower leaf nitrogen percentage, and smaller root diameters when compared with seedlings grown in noncompacted soils.

4. Abernathy, M. C., D. J. Morris, and R. Van Wormer. Wetland Reclamation Planning at the John Henry Mine in Western Washington. Paper in Wetlands and Water Management on Mined Lands, ed. by R. P. Brooks, D. E. Samuel, and J. B. Hill (Proc. Conf. PA State Univ., State College, PA, Oct. 23-24, 1985). PA State Univ., State College, PA, 1985, pp. 153-158.

Article describes Pacific Coast Coal Co. reclamation plan for the restoration of wetlands disturbed by the mining operations.

5. Acker, P. P., and J. A. Holbrook II. The AML Emergency Program in the Anthracite Coal Fields of Pennsylvania. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 295-298.

Background information on the mining history of the Anthracite region of northeastern and east central Pennsylvania is presented. The main focus of this paper is to describe the type, frequency, and cost of emergency abandoned mine land (AML) problems in this region and to project future changes in the emergency program. There are five main categories of emergency problems recognized: subsidence, coal refuse, mine fires, open shafts and portals, and mining related water or gas problems. Subsidence events are the most common followed by mining related water and gas problems. The most costly kind of AML problems in the Anthracite region to abate is fire. It is estimated that the number of emergency projects will stabilize at 95 annually at a projected cost of $2 million.

6. Adams, J. F., D. E. Kissel, D. A. Whitney, and S. J. Thien. Effect of pH on Heavy Metal Availability in Sludge-Amended Soil. Am. Soc. Agron., Agron. Abstr., 1984, p. 22.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. A greenhouse experiment was conducted to study the availability of heavy metals in two sludges applied at 0, 200, 400, 800, and 1,600 mg kg^{-1} Zn to soil adjusted to pH's of 5.0, 6.2, and 7.5. One sludge was anaerobically digested with a $Ca(OH)_2$ treatment, while the second sludge was anaerobically digested with a $FeCl_3$ treatment. Soybean (*Glycine max* (L.) Merr.) was used as an indicator crop. Yield was significantly decreased when both sludges were applied at the 200-mg-kg^{-1} Zn rate and above. Liming the soil prior to sludge application had little effect on yield.

7. Adams, L. M., J. P. Capp, and E. Eisentrout. Reclamation of Acidic Coal-Mine Spoil With Fly Ash. BuMines RI 7504, 1971, 29 pp.

Plots were established at two sites on acidic mine spoil in northern West Virginia. Varying tonnages of fly ash were applied to the plots at both sites. Several woody and herbaceous species were evaluated to determine growth potential in spoil with adverse chemical and physical properties. Fly ash additions improved soil texture, increased soil pH to tolerable levels for some herbaceous species, and increased available soil water. Tree and shrub survival, however, was poor even with the addition of fly ash to the mine spoil.

8. Adams, M. B., R. G. Campbell, H. L. Allen, and C. D. Davey. Root and Foliar Nutrient Concentrations in Loblolly Pine: Effects of Season, Site, and Fertilization. For. Sci., v. 33, No. 4, 1987, pp. 984-996.

The status of nitrogen and phosphorus in the roots and foliage of 10- to 13-year-old loblolly pine (*Pinus taeda* L.) trees in four plantations on the lower Coastal Plain of North Carolina were examined. Root and foliage samples were collected from four sites representing distinct combinations of soil moisture (high and low) and soil fertility (high and low). Three fertility treatments were applied to each site: a control, 225 kg ha^{-1} N, and 225 kg ha^{-1} N plus 75 kg ha^{-1} P. The seasonal patterns of root and foliar nutrient concentration of nonfertilized (control) trees were variable, suggesting that annual climatic variation may influence seasonal nutrient levels. Both root and foliage nutrient concentrations varied significantly among the different sites studied. Different fertility treatments also affected the root and foliage nutrient concentration of loblolly pine, however, the effects of fertilization varied as a function of site and date. Although fertilization of the high moisture, high fertility site resulted in additional nitrogen and phosphorus in the foliage, it also resulted in greater leaf area and a decrease in volume growth. Root nitrogen and phosphorus concentrations were more sensitive to fertilizer induced changes than were foliar nutrient concentrations on some sites, indicating that roots may have integrated site factors more efficiently. In general, foliage tended to be more sensitive to nitrogen deficiencies, while roots seemed to be more sensitive to phosphorus deficiencies. The authors suggest, however, that further research is needed to qualify the potential predictive use of these trends.

9. Adamsen, F. J., and B. R. Sabey. Ammonia Volatilization from Liquid Digested Sewage Sludge as Affected by Placement in Soil. Soil Sci. Soc. Am. J., v. 51, No. 4, 1987, pp. 1080-1082.

The effect of covering liquid sewage sludge with 25 mm of soil on ammonia volatilization was studied using a laboratory incubation technique. Liquid sludge, at an equivalent rate of 7.6 mg ha^{-1} of sludge solids and 85 kg ha^{-1} of ammonium-nitrogen, was placed on the surface or 25 mm below the surface of a sandy loam soil and incubated for 12 weeks. Placement of the liquid sewage sludge below the soil surface reduced the loss of ammonia; 0.35 pct of the applied ammonium-nitrogen in the sludge was lost when placed 25 mm below the surface, while surface applied sludge lost 40.3 pct of applied ammonium-nitrogen during the first 2 weeks of the incubation. The net loss of ammonium-nitrogen as ammonia from the surface treatment was 36.0 kg ha^{-1} or 42.2 pct of the applied ammonium-nitrogen. Placement of the sludge below the surface almost eliminated the volatile loss of nitrogen as ammonium-nitrogen, indicating that subsurface placement

of sludge, compared with incorporation, or surface application, is more effective in reducing nitrogen loss as ammonia volatilization.

10. Adriano, D. C., and A. L. Page. Co-Recycling of Sewage Sludge and Fly Ash: Heavy Metal Uptake by Crop. Paper in Proceedings: Third International Conference on Heavy Metals in the Environment (Amsterdam, Netherlands, Sept. 1981). 1981, pp. 185-188. For inf., contact M. R. Norland, Twin Cities Res. Cent., BuMines, Minneapolis, MN.

This paper reports the results of a greenhouse study conducted to evaluate the feasibility of corecycling municipal sewage sludge and fly ash on croplands. Fly ash additions to sludge-amended soils resulted in large increases in soil pH with large reductions in cadmium and zinc uptake by sudangrass (*Sorghum sudanese* (Piper) Stapf.). The two most immediate and apparent effects of fly ash additions on soil properties were alkalinity and salinity. Alkalinity depressed the cadmium and zinc concentrations in the soil and reduced the uptake of these elements by plants. Salinity resulted in reduced plant growth.

11. Agricultural Research. Strip Mining Without Harming the Environment. V. 27, No. 6, 1978, pp. 10-14.

Several factors that affect the reclamation of western coal mines are discussed. General descriptions are given of research being conducted in Colorado, North Dakota, and Wyoming. Of particular interest to researchers in the West are topsoil replacement, water quality, water utilization, plant species selection, planting methods, soil nutrient relations, irrigation, fertilization, and the effects of animal grazing on revegetated areas. The goal of these research projects is not only to restore lands to a productive state, but to improve them whenever possible.

12. Aguilar, R., and R. D. Heil. Soil Organic Carbon, Nitrogen, and Phosphorus Quantities in Northern Great Plains Rangeland. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1076-1081.

Changes in soil properties as a function of landscape position and parent material within a specific geographic region were evaluated. Soils along toposequences weathered in sandstone, siltstone, and shale parent material were characterized to evaluate quantities of organic carbon, nitrogen, phosphorus, and total phosphorus. Each of the toposequences had distinct geometric configurations that reflected the weathering characteristics of the parent material, which was characterized. Average organic carbon, nitrogen, and phosphorus contents across all landscape segments varied with parent material and landscape position, but generally increased on the lower landscape position. Organic matter enrichment is attributed to runoff and erosion from upper segments. Parent material exerted a strong influence on organic carbon-content. Average carbon content across all landscape segments with the sandstone, siltstone, and shale toposequences were 12.1, 14.1, and 16.0 kg m^{-3}, respectively. In the sandstone toposequence, organic-carbon concentrations decreased uniformly with depth indicating greater rooting depths. These soils had the lowest quantities of organic carbon, nitrogen and total phosphorous, but the greatest quantity of organic phosphorous on every comparable landscape segment. Total phosphorus content varied along the toposequence and reflected differences in parent material and the redistribution of sediments.

13. Aguilar, R., E. F. Kelly, and R. D. Heil. Effects of Cultivation on Soils in Northern Great Plains Rangeland. Soil Sci. Soc. Am. J., v. 52, No. 4, 1987, pp. 1081-1085.

The cumulative effects of 44 years of cultivation on organic-carbon, total-nitrogen, organic and total-phosphorus contents, and their relationship to soil losses or gains along toposequences in North Dakota were discussed. Paired rangeland and cultivated soils were selected for study along toposequences formed in sandstone, siltstone, and shale parent material. Cultivated fields had been in wheat (*Triticum aestivum* L.) and fallow rotation for 44 years prior to sampling. Organic carbon, nitrogen, phosphorus, and total phosphorus were quantified along the toposequence and characterized as a function of parent material, landscape position, and land use. Sandstone and siltstone derived soils that were cultivated lost larger proportions of organic carbon, nitrogen, and phosphorus through mineralization than did soils formed in shale. Losses of organic carbon, nitrogen, and phosphorus in cultivated soils formed in finer textured shale were linked to erosion.

14. Ahlrichs, J. S., and L. R. Hossner. Selenate and Selenite Mobility in Overburden by Saturated Flow. J. Environ. Qual., v. 16, No. 2, 1984, pp. 95-98.

Lignites in Texas may contain up to 22.9 mg kg^{-1} of selenium. This is of concern because the potential mobility of selenium anions from lignite and associated overburdens at high levels may result in toxic conditions for animals. In this study, the effect of overburden pH and leaching volume on the movement and distribution of selenate and selenite (oxidized states) through a composite of surface mine overburden materials were determined. Deep cores (7.6 by 20 to 60 cm) were composited to create samples that had a sandy loam texture. Surface mine overburden was adjusted to pH values of 2, 3, 5, 7,

and 9 and packed into 2.8- by 30-cm glass columns. Selenium was added to the surface as a sodium salt of selenate or selenite, and each column was loaded with 1.5, 10, or 50 pore volumes of 0.01*M* $CaCl_2$. Soil pH was the primary factor influencing the rate of selenate movement through these materials. The greatest retention of selenate occurred at pH 3. At pH values near 2, mineral oxides began to dissolve, which interfered with selenium absorption. Selenate was mobile at all pH values and was completely leached from columns with less than three pore volumes of solution, with the most rapid movement occurring at pH 7 and 9. Selenite was rapidly absorbed at all pH values, while very little selenate was absorbed by the overburden. The authors state that selenite movement would be minimal in acid and alkaline conditions (pH values between 2 and 9). In alkaline materials, however, selenite may readily oxidize to selenate, which is highly mobile.

15. Ahlrichs, J. S., L. R. Hossner, J. B. Dixon, and A. L. Senkayi. Chemical and Physical Properties of Lignite Overburden as Related to Environments of Deposition. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 431-461.

The geologic environments of deposition in the overburden at selected sites along the outcrop of the Wilcox geological group in near-surface lignite in Texas were determined, along with the chemical and physical properties of these materials. Depositional environments were studied to determine the feasibility of using them as a unit for assessing the quality of overburden. Cores were taken along the outcrop of the Wilcox group in central and northeast Texas. The cores were characterized based on their lithological characteristics (composition, texture, and sedimentary structure). These characteristics were used to delineate the various environments of deposition. Particle size distribution, moisture retention, electrical conductivity, pH, acid neutralizing potential, CEC, sodium, sulfur, and heavy-metal concentrations were determined. The following deposition and environments were recognized based on sand content: bed and mixed load channels, bay fill, bay center, levee, flood basin, marsh, and overbank. Potential acidity, CEC, available water, and heavy metals were related to the energy of the environment in which the sediments accumulated and whether or not the sediments had been affected by surface weathering processes.

16. Ahuja, L. R., B. B. Barnes, D. K. Cassel, R. R. Bruce, and D. L. Nofziger. Effect of Assumed Unit Gradient During Drainage on the Determination of Unsaturated Hydraulic Conductivity and Infiltration Parameters. Soil Sci., v. 145, No. 4, 1988, pp. 235-243.

Although the research conducted is not directly related to coal surface mined land reclamation, the information presented on unsaturated hydraulic conductivity and infiltration parameters may be useful in the soil characterization of coal surface mined lands. The authors evaluated the unit-gradient approximation (which assumes that hydraulic gradients during drainage in a uniform soil profile that do not have a shallow water table are nearly equal and that the hydraulic conductivity of a soil is a function of soil water content), the unsaturated hydraulic conductivity at different depths using the unit-gradient approximations, and the Green-Ampt infiltration parameters (field saturated hydraulic conductivity, wetting front suction, and soil water content at saturation) derived from the determined conductivities in soils of four soil orders of the southern United States. These soils, from Georgia, North Carolina, and Oklahoma, encompassed a range of profile layering and complexity in order to evaluate the unit-gradient approximation for use in complex stratified soils.

The results indicate that the hydraulic gradients were greatly influenced by the nature and complexity of the soil profile. Soil layering influenced the initial soil-water pressure gradients at the end of infiltration. Soil layering also caused changes in pressure gradients as the soil drained. At these and various depths, the hydraulic gradients in the soils studied were two to five times smaller or greater than unity, with the target departures consistently occurring in 30 to 40 cm of soil. The determination of unsaturated hydraulic conductivities using the unit-gradient approximation resulted in large discrepancies in the upper soil horizons, at depths less than 20 cm for uniform profiles to depths less than 65 cm in the more complex layered profiles. At those depths, the unit-gradient approximation resulted in smaller unsaturated hydraulic conductivities at low suction than values calculated using measured gradients. Infiltration parameters derived from the unit-gradient hydraulic conductivities were smaller than the actual values in the upper soil depths. The authors state that the most serious effect in using the unit-gradient approximation is when it is used to determine the hydraulic conductivities of saturated or nearly saturated topsoil. The discrepancy in the conductivities of the topsoil occurred in both uniform and layered soils. These results suggested to the authors that in topsoil, hydraulic gradients should be measured using tensiometers.

17. Ahuja, L. R., J. D. Ross, R. R. Bruce, and D. K. Cassel. Determining Unsaturated Hydraulic Conductivity from Tensiometric Data Alone. Soil Sci. Soc. Am. J., v. 52, No. 1, 1988, pp. 27-34.

Although this research does not apply directly to the unsaturated hydraulic conductivity of surface mine soils,

this paper may contain information that is useful to those interested in this area of soil physical property characterization. The authors evaluated the assumptions made in their earlier work on the simplified function approach for determining soil hydraulic conductivity from field tensiometric data using tow contrasting soil types and at two ranges, shallow and deeper depths. The two soil types differed by textural class and complexity of layer. One of the soil types used had a complex layered profile with texture varying from sandy to clayey, while the other soil type had a uniform sandy profile. The final hydraulic conductivities of these soil types obtained by the simplified method are compared with values obtained by the Darcian analysis. In each of the soil types tested, the results show that the assumptions made in the simplified method hold. When unsaturated hydraulic conductivity values obtained using the simplified approach are compared with those values obtained using the detailed Darcian analysis, good agreement of values between the tow methods was obtained for all depths. The authors state that this observation provides confidence in the simplified method. When the simplified method is used, however, the following requirement should be considered; frequent tensiometric data should be obtained at small time and depth intervals, especially at low suction.

18. Albrecht, S. C., and E. R. Thompson. Impact of Surface Mining on Soil Compaction in the Midwestern U.S.A. (contract J0208016, Hittman Assoc., Inc.). Bu-Mines OFR 174-82, Feb. 1982, 318 pp.; NTIS 83-120 170.

The objective of this study was to evaluate the soil compaction that occurs during surface mining and reclamation activities in the midwestern area of the United States. The areas used in the study had been designated prime farmland. The study locations included the Brazil Mine in Indiana, the Captain Mine in Illinois, the Delta Mine in Illinois, and the Power Mine in Missouri. Moist bulk densities of natural and replaced soils were measured and compared for the top 48 in of the soil profiles. Fertility of the topsoil was also assessed for natural and replaced soils. A case study for each minesite based on field sampling and observations is provided.

19. Alden, J. N. Species Selection for Forest Development in Alaska. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv. Gen. Tech. Rep. PNW-219, 1988, pp. 110-120.

The silvicultural and genetic characteristics of several exotic and native tree species with the potential for improving yield in the interior and south central regions of Alaska are described. The major tree species with potential for wide adaptation and forest improvement uses are described for the four major climatic zones of Alaska: the maritime, maritime-continental transitions, continental, and arctic zones.

20. Alderdice, L., and D. H. Graves. Vegetative Response to Topsoil Versus Alternative Growth Materials in a Four-Year Old Study in Kentucky. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 497-501.

This study investigated the response of a diverse vegetative cover to various types and rates of mulch treatments and topsoil replacement levels on mine spoil located in Breathitt County, KY. The effect of these treatments on the availability of various plant nutrients was also studied. The study showed no significant differences between treatments and total biomass produced after four growing seasons. Percent cover was not significantly affected by treatment after three growing seasons. The pH values of the amendment-spoil interface also had no significant effect on vegetative cover or biomass production. Bark treatments resulted in higher nitrogen and phosphorus values with the nitrogen levels being highly correlated to cover and biomass yield. Potassium levels were greater in the wood fiber mulch, pelletized leaves, bark-chicken manure, and bark-sewage sludge treatments. With proper site preparation and spoil amendments, a more suitable medium for successful plant establishment is created, which results in greater percent ground cover and plant productivity.

21. Alderdice, L., R. L. Howard, and D. H. Graves. Possible Treatments as Alternatives to Topsoil Replacement on Surface Mine Sites. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 251-255.

This paper reports the results of 13 topsoil modifications, amendments, and substitutes tested in eastern Kentucky. The results suggest some of the methods could support significantly faster establishment and maintenance of permanent ground cover.

22. Aldon, E. F. Endomycorrhizae Enhance Shrub Growth and Survival on Mine Spoils. Ch. in Reclamation of Disturbed Arid Lands. Univ. NM Press, 1978, pp. 174-179.

The author discusses the importance of vesicular-arbuscular (VA) endomycorrhizae on the growth and yield

of 14 shrub species common to the arid regions of the Southwest. Four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) and rubber rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Britt.) were established in the greenhouse, and endomycorrhizae enhanced shrubs showed significant increases in growth and yield when inoculated with *Glomus mossae* and *Glomus fasciculatum*, respectively. A field trial using four-wing saltbush inoculated with *Glomus mossae* on coal mine spoil in western New Mexico, showed that after 2 years, growth and survival were significantly better on plants grown in the spoil inoculated with *Glomus mossae* than in spoil not infected. These studies show the importance that endomycorrhizal fungi have on the growth and survival of shrub species planted on surface mine spoil in New Mexico.

23. Aldon, E. F. Hydrologic Parameters of Surface Mine Spoils in the Southwest. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 228-231.

Measured runoff and sediment production from graded, but untreated and unreclaimed spoil are reported from a Southwestern surface coal mine. Over an 8-year period runoff averaged 0.77 cm per storm, while sediment yield averaged 2,456 kg ha^{-1} per storm from each storm. Treatment possibilities to reduce runoff and sediment yield are presented and include topsoiling, mulching, adding sludge, inoculum for microorganisms, seeding, and irrigation.

24. Aldon, E. F. Reclamation of Coal-Mined Land in the Southwest. J. Soil and Water Conserv., v. 33, No. 2, 1978, pp. 75-79.

This general article describes the revegetation techniques that were utilized to reclaim the major coal mines of New Mexico and Arizona. Information is presented on the soils, climate, and natural vegetation of the area. The species that had the most promise for future use in reclamation in the Southwest were alkali sacaton (*Sporobolus airoides* (Torr.) Torr.), western wheatgrass (*Agropyron smithii* Rydb.), four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.), and Indian ricegrass (*Oryzopsis hymenoides* (Roem. & Schult.) Ricker). Planting methods (direct seeding and transplanting), amendments (organics, topsoiling, mulches, and fertilizers), and irrigation are other revegetation techniques that were discussed. The author concludes with a list of eight items that are directly concerned with the physical success of surface rehabilitation and revegetation.

25. Aldon, E. F. Techniques for Establishing Native Plants on Coal Mine Spoils in New Mexico. Paper in Third Symposium on Surface Mining and Reclamation, Volume 1 (Louisville, KY, Oct. 21-23, 1975). Natl. Coal Assoc., Washington DC, 1975, pp. 21-28.

This paper highlights seed application, sprinkler irrigation, drip irrigation, and water harvesting methods in establishing selected native species.

26. Aldon, E. F., and C. P. Pase. Plant Species Adaptability on Mine Spoils in the Southwest: A Case Study. U.S. For. Serv., Rocky Mt. For. and Range Exp. Stn., Res. Note RM-398, Apr. 1981, 3 pp.

This research note briefly presents the results of a study initiated in 1973 to evaluate the adaptability of several native grass and shrub species at the McKinley Mine in New Mexico. Fourteen species of native and introduced 3-month old perennials were transplanted and watered-in at the minesite. Initial survival was checked in 1973, and then survival rates were checked in 1974, 1978, and 1979. Of the 14 species tested, five native and one introduced species showed high survival rates (67 to 100 pct), good vigor, and propagation by seed or rhizomes into adjacent areas. Survival rates and climatic data are detailed in the research note.

27. Aldon, E. F., D. G. Scholl, and C. P. Pase. Establishing Cool Season Grasses on Mine Spoils. Paper in Symposium on Watershed Management 1980 (Boise, ID, July 21-23, 1980). Am. Soc. Civ. Eng., 1980, pp. 91-97.

Several surface reclamation treatments were tested on experimental plots on large demonstration areas at a coal strip mine operation about 40 miles west of Raton in northeastern New Mexico. The best combination of treatments for establishing of western wheatgrass (*Agropyron smithii* Rydb.) and Russian wildrye (*Elymus junceus* Fisch.) utilized contour furrowing, seed drilling, and straw mulching. Plant density for this combination of treatments was 43 grass plants per square meter on the clay loam topsoil material.

28. Alexander, E. B. Rates of Soil Formation: Implications for Soil-Loss Tolerance. Soil Sci., v. 145, No. 1, 1988, pp. 37-45.

Although this article does not contain specific information on the characterization of coal surface mine soil, it does contain useful background or reference information on the rates of soil formation on noncoal lands. A model is presented which predicts the rate of soil formation based on the volume of runoff. The constant and coefficients for the model were developed from previously published data from 18 small watersheds. Chemical denudation was also calculated for each of the watersheds utilized in developing the model; watersheds that contained carbonates were not used. The results show that the logarithmic correlations of runoff with chemical denudation and soil formation are highly significant. Rates of soil formation were found to range from 0.02 to 1.90 mg ha^{-1} yr^{-1},

with rates being dependent upon the volume of runoff water and the soil; two parameters had a coefficient of determination of 0.94. Erosion losses from moderately deep or shallow soils, which are faster than replenishment by the weathering of underlying bedrock or consolidated sediments, will result in a decline in soil productivity over time. As a result, the author states that the rate of soil formation can be considered a constraint on tolerable soil losses from shallow or moderately deep soils. Long-term soil-loss tolerances can be equated with rates of soil formation from bedrock or other consolidated sediments.

29. Allen, E. B. The Role of Mycorrhizae in Mined Land Diversity. Paper in Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 273-295.

This paper is an excellent review of pertinent literature focusing on the importance of mycorrhizae to the physiology and ecology of reclamation plants and how these relationships may affect diversity on mined lands. The problems and solutions of maintaining and introducing vesicular-arbuscular mycorrhizae (VAM) are discussed. The author states that mycorrhizae may improve the ability of desirable species to compete with weeds and increase the rate of succession from a weed stage to a stable, diverse community.

30. Allen, E. B., and M. F. Allen. Facilitation of Succession by the Nonmycotrophic Colonizer *Salsola Kali* (Chenopodiaceae) on a Harsh Site: Effects of Mycorrhizal Fungi. Am. J. Bot., v. 75, No. 2, 1988, pp. 257-266.

The effects of mycorrhizal inoculation using vesicular-arbuscular mycorrhizal fungi on a plant community consisting of both nonmycotrophic (plants that do not form a mycorrhizal association) pioneer species, annuals, and mycotrophic latter successional species were described for a surface mine located in southwestern Wyoming. A subsoil was used as the growth medium since it contained little or no inoculum and was seeded with a mixture of native species. In addition to the seeded native species, several annual species colonized the site. The annuals which colonized the site do not form mycorrhizal associations even when inoculum is present. The mycorrhizal inoculum used was a clay loam topsoil collected from an adjacent undisturbed site, and the topsoil was spread to a depth of 1 to 2 cm over the subsoil or treated plots. Treatments consisted of annuals present with mycorrhizal inoculum, annuals present with no mycorrhizal inoculum, annuals removed with mycorrhizal inoculum, and annuals removed with no mycorrhizal inoculum. These treatments were used to test for the interaction of competition and mycorrhizae on perennial species. Colonizing annuals were removed from the appropriate plots by pulling the seedlings out by hand in the spring and when needed throughout the growing season. Soil samples for mycorrhizal analysis were collected late in the growing season each year using a soil core method. The roots were sieved out, and the remaining soil was used for spore and hyphal length analysis. Roots were stained and assessed for percentage of infection, while spores were separated from 5 g soil samples by sucrose flotation and counted.

Third and fourth year results show that the density and percent cover of Russian thistle (*Salsola kali* L. var. *tenuifolia* Tausch.) were significantly higher in uninoculated plots, with inoculation the density and percent cover of Russian thistle decreased by one-half to one-third with inoculation. The roots of Russian thistle formed no vesicles or arbuscules indicating that there were no mycorrhizal infections, however, external hyphae were present. Hyphae did occasionally penetrate the Russian thistle in 1 to 2 pct of the root sections studied. The seeded species, particularly the *Agropyron* species, exhibited a complex pattern to inoculation and to the presence of Russian thistle. Russian thistle had a beneficial effect on grass density; where Russian thistle had the greatest density, the grasses had the greatest density. However, following inoculation, where the density of Russian thistle decreased, there was a corresponding decrease in the density of the grasses. Infection of spore numbers of inoculated plants was greatest in western wheatgrass (*Agropyron smithii* Rydb.) the first growing season (30 pct) than in uninoculated plants, but the infection percentage decreased and remained below 8 pct in the other 3 years of this study.

It has been hypothesized that the abundance of mycorrhizal inoculum in soil may regulate the patterns of succession. Increased inoculum density would increase the rate of succession by allowing later seral species to become more competitive with the early seral, nonmycotrophic species. However, where facilitation causes successional change, the role of mycorrhizal fungi may be different. In the harsh site where this study was conducted (a windy ridge top) and in other primary successions, facilitation may be a more important process than competition. Evidence is presented where the presence of Russian thistle in high densities in succession reduces the abundance of the later seral species. However, at the site studied, grass densities were greatest where Russian thistle was most abundant, the uninoculated plots, suggesting that facilitation is an important process. Russian thistle is providing an improved microenvironment for grass seedling establishment. Inoculation of early seral plants with VA mycorrhizae on these types of harsh sites in the Rocky

Mountain coal mining region may slow primary succession at those sites. In conclusion, the authors state that whether inoculation would be of benefit in the later stages of succession by increasing the growth of later seral species is an area that needs further research and long-term study.

31. Allen, E. B., J. C. Chambers, K. F. Connor, M. F. Allen, and R. W. Brown. Natural Reestablishment of Mycorrhizae in Disturbed Alpine Ecosystems. Arct. and Alp. Res., v. 19, No. 1, 1987, pp. 11-20.

The distribution and importance of mycorrhizae is not well known for alpine ecosystems. To understand the role of mycorrhizae in alpine ecosystems, the occurrence of vesicular-arbuscular (VA) mycorrhizal spores and root infection in undisturbed and seral alpine areas of the Beartooth Mountains, in Montana, were determined. Roots were examined for percentage of mycorrhizal infection, and spores were counted from soils of an undisturbed, 25-year-old successional community, and 3- and 7-year old revegetated mined (gold, silver, and copper) areas. The revegetated areas had been limed, fertilized, and mulched. Mycorrhizal spore counts and percent root infection varied among species, areas, and collection dates. The three most abundant grasses had lower spore counts and percent root infection in the revegetated areas compared with the successional and undisturbed areas. The following year, however, spores and infection of the grasses increased in the revegetated areas to values similar to those of the successional and undisturbed areas. Patterns of mycorrhizal infection varied with other species, and no patterns which might relate to age of an area with spore counts or percent infection of a species were found. In a late successional dominate, *Geum rossii*, an unidentified fungi covering up to 98 pct of the root length was found. This fungus acted as a mycorrhizae. Several species of *Glomus* were identified.

Vesicular-arbuscular mycorrhizal fungi are abundant in the roots of several plant species found in this alpine ecosystem. Spores range from 1 to 76 spores per gram of soil and 0 to 60 pct infection in undisturbed areas to 1 to 4 spores per gram of soil and 0 to 46 pct infection in revegetated areas. In some cases the values found for revegetated areas are as high as or higher than undisturbed areas. As a result, a simple successional chronosequence based on mycorrhizae cannot be constructed for alpine ecosystems. More mycorrhizal species were found in the older areas (11 species) compared with revegetated, younger areas (one species). To develop an adequate model on the role of mycorrhizae fungi in alpine communities, variables such as spore dispersal, host presence, host response, soil conditions, and environmental fluctuations must become more predictable.

32. Allen, M. F. Spatial Patterning and Soil Saprophytic Microbiota: Impact of Strip Mining, Importance and Management Strategies. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 322-326.

This article discusses the effects of surface mine disturbance on soil micro-organisms and suggests strategies that may be useful for managing disturbed areas to maximize recovery. To describe and manage the soil processes regulated by micro-organisms, it is necessary to understand the effects of surface mining and revegetation on the mass, diversity, and structure of soil micro-organisms. Surface mining affects all three parameters of soil microbial activity. The goal of revegetation should be to provide environmental characteristics which are favorable for establishing appropriate soil micro-organisms. The author recommends that vegetation should be planted in clumps or patches to enhance organic matter accumulation and nutrient cycling, reduce over production and nutrient immobilization, and provide a range of temperature and moisture conditions for differing microbiota. The author suggests that this type of management will result in greater site productivity and diversity.

33. Allen, M. F., and J. A. MacMahon. Impact of Disturbance on Cold Desert Fungi: Comparative Micro-scale Dispersion Patterns. Pedobiologia, v. 28, No. 4, 1985, pp. 215-224.

Fungal community and ecosystem properties of an undisturbed shrub-steppe and a surface minesite, immediately following topsoil replacement, were compared. The topsoil had been stored for 8 years prior to replacement. Two sets of 25 samples were taken from both sites. The first set was analyzed for colony counts, saprophytic fungal taxa, total hyphal length, vesicular-arbuscular mycorrhizae (VAM) fungal spore counts and hyphal length, soil moisture, and organic matter. The second set was used for soil physical and chemical characterization.

The soils differed between sites; topsoiling resulted in a horizontal and vertical soil mosaic. The stored respread topsoil had significantly lower nitrogen, phosphorus and organic matter when compared with the undisturbed site. These chemical changes were correlated with changes in soil fungal characteristics. Fungal hyphal length was low at the disturbed site and the hyphae were randomly dispersed; no VAM hyphae or spores were observed. The undisturbed site had distinct, consistent patterns, in terms of the soil and fungal characteristics measured. Disturbance had little effect on VAM species composition. The major effect of disturbance was the loss of spatial

integration among fungi, organic matter, and nutrients. The loss of correlative fungal-soil chemical structure with disturbance may have a major effect on nutrient retention and plant recolonization. Community structure analysis indicated that in the undisturbed site, fungi were organized around a plant unit, while in the topsoiled disturbed site, fungi were broadly dispersed.

34. Amemdola, F. A., M. D. Mitchell, and D. W. Simpson. Reclamation of Tree and Shrub Species at the Absaloka Mine. Paper in Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 237-250.

This paper describes several techniques developed by Westmoreland Resources, Inc., for establishing ponderosa pine (*Pinus ponderosa* Laws.) and deciduous tree-shrub thicket communities on reclaimed mined land. These studies were conducted at the Absaloka Mine, approximately 75 miles east of Billings, MT. Recent plantings of ponderosa pine employing standardized procedures that consider north aspect, steep slopes, coarse soil texture, furrowing, and delayed seeding of herbaceous species exhibited high survival rates. Containerized seedlings are reported to perform better than bare-root seedlings. The program for establishing deciduous tree and shrub thicket communities is in its initial stages and is continuing.

35. Ames, R. N., K. L. Mihara, and G. J. Bethlenfalvay. The Establishment of Microorganisms in Vesicular-Arbuscular Mycorrhizal and Control Treatments. Biol. and Fertil. Soils, v. 3, 1987, pp. 217-223.

Methods for the introduction and establishment of micro-organisms in soils treated with inoculum commonly used in research with vesicular-arbuscular (VA) mycorrhizal fungi were examined. The following questions were addressed in this research: (1) Do the same functional group of organisms become established in soil after inoculation with various types of VA mycorrhizal fungi and control inocula? (2) Does the type of inoculum affect microbial populations? (3) Do the various types of inocula affect plant growth? Microbial activity (CO_2 evolution) and the populations of protein, chitin- and cellulose-decomposing organisms, fluorescent *Pseudomonas* spp., and total fungi, bacteria, and protozoa were determined. The typed of inoculum used influenced the establishment of microbial groups in closed, nonplanted soil systems. In open systems (planted pots), however, the type of inoculum used affected microbial populations, shoot dry weight, and root and shoot phosphorus content. In the open systems, the inoculum used did not affect root dry weight or shoot and root nitrogen content. Functional groups of micro-organisms, which are similar, can establish VA mycorrhizal fungi and control treatments if a VA mycorrhizal fungal inoculum is applied to both treatments. An adequate control treatment cannot be prepared from non-VA mycorrhizal fungi inoculum. All assumptions behind establishing an appropriate non-VA mycorrhizal control cannot be met. These assumptions are as follows: (1) The same species of micro-organism (except the VA mycorrhizal fungus) will be introduced into all treatments; (2) micro-organisms will have an equal chance to establish in all inoculated soils; and (3) the VA mycorrhizal fungus and not the method of inoculation will affect plant growth and soil microbial populations.

36. Ammons, J. T. Minesoil-Properties, Root Growth, and Land Use Implications. Ph.D. Thesis, WV Univ., Morgantown, WV, 1979, 221 pp.

Mine soil profiles from the Interior and Eastern Coal Mining Regions were characterized morphologically, chemically, and physically and related to root patterns. Field water conditions are related to properties of mine soil classes. Variability of mappable polypedons was examined. Root behavior of several plant species in response to soil morphology, as well as to physical and chemical properties, is illustrated with scaled root sketches and photographs. Classification of mine soils is stressed and supported by an economic analysis comparing classified mine soils with natural soils for alternative cropping systems. A review of pertinent literature is included.

37. Ammons, J. T., T. A. Keeney, and R. W. Smith. Minesoil Properties Affecting Rootgrowth. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 111-126.

This article describes mine soil chemical and physical properties which affect root growth; nine soil properties are identified. Consideration must be given to those properties in the premining planning process, so that desirable postmining land uses can be achieved.

38. Ammons, J. T., and E. F. Perry. The Relationship of Overburden Analysis to Minesoil Properties in Post Mining Land Use. Paper in Surface Coal Mining and Reclamation Symposium, Coal Conference and Expo V (sponsored by Coal Age, Louisville, KY, Oct. 23-25, 1979). McGraw-Hill, 1979, pp. 170-176.

This paper discusses the role of material characterization in premining planning to allow for the selection

and placement of the chemically and physically superior materials as topsoil in postmining reclamation activities.

39. Ammons, J. T., and P. A. Shelton. Disturbed Soil Classification-Divide Section of the Tennessee-Tombigbee Waterway. Paper in Proceedings of the Fifth Annual Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 127-143.

Four soil profiles were excavated and classified on three disposal areas along the Tennessee-Tombigbee Waterway. Soils were classified using a disturbed soil classification scheme and using the proposed suborder for the order Entisols. All profiles were classified to the family level of the proposed taxonomy as Matrix Udispolents, coarse-loamy, mixed, extremely acid, and thermic. This study showed that the proposed mine soil classification scheme is applicable to disturbances on noncoal land.

40. Anderson, C. E., and J. M. Briggs. Planning Erosion Control for Coal Mining and Reclamation. J. Soil and Water Conserv., v. 34, No. 5, 1979, pp. 234-236.

This article describes the methods used to reduce off-site sediment losses and erosion of terraces that were constructed at the Iowa Coal Project Demonstration Mine in southwestern Iowa. One year after the completion of the restoration work, sediment discharge had no effect on water quality, and there was no apparent erosion on the terraces. However, soil compaction and drainage were problems that needed to be resolved if row-crop farming was to be successful on the site. The cost of erosion and drainage control during mining was less than 1 pct of the total cost of mining, and the cost of reclamation was about 16 pct of the total.

41. Anderson, C. P. Concurrent Establishment of Hardwood Tree Seedlings and Low Ground Cover on Reclaimed Mineland. M.S. Thesis, Purdue Univ., West Lafayette, IN, 1983, 109 pp.

This study compared site productivity of surface-mined land and an unmined reference area in Sullivan County, IN. Comparisons were made on establishing a herbaceous ground cover and hardwood tree seedlings planted concurrently using the same levels of management on both sites. Tree and herbaceous species used were black walnut (*Juglans nigra* L.), northern red oak (*Quercus rubra* L.), Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), and red clover (*Trifolium pratense* L.). Different seedling production methods were evaluated, and chemical plant control was utilized as a means of reducing competition and improving seedling survival and growth. Soil physical and chemical properties were also analyzed, and comparisons were made between the two sites. The results indicate that herbaceous ground cover was adequate on the minesite, meeting the reclamation requirements of Public Law 95-87. However, aboveground biomass production was significantly higher on the reference site (6,152.8 kg ha^{-1}) than on the minesite (2,785.6 kg ha^{-1}) after two growing seasons. Tree survival was also significantly higher on the reference area. However, with herbicide treatment, tree survival increased significantly on the minesite.

42. Anderson, C. P., P. E. Pope, W. R. Byrnes, W. R. Chaney, and B. H. Bussler. Hardwood Tree Establishment in Low Plant Cover on Reclaimed Mineland. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 158-170.

A reclaimed surface-mined site was compared with an unmined reference site to evaluate the effectiveness of reclaiming land in accordance with Public Law 95-87, the Surface Mining and Control and Reclamation Act of 1977. Both sites were located in Sullivan County, IN. Established success of grass and/or herbaceous ground cover and hardwood seedlings planted concurrently and maintained under the same level of management was used to compare site productivity of the reclaimed and the unmined areas. Bare-root and containerized seedlings of black walnut (*Juglans nigra* L.) and northern red oak (*Quercus rubra* L.) were planted on each site along with a cover crop of Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) and red clover (*Trifolium pratense* L.). One-half of each combination was treated with herbicide (mixture of amizine and dalapon) to control low ground cover plants and to assess the competitive effects of ground cover on hardwood seedling establishment and growth.

The topsoil of the reclaimed mine land had higher bulk density and lower organic matter content than the topsoil or the reference area. The topsoil of both sites exhibited similar pH. Mean ground cover percent and overall hardwood seedling survival after two growing seasons was sufficient to meet requirements specified by Public Law 95-87 for forest land. After 2 years of growth on the reclaimed minesite, individual container-grown seedlings exhibited higher survival rates than bare-root seedlings. Black walnut seedling survival and growth were improved by herbicide application to control competing grass and herbaceous ground cover. Similar treatments had no significant effect on red oak survival or growth. Red oak seedlings generally exhibited lower survival and net growth than black walnut seedlings.

43. Anderson, D. C., W. K. Ostler, C. M. McKell, and V. Isaman. An Innovative Approach to Reclaiming Processed Oil Shale. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 158-163.

This study evaluated topsoil as an amendment on an oil shale disposal pile in Colorado. Trenches were dug in the disposal pile and filled with topsoil to a depth of 25 cm. Native, container-grown species were transplanted in the constructed trenches and in the disposal pile. Plant survival, height, and crown cover were monitored along with salt migration, electrical conductivity (EC), and pH of the trenches and disposal piles over a period of 6 years. Overall plant survival was 87 pct. Plant mortality was greatest during the first year. Plants in the trenches had greater height and coverage than did plants in the disposal pile. Changes in salt migration, EC, and pH are presented. The general trend with time is an initial increase in salts followed by a leveling off; pH increased slightly during the first 3 years, followed by a slight decline; EC showed no significant change with time. Root biomass (grams per 100 g soil) was significantly different between soil and shale samples. Roots will grow into the shale as long as it is not compacted.

44. Anderson, S. H., C. J. Gantzer, J. M. Boone, and R. J. Tully. Rapid Nondestructive Bulk Density and Soil-Water Content Determination by Computed Tomography. Soil Sci. Soc. Am. J., v. 52, No. 1., 1988, pp. 35-40.

Although the research discussed in this paper does not deal with mine soils directly, the methodology used and the results of the study may be applied to the physical characterization of coal surface mine soils. The authors utilized X-ray computer-assisted tomography as a rapid, nondestructive method of determining bulk density and soil-water content of two Missouri soils. This study was conducted to compare the relationship of linear attenuation coefficients and bulk density measured by computed tomography (CT) for the two soils, and to evaluate the effects of swelling and iron content on the attenuation coefficients. Experiments were conducted on dry soil, wet soil, and dry soil with added iron. Air-dry soil was initially packed into polyvinyl chloride (PVC) cylinders at densities between 1.2 and 1.6 mg cm^{-3}, an equal number of cylinders for each soil typed. CT slides or tomographs were taken before and after water was added. Iron was added to one soil type using dry soil only, and the differences in CT between the soil types were compared.

The results showed that X-ray CT can be used to determine the bulk density and water content of intact soil cores. For each of the dry soils, 99 pct of the variation in CT attenuation coefficients were accounted for by a linear relationship with the volume fraction of solids. For wet soil cores, 98 pct of the variation in CT attenuation coefficients were accounted for by the regression relationship with the volume fraction of soil water, after correcting for swelling effects, and the volume fraction of solids. The results of the added iron experiment suggested that the differences in attenuation coefficients for the soils studied were due to differences in iron content. These results indicate that a universal relationship could possibly be developed for CT and soil-bulk density or soil-water content; however, further research is needed in order to characterize the effect of sample core size on CT results.

45. Andreuzzi, F. C. Reclaiming Strip-Mined Land for Recreational Use in Lackawanna County, PA. A Demonstration Project. BuMines IC 8718, 1976, 21 pp.

This report discusses a demonstration of a 125-acre reclamation project on abandoned anthracite coal spoil in Lackawanna County, PA. The land use plan developed by the U.S. Bureau of Mines consisted of utilizing the area for public recreation, historical purposes, and as an educational facility. As a park, the project serves as a prototype for reclaiming existing and future surface mined lands.

46. Anselmi, K. M. Ameliorating the Adverse Chemical and Physical Properties of Bentonitic Clays. Paper in Proceedings of the Eighth Annual National Abandoned Mine Lands Conference (Billings, MT, Aug. 10-15, 1986). MT Dep. State Lands, Helena, MT, 1986, pp. 204-209.

The reclamation of bentonite spoils is discussed. Amendments that alleviate the adverse physical (clay dispersion and surface crusting) and chemical (soluble salts) characteristics of the spoil are necessary. Amendments, which have been used, include lime, calcium chloride, phosphogypsum, and gypsum to replace and leach sodium out of the root zone, wood chips to break the surface crust, and nitrogen and phosphorus fertilizers. Based on the research conducted on the reclamation of bentonite spoils, the Wyoming Abandoned Mine Reclamation Program includes a combination of amendments, physical manipulations to the seedbed, and the use of salt-tolerant grass and shrubs to reclaim abandoned bentonite mines in Wyoming.

47. Antisari, L. V., and P. Sequi. Comparison of Total Nitrogen by Four Procedures and Sequential Determination of Exchangeable Ammonium, Organic Nitrogen, and Fixed Ammonium in Soil. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1020-1023.

The main pool of nitrogen in the soil is organic nitrogen; however, nitrogen, in the form of NH_4, may be trapped or fixed in the lattices of clay minerals in some soils. This study compared four different procedures for determining soil total nitrogen and sequentially determined exchangeable NH_4, organic nitrogen, and fixed nitrogen in the same soils. Eight aluminum horizons were analyzed for total nitrogen by: (1) steam distillation of NH_3 yield after conventional H_2SO_4 digestion (Kjeldahl method), (2) HF-H_2SO_4 digestion (hydrofluoric acid modification of the Kjeldahl method), (3) HF-HCl treatment in a microwave system, and (4) a combination gas chromatography carried out by an automatic CHN analyzer.

Results show that total nitrogen determination using the Kjeldahl procedures were always lower than those obtained by the microwave system and CHN analyzer. The Kjeldahl methods underestimated total nitrogen because concentrated H_2SO_4 was not able to release native NH_4 trapped in the internal sites of clay mineral lattices. The drastic sample destruction during acid digestion by the microwave system and the total combustion of the sample by the CHN analyzer were able to release trapped NH_4. The sequential determination of exchangeable NH_4, organic nitrogen, and fixed NH_4 on the same samples gave similar results. The sum of the separate analytic values against total data determined by the microwave system and CHN analyzer gave correlation coefficients of 0.9943 and 0.9931, respectively. This suggests that the sequential determination of nitrogen forms in soils is reliable and that it can facilitate the determination of the three main nitrogen pools in soils.

48. Argonne National Laboratory. Land Reclamation Program, Annual Report, 1978. ANL/LRP-5, July 1979, 110 pp.

This annual report describes the Argonne Land Reclamation Program and reviews several ongoing or recently completed field and laboratory studies. Preliminary results, accomplishments, and planned future activities are presented for the Jim Bridger Mine Project in southwest Wyoming; the Bighorn Mine-Tongue River Project near Sheridan, Wyoming; the Navajo Mine Project — Breeding and Selection of Plant Materials for Mined Land Reclamation Project near Staunton, IL; the evaluation of selected overburden materials and management techniques for returning surface mined land to row crop production (Burning Star Mine No. 3 in Randolph County, IL); the Eastern Project considering impacts of surface coal mining throughout Illinois. The information presented in these discussions is primarily relevant to the coal mining regions in which the projects are located.

49. Argonne National Laboratory, and Ford, Bacon, and Davis Utah, Inc. Characterization of Uranium Tailings Cover Materials for Radon Flux Reduction (Appendix B, Characteristics of Plant Species Selected, Plant Growth as a Factor in Radon Gas Leakage From Uranium Mill Tailings, by Native Plants, Inc.). U.S. Nucl. Regul. Comm., NUREG/CR-1081, Mar. 1980, 153 pp.

This addendum describes a study conducted by Native Plants, Inc., Salt Lake City, UT, that was designed to help determine whether or not soil-covered uranium tailings would leak radon gas via root channels of deep-rooted plants. This paper was reviewed and included in this bibliography for its unique experimental design. Test plants were grown in large containers. The growth medium was put into the containers to simulate actual reclaimed field conditions. These containers were then placed in a greenhouse where climatic conditions could be controlled.

50. Arora, H. S., C. E. Pugh, J. B. Dixon, and L. R. Hossner. Pyrite and Acidity Formation. Ch. in Reclamation of Surface Mined Lignite Spoil in Texas. TX Agric. Exp. St., College Station, TX, Rep. RM-10, 1980, pp. 22-35.

This article contains a review on pyrite morphology and reactivity and the results of a field study conducted to determine the concentration and location of pyrite samples collected from Milan and Freestone Counties, TX. Each sample was examined to determine the location, concentration, morphology, and reactivity of the pyritic materials present. Total sulfur content was between 0.30 and 16.79 pct on a freeze-dried-weight basis. Iron sulfides and organic sulfur were the major sulfur components. Up to 60 pct of the total sulfur content may be in the pyritic form (iron sulfides). Fluctuations in sulfur content were due to fluctuations in the pyrite content. The establishment of vegetative cover is difficult when oxidation of pyritic materials occurs.

51. Asay, K. H. Breeding Grasses for Revegetation of Surface Mining Spoils in Western U.S.A. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 1007-1011.

This paper reviews grass breeding programs being conducted by State and Federal agencies in the Western United States and specifically discusses species and interspecific hybrids included in growth trials at the Decker, MT minesite.

52. Asay, K. H. Grasses for Revegetation of Surface Mining Areas in Western U.S. Paper in Surface Coal Mining and Reclamation Symposium, Coal Conference and Expo V (sponsored by Coal Age, Louisville, KY, Oct. 23-25, 1979). McGraw-Hill, 1979, pp. 155-159.

This paper provides an excellent review of breeding programs for native, introduced, and interspecific hybridized grasses and includes numerous successful examples of these types of plant materials.

53. Ashby, W. C. Is Good for Corn Good for Trees? Paper in 1982 Seminar on Post-Mining Productivity With Trees (Carbondale, IL, Mar. 31-Apr. 2, 1982). South. IL Univ., Carbondale, IL, 1982, pp. 15-18.

While reclaiming areas with trees is supported by regulations, it often losses out to other land uses. This article examines why areas in Illinois that could be reclaimed for forestry purposes are instead reclaimed for farmland. The author advocates a new regulatory reclamation formula that includes mine soils truly "capable of tree production."

54. Ashby, W. C. Reclamation With Trees Under P. L. 95-87. Paper in Proceedings 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 315-319.

The impacts of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) on reclamation using trees are discussed. The major hindrances of Public Law 95-87 associated with the lack of tree planting or successful tree establishment are soil compaction and excessive ground cover. Regulations have resulted in increased preserved land capabilities for agriculture and diminished interest and the amount of intended or current forest postmining land use. The author states that Public Law 95-87 has not fulfilled the promise or need for reclamation with trees.

55. Ashby, W. C. Soil Biology. Paper in Proceedings of the Fifth Annual Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 8-14.

This paper discusses what is known and not known about soil biological processes and the soil organisms involved in surface mined lands. Emphasis is placed on the need for knowledge and an understanding of soil biology so that vegetation establishment during reclamation may be enhanced. Examples are given where soil organisms have been used successfully in reclamation, such as mycorrhizae fungi, bacteria, and actinomycetes which are used to inoculate and are found in the nodules of nitrogen-fixing plant species.

56. Ashby, W. C., C. A. Kolar, and G. R. Philo. Reclamation With Trees. Paper in Annual Progress Report: July 1, 1980-June 30, 1981, Volume II, Research Development Summaries, Final Draft. Coal Extr. and Util. Res. Cent., South. IL Univ., Carbondale, IL, Mar. 1982, pp. 94-98.

This report summarizes investigations conducted at the Sahara Coal Co. minesite in Saline County, IL. The studies were designed to evaluate revegetation performance for several kinds of trees on unmined lands, lands mined and ungraded, lands mined and graded, and lands mined and graded with topsoil replacement. Fall and spring planting of seed and seedlings were tested. Additional studies on herbicides, super sluper, mycorrhizae, and containerized seedlings are described. The report also describes studies conducted at the Freeman United Coal Mining Co. in Perry County, IL, designed to evaluate the reclamation potential of several kinds of trees and shrubs planted along with a herbaceous ground cover to control erosion. These studies included both field and greenhouse work emphasizing root system development. Few hard data are reported, and results are discussed in a general way. However, this summary is a source of potentially useful information for revegetation planning.

57. Ashby, W. C., M. R. Norland, and D. A. Kost. Establishment of Trees in Herbaceous Cover on Graded Lenzburg Minesoil. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 48-53.

This paper reports the results of a study conducted to evaluate the survival at 1, 2, 3, 5, and 6 years after planting and height growth at years 5 and 6 of tree planted in a developing cover of highly competitive herbaceous species. Although the emphasis of this paper is on tree survival and growth, some information is presented on soil characterization and the soil amendments used on the research site. Information is presented on the mine soil bulk density, potassium availability, and available and reserve phosphorus. Additionally, the rates of ammonium nitrate and triple-super phosphate fertilizer that were broadcast over the site prior to herbaceous and tree species establishment are given.

58. Ashby, W. C., W. G. Vogel, and C. A. Kolar. Use of Nitrogen-Fixing Trees and Shrubs in Reclamation. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Comm. Coll., Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 110-118.

This article provides a relatively brief literature review on the use of nitrogen-fixing woody plants in reclamation

or reviewing reclamation plans. Included is a section on the effects of present legal requirements on the use of nitrogen-fixing woody plants for reclamation.

59. Ashby, W. C., W. G. Vogel, C. A. Kolar, and G. R. Philo. Productivity of Stony Soils on Strip Mines. Ch. in Erosion and Productivity of Soils Containing Rock Fragments, ed. by J. D. Nichols, P. L. Brown, and W. J. Grant (Proc. Symp., Anaheim, CA, Nov. 28-Dec. 3, 1982). Soil Sci. Soc. Am., Madison, WI, SSSA Spec. Publ. 13, 1984, pp. 31-44.

This article provides a general literature review on the rock fragment content of mine soils and the effect that rock fragments have on productivity. The effects of rock fragments on plant productivity is based on a literature review and research conducted by the authors. A literature review is presented on the rock fragment content and its effect on rooting volume and mine soil chemical and physical properties. The second half of the chapter is devoted to the productivity of strip mines as related to rock fragment content and land use. The beneficial effects of coarse fragments in mine soils are presented for row crop, pasture, and forest land uses. Production potential of mine soils containing coarse fragments may be higher for trees and pasture species than for mine soils which have been prepared under the current regulations. The authors state that the successes in reclamation with trees on stony, ungraded spoil banks, which preceded current regulations, has been altered by the requirements for grading and soil replacement. Factors that may be more limiting to productivity than coarse fragments are given. When compared with trees, pasture grasses and crops were determined to be less effective in promoting soil development by the authors.

60. Askenasy, P. E., L. R. Hossner, and E. L. Whiteley. Row Crop Production on Leveled Lignite Mine Spoil Banks. Ch. in Reclamation of Surface Mined Lignite Spoil in Texas. TX Agric. Exp. St., College Station, TX, Rep. RM-10, 1980, pp. 48-56.

This study was conducted to test the feasibility of using leveled mine spoil for row-crop production on lignite spoils near Fairfield, TX. The species tested were Texas 28 A corn (*Zea mays* L.), Top Hand sorghum (*Sorghum bicolor* (L.) Moench), Hill soybean (*Glycine max* (L.) Merr.), and Lee soybean. Nine different nitrogen-phosphorus fertilizer treatments were used in all combinations of 0, 84, and 168 kg ha^{-1} N and 0, 56, and 112 kg ha^{-1} P_2O_5. All row crops were grown successfully on the leveled mine spoil if proper fertilization and cultural practices were used. Grain sorghum was the most promising of the species tested and produced yields that were comparable with those for central Texas. For all species tested, phosphorus and nitrogen additions significantly increased yields during the first year. However, only nitrogen additions had an effect during the second and third years. The influence of the row crops on mine spoil nutrient content and pH was also evaluated during the 3-year study.

61. Auchmoody, L. R., and R. S. Walters. Revegetation of Brine-Killed Forest Site. Soil Sci. Soc. Am. J., v. 52, No. 1, 1988, pp. 277-280.

Brines, fluids which are produced during oil production, are an environmentally regulated waste with a high salt concentration that cannot be discharged onto the surrounding land or into waters. The authors studied a 1-ha area in the Allegheny National Forest in western Pennsylvania that had been impacted by an accidental discharge from a brine impoundment. The composition of the brine and the damage caused by it were measured. The residual phytotoxicity of the brine was assessed by monitoring natural vegetation establishment and growth on the impacted site. Methods of soil sampling and soil chemical analysis are given. Soil chemical properties of an adjacent unaffected forested sites were compared with the brine-killed area over a 2-year period.

The results show that soil pH and concentrations of calcium and magnesium were significantly higher during the first year, but by the second year had declined to levels that were not significantly different from the forested area. The authors attribute the decline in sodium and chloride concentrations in the brine-affected area to leaching. Soil concentrations of phosphorus, potassium, and manganese were not affected by the brine seepage. Soil mitigation is not needed on forested sites, which are damaged by brine from oil wells in western Pennsylvania, if the source of the brine contamination is eliminated and there is abundant rainfall to leach the soils of excess salts. Results are also presented on the chemical composition of the brine water and the changes which occur in the number of herbaceous species, percent cover, number of established trees, and the height of established trees on the brine-affected area over a 4-year period.

62. Aulakh, M. S., and D. A. Rennie. Effect of Wheat Straw Incorporation on Denitrification of N Under Anaerobic and Aerobic Conditions. Can. J. Soil Sci., v. 67, No. 4, 1987, pp. 825-834.

This laboratory incubation study investigated the relationship between soil moisture, mineral nitrogen, and the incorporation of different levels of wheat straw on denitrification. Wheat straw was incorporated into a clay soil at 0, 0.25, 0.5, and 1.0 pct and each straw treatment was subjected to three moisture levels; 60, 90, and 120 pct

of saturation. Eight incubation periods were used, and at the end of each period, the soils were sampled to determine denitrification, immobilization of nitrogen, and carbon mineralization. Denitrification rates were very low in the 60 pct water treatment, but increased when the water content increased to 90 and 120 pct saturation. Rates of denitrification also increased with increasing applications of wheat straw. Over the total incubation period of 96 days, the 1.0 pct wheat straw treatment increased nitrogen losses from 2.5 μg N_2O-N per gram (0 pct straw) to 10.1 μg N_2O-N per gram (1.0 pct straw) at 60 pct saturation and from 61.6 μg N_2O-N per gram (0 pct straw) to 83.9 μg N_2O-N per gram (1.0 pct straw). When NO_3-N was present, the pattern of CO_2-C evolved was identical to the denitrification rate. In flooded soils (anaerobic conditions), the supply of available carbon, whether from organic matter or organic residues, was a major factor influencing denitrification, especially when soils were supplied with sufficient NO_3-N. Denitrification rates decreased rapidly when NO_3-N was low, even with a sufficient carbon supply. Fertilizer nitrogen (50 μg N per gram as $K^{15}NO_3$) was rapid with 90 pct of the total nitrogen immobilized within 4 days. Straw incorporated at 1.0 pct increased immobilization of fertilizer nitrogen from 8.4 (0 pct straw) to 42.8 pct at the 60 pct water saturated treatment and from 1.0 (0 pct straw) to 7.6 pct at the 120 pct water saturated treatment. The results indicate that by leaving residues on the soil surface, denitrification rates should be reduced unless the organic residues left are accompanied by significantly higher soil moisture contents.

63. Baker, D. E., and J. K. Buck. Using Computerized Expert Systems, Unique Soil Testing Methods, and Monitoring Data in Land Management Decisions. Paper in Mine Drainage and Surface Mine Reclamation Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 246-256.

This paper discusses the theory and practice in soil testing that lead to the development of the Baker Soil Test and the use of this method in the decision making process for the management and chemical monitoring of disturbed soils, coal refuse, coal fly ash, and other potential growth media. Additionally, a hypothesis is presented that information needed to relate monitoring data and existing technology to site-specific requirements can be obtained through computerized systems. Advantages to the computerization of a soil chemistry system or similar decision-making systems are presented. Computerized expert systems are beneficial to land management decisions since explanations of soil tests and possible mitigative treatments may be transferred from the expert to the decision maker. The authors state the goal of their presentation is to have those involved in land reclamation and land management policy become more aware of the need for interaction in the development of alternatives in land management. The examples in this paper dealt directly with soil chemistry issues, which may be of concern in the reclamation process; however, the authors feel that the potential scope of the expert system in land reclamation is limited.

64. Baldock, J. A., and B. D. Kay. Influence of Cropping History and Chemical Treatments on the Water-Stable Aggregation of a Silt Loam Soil. Can. J. Soil Sci., v. 67, No. 3, 1987, pp. 501-511.

It has been shown that cropping treatments influence the structural characteristics of soil aggregates, in particular, the proportion of water-stable aggregates. The changes in water-stable aggregates are related to changes in the nature and amount of binding agents present. This study characterized the influence of continuous row cropping and continuous forage production on the aggregate stability of a silt loam soil. Five cropping treatments ranging from 15 years of continuous corn (*Zea mays* L.) to 15 years of continuous bromegrass (*Bromus inermis* Leyss) production were investigated. Additionally, the rate of change in aggregate stability caused by row cropping as compared with forage production was assessed along with an evaluation of the importance of periodate and pyrophosphate, chemicals used to determine the nature of binding agents, which are materials sensitive to changes in aggregate stability. Selected soil chemical and physical properties and the mineralogy of the soils studied are presented.

The results show that bromegrass increased the proportion of large aggregates and these aggregates were more stable. Corn growth resulted in structural deterioration and the loss of stable aggregates. The results also show that the accumulation of aggregating constituents due to bromegrass production is a slower process relative to the loss due to corn production. Periodate- and pyrophosphate-sensitive materials appear to be involved in the structural stabilization of the soil.

65. Banaszak, K. J. Predicted Changes in the Mineralogy of Spoil as a Function of Net Neutralization Potential and Rate of Flushing. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 459-462.

This research was conducted to assess the changes in the mineralogy of spoil material resulting from pyrite oxidation. In general, the mineralogy of fresh spoil is a mixture of silicates, carbonates, and sulfides. The changes caused by pyrite oxidation are dependent upon the flushing time of acid water and the net neutralization potential

(NNP) of the spoil material. Slow flushing and low NNP favor a change in the silicates and the formation of sulfates. Fast flushing and high NNP results in little change in the silicates, but there is a loss of carbonates, and hydroxides are produced from sulfides. Fast flushing and low NNP will create incomplete silicate alteration and a loss of metals from sulfides. Slow flushing and high NNP create a partial alteration of the silicates, and hydroxides are produced from sulfides.

A computer simulation resulted in differing ratios of phases created or destroyed by reacting various waters with overburden mineralogies. When calcite continually reacted with the solution, a final pH of 6.5 was achieved, and for every gram of pyrite oxidized 2.23 g of calcite and 0.003 g of 2:1 clay (+-o-+) were destroyed and 0.7 g and 0.001 g of goethite and gibbsite were formed, respectively. When calcite was absent, the final solution pH was 4.0 and for every gram of pyrite oxidized 0.03 g of 2:1 clay (+-o-+) was destroyed, and 0.7 and 0.01 g of goethite and gibbsite were produced. The greatest destruction of soil is not the loss of 2:1 clays (+-o-+), but the loss of cation-exchange capacity by the precipitation of iron-aluminum flocs.

66. Barnett, J. P., and A. E. Tiarks. Reforesting Disturbed Sites in the South With Pine Species. Paper in Fourth Biennial Symposium on Surface Mining and Reclamation on the Great Plains and Fourth Annual Meeting of the American Society for Surface Mining and Reclamation (Billings, MT, Mar. 17-19, 1987). Reclam. Res. Unit, MT State Univ., Bozeman, MT, Rep. 8704, 1987 pp. H-5-1 - H-5-7.

This article reviews methods of reforesting disturbed sites with pine species in the southern United States. Four native pine species have widespread potential for reforestation; loblolly pine (*Pinus taeda* L.), slash pine (*Pinus elliottii* Engelm.), longleaf pine (*Pinus palustris* Mill.), and shortleaf pine (*Pinus echinata* Mill.). Loblolly pine is generally considered the preferred species for most sites, but slash pine is better suited for flat, wet sites near the coast. Information is presented on the soil-mine soil environment, the need for competition control, and reforestation options. Included is information on direct-seeding, planting container-grown seedlings, and planting bare-root seedlings. Agroforestry, combining trees for timber and grasses and legumes for animal grazing, is suggested as an alternative reclamation technique.

67. Barnhill, M. A. Endomycorrhizae in Some Nursery-Produced Trees and Shrubs on a Surface Mined Area. Tree Plant. Notes, v. 32, No. 1, 1981, pp. 20-22.

This study was designed to determine whether woody plants propagated under nursery practices (high nitrogen and phosphorous fertilization and frequent fumigation) were colonized with indigenous vesicular-arbuscular mycorrhizae (VAM), and, if so, whether the associations survived after out-planting on mine spoil. Root systems of seven 1-year-old plants from each of 11 species were collected from a nursery. The nursery used summer cover cropping methods, fertilizer, and soil fumigation prior to fall seeding. Additionally, seven plants each of seven species produced in the nursery and outplanted at the Ollis Creek Mine in Campbell County, TN, were collected. All plants were examined for degree of VAM infection. Results showed significant differences in degree of infection between species, and infection was less extensive on plants collected at the minesite than on those grown in the nursery.

68. Barnhisel, R. I. Lime and Fertilizer Recommendations for Reclamation of Surface-Mined Spoils. Dep. Agron., Univ. KY, Lexington, KY, AGR-40 (rev.), Oct. 1976, 4 pp.

Recommendations are made for lime and fertilizer rates when a grass-legume cover is established for erosion control when land use is projected as (1) timber, wildlife, or recreation, or (2) pasture or hay production. Three methods of determining lime requirements are discussed.

69. Barnhisel, R. I. Reclamation of Surface Mined Coal Spoils. U.S. EPA, Rep. EPA-600/7-77-093, Aug. 1977, 57 pp.

Field experiments were established on four types of surface-mined spoil that are commonly found in western Kentucky. The specific objectives of the study were (1) determine the spoil chemical and physical properties and how these properties affect the establishment and survival of herbaceous cover, (2) develop a method of site preparation that will produce a stable microrelief with no adverse effects on spoil physical properties, and (3) evaluate different rates of lime incorporation into the spoil. The results show that when proper fertility levels are restored in combination with site preparation, mine spoils may be successfully reclaimed.

70. Barnhisel, R. I., and J. L. Powell. Effect of Soil Depth, Subsoil Liming and Subsoiling of Restored Mined Soils on Plant Growth. I. Alfalfa. Am. Soc. Agron., Agron. Abstr., 1987, p. 23.

Abstract of a paper presented at the 1987 Annual Meeting of ASA, CSSA, and SSSA. The yield of alfalfa (*Medicago sativa* L.) was affected by soil depth, subsoil liming, and subsoiling. Changes in soil depth resulted in significant differences in yield. Although increased yields

did result from subsoil liming, these increases were not significant. After the first year, subsoiling did not affect yield. Compared with the same soil series in nonmined areas, alfalfa yields on restored surface mined soils were higher. Growing alfalfa on mined soil also reduced the bulk density in the upper 50 cm of soil when compared with plots where other crops were grown.

71. Barnhisel, R. I., J. L. Powell, and G. W. Akin. Keys to Successful Reclamation in Western Kentucky. Paper in Third Symposium on Surface Mining and Reclamation, Volume 2 (Louisville, KY, Oct. 21-23, 1975). Natl. Coal Assoc., Washington, DC, 1975, pp. 140-151.

This paper reports the results of four related studies investigating the effects of tillage methods used in site preparation, phosphorus fertilization, types of phosphorus fertilizers, vegetation methods, and lime applications on establishing and maintaining acceptable vegetative cover. Five key factors for reclamation in western Kentucky are identified.

72. Barnhisel, R. I., J. L. Powell, J. R. Armstrong, M. L. Ellis, and F. A. Craig. Effect of Soil Depth, Liming, and Subsoiling of Reconstructed Prime Farmland on Alfalfa Production. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 266-273.

The bases of the research reported in this paper are the rules and regulations in the restoration of prime farmland mandated by the Surface Mining and Reclamation Act of 1977. The authors address two areas of research which have been of interest over the past 10 years in western Kentucky. A research project was conducted to determine the affects of soil depth, subsoil liming, and subsoiling on alfalfa (*Medicago sativa* L.) yield. A second area of interest was to determine the affect of soil moisture, at the time of subsoiling, on alfalfa growth and soil-bulk density. At one site, three test plots with varying subsoil depths (B and C horizons) were established at 0, 4, and 80 cm. Each plot was divided into two areas with lime being applied at a rate of 45 Mg ha^{-1} to one of the areas. The entire area was disked twice to a depth of 15 to 20 cm followed by the addition of 20 cm of topsoil resulting in soil depths of 20, 60, and 80 cm. Limestone, phosphorous, and potassium were applied to the topsoil at rates of 11.2 Mg ha^{-1}, 100 kg ha^{-1}, and 100 kg ha^{-1}, respectively. In addition to these treatments, subplots were subsoiled and test crops planted. At the second mined site, soil was replaced as two horizons with the topsoil and subsoil being replaced to a thickness of 20 and 90 cm, respectively. The entire area was ripped with one of four treatments; a control and ripping at three soil moisture levels (dry—near the wilting point, midway between field capacity and the wilting point, and near field capacity). The areas were fertilized with phosphorous and potassium and limed. Methods used for testing soil-bulk density and the soil chemical properties are given.

Results of the soil depth experiment produced significant differences in alfalfa yields, but the differences were not consistently related to soil depth. Liming the subsoil prior to topsoil replacement did result in significant yield responses in 7 of the 15 treatment pairs. Additionally, the subsoil lime treatment resulted in significantly higher levels of exchangeable calcium and lower exchangeable acidity in the upper 15 cm of all subsoil treatments. Soil-bulk density, at 0 to 15, 30 to 45, and > 45 cm, were not reduced by subsoiling, liming the subsoil prior to topsoil replacement, or growing alfalfa.

At the second minesite, subsoil did not result in any significant changes in soil chemical properties. Ripping or subsoiling at the various soil moisture levels had little effect on the changes in bulk density with time. In the 0 to 15 cm depth section, however, the soil-bulk density increased in the nonripped control and intermediate moisture condition from 1.45 to 1.69, and 1.55 to 1.60 Mg m^{-3}, respectively, over a 36-month period. Over the same time period in the 30 to 45 cm soil depth section, there was a significant increase in the bulk density of the nonripped control from 1.65 to 1.72. Ripping did not cause a significant change in bulk density at this depth section. In the 45 to 60 cm depth section, over the same 36-month period, soil-bulk density decreased in the control from 1.82 to 1.78 Mg cm^{-3} and increased in the dry and intermediate moisture conditions from 1.65 to 1.81, and 1.72 to 1.78 Mg cm^{-3}, respectively. There was no change in the bulk density at the 45 to 60 cm depth for the wet ripped treatment.

73. Barnhisel, R. I., J. L. Powell, and F. R. Cox, Jr. Restoration of Prime Farmland Following Surface Mining: I. Changes in Physical and Morphological Properties. Am. Soc. Agron., Agron. Abstr., 1988, p. 36.

Abstract of a paper presented at the 1988 Annual Meeting of ASA, CSSA, and SSSA. Significant changes have occurred in the physical and morphological properties of mine soils subjected to various experimental soil and crop management systems. Initial soil structure was described as massive; after 10 years, strong, moderate, or angular block structures predominate as a result of soil and crop management. Improvement in soil structure was greatest when forage crops were grown, while continuous row cropping resulted in poor soil structure development. Below the plow layer, strong platy structure development was observed especially when the disk harrow was used in seedbed preparation.

74. Barnhisel, R. I., J. L. Powell, M. L. Ellis, J. R. Armstrong, F. A. Craig, and S. K. Laue. Selection of Legume Species and Varieties for Reclamation of Mined Lands. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 40-49.

A summary is presented on several experiments conducted to assist in making recommendations for selection of species and varieties within a species to meet specific reclamation goals. Species of legumes and grasses were established and maintained on western Kentucky surface-mined land under two management systems, hayland and nonharvested hayland. Emphasis is placed on changes that have occurred in plant cover and yield over several years. Species comparisons were made between two mines, one where topsoil was replaced and the other where spoil was used as the growth medium. Evaluations of grass and legumes planted on both growth mediums are presented. This paper was included in the review process because of the information presented on liming and fertility treatments (type, rate, and technique of application) and on the effects of topsoiling on species ground cover and biomass over an extended period of time.

75. Barnhisel, R. I., J. L. Powell, J. S. Osborne, and S. Lakhakul. Estimating Agricultural Limestone Needs and Observed Responses for Surface Mined Coal Spoils. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 319-344.

Field and greenhouse studies were conducted to evaluate the accuracy of the hydrogen peroxide (H_2O_2) total potential acidity test for estimating lime requirements and what effect lime had on the chemical properties of acidified spoil materials. The field study was conducted on a western Kentucky acid sandstone spoil, which had a water pH of 3.6, SMP (Shoemaker-McLean-Pratt) buffer pH lime requirement of 9.0 Mg ha^{-1}, and a H_2O_2 total potential acidity of 44.8 Mg ha^{-1}. Calcitic limestone was applied at rates of 11.2, 22.4, 44.8, and 89.7 Mg ha^{-1} and incorporated into the spoil. Spoil samples were taken over a 2-year period to monitor the effects of the various liming rates on soil chemical properties. The greenhouse study was performed using freshly exposed, nonweathered shale materials. The spoil materials evaluated were an acidic siltstone, an acidic black shale, and a 50:50 mixture of the black shale and siltstone spoil (mixed spoil). The potential acidity lime requirements of each material was 20, 250, and 135 Mg ha^{-1}, respectively. Each material was limed at rates representing 0, 50, and 100 pct of the lime requirement as predicted by the H_2O_2 total potential acidity method. Once a month the spoils were subjected to two leaching intensities, 5 and 10 mm leaching rates. The pH of the acid sandstone spoil increased from 3.0 to 4.8, 5.6, 6.5, and 6.8 with the addition of 11.2, 22.4, 44.8, and 89.7 Mg ha^{-1} limestone, respectively, after 1 month. The pH was maintained at all levels, except for the 11.2 Mg ha^{-1} treatment, where there was a gradual decline resulting from the oxidation of sulphide minerals. After a 2-year period, only the low-lime treatment (11.2 Mg ha^{-1}) had pH values below acceptable values. In the greenhouse study, the initial pH of the black shale, siltstone, and mixed spoil was 5.5, 6.1, and 5.9, respectively. Prediction of lime requirement by the H_2O_2 total potential acidity method underestimated the actual lime needs of the black shale sample.

76. Barnhisel, R. I., and W. O. Thorn. The Potential Use of Atmospheric Fluidized Bed Combustion (AFBC) Material as a Liming Agent for Acid Soils. Paper in Proceedings: Eighth International Ash Utilization Symposium, Volume I (Washington, DC, Oct. 28-31, 1987). Electr. Power Res. Inst., Palo Alto, CA, 1987, pp. 31-1—31-13.

Atmospheric fluidized bed combustion (AFBC) spent bed material (SBM) was evaluated as a possible substitute for calcium carbonate as a liming agent for highly acidic western Kentucky mine soil. Several laboratory and greenhouse experiments were conducted to characterize the differences between SBM and lime, including: SBM characterization, effect of soil wetting and drying cycles on soil pH when treated with SBM or calcium carbonate, effect of SBM on the germination of alfalfa (*Medicago sativa* L.) and soybeans (*Glycine max* (L.) Merr.), and the effect of SBM on soil pH and exchangeable cations. The pH of the highly acidic mine soil was increased significantly as a result of applying lime as either SBM or pure calcium carbonate. Excessive rates of SBM, twice the rate needed to raise the pH of mine soil to 6.4, may result in too rapid a rate of increase in soil pH, which may reduce plant growth. SBM also needs to be adequately mixed with the soil to avoid problems with soil crusting, especially at high rates of SBM addition. The twice rate of SBM also resulted in pH values that were high enough to effectively reduce the germination of alfalfa (small seeded species), but not soybeans (large seeded species). SBM provided a plant available source of calcium, zinc, boron, and SO_4. Tissue analysis of alfalfa showed that heavy metal concentrations (lead, cadmium, copper, nickel, and chromium) were not related to application rates of SBM, and the levels of heavy metals were at or below detection limits. In contrast, some concentrations of aluminum, manganese, zinc, and molybdenum in alfalfa grown on SBM treated

soils were at or near levels considered to be excessive. This article provides good background information on the use of SBM as an alternative to calcium carbonate as a liming agent on acid coal surface-mined soil.

77. Barret, J., P. C. Deutsch, F. G. Ethridge, W. T. Franklin, R. D. Heil, D. B. McWhorter, and A. D. Youngberg. Procedures Recommended for Overburden and Hydrologic Studies of Surface Mines. U.S. For. Serv., Gen. Tech. Rep. INT-71, 1980, 106 pp.

There were two objectives for this study. The first was to determine the required information to evaluate the soils, overburden, and hydrology of a site to make appropriate management decisions for the selection of lease sites, development of lease stipulations, and formulation of mining and reclamation plans. The second objective was to recommend cost-effective procedures for data acquisition and analysis associated with soils, overburden, and hydrologic studies. These objectives were achieved by defining soils, overburden, and hydrologic information requirements and by evaluating alternative approaches when available. Not all of the technology and information available for the study of soils, overburden, and hydrology were identified. Only proven methods and procedures known to give good results are recommended for use.

78. Barth, R. C. Reclamation Practices in the Northern Great Plains Coal Province. Min. Congr. J., v. 63, No. 5, 1977, pp. 60-64.

This article discusses the reclamation practices that are used in the Northern Great Plains Coal Province. Various components of reclamation are discussed, and information is included on site preparation, species selection and planting, and soil amendments. Plant productivity was found to be higher on mined land than on unmined reference areas in the Northern Great Plains. This article contains little technical information, but it could serve as a reference to what reclamation practices have been used successfully in the Northern Great Plains Coal Province.

79. Barth, R. C. Reclamation Technology for Tailing Impoundments—Containment and Revegetation. Am. Soc. Agron., Agron. Abstr., 1986, pp. 27-28.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. The conceptual approach to tailings reclamation is discussed. Reclamation must control leaching, capillary rise, seepage, diffusion, water table formations, wind erosion, and water erosion. The suitability of the tailing for revegetation must first be evaluated, followed by modification of undesirable traits.

80. Barth, R. C., and B. K. Martin. Soil-Depth Requirements To Reclaim Surface-Mined Areas in the Northern Great Plains (contract JO265025, CO Sch. Mines Res. Inst.). BuMines OFR 202-82, 1982, 191 pp.; NTIS PB 83-148221.

Fourteen wedge-type field plots were established in North Dakota, Montana, and Wyoming to quantify soil depth requirements for reclamation of surface-mined land with perennial grasses. Plots were grouped into four types based on spoil chemical and physical properties and plant biomass. Results showed that precipitation and plant species determined soil depth requirements.

81. Barth, R. C., and B. K. Martin. Soil Depth Requirements for Revegetation of Surface-Mined Areas in Wyoming, Montana, and North Dakota. J. Environ. Qual., v. 13, No. 3, 1984, pp. 399-404.

The depth of soil that should be applied over spoil to ensure adequate production of cool-season grasses at surface mines in the Northern Great Plains was determined. During a 6-year period, 15 wedge-type plots were constructed at surface coal mines in Wyoming, Montana, and North Dakota using a uniform depth gradient ranging from 0 to 152 cm. Soil was obtained from existing stockpiles, soil was defined as portions of the A, B, and C horizons having chemical and physical traits conducive to plant establishment and growth. Following seedbed preparation and fertilization, perennial cool-season grasses were drill seeded into the wedge-type-plots. Plants were harvested for dry weight determination. Standard methods were used to determine soil chemical, physical, and mineralogical properties.

Four spoil types were recognized based on the chemical and physical traits of the underlying spoil: (1) generic, (2) sodic, (3) acidic, and (4) soil-like. Generic type spoil lacked distinguishing characteristics and differed from soil in terms of origin, biological activity, and ability to support plant growth. Generic spoil pH was near neutral, was saline, moderately fertile, had a clay loam texture, and kaolinite was the dominant clay mineral. It was the most common spoil type, being found at 10 of the 15 study locations. Grass production was lowest in this spoil, averaging 34 pct of maximum. As soil depth increased, so did production; at a soil depth of 6 cm, production was 50 pct of maximum, and production peaked at 60 pct of the maximum at a soil depth of 50 cm. Production of cool-season grasses fluctuated at soil depths above 50 cm. Root penetration into the spoil under soil averaged 10 cm across all soil treatments. Sodic spoil type was characterized by pH values >8.0, SAR values ranging from 25 to 81, and low rates of water infiltration. Plant establishment was lowest on sodic spoil indicating that sodic spoil has

little ability to support biological activity. Production on the spoil alone was only 2 pct of the maximum yield. Production consistently increased from spoil to a soil depth of 71 cm, followed by little change in production as soil depth increased from 71 to 152 cm. Again, root penetration into sodic spoil overlain with soil was limited to a depth of 10 cm. The acid spoil type was characterized by low pH values, which ranged from 3.6 to 4.3. The response of grass production to increasing soil depth was linear. The soil-like spoil type was mildly alkaline, low in soluble salts, carbonaceous material, and heavy metals, and silt loam in texture. Forage production was 80 pct of the maximum yield when spoil was the growth medium. There was no indication that roots concentrated at the soil-spoil interface, root penetration exceeded 110 cm. Precipitation had no significant influence on soil depth requirements for maximum production of cool-season perennial grasses.

82. Barth, R. C., R. C. Severson, and G. Weiler. Boron. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 135-153.

This chapter discusses boron in surficial materials (geologic materials, soils, and factors affecting availability), in plants (physiological role, deficiencies, and toxicity), and boron sampling and analysis in plants and soils. In a reclamation situation, boron in the growth medium is viewed in terms as boron toxicity rather than deficiency. Reclamation strategies for mitigating high boron concentrations include amendment application (lime and sewage sludge), overburden placement and soil cover, leaching treatments, and the use of boron tolerant species.

83. Bassman, J. H. Physiological Morphological Responses of Northwest Forest Tree Species to Thinning and Fertilization. Paper in Future Forests of the Mountain West: A Stand Culture Symposium (Missoula, MT, Sept. 29-Oct. 3, 1986). U.S. For. Serv., Gen. Tech. Rep. INT-243, 1988, pp. 249-254.

A review on the effects of thinning and fertilization on the physiological responses of established (20- to 40-year old) Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and other Northwest forest tree species are presented. Studies on tree physiological and morphological responses to fertilization alone, thinning alone, and combinations of fertilization and thinning were considered. Studies relating to seedlings were not considered. Tree responses presented in response to fertilization and thinning include stem growth, leaf production, biomass production, net assimilation, photosynthesis rate, and water relations. The increased growth, which results from thinning and fertilization, is acquired from different, but corresponding physiological influences. This article was included in the review process because of the information it contains on the physiological and morphological responses of tree species to fertilization.

84. Beauchamp, E. G. Availability of Nitrogen From Three Manures to Corn in the Field. Can. J. Soil Sci., v. 66, No. 4, 1986, pp. 713-720.

The response of corn (*Zea mays* L.) to three manures, with variable ammonium (NH_4) and organic nitrogen contents, was compared to the response with urea fertilization over a 3-year period. Liquid poultry manure, liquid dairy cattle manure, and solid beef manure were applied prior to planting at rates of 100, 200, and 300 kg total N ha^{-1}. Urea was applied at rates of 50, 100, and 50 kg N ha^{-1}. Both the manures and urea were broadcast and immediately incorporated into the soil. The manures varied in the proportions of total nitrogen present as NH_4 from year to year due to differences in ammonia (NH_3) losses during collection and storage and changes in feeds. Urea and manure nitrogen significantly increased grain yields over controls in all 3 years. The yield response to manure at equal rates of applied nitrogen was ordered: liquid poultry manure > liquid dairy cattle manure > solid beef manure. Yield response was closely related to the NH_4 content of the manures, with similar amounts of applied NH_4 producing similar yields independent of source. Regression analysis of paired data sets indicate that 75 to 88 pct of the NH_4 fraction was equivalent to urea nitrogen. This suggests that a substantial portion of the manure nitrogen was lost or unavailable through volatilization and denitrification.

85. Beauchamp, E. G. Corn Response to Residual N From Urea and Manures Applied in Previous Years. Can. J. Soil Sci., v. 67, No. 4, 1987, pp. 931-942.

The response of corn (*Zea mays* L.) to residual nitrogen from fertilizer and manure applied 1, 2, or 3 years previous, was determined. The occurrence of a residual organic manure effect or the effect of manure in increasing yields over those obtained with chemical fertilizers was evaluated. The results show that the response (grain yield) to urea nitrogen was generally greater than manure nitrogen in the first residual year. Responses to residual urea and manure nitrogen treatments were similar by year 3. Decay series indicate that the residual value of manure nitrogen may persist for 4 years. The total recovery of nitrogen applied in manures, however, was considerably lower than that in urea. Although the benefits of organic

manuring and the effects of manures have been documented, there was no clear evidence in this study that manures would provide the organic manuring effect of increasing corn yields over those obtained with chemical fertilizers only.

86. Beckjord, R. R., and M. S. McIntosh. Growth and Fungal Persistence by *Quercus rubra* Inoculated With Ectomycorrhizal Fungi and Planted on a Clear-Cutting and Strip Mine. Can. J. Bot., v. 62, 1984, pp. 1571-1574.

The growth and fungal persistence of northern red oak (*Quercus rubra* L.) seedlings inoculated or infected with ectomycorrhizal fungi on a clear-cut site and an unreclaimed strip-mined spoil in Maryland was evaluated. Red oak seedlings were grown in containers in the greenhouse in media inoculated with and without the vegetative hyphae of *Pisolithus tinctorius, Cenococcum geophilum, Scleroderma auranteum*, and *Rhizopogon nigrescens*. Basidiospores of *P. tinctorius* and *S. auranteum* were also used to infect seedlings in the greenhouse. The container-grown seedlings were outplanted and grown for two seasons on both experimental sites. Some seedlings that were not inoculated in the greenhouse were inoculated with basidiospores of *P. tinctorius* or *S. auranteum* at the time planting. Seedlings inoculated with vegetative inocula of all fungi were ectomycorrhizal with the fungal isolate introduced, except for *R. nigrescens*. Seedings inoculated with basidiospores in the greenhouse were also ectomycorrhizal.

Seedlings inoculated with *P. tinctorius* had the most growth. At the clear-cut site, growth did not differ significantly among seedlings of the inoculation treatments after two growing seasons. Root-core samples after one season indicated that seedling inoculated with *P. tinctorius, S. auranteum,* and *C. geophilum* were still infected. After two growing seasons, root excavations showed fungal persistence as well as new infection by *P. tinctorius* and *S. auranteum* to seedlings inoculated with basidiospores at the time of planting. Control seedlings also exhibited some infection by *P. tinctorius* and *S. auranteum*. Hyphae radiating from neighboring infected trees or native fungi may have caused the infection of control seedlings.

87. Bell, J. C., D. F. Amos, and J. C. Parker. Evaluation of Slope Stability and Foundation Suitability for Four Southwestern VA Mine Spoils. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 549-554.

This study was conducted to evaluate the stability of spoil banks and the suitability of reclaimed benches for shallow foundations in spoils located near Norton, VA. Mine spoils were analyzed for particle size distribution, particle density, shear strength parameters, compaction characteristics, and bulk density. The relative quantities of sandstone and siltstone had a direct affect on the particle size distribution and shear strength of the spoil material. However, these quantities had little affect on the coarse fragment content and dry bulk density. Blasting, handling, and placement of spoil material during mining and reclamation were the most likely causes for the variations in coarse fragment content and dry bulk density. As soil compaction increased, so did the shear strength of the <2 mm fraction of the spoil material. Of the spoil banks observed, several had inadequate safety factors against slope failure. The authors feel that increased soil compaction, which will increase shear strength, or slope reduction will increase slope stability if drainage is adequate. Of the spoils observed, slope stability is largely dependent on the slope angle and the angle of internal friction. Due to the high variability observed in bulk density, differential settlement of conventional strip footings would occur, creating unsuitable foundation conditions.

88. Bell, J. C., and W. L. Daniels. Four Case Studies of Slope Stability on Surface Mined Lands Returned to Approximate Original Contour in S.W. Virginia. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 243-247.

Specific factors contributing to slope instability at four Virginia surface-mined sites where slope failures on approximate original contour backfills had occurred or appeared imminent were identified. At each site, detailed transects were surveyed to obtain accurate cross sections for stability analyses. Particle size distribution, compaction characteristics, and shear strength parameters were determined for samples taken from each site. Modes of slope failure include: (1) rotational, motion is along a curved surface resulting in a slumping effect; (2) sliding wedges or blocks, movement is along a planar surface, generally along an inclined foundation; or (3) a combination of 1 and 2. Models were used to evaluate slope stability. Four factors were identified as contributing to slope failures at the sites studied: (1) excessively steep final regraded surfaces, (2) excessive seepage into fills resulting in the development of positive pore water pressures and strength reduction, (3) placement of the top of the fill beyond and below the mining bench (off bench), and (4) excessive seepage that caused rapid watering of spoil and a reduction in shear strength.

89. Bell, R., C. S. Evans, and E. R. Roberts. Decreased Incidence of Mycorrhizal Root Tips Associated With

Soil Heavy-metal Enrichment. Plant and Soil, v. 106, No. 1, 1988, pp. 143-145.

Although this research does not address soil characterization or soil amendment use on coal surface mined lands, it is a good reference on the effects heavy metals can have on soil processes. The author assessed whether changes in mycorrhizal root tip counts could be related to natural enrichments of copper, lead, and zinc. Two different areas in south-central Virginia were utilized for this study. At each location, two sites within 1 km were chosen for sampling. Within locations, the mineralized site had significantly higher soil concentrations of lead, copper, and zinc than did control sites, as determined by soil analysis. For each randomly selected sample, active fungal root tip counts were made. The results indicated that at both locations there was a reduced level of active mycorrhizal root tips in samples from the mineralized sites. Heavy metal inhibition is given as a possible explanation of the reduction in mycorrhizal development. Decreased mycorrhizal infection due to heavy metal enrichment is reducing the effective root absorption area which decreases root biomass and reduces the root surface area available for nutrient and water uptake. This research may apply to those surface-mined sites where sludges are to be used as a soil amendment and mycorrhizal inoculated tree seedlings are to be planted. Sludge materials usually contain heavy metals, which may limit mycorrhizal development on newly transplanted seedlings.

90. Bengson, S. A. ASARCO's Revegetation of Mill Tailings and Overburden Wastes from Open-Pit Copper Mining Operations in Arizona. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 164-172.

This article discusses the vegetative stabilization techniques used by ASARCO Incorporated in Arizona on copper overburden wastes and mill tailings. The site is first prepared for planting by topsoiling or using organic amendments. This is followed by species selection based on the physical environment of the site, species value for forage, aesthetics, and blending into the natural ecosystem. The vegetation is established by direct seeding (broadcast or drill seeding) or hand planting. Once seeded, mine wastes are irrigated.

91. Benjamin, J. G., R. M. Cruse, A. D. Blaylock, and L. V. Vogl. A Small-Plot Point Injection for Liquid Fertilizer Application. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1194-1195.

Point injection of liquid fertilizer has shown promise as an alternative to subsurface fertilizer applications. Benefits of point injection include subsurface fertilizer placement with minimal surface residue incorporation, less root pruning, ability to make multiple nitrogen applications through the growing season, and increased fertilizer efficiency by placing the fertilizer closer to the plant. Field scale point injection applicators are difficult to use in small plots. This paper describes the development and construction of a small-plot point injection fertilizer application system, which simulates fertilizer injection by a large point injection applicator. The small-plot applicator has been used for 3-years, and the unit has proven to be accurate, durable, and compatible with a variety of fertilizers including urea ammonium nitrate, ^{15}N-depleted ammonium nitrate solution, diammonium phosphate, and potassium chloride. Total cost of each applicator was estimated to be $150.

92. Bennett, O. L. Potential for Reclamation and Revegetation of Eastern Strip Mine Spoils. Paper in C = me², Conservation, Materials, Environment, Energy (Proc. 3d Int. Conf. on Environmental Problems of the Extractive Industries, Dayton, OH). Wright Co., 1977, pp. 10.5.1-10.5.9.

This paper provides a review of the anticipated impacts of the Surface Mining Control and Reclamation Act of 1977 on mine land reclamation and reclamation research. The author reviews the results of the major research efforts in mine land reclamation in the Eastern Coal Mining Region. This paper offers a good overview of reclamation research in this region conducted prior to 1977.

93. Berg, W. A. Nitrogen and Phosphorous Fertilization of Mined Lands. Paper in Symposium on Adequate Reclamation of Mined Lands? (Billings, MT, Mar. 26-27, 1980). Soil Conserv. Soc. Am., 1980, pp. 20-1—20-8.

This paper provides a concise discussion of the use of nitrogen fertilizer to establish optimum vegetative cover and achieve species diversity. Straw mulching is assumed to increase the need for nitrogen fertilizer. The author suggests the use of test plots to establish nitrogen requirements rather than depending on standard soil tests. He also states that the sodium bicarbonate extraction soil test for plant-available phosphorus seems to be a dependable guide for determining phosphorus status.

94. Berg, W. A. Use of Soil Laboratory Analyses in Revegetation of Mined Lands. Min. Congr. J., v. 61, No. 4, 1975, pp. 32-35.

This paper provides a concise discussion of the role soil tests play as a management tool for evaluating revegetation potential of disturbed lands.

95. Berg, W. A., M. Guillaume, and J. T. Herron. Effect of Fertility Treatments and Mulches on Revegetation of Alpine Disturbances. Paper in Proceedings of the High Altitude Revegetation Workshop No. 7, ed. by M. A. Schuster and R. H. Zuck. CO Water Resour. Res. Inst., CO State Univ., Fort Collins, CO, Inf. Ser. 58, 1986, pp. 142-152.

Long-term (7 years) effects of fertility treatments and mulches on the vegetative cover and frequency of native species seeded on disturbed alpine sites are reported. The research was conducted on Climax Molybdenum Mine located near Climax, CO. The two sites studied were a silty clay loam subsoil 130 m above tree line and a mine rock wastesite located 330 m above tree line. Fertility treatments included inorganic fertilizers and sewage sludge. The inorganic fertilizer rates were (1) diammonium phosphate (18-46-0) applied at 336 kg ha^{-1} prior to seeding, and (2) same as (1) plus 112 kg ha^{-1} N ammonium nitrate applied in early summer 2 years after seeding. Sewage sludge treatments were (1) 11 Mg ha^{-1} dry anaerobically digested sludge and (2) 88 Mg ha^{-1} dry anaerobically digested sludge. The subsoil and rock wastesites had the following mulch treatments: (1) 44 Mg ha^{-1} wheat straw held by plastic netting, (2) jute, (3) excelsior erosion blanket, (4) 44 Mg ha^{-1} woodchips, and (5) 4.4 Mg ha^{-1} wheat straw plus plastic netting, which was removed 1 year after placement. Additionally, a 7.5-cm cover soil treatment was applied to the waste rock, and the following fertility treatments were imposed: (1) none, (2) 336 kg ha^{-1} 18-46-0, and (3) same as (2) plus 112 kg ha^{-1} N. Vegetative ground cover, species frequency, and standing crop biomass were determined.

By the seventh growing season, the vegetative ground cover was 1.5 to 2.5 times greater on the high sludge treatments when compared with inorganic fertilizer treatments. The increase in vegetative cover was a response to fertility treatments; mulch type used had no effect on the vegetative cover. Treatment of rock waste with stock-piled soil was slightly more effective in producing vegetative cover after 7 years than inorganic fertilizer treatment. Frequency of vegetation was not influenced by fertility treatments. The type of mulch applied to both sites had no significant effect on the amount of cover produced. Increased vegetative cover with fertility treatments, particularly sewage sludge, indicates that soil nutrients, especially nitrogen, are limiting plant growth.

96. Berry, C. R. Dried Sewage Sludge Improves Growth of Pines in the Tennessee Copper Basin. Reclam. & Reveg. Res., v. 1, No. 2, 1982, pp. 195-201.

This study was conducted to determine whether dried sewage sludge, interacting with *Pisolithus tinctorius* (Pt) ectomycorrhizae, would improve survival and accelerate the early growth of loblolly pine (*Pinus taeda* L.), Virginia pine (*Pinus virginiana* Mill.), and shortleaf pine (*Pinus echinata* Mill.) on severely eroded sites in the Tennessee Copper Basin. Four different treatments were used in this study, noninoculated (naturally inoculated by *Thelephora terrestris*) or Pt mycorrhizal treatments combined factorially with sludge (34,000 kg ha^{-1}) or fertilizer (10-10-10, applied at a rate of 896 kg ha^{-1}). All three tree species grew significantly better on plots amended with sludge than on those with fertilizer. Pt ectomycorrhizae failed to stimulate the growth of the pine species. This response is apparently due to the high application rates of fertilizer and sludge. The results of the study demonstrate that the growth responses of the pine species used in this study are improved on sites amended with sewage sludge.

97. Berry, C. R. Growth and Heavy Metal Accumulation in Pine Seedlings Grown with Sewage Sludge. J. Environ. Qual., v. 14, No. 3, 1985, pp. 415-419.

A nursery experiment was conducted to evaluate the nutritional and phytotoxic properties of five different sources of sewage sludge as they affect the development of ectomycorrhizae and the growth of loblolly pine (*Pinus taeda* L.). The sludges were applied at two rates (34 and 68 Mg ha^{-1}), while control plots received 560 kg ha^{-1} of 10-10-10 fertilizer when the seedlings were planted and three applications of 56 kg ha^{-1} N (NH_4NO_3) at monthly intervals. Seedlings were inoculated naturally or with surface applications of *Pisolithus tinctorius* (Pers.) Coker & Couch (Pt) or *Thelephora terrestris* Ehrh. ex. Fr. (Tt). Seedlings were measured for height, root-collar diameter, and top and root fresh weight. Ectomycorrhizal development was estimated visually. Needle, stem, and root tissues were analyzed for total nitrogen using Kjeldahl procedures and 18 other elements by plasma emission spectrography. Seed germination and seedling survival rate were not affected by sludge source or rate; however, the percentage of seedlings that reached plantable size did vary according to sludge source. Formation of Pt mycorrhizae in sludge amended soil was less than formation with seedlings in fertilized soil when inoculated artificially. There was no natural Pt inoculation in either the sludge or fertilizer treatment. Formation of mycorrhizae by Tt was as good in sludge-amended plots as with fertilizer when artificially inoculated. Heavy-metal concentrations in seedling tissues varied with the heavy-metal concentration of the sludge applied, particularly cadmium. The author concludes that sewage sludges from selected sources will support loblolly pine seedling growth in the nursery and could be used to supply organic matter and nutrients.

98. Berry, C. R. Growth Response of Four Hardwood Tree Species to Spot Fertilization by Nutrient Tablets in

the Tennessee Copper Basin. Reclam. & Reveg. Res., v. 2, No. 3, 1983, pp. 167-175.

The feasibility of using sewage sludge tablets and fertilizer tablets to achieve stand establishment of sweetgum (*Liquidambar styraciflua* L.), sawtooth oak (*Quercus acutissima* Carruth.), black alder (*Alnus glutinosa* (L.) Gaertn.), and black locust (*Robinia pseudoacacia* L.) was tested in the Tennessee Copper Basin. Six fertility treatments were used on each species and consisted of a control; sludge tablets of 30, 60, and 90 g; and fertilizer tablets of 9 g (22.0 pct N, 3.5 pct P, and 1.7 pct K) and 21 g (20.0 pct N, 4.5 pct P, and 4.3 pct K). For all species, the 21 g fertilizer tablet produced significantly faster growth than did any of the other treatments. The 90-g sludge tablet and the 9-g fertilizer tablet produced similar growth responses for all species. The two nitrogen-fixing tree species, black locust and black alder, had average growth rates greater than either sweetgum or sawtooth oak, but not significantly greater. Fertility treatments did not affect the concentration of the foliar elements, particularly nitrogen, phosphorus, or potassium in the tree species. However, high concentrations of foliar manganese, copper, zinc, and iron were found in all species. The author concluded that because of their high growth rates, black locust and black alder could be used as alternatives to pine in the Tennessee Copper Basin.

99. Berry, C. R. Slit Application of Fertilizer Tablets and Sewage Sludge Improve Initial Growth of Loblolly Pine Seedlings in the Tennessee Copper Basin. Reclam. Rev., v. 2, No. 1, 1979, pp. 33-38.

This study evaluated the potential use of dried sewage sludge and starter forest fertilizer tablets placed in slits to stimulate the growth of loblolly pine (*Pinus taeda* L.) seedlings in the copper basin of southeastern Tennessee. The treatments used were control (no treatment), 30, 60, and 90 g of sludge, and 9 and 21 g of Agriform forest starter tablets. The sludge or fertilizer tablets were placed in the closing hole created by planting the loblolly pine with a planting bar. After 3 years the seedlings on the control plots grew poorly, while the seedlings on the five treatment plots grew significantly better. The fertilizer tablets were the most convenient to use and stimulated seedling growth. By the end of the third year, the 21 and 9 g fertilizer tablets increased seedling volume by 20 and 9 fold, respectively, over the control treatment. The results of this study indicate that slit application of nutrients is an alternative to broadcast application. Although broadcast application of fertilizer and sludge results in more production, slit applications are less expensive, easier to apply on rugged terrains, and less stimulating to growth of competing vegetation.

100. Berry, C. R. Subsoiling Improves Growth of Trees on a Variety of Sites. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 360-367.

The results of three studies on the effects of subsoiling on the early growth of trees in the southeast are presented. Various inorganic fertilizers and organic amendments (sewage sludge) were included in the studies. At each site, subsoiling consistently improved tree growth (height, survival, DBH, or root-collar diameter) over plots that were disked. Additionally, root penetration was as deep as the depth of the tillage method used; 15 to 20 cm on disked plots, 92 cm on plots subsoiled to that depth, and only a few centimeters on nontreated plots. When used in conjunction with subsoiling, sewage sludge amendments resulted in better tree growth than inorganic fertilizers due to the leaching potential of inorganic fertilizers. Subsoiling resulted in reduced bulk density values, improved moisture relations, and improved root penetration allowing for improved moisture and nutrient relationship and better anchorage. The author recommends that sewage sludge should be used with subsoiling for tree seedling establishment on severely eroded sites.

101. Berry, C. R. Subsoiling and Sewage Sludge Aid Loblolly Pine Establishment on Adverse Sites. Reclam. & Reveg. Res., v. 3, No. 3, 1984-85, pp. 301-311.

On a borrow pit, 18 treatments (two amendments by nine physical treatments) were randomly assigned to plots in five blocks. Sewage sludge, 17 mt ha^{-1} was applied to nine plots in each block, while fertilizer (10-10-10) and limestone were applied at a rate of 1,121 kg ha^{-1} and 2,242 kg ha^{-1}, respectively, to the remaining nine plots in each block. Nine physical treatments were applied to both the fertilized and sludge amended plots. The physical treatments were disking only and eight intensities of subsoiling which varied in depth (46 or 92 cm deep), direction (one or two directions), and spacing of furrows (110 or 220 cm apart). Loblolly pine (*Pinus taeda* L.) seedlings, inoculated with the mycorrhizal fungus *Pisolithus tinctorius* (Pers.) Coker & Couch, were planted in each of the treatments. Survival height, and DBH were determined after the first, second, and fourth growing season. Soils were analyzed after the first year for total nitrogen, phosphorous, organic matter, CEC, potassium, and pH. After the fourth year, foliage was analyzed for nutrient content.

Application of sewage sludge significantly increased soil nitrogen, phosphorus, manganese, zinc, and copper when compared with fertilized plots. Fertilized plots had more potassium and magnesium and a higher pH relative to

sludge amended plots. Organic matter and CEC were not affected by treatment. Foliar concentrations of nitrogen, manganese, barium and on disked plots, zinc, were higher in loblolly pine when amended with sewage sludge. Fertilization resulted in higher tissue concentrations of potassium and magnesium when compared with sludge plots. Trees planted in sludge amended plots were 37 pct taller and 76 pct greater in DBH after 4 years than did trees grown on fertilizer amended plots. Survival was not affected by amendment. Subsoiling affects varied with the amendment used. On fertilized plots, trees were 9 pct taller and had a diameter that was 17 pct greater when subsoiled to 46 cm compared with the 92 cm subsoil depth. When amended with sewage sludge, there was significantly more growth when plots were subsoiled to a depth of 92 cm compared with 46 cm depth. These results demonstrate the value of sewage sludge for stimulating loblolly pine growth. Root excavations of selected trees showed that root penetration was as deep as the physical treatment. The author recommends that the following sequence should be followed: (1) application of amendment—prior to incorporation, (2) incorporation of amendment—prior to subsoiling, (3) subsoiling, and (4) planting.

102. Berry, C. R. Use of Municipal Sewage Sludge for Improvement of Forest Sites in the Southeast. U.S. For. Serv., Res. Pap. SE-266, 1987, 33 pp.

Eight field experiments, which utilized dried municipal sewage sludge as an amendment treatment, were discussed. The sewage sludge was applied to the forest sites prior to seedling planting. Four studies were conducted on borrow pits; one on a kaolin spoil, one in the Tennessee Copper Basin, and two on routine reforestation sites in South Carolina. At each site, the effects of dried sewage sludge on soil nutrients, tree growth, and nutrient concentrations in tree foliage were determined. In all studies, total soil nitrogen concentrations were higher on sludge treated plots than on control or fertilized plots. In seven of the eight studies, a good routine reforestation site being the exception, phosphorous was also higher on sludge amended plots than on fertilized plots. On plots where sewage sludge was applied, organic matter and the cation exchange capacity were also, in general, higher than on plots that were fertilized. Potassium levels were equal on sludge and fertilized plots, while concentrations of calcium and magnesium and soil pH were higher on fertilized plots. At all study sites, sewage sludge applications resulted in faster tree growth over a 2- to 10-year period than did applications of fertilizers. The accelerated growth of trees on sludge plots indicate the long-lasting site benefits provided by sludge application. Of the sites studied there was an indication that tree growth was slowing down on plots amended with sewage sludge. In general, foliar nutrient concentrations of nitrogen, phosphorus, and zinc were greater in trees grown on sludge amended plots than fertilized plots. In fertilized plots, however, calcium and magnesium foliar concentrations were generally higher. The author states that if sludge is used instead of fertilizer, plot nutrients will be retained on site because they are released at a slower rate when compared to fertilizer treatments.

103. Berry, C. R., and D. H. Marx. Growth of Loblolly Pine Seedlings in Strip-Mined Kaolin Spoil as Influenced by Sewage Sludge. J. Environ. Qual., v. 6, No. 4, 1977, pp. 379-381.

This study was conducted to determine whether additions of sewage sludge would improve the growth of loblolly pine seedlings (*Pinus taeda* L.) on kaolin spoil obtained from surface-mined sites near Macon, GA. If growth improved, a second objective was to determine the minimum quantity of sewage sludge needed to significantly increase growth. Twenty-five microplots were constructed, and kaolin spoil was added. Anaerobically digested dried sewage sludge was added to the kaolin spoil at the following equivalent rates: 0, 34, 69, 138, and 275 mt ha^{-1}. Height, stem collar diameter, and fresh weight were significantly improved by sludge amendments. The mean values for each of the growth factors were highest in plots containing 69 mt ha^{-1} sludge. However, these parameters were not significantly different from those in plots containing 34 mt ha^{-1} sludge. When 275 mt ha^{-1} were applied, all growth factors were significantly lower than with any other treatment. The survival of all planted seedlings decreased as sludge application rates increased. The degree of ectomycorrhizal development was proportional to the amount of seedling growth. The 34 and 69 mt ha^{-1} sludge treatments resulted in short roots with the highest proportion of ectomycorrhizae development. The lowest amount of ectomycorrhizae development occurred in the 0 and 275 mt ha^{-1} treatments. Sludge application also increased the concentration of organic matter and essential plant nutrients in the soil. The authors concluded that sewage sludge is an excellent organic amendment for kaolin spoil, with small amounts significantly stimulating growth and mycorrhizal development of loblolly pine seedlings. The lower rates of application are also economically attractive owing to transportation costs and the amount of kaolin spoil acreage that is in need of reclamation.

104. Berry, C. R., and D. H. Marx. Significance of Various Soil Amendments to Borrow Pit Reclamation With Loblolly Pine and Fescue. Reclam. Rev., v. 3, No. 2, 1980, pp. 87-94.

The purpose of this study was to determine whether borrow pits located in South Carolina could be reclaimed by deep subsoil applications of various inorganic and organic amendments, and by planting loblolly pine (*Pinus taeda* L.) seedlings colonized with a specific ectomycorrhizal fungus. The site was prepared by removing all trees, subsoiling, and ripping furrows 0.9 m deep. Following subsoiling, the area was disked and seeded with Kentucky-31 fescue (*Festuca arundinacea* Schreb.) prior to tree planting. Two ectomycorrhizal treatments were utilized and combined with nine different fertility treatments: (1) control, (2) fertilizer and lime, (3) fertilizer and lime plus tree bark, (4) fertilizer and lime plus ash, (5) fertilizer and lime plus bark plus ash, (6) sewage sludge, (7) sewage sludge plus bark, (8) sewage sludge plus ash, and (9) sewage sludge plus bark plus ash. The sewage sludge treatments (treatments 6-9) improved pine seedling growth and fescue biomass when compared with the other soil treatments. Mean seedling volume was 28 times greater and fescue biomass five times greater on sludge plots than on nonsludge plots. There was also more soil nitrogen, phosphorous, and organic matter along with a higher cation exchange capacity on the sludge amended plots than on nonsludge plots. Foliar analysis of loblolly pine indicated that with sludge amendments, the nitrogen and calcium concentrations were higher than on other treatment plots. The authors conclude that amelioration of a borrow pit considered unsuitable for plant growth can be accomplished by deep subsoiling and application of dried sewage sludge.

105. Best, C. Vesicular-Arbuscular Mycorrhizal Associations in the Revegetation of Acid Strip Mine Spoil. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 53-68.

The ecology of vesicular-arbuscular (VA) mycorrhizae in acid soils or soils that contain toxic minerals is not well understood. Vesicular-arbuscular mycorrhizal associations among plants colonizing acid coal spoils were studied to identify plant species and their mycorrhizal symbionts, which are adapted to acid spoils, and to determine if the chemical characteristics of acid spoils are detrimental to the formation of VA mycorrhizae. Two southern Illinois minesites, varying in age and vegetation, were studied. At each site a nonacid area was present. Soil and vegetation sampling was done using line intercept methods which passed through the acid areas and extended into the adjacent nonacid areas. The species best adapted to the acid areas were nonmycorrhizal, although spores were abundant in all study areas. Spores were identified to species. The diversity and abundance of VA mycorrhizal fungi, along with the absence of inhibiting factors, indicated that the poor plant growth in acid sites was not the result of the absence or failure of mycorrhizal formation. Poor plant growth in the acid areas is attributed to potentially toxic levels of aluminum in the soil solution.

106. Best, G. R., P. M. Wallace, W. J. Dunn, and J. A. Feiertag. Enhancing Ecological Succession: 4. Growth, Density, and Species Richness of Forest Communities Established From Seed on Amended Over-burden Soils. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 27-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 377-383.

This study assessed the germination, survival, growth, density, and species richness of 25 tree species, ranging from early to late successional species, direct-seeded on amended phosphate mine overburden from north central Florida. The amendments used were (1) vesicular arbuscular fungi inoculum (VA mycorrhizae), (2) ectomycorrhizal fungi inoculum (Pt mycorrhizae), (3) fertilizer (15-0-15 applied at a rate of 320 kg ha^{-1}), (4) soil surface organic matter (straw mulch applied at a rate of 4,500 kg ha^{-1}), (5) soil amendment (phosphogypsum) applied at a rate of 1,750 kg ha^{-1}, and (6) topsoil. First year growth of the tree seedlings was significantly increased with the mulch, topsoil, and VA mycorrhizae amendments, while Pt mycorrhizae, gypsum, and fertilizer amendments significantly decreased growth. A community development index (CDI) was developed comprising relative values for growth, density, and species richness of tree seedlings. The CDI was used to assess the effectiveness of the soil amendments on community establishment. During the first growing season mulch, topsoil, and VA mycorrhizal inoculum had a positive effect on the CDI, Pt mycorrhizae inoculum had no effect on the CDI, and gypsum and fertilizer had a negative effect. There were no treatment effects on the CDI during the second growing season. The authors feel that this is due to the dominance of the early successional species *Albizzia julibrissins* and *Catalpa bignoniodes*.

107. Bevenger, G. S. Jones Branch Artificial Wetland Project. Hydata News and Views, v. 7, No. 1, 1988, pp. 18-19.

This general article provides background information on the construction of an artificial wetland to treat acid mine drainage in and around Daniel Boone National Forest in eastern Kentucky. Past acid mine drainage treatment methods have proven to be costly. These methods include addition of bases, oxidation by aeration, precipitation in settling ponds, and hydraulic sealing of portals and seeps.

Artificial wetlands provide a cost-effective method for treating acid mine drainage. General information is presented on wetland size, construction of wetland floor, choice and planting of wetland species, watering with unpolluted water, and the release of acid mine drainage into the wetland. Several treatment phenomena, which result from this method of acid mine drainage abatement, are presented. The author states that if properly constructed and maintained, artificial wetlands can bring acid mine drainage effluent within State and Federal water quality standards.

108. Bhumbla, D. K., H. E. Ghazi, R. F. Keefer, and R. N. Singh. Effect of Fly Ash and Rock Phosphate Application on Wheat and Alfalfa Grown on Very Acid Mine Land. Am. Soc. Agron., Agron. Abstr., 1984, p. 23.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. Fly ash and rock phosphate were evaluated as amendments to ameliorate acid mine soils for alfalfa (*Medicagos ativa* L.) and wheat (*Triticum aestivum* L.) production. Rates of application were 0, 400, and 800 mt ha^{-1} for fly ash and 0, 5, and 30 mt ha^{-1} for rock phosphate in a factorial design. Lime and fertilizer were applied to control plots. Higher yields were achieved on plots treated with lime and fertilizer than rock phosphate when no fly ash was added. First year yields of alfalfa and wheat were greatest on plots treated with 400 mt ha^{-1} fly ash and 30 mt ha^{-1} rock phosphate. Second year alfalfa yield was highest on plots treated with 800 mt ha^{-1} fly ash and 30 mt ha^{-1} rock phosphate. Nitrogen concentrations were higher in alfalfa with fly ash additions, while boron concentrations in both crops decreased with the use of rock phosphate.

109. Bhumbla, D. K., R. F. Keefer, and R. N. Singh. Microbial Biomass in Acid Mine Soil Affected by Fly Ash-Rock Phosphate Treatments and Cropping. Am. Soc. Agron., Agron. Abstr., 1985, p. 21.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. Mine soil was treated with fly ash and rock phosphate, incubated with alfalfa meal, and soil microbial biomass quantified by CO_2-C evolution. Acid abandoned mine soil was treated with fly ash (0, 400, and 800 mt ha^{-1}) and rock phosphate (0, 15, and 30 mt ha^{-1}). Soils were cropped with wheat (*Triticum aestivum* L.) and alfalfa (*Medicago sativa* L.) and after 2 months CO_2-C evolution was assessed. The application of fly ash prior to incubation suppressed microbial activity at all rates. This trend was reversed when the soils were cropped. The increased microbial biomass after cropping was attributed to changes in soil pH at the high fly ash application rates.

110. Bhumbla, D. K., R. F. Keefer, and R. N. Singh. Rock Phosphate Dissolution and Pyrite Oxidation in Amended Coal Mine Spoils. Am. Soc. Agron., Agron. Abstr., 1987, p. 23.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. A laboratory incubation study was conducted to determine the rates of oxidation of pyrite and dissolution of rock phosphate. Three pyritic coal mine spoils were amended with rock phosphate at the following rates: 0, 50, and 100 pct of the spoil cation-exchange capacity and one equivalent of phosphorus as rock phosphate for each equivalent of pyritic sulfur present in the spoil. During the initial period of the incubation, most of the rock phosphate dissolved. At the highest treatment level, however, about 50 pct of the added rock phosphate remained unreacted after 1 year of incubation. The results show that rock phosphate reduced the rate of pyrite oxidation.

111. Bhumbla, D. K., R. F. Keefer, and R. N. Singh. Selenium Uptake by Alfalfa and Wheat Grown on a Mine Spoil Reclaimed With Fly Ash. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 15-21.

The introductory material of this paper contains a good review and bibliography on pyrite oxidation, fly ash elemental concentration and fly ash as a soil amendment. This study was designed to examine selenium uptake and accumulation by alfalfa (*Medicago sativa* L.) and wheat (*Triticum aestivum* L.) grown on fly ash amended mine soils. This study was conducted near Westover, WV. Treatments consisted of three rates of fly ash, 0, 400, and 800 Mg ha^{-1} and three rates of rock phosphate, 0, 15, and 30 Mg ha^{-1} using a randomized complete block, factorial arrangement as the experimental design. During the first year of crop production, wheat was sampled at jointing and at maturity; at maturity, the wheat was separated into grain and straw. Alfalfa was sampled at two cutting dates. All plant samples were analyzed for phosphorous and selenium content and soils were analyzed for selenium concentration.

The additions of selenium through fly ash amendments were high enough to result in hazardous accumulations of selenium in the plants studied. In alfalfa, selenium concentrations increased significantly with increases in the amount of fly ash applied. With the addition of rock phosphate, the selenium content of alfalfa grown on fly ash amended soils decreased with increasing levels of rock phosphate. In wheat, there were no significant differences in the selenium content among the plots receiving fly ash or in selenium content when rock phosphate was also

added. The selenium concentrations found in the wheat grain were less than one-half of that found in the straw. The authors conclude that the application of varying rates of fly ash to the mine soil studied did increase the selenium content of both alfalfa and wheat. However, the values obtained for both species were in a range between deficient and toxic. The differences in selenium uptake behavior between the two species is related to physiological differences. The low selenium uptake from the fly ash treated mine soils are attributed to the adsorption of selenium on oxides of iron and aluminum present in the fly ash and to the low pH of the mine soil.

112. Bickelhaupt, D. H. Use of Sulfur to Correct Soil pH. Paper in Meeting the Challenge of the Nineties: Proceedings, Intermountain Forest Nursery Association (Oklahoma City, OK, Aug. 10-14, 1987). U.S. For. Serv., Gen. Tech. Rep. RM-151, 1987, pp. 50-65.

Soil pH in tree nursery operations should range from 5.5 to 6.0. Values above and below this recommended range may result in nutrient imbalances, diseases, and, in some instances, reduced growth and dry weight of intolerant species. A study was conducted at the Saratoga Tree Nursery, NY to reduce soil pH and improve Norway spruce (*Picea abies* (L.) Karst.) seedling quality. A single 6-in application of composted horse manure, which contained lime, resulted in an increase in soil pH from 5.7 to 7.2. At the time of this study, the pH was 6.5. Several sulfur treatments were utilized to reduce soil pH: single applications of granular sulfur at 0, 890, 1,780, 2,670, and 3,560 lb acre^{-1}; concentrated sulfuric acid at 890 and 1,780 lb acre^{-1}; and granular sulfur and sulfuric acid both applied at 890 and 1,780 lb acre^{-1}.

Sulfur application resulted in a significant decrease in soil pH 8 months after application. Compared with other sulphur treatments, the application of 1,780 lb acre^{-1} granular sulfur and 1,780 lb acre^{-1} sulfur as sulfuric acid resulted in the lowest soil pH values. This treatment was the only one that reduced soil pH within the desired range. After 23 months, this treatment resulted in a significantly lower pH value, 6.1, when compared with the pH of the control, 6.9. Sulfur treatments did not cause a significant change in soil pH after 23 months. After two growing seasons, Norway spruce seedlings growing on the sulfur plus sulfuric acid treatment were taller, had larger root collars, and a greater root volume than the control grown seedlings. These seedling quality variables were strongly correlated with soil pH at the time of sowing.

113. Bidwell, A. M., and R. H. Dowdy. Cadmium and Zinc Availability to Corn Following Termination of Sewage Sludge Applications. J. Environ. Qual., v. 16, No. 4, 1987, pp. 438-432.

The long-term effect of sewage sludge application on cadmium and zinc accumulation by successive corn (*Zea mays* L.) crops following the termination of sludge application was assessed. Corn stover and grain, and soils were sampled and analyzed for 6 years following the termination of three annual applications of sewage sludge. The total amount of sludge applied over the 3 years was 0, 60, 120, and 180 Mg ha^{-1}. The application of sewage sludge at the various rates had no significant effect on stover yields or total dry yield. Only in the second year was the grain yield from control plots significantly greater than grain yield from any of the sludge treatments. Tissue analyses revealed that cadmium and zinc were the only metals that increased in corn stover and grain when compared with the control, as a result of sludge applications. Stover cadmium and zinc concentrations increased linearly with increasing sludge levels for all years. Concentrations of other metals (copper, lead, chromium, and nickel) in the stover and grain did fluctuate yearly, but there was no uniform effect of sludge on metal concentration. Of the metals analyzed, only stover cadmium concentration was higher than the National Research Council tolerance level in animal feed for all sludge treatments in all years. Cadmium uptake had declined by 80 pct by the sixth year when compared with the first year after final sludge application. Zinc uptake declined only 25 pct, sludge applied zinc remains available for plant uptake for longer periods than does sludge applied cadmium.

114. Biggerstaff, S. D., I. D. Moore, and R. C. Warner. Effects of Mulches on Infiltration, Runoff and Erosion of Reclaimed Minelands. Coll. Agric., Coop. Ext. Serv., Univ. of KY, Lexington, KY, Reclam. News and Views, v. 2, No. 2, Apr. 1984, 5 pp.

The effects of mulches on infiltration, runoff, and sediment yield from interrill areas on reclaimed mine soil were examined. Treatments investigated were bare soil compared with screen over bare soil, straw (1, 2, and 3 mt acre^{-1}), hydromulching (1 mt acre^{-1}), and wood chips (3 to 6 mt acre^{-1}). Rainfall was generated using the Kentucky rainfall simulator. The focus of this research was to determine the effects of mulches in reducing surface sealing (high-bulk density and lower permeability at the soil surface) and its influence on infiltration, runoff, and sediment production and yield. When compared with straw mulched plots, bare soil had significantly reduced infiltration rates over the first hour of rainfall. Longer rainfall events resulted in diminished treatment differences. Bare plots had significantly greater sediment yields than did straw mulched plots; however, there is a diminishing marginal return for additional straw mulching above 1 mt acre^{-1}. There was no significant difference in effluent sediment concentration above the 2 mt acre^{-1} straw mulch

application rate. Both the hydromulch and straw mulch reduced the development of surface seals by dissipating the impact of rainfall energy. When rainfall rates were greater than 0.8 in h^{-1}, both wood chips and hydromulch were washed downslope. The authors state that mulches should be judged on their ability to remain in place and to absorb rainfall impact.

115. Biondini, M. E., C. D. Bonham, and E. F. Redente. Relationships Between Induced Successional Patterns and Soil Biological Activity of Reclaimed Areas. Reclam. & Reveg. Res., v. 3, No. 3/4, 1984-85, pp. 323-342.

The effects of topsoil thickness, nitrogen and phosphorus fertilization, and seed mixtures on the patterns of secondary succession and soil biological activity of seeded plant communities were determined for Colorado retorted shale. Introduced and native species seed mixtures were seeded onto retorted shale utilizing the following treatments: (1) 30 cm of topsoil over 60 cm of retorted shale, (2) 30 cm of topsoil over 60 cm of retorted shale plus 112 kg ha^{-1} N and 56 kg ha^{-1} P, (3) 60 cm of topsoil and 30 cm of rock capillary barrier over 60 cm of retorted shale, and (4) 60 cm of topsoil and 30 cm of rock capillary barrier over 60 cm of retorted shale plus 112 kg ha^{-1} N and 56 kg ha^{-1} P. Plant canopy cover by species was estimated at the end of the growing season over a 5-year period. Soil biological activity was assessed by measuring soil organic matter, dehydrogenase and phosphatase enzymatic activities, and nitrogen fixation using acetylene reduction.

After 2 years, soil thickness and fertilization within treatments with thicker soils had a significant affect on species composition; however, after 5 years, there was convergence in species composition. This indicates that soil thickness and fertilizer levels do not have a lasting effect on species composition or successional rate. A shallow soil without fertilization did, however, produce a forb-dominated community. There was a relationship between species composition and soil biological activity. Dehydrogenase activity was directly related to the perennial species composition. Lower enzymatic activity was found in the early stages of succession, with increased activity with time. Acetylene reduction and phosphatase activity were more affected by type of treatment and time than vegetative composition. Vegetation successional patterns are presented.

116. Biondini, M. E., and E. F. Redente. Interactive Effect of Stimulus and Stress on Plant Community Diversity in Reclaimed Lands. Reclam. & Reveg. Res., v. 4, No. 3, 1986, pp. 211-222.

In plant communities, stimulus and stress play an important role in the development and maintenance of structural diversity. Species diversity changes in developing plant communities growing under conditions of stress and stimulus on retorted shale were studied in northwestern Colorado. Four treatments were imposed on the retorted shale: (1) 30 cm of topsoil over 60 cm of retorted shale, (2) 30 cm of topsoil over 60 cm of retorted shale plus 112 kg ha^{-1} N and 56 kg ha^{-1} P, (3) 60 cm of topsoil and 30 cm of rock capillary barrier over 60 cm of retorted shale, and (4) 60 cm of topsoil and 30 cm of rock capillary barrier over 60 cm retorted shale plus 112 kg ha^{-1} N and 56 kg ha^{-1} P. For each treatment, two types of seed mixtures were utilized; one was composed of introduced species and one was composed of species native to the western United States. The stress factor was the layer of retorted shale, and the stimulus was nitrogen and phosphorus fertilization. Vegetation measurement consisted of plant canopy cover, biomass by species, percent relative cover, and diversity.

The effects of topsoil thickness and fertilization on species diversity followed a similar pattern for both seed mixtures. Plots fertilized, with 60 cm topsoil plus a capillary barrier, had lower diversity than unfertilized and 30 cm topsoil plots. In the introduced seed mixture treatment, the stress factor increased species diversity, while stimulation created conditions for rapid establishment, high rates of growth, and rapid dominance by crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.), pubescent wheatgrass (*Agropyron trichophorum* (Link.) Richt.), and intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.) resulting in decreased species diversity. Stimulus resulted in higher aboveground biomass and production was inversely related to diversity. The same trends were observed in the native seed mixture treatment; stimulus reduced species diversity, while stress increased diversity. Conditions, which promote high diversity, were those that reduced growth rate, resulting in lower biomass production. High diversity and high production cannot be achieved at the same time. In the early stages of succession, species diversity is not a reliable index of potential community stability.

117. Bishoff, S. M. Costs and Cost Effectiveness of Coal Mining Reclamation. Min. Eng. (N. Y.) v. 36, No. 2, 1984, pp. 166-170.

The major operational consequence of the reclamation related provisions of the Surface Mining Control and Reclamation Act (SMCRA) is the increased costs and complex procedures necessary to accommodate the regulatory authorities. Because of this, it is necessary to examine the reclamation processes, the affect of those processes on production costs, and the methods used to minimize their impact on the overall operation. This article discusses the permanent disturbances relative to the life of the mine that

will not undergo reclamation until active coal production has ended. The reclamation standards established under the authority of the SMCRA concern physical, chemical, and biological processes; the majority of the standards deal with physical processes such as the mining operation and restoration of the landscape to its previous condition. To evaluate reclamation costs, it is necessary to understand the purposes of the various reclamation requirements. These requirements can be divided into three categories based on their social and environmental implications: (1) safety-related reclamation procedures (procedures to prevent injury or loss of life from hazards existing at the site), (2) pollution control reclamation (procedures to control or prevent water, air, or land pollution), (3) aesthetic reclamation procedures (procedures to satisfy social desires for emotionally pleasing surroundings). In terms of company liability (1) is the most important, while (3) has the least social concern and potential liability, but the highest potential for minimizing overall reclamation costs and maximizing cost effectiveness.

Reclamation costs are divided into two categories, physical reclamation costs and reclamation monitoring costs. Physical reclamation costs are one-time expenditures necessary to reclaim the site to its final configuration and compliance with the reclamation plan. Reclamation monitoring costs include all procedures necessary to comply with the reclamation plan, monitor the success of the plan, and maintain the reclaimed site until it is self-sufficient. Reclamation costs are operational expenses, which must be incurred following production. They must be estimated with reasonable accuracy so that a production surcharge will generate enough funding to complete all reclamation work. This surcharge must by maintained or adjusted to reflect economic inflation, changes in reclamation requirements, and changes in reclamation methodologies.

118. Bisoyi, R. N., and P. K. Singh. Effect of Phosphorous Fertilization on Blue-Green Algal Inoculum Production and Nitrogen Yield Under Field Conditions. Biol. and Fertil. Soils, v. 5, 1988, pp. 338-343.

The research described in this paper does not involve surface coal mine reclamation. Even though this research is concerned with maintaining soil fertility and sustaining rice yields in India, the materials used and results obtained do provide background information on the effects of phosphorous fertilization on inoculated and native blue-green algae production and their nitrogen yields. Algal biomass was found to respond to phosphorous according to the amount of phosphorous applied and the method of application. As the amount of phosphorous applied and the number of applications of a specific level of phosphorous were increased, there was a corresponding increase in the dry weight of blue-green algae and their nitrogen yields. Three different blue-green algae inoculum are compared with respect to their growth (biomass) and nitrogen fixing capacity in response to phosphorous fertilization. Responses of the inocula vary with the amount of phosphorous applied. Indigenous blue-green algae also responded to the additions of phosphorous; however, when inoculum from outside of the district were tested, biomass and nitrogen yield decreased when compared with the local cultures.

119. Bjugstad, A. J. Hybrid Poplar Cultivars for Maximizing Phytomass Production on Gold Mine Tailings in the Black Hills. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 263-265.

Five-year survival and growth of 26 hybrid poplar clones (*Populus* spp.) planted on gold mine tailings in the Black Hills are reported. Survival ranged from 8 to 92 pct, with an average of 58 pct. The survival of the top 10 clones ranged from 69 to 92 pct, with an average of 78 pct. Four of these clones were identified as having very good survival and growth.

120. Bjugstad, A. J. Shrub and Tree Establishment on Coal Spoils in Northern High Plains—USA. Paper in Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min., Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 223-236.

Trickle irrigation during establishment was shown to increase survival two-fold for seven species of shrubs and trees planted on coal mine spoil in the semi-arid area of northeastern Wyoming. The species used in this study included green ash (*Fraxinus pennsylvanica* Marsh.), Russian olive (*Elaeagnus angustifolia* L.), silver buffaloberry (*Shepherdia argentea* (Pursh) Greene.), Siberian pea shrub (*Caragana arborescens* Lam.), American plum (*Prunus americana* Marsh.), ponderosa pine (*Pinus ponderosa* Laws.), and Rocky Mountain juniper (*Juniperus scopulorum* Sarg.). The increased survival persisted for 5 years following the initiation of the study. This period included two growing and two winter seasons after cessation of irrigation.

121. Blake, G. Exotics Vs. Natives. West. Wildlands, v. 7, No. 3, 1981, pp. 26-27.

The author discussed the use of exotic and native vegetation for reclaiming surface-mined land in eastern Montana. The use of exotic or introduced species may

create new environmental problems since they are not adapted to the environmental conditions of eastern Montana. The regeneration of natural vegetation on surface-mined land involves three factors: (1) seed that is adapted to the local environment, (2) site preparation of the seedbed, and (3) climatic conditions. When all three are considered correctly, natural regeneration occurs.

122. Blauch, B. W. New Resources for AML Reclamation. Paper in Tenth Annual Coal Conference (Wilkes-Barre/Poconos, PA, Oct. 10-14, 1988). Assoc. Abandoned Mine Land Prog., 1988, 6 pp.

This article discusses abandoned mine land (AML) reclamation as influenced by the Surface Mining Control and Reclamation Act (SMCRA) of 1979. There is a need to attract industry interest in AML reclamation through governmental action, possibly through remining and amendments to SMCRA, since AML reclamation programs as addressed in SMCRA will end in 1992. In addition to regulatory policy, industry interest in AML reclamation should be encouraged through alternative projects such as using coal wastes as a fuel for small power production facilities and the ash by-product in fluidized-bed combustion as a soil amendment in AML reclamation.

123. Bogner, J. E., and A. O. Perry. A Case Study of Surface Mining and Reclamation Planning: Cannelton Mine No. 9-S, Cannelton, West Virginia. Integrated Mine-Area Reclamation and Land Use Planning, v. 3F. Argonne Natl. Lab., ANL/EMR-1, Feb. 1977, 54 pp.

This report is one in a 10-volume series prepared by the Energy and Environmental Systems Division of Argonne National Laboratory and the Resource and Land Investigations (RALI) Program of the U.S. Department of the Interior under the sponsorship of the U.S. Geological Survey. In this case study a mountaintop-removal coal mining operation in south-central West Virginia is examined. Steep-sided hills characterize the area surrounding the mining area. The area generally lacks extensive tracts of level land suitable for agricultural or residential-commercial development. The Cannelton operation already has several ridges and through innovative reclamation planning is creating areas that may have a higher land use potential than before mining. Although a new town site, the end use identified by a planning team, may not have been realistic, it is a good example of integrated mine and reclamation planning. The study provides a very complete report of the mining operation and the reclamation techniques. Specific details of the report are probably unique to this part of the Eastern Coal Mining Region.

124. Bole, J. B. Amelioration of a Calcareous Solonetzic Soil by Irrigation, Deep Ripping, and Acidification with Elemental Sulfur. Can. J. Soil Sci., v. 66, No. 2, 1986, pp. 347-356.

The effects of leaching, deep ripping, and acidification on the amelioration of newly irrigated, calcareous Solonetzic soil were determined. Two levels of ripping and three sulfur treatments (0, 3.3 mt ha^{-1} elemental sulfur, and 3.3 mt ha^{-1} sulfur plus inoculation with *Thiobacillus thioparus* Beijerinck were established. The area received nine light irrigations (190 mm total) the first year and 11 irrigations (140 mm) the second year to maintain surface moisture and promote leaching. Following these treatments, barley (*Hordeum vulgare* L.) was grown the following 2 years with three irrigations annually. Frequent light irrigations in the absence of a crop leached over half of the soluble salts and a great proportion of sodium. The SAR was reduced from 20 to less than 10 in the surface 60 cm after 2 years of irrigation. Sulfur treatments (3.3 mt ha^{-1}) without a crop reduced the pH of the surface 15 cm of soil from 7.2 for unamended soil to 5.3 in treated soils. Naturally occurring lime was dissolved by the sulfur treatment, thus increasing the soluble calcium and magnesium. Inoculation with *Thiobacillus thioparus* did not result in significant differences in soil pH or in levels of soluble cations from uninoculated treatments. Deep ripping did not significantly affect the amelioration effort, but surface infiltration and hydraulic conductivity remained high over the 4 years of the study due to ripping. Barley yields were not significantly affected by deep ripping or sulfur treatments during either cropping season. The results of this study document the reclamation of Solonetzic soil through careful application of irrigation water. Deep ripping and acidification may aid this reclamation.

125. Bole, J. B. Uptake of ^{15}N-Labelled Urea and ^{32}P-Labelled Phosphate from Acid-Based Urea Phosphate and Granular Fertilizers. Can. J. Soil Sci., v. 66, No. 1, 1986, pp. 189-193.

It has been claimed that there is a greater availability of fertilizer and soil nutrients from acid-based fertilizers than from conventional granular or solution fertilizers. In a growth chamber experiment, the availability of nitrogen and phosphorus in fertilizer products labeled with ^{32}P and ^{15}N was determined. Total uptake, determined as the product of the proportional content and the total yield of the nutrient, by spring wheat (*Triticum aestivum* L.) from a solution of acid urea phosphate fertilizer did not significantly differ from that of a mixture of granular urea and monammonium phosphate fertilizer. The uptake efficiency, determined as the relative amount of each nutrient applied in the labeled fertilizer sources, of

phosphorus-fertilizer was higher in neutral than in acid or calcareous soils for both phosphorus sources. Band applications increased the uptake of fertilizer phosphorus compared with phosphorus fertilizer mixed with the soil. Fertilizer nitrogen uptake was not affected by application method.

126. Boles, P. H. Reclamation of Surface Mined Lands in Wyoming for Livestock Grazing and Wildlife Habitat. Paper in Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (co-chaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 342-371.

The author presents information on revegetation results and on species of plants that have been successful on reclaimed lands, as well as those that have failed. The article contains discussions on a number of topics including restoring wildlife habitat; methods of evaluating reclamation; the use of adapted species, varieties, and subspecies; the role of hybridization in developing plants for reclamation; the use of shrub tubelings; the advantages of different seeding techniques; and the role of mycorrhizal fungi in revegetation of mine lands. The discussions are extensively referenced to available literature.

127. Boll, J. E., and G. Deshinsky. The Use of Potassium Permanganate for Iron and Manganese Removal from Acid Mine Drainage. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 219-223.

This article discusses the use of potassium permanganate ($KMnO_4$) as an oxidant for treatment of acid mine drainage water. Potassium permanganate treatment effectively oxidized soluble iron and manganese to insoluble forms in a range of pH values. As the pH of acid mine drainage water decreases below 4, the reaction is slowed to an ineffective rate. Prior to $KMnO_4$ treatment, it is necessary to adjust the pH to neutral or slightly alkaline. $KMnO_4$ treatment of acid mine drainage results in insoluble products, is fairly rapid, and requires minimal chemical treatment.

128. Bonfert, G. A., and W. C. Ashby. Native Prairie Grasses for Reclaiming Ungraded Mine Spoil in Southern Illinois. Paper in Proceedings 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 2-7, 1984). Univ. KY, Lexington, KY, 1984, pp. 19-24.

Native warm-season grasses were utilized in a study on environmental factors affecting vegetative establishment on ungraded mine spoil in southern Illinois. The research area was mined in the late 1960's using a bucket-wheel excavation, and the resulting spoil material was left ungraded. The area was initially seeded with a standard reclamation mix of forage species. Prior to plot establishment, the existing vegetation on the west and east aspects of a spoil bank was killed. Five treatments were imposed which combined differences in aspect and topography. The treatments were (1) upper-slope-west aspect, (2) upper-slope-east aspect, (3) lower-slope-west aspect, (4) lower-slope-east aspect, and (5) level area below the lower-east treatment. The soils of the study area were chemically and physically characterized prior to any site preparation. Site preparation technique involved herbicide to kill any existing vegetation, burning to remove the litter of the dead vegetation, fertilization with 0-0-60 at 112 kg ha^{-1} based on soil testing, and mulching with shredded hardwood following seeding. Switchgrass (*Panicum virgatum* L.) and little bluestem (*Schizachyrium scoparium* (Michx.) Nash) were chosen as the test species based on their dominance in presettlement Illinois tall grass prairies and their habitat preference; switchgrass in lowland prairies and little bluestem in upland prairies. Vegetative establishment and survival was measured over two growing seasons.

The chemical analyses indicated that the spoil at all treatment sites was similar. The average pH was 7.8 and the spoil was high in calcium, magnesium, zinc, manganese, and iron, and low in nitrogen, phosphorus, and potassium. Particle size analysis indicated that the slopes were either clay loam or loam, while the level area was a silt loam. Soil moisture desorption curves were similar for each treatment site. During the first growing season planted vegetation was less dense on the upper slopes with stem density increasing to a high on the level area. Vegetation was characterized by 27 stems per square meter on upper slopes, 41 stems per square meter on lower slopes, and 64 stems per square meter on the level area. Second-year measurements indicated that stem density had increased on all treatments with an average of 260 stems per square meter on each treatment. There were no significant differences by topographic position. The authors conclude that prairie grass establishment was successful for all treatment sites.

129. Bonfert, G. A., S. J. Josiah, and W. C. Ashby. Reclamation Techniques and Combustion Technologies. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 185-190.

This paper presents the fifth year performance of seeded switchgrass (*Panicum virgatum* L.) and little bluestem (*Schizachyrium scoparium* (Michx.) Nash) on

nongraded bucket-wheel spoil in southern Illinois. All existing vegetation was removed. The sites were fertilized with potassium fertilizer (0-0-60) at a rate of 112 kg ha^{-1}, and the native species were seeded. During the fifth growing season, density and biomass of planted and invading species were measured. Little bluestem had the greatest density and switchgrass had the greatest biomass, introduced species contributed slightly to the vegetative composition. Changes in the spoil chemical and physical characteristics over 5 years are reported.

130. Boon, D. Y., and P. J. Smith. Carbonaceous Materials Problems Associated with Reclamation. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 248-256.

This article discusses acid production due to the oxidation of highly carbonaceous materials. Carbonaceous materials associated with acid production include small coal lenses, partings, leonardite, and carbonaceous shales. These materials may contain high concentrations of sulfur and greater quantities of pyrite than the associated coal. These carbonaceous materials may also contain significant concentrations of arsenic, boron, cadmium, mercury, molybdenum, lead, and selenium which may also limit reclamation success.

131. Booth, D. T. Emergence of Bitterbrush Seedlings on Land Disturbance by Phosphate Mining. J. Range Manage., v. 33, No. 6, Nov. 1980, pp. 439-441.

This article reports the results of a study designed to evaluate the effects of planting depth, number of seeds per seed spot, and the application of fungicide and/or vermiculite on the emergence of fall-seeded bitterbrush (*Purshia tridentata* (Pursh.) DC.) in medium-fine textured phosphate mine spoil in southeastern Idaho. A planting depth of 1.3 to 2.5 cm resulted in optimum emergence. Less emergence was obtained on plots of 20 seeds per seed spot than from plots with 1, 5, or 10 seeds per seed spot. Mixing the seed with a volume of vermiculite 10 to 40 times the volume of the seed and dusting the seed with Captan fungicide improved emergence.

132. Borovsky, J. P., D. F. Grigal, and R. L. Strassman. Reclamation of Tailing Basins Resulting From Copper-Nickel Milling (contract J0205050, Barr Eng. Co.). BuMines OFR 214-83, Aug. 1983, 149 pp.; NTIS PB 84-142 587.

This publication reports the results of a 3-year study that evaluated the potential for using vegetation to stabilize tailings from a potential Minnesota copper-nickel milling operation. The investigation consisted of (1) a waste characterization study, (2) a greenhouse study, and (3) a field study. Most physical and chemical characteristics of the tailings were within the range of properties exhibited by Minnesota soils. The tailings were found to lack organic matter, be deficient in nitrogen, phosphorus, and potassium, and contain elevated levels of soluble salts and heavy metals. Numerous grass, forbs, and woody plants tolerant of the tailings material as a rooting medium are reported. Incorporation of peat or a topsoil dressing was found not to be necessary for adequate revegetation of the copper-nickel tailings since they provided few benefits to the revegetation process that were not provided by a fertilizer application. Grass legume production with a fertilizer treatment was comparable to local agricultural yields. Heavy metals concentrated in grasses grown on the tailing remained within acceptable tolerance limits. Legumes concentrated more copper and nickel.

133. Bowers, M. E., and D. E. Baker. Soil Amendments To Reduce Cd and Zn Uptake by Plants Grown on Contaminated Soils. Am. Soc. Agron., Agron. Abstr., 1987, p. 23.

Abstract of a paper presented at the 1987 Annual Meeting of ASA, CSSA, and SSSA. Results of a greenhouse study using three soils collected near two zinc smelters in Pennsylvania are presented. Lime, peat, and slaughterhouse sludge were incorporated into each soil in various combinations. Lettuce (*Lactuca sativa* L.) was used as a test species and analyzed for cadmium, zinc, copper, and lead after 10 weeks of growth. There were strong correlations between tissue cadmium and zinc levels and soil pH, cadmium, and zinc levels. As an example, the level of plant tissue cadmium was a function of soil pH and extractable cadmium.

134. Bowman, R. A. A Rapid Method To Determine Total Phosphorus in Soils. Soil Sci. Soc. Am. J., v. 52, No. 5, 1988, pp. 1301-1304.

Several methods of extracting total phosphorus from soils have been developed. Of these, the sodium carbonate (Na_2CO_3) fusion and perchloric acid ($HClO_4$) digestion methods are the recognized standards, both of which are tedious and time consuming. This paper describes a new and rapid acid extraction procedure for the estimation of total phosphorus using H_2SO_4-H_2O_2-HF. Eleven surface soils and four subsurface calcareous soils were selected for testing the proposed method. The proposed method for extraction of total phosphorus was compared with the Na_2CO_3 fusion and $HClO_4$ digestion methods. For all soils tested, the proposed method recovered an average of 98 pct of the phosphorus as measured by the fusion method

method and 107 pct of the phosphorus as measured by the $HClO_4$ digestion method. Treatment with H_2O_2 oxidized organic phosphorus, while HF additions released the mineral phosphorus associated with the alumino-silicate fraction. The proposed method is presented. The time required for the procedure totals 20 to 30 min, the method is more rapid than those previously used, and is less expensive. The proposed method is especially useful for analyzing small numbers of soil samples.

135. Boyle, P. L., J. L. Powell, R. I. Barnhisel, and J. H. Grove. Sulphur Coated Phosphorus as a Source of P for Topsoiled Mine Land in Western Kentucky. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 123-128.

This paper reports the results of a study comparing the effectiveness of sulfur-coated ammonium polyphosphate (SCP), 7-34-0-30 sulfur, to that of triple superphosphate (TSP) fertilizer, 0-46-0, and triple superphosphate plus elemental sulfur (PS), as measured by yields of alfalfa (*Medicago sativa* L.). Plant response to the more conventional TSP fertilizer was greater than response to the slow-release SCP fertilizer. Both types of fertilizers raised the Bray-P_1 soil phosphorus to the same level. The observed response differences were attributed to poorer seedling establishment in the SCP-treated plots due to slow phosphorus release and low residual soil phosphorus. The authors suggest either applying the SCP fertilizer type sufficiently in advance of seeding or including a small application of a much more soluble phosphorus fertilizer to improve plant establishment.

136. Bray, B. J., R. H. Dowdy, R. D. Goodrich, and D. E. Pamp. Trace Metal Accumulations in Tissues of Goats Fed Silage Produced on Sewage Sludge-Amended Soil. J. Environ. Qual., v. 14, No. 1, 1985, pp. 114-118.

Sludge-borne trace metal accumulation in goat tissues were determined over a 3-year period. Goats were fed corn (*Zea mays* L.) silage grown on sludge-amended soil. Sludge was applied at control (0 g Mg ha^{-1}), low, medium, and high rates. The cadmium concentrations in goat livers increased as the amount of silage borne cadmium increased, reaching a maximum of 294 mg kg^{-1} at the high rate. Kidney concentrations were 10 times greater than those in the liver, ranging from 3 mg kg^{-1} for control fed goats to 22 mg kg^{-1} for goats fed silage grown on soil amended with the highest rate of sewage sludge. The highest level of kidney cadmium was still less than the critical cadmium level for induction of renal dysfunction. Zinc concentrations in liver tissue did not differ significantly among treatments, while kidney zinc concentrations ranged from 76.6 (control) to 91.8 mg kg^{-1} (high). Copper concentrations in livers and kidneys were significantly lower in animals fed silage amended with sewage sludge than controls due to the antagonistic blocking by cadmium of the protein necessary for copper absorption. The elemental concentrations of 12 other metals and minerals in goat liver and kidney, analyzed by inductively coupled plasmas (ICP), were not affected by sludge treatment.

137. Breitenbeck, G. A., and J. M. Bremner. Effects of Rate and Depth of Fertilizer Application on Emission of Nitrous Oxide From Soil Fertilized With Anhydrous Ammonia. Biol. and Fertil. Soils, v. 2, 1986, pp. 201-204.

The effects of different rates of anhydrous ammonia application on emission of N_2O from soil were compared. Additionally, it was determined if the depth at which anhydrous ammonia is injected into the soil had an effect on the emission of N_2O. Anhydrous ammonia was injected at a depth of 20 cm at rates of 75, 150, 225, 300, 375, and 450 kg ha^{-1} N. Nitrous oxide emissions from fertilized and unfertilized plots were monitored for 116 days. Additionally, to study depth effects, anhydrous ammonia was injected at 112 or 225 kg ha^{-1} N at 10, 20, or 30 cm. Emissions of N_2O were monitored for 156 days.

Emissions of N_2O increased as the rate of application increased. Fertilizer-induced emissions at the highest application rate were 2.87 kg ha^{-1} greater than at the lowest rate. The percentage of fertilizer nitrogen evolved as N_2O decreased with increased rate of application, from 1.6 to 0.9 pct as application was increased from 75 to 450 kg ha^{-1} N. A 100-pct increase in the rate of anhydrous ammonia applied resulted in only a 60-pct increase in fertilizer induced N_2O emission. Of the fertilizer induced emissions of N_2O, 76 to 80 pct occurred 14 to 56 days after fertilization. Emissions of N_2O from fertilized plots were identical to unfertilized plots 72 days after fertilization. The emission of N_2O induced by injecting 112 kg ha^{-1} N at 30 cm was 107 and 21 pct greater than emissions induced by the same amount of nitrogen at 10 and 20 cm. The effect of depth of application on N_2O emission was not as great when anhydrous ammonia was applied at a rate of 225 kg ha^{-1} N.

138. Breitenbeck, G. A., and J. M. Bremner. Effects of Various Nitrogen Fertilizers on Emission of Nitrous Oxide From Soils. Biol. and Fertil. Soils, v. 2, 1986, pp. 195-199.

The effects of anhydrous ammonia, aqueous ammonia, calcium nitrate, and urea on the emission of N_2O from soil were compared. All fertilizers were applied at a rate of 180 kg ha^{-1} and emissions were compared with unfertilized controls. A laboratory study was also conducted to

determine if the large emissions of N_2O induced by anhydrous ammonia fertilization are related to the method of application, in particular, band application. Emissions of N_2O induced by anhydrous ammonia application were 16 to 18 times greater than emissions induced by urea or aqueous ammonia applications. Emissions of N_2O from soil fertilized with calcium nitrate was only 0.06 kg ha^{-1} greater than emissions from unfertilized soil. The laboratory study suggests that the large emissions of N_2O induced by anhydrous ammonia application may be due to the alkaline soil zones of high ammonium-nitrogen produced when the fertilizer is injected into the soil. This does not occur when urea or aqueous ammonia fertilizers are broadcast and incorporated into the soil.

139. Brenner, F. J. Evaluation and Mitigation of Wetland Habitats on Mined Lands. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 181-184.

A wetland evaluation and mitigation policy based on ecological principles is proposed as a guide to protect and enhance wetland resources on mined lands. Guidelines for the evaluation and mitigation of wetlands are presented. When wetlands have to be mitigated, consideration should be given to the principal species affected by disturbance. Wetland species recommended for mitigated wetlands in the eastern and midwestern United States are given.

140. Brenner, F. J., and R. P. Steiner. Alternative Reclamation Strategies for Mined Lands. Ch. in Environmental Consequences of Energy Production: Problems and Prospects, ed. by S. K. Majumdar, F. J. Brenner, and E. W. Miller. PA Acad. Sci., 1987, pp. 115-130.

This chapter contains information on alternative land use and reclamation practices based on current regulations and the development of diverse and stable ecosystems following mining. Introductory remarks concerning the history of coal mining and reclamation regulations in the United States are presented. The remainder of the chapter is divided into two sections, site preparation and revegetation according to land use categories. In the site preparation section, models are used to illustrate the potential effects of water diversions and terracing in limiting soil erosion on reclaimed mined lands. The discussion in this section centers on the Universal Soil Loss Equation and the Terrace Spacing Equation to predict soil loss and the number of diversions or terraces needed to reduce soil loss on mined lands. The second section describes general reclamation practices according to land use categories.

141. Brenner, F. J., M. Werner, and J. Pike. Ecosystem Development and Natural Succession in Surface Coal Mine Reclamation. Miner. and Environ., v. 6, No. 1, 1984, pp. 10-22.

Biotic and abiotic factors affecting soil characteristics, soil microorganisms, and the diversity and productivity of plant communities of 81 surface mines in Mercer County, PA, were studied to determine the function of natural succession on surface coal mines. General vegetative and soil characteristics were examined on the 81 surface mines ranging in age from 1 to 40 years. Soils were chemically and physically characterized along with the determination of soil microbial populations. Annual growth of forage and species composition on 20 of the 81 surface mines was determined by clipping at ground level, the living material was separated by species and weight. Chlorophyll analysis was conducted and importance values for each forage species was determined by using the percent total biomass per square meter, percent chlorophyll-a per square meter, and frequency of a species on the quadrant. The relative frequency, relative dominance, and growth rates of woody species were determined on 20 minesites. Decomposition rates of forage leaves, deciduous leaves, and coniferous needles were determined using a standard litter bag technique.

Spoils exhibited considerable chemical variation due to a variety of factors including geologic origin, previous land use, and the reclamation procedure used. Variations also occurred within spoil profiles. Macronutrient and micronutrient concentrations did not vary significantly between minesites or between years. Organic and soil moisture content were the two factors most responsible for determining the establishment and growth of vegetation on mined land. These two factors were significantly correlated with total plant biomass. Since organic matter and moisture content increase with mine age, one of the more important aspects of any reclamation effort should be the development of procedures that will increase both variables early in the initial reclamation program. Populations of soil bacteria and fungi were also correlated with these soil conditions. Soil micro-organisms are important for the decomposition of organic material and nutrient cycling within the minesite. The succession or invasion of native plant species onto mined lands increases the density and stability of plant communities on these sites. Initial reclamation should be designed to stabilize the site and provide suitable habitat for the invasion of native species.

142. Bridgen, M. R. Genetic Variation of Black Locust Seedlings on Reclaimed Surface Mine Soils. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 40-47.

This paper describes tests that were conducted to determine the genetic variability in black locust (*Robinia pseudoacacia* L.) through provenance tests. Seeds were

collected throughout the range of black locust and plantings were made in West Virginia. Information is given on black locust growth characteristics and product uses. Genetic traits studied were variations in chlorophyll concentration, leaf nutrients, and height growth between seedlots. Although no geographic patterning has been associated with genetic variation, the author states that selected seedlots can be identified which are superior to others when planted on surface mined lands. This paper contains no information on soil amendments, but was included in the review process because the species fixes atmospheric nitrogen, which helps to improve soil quality.

143. Brierley, C. L., and G. R. Lanza. Microbial Technology for Aggregation and Dewatering of Phosphate Clay Slimes: Implications on Resource Recovery. Ch. in Soil Reclamation Processes: Microbiological Analyses and Applications, ed. by R. L. Tate III and D. A. Klein. Marcel Dekker, 1985, pp. 243-276.

The mining and beneficiation processes associated with phosphate recovery in Florida are reviewed. The clays associated with Florida phosphate deposits are characterized mineralogically, chemically, and physically. The use of biopolymers, polymers produced by microorganisms, can flocculate clays generated during mining and beneficiation activities. Differences in polymer composition result when different energy sources are supplied to the organisms. Exopolysaccharides are polymers that flocculate clays, while nucleic acids and proteins are biopolymers which play a role in aggregation. Factors that affect biopolymer formation are presented. Microbial interactions with liquids, gases, and solids are of interest for application in flocculation and waste water clarification. Discussed are biosurfactants, bacterial surface adhesion and flocculation, and adsorption of inorganic materials to microbial structures. The effects of clays on the growth, respiration, and activity of the microorganisms are presented. Future research needs are addressed.

144. Briggs, R. W., and R. C. Freas. Sludge to Fertile Soil—Research Results. J. Test. Eval., JTEVA, v. 8, No. 5, 1980, pp. 265-269.

This article describes research conducted by the Dravo Lime Co., Pittsburgh, PA, on the development of fertile soil from combining flue gas desulfurization sludges with municipal waste sludges. A second objective was to stabilize and combine coal fine refuse with municipal waste to identify potential stabilization and revegetation techniques. Testing of the various mixtures involved both greenhouse and field trials using a variety of agronomic species. Both the physical and chemical properties of the synthetic soils (sludge combinations) have been monitored and compared with desired soil parameters. The results of this study demonstrate that both flue gas desulfurization sludges and coal fine refuse can be combined with municipal waste sludge to produce a fertile soil.

145. Brisbin, I. L., Jr. The Principles of Ecology as a Framework for a Total Ecosystem Approach to High Altitude Revegetation Research. Paper in Proceedings: High Altitude Revegetation Workshop No. 5 (CO State Univ., Fort Collins, CO, Mar. 8-9, 1982). CO Water Resour. Res. Inst., CO State Univ., Fort Collins, CO, Inf. Ser. 48, Dec. 1982, pp. 1-11.

This paper contains a concise, but general overview of the basic principles of modern ecology as they relate to planning projects and subsequent revegetation programs in high-altitude areas. It provides a good synopsis of these principles and would be of value to individuals with little or no background in the biological sciences. Although the major emphasis is on high-altitude ecosystems, the principles presented are applicable to most surface mining situations as well.

146. Brissette, J. C., and W. C. Carlson. Effects of Nursery Bed Density and Fertilization on the Morphology, Nutrient Status, and Root Growth Potential of Shortleaf Pine Seedlings. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 198-205.

The effects of seedbed density and different levels of phosphorus and nitrogen fertilization on the morphology and physiology of shortleaf pine (*Pinus echinata* Mill.) seedlings grown in a nursery were determined. This study was included in the review because shortleaf pine is an important species for use in artificial regeneration in the South. Seedling diameter, height, and root volume were all affected by seedbed density and amount of nitrogen applied, but not by phosphorus. Seedling diameter and root volume decreased with increasing density, while height increased with density. Diameter and root volume also increased as the amount of nitrogen increased. Nutrient concentrations of seedlings were most affected by nitrogen applications. As the amount of nitrogen fertilizer was increased, there were significant linear decreases in phosphorus and potassium concentrations.

147. Brockway, D. G., P. V. Nguyen, and J. B. Hart. Forest Application of Municipal Sludge in Northern Michigan: Water Quality, Wildlife and Food Chain Effects. Am. Soc. Agron., Agron. Abstr., 1987, p. 24.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. The effects of sludge addition (9 Mg ha^{-1}) on the water quality, wildlife habitat, populations, and food chains in a northern hardwood forest was assessed. Nitrate-nitrogen levels increased in groundwater, but returned to background levels. Along with NO_3-N leaching, minor loss of calcium, magnesium, potassium, and sodium occurred. There was no movement of trace elements below the rooting zone. Sludge application resulted in increased plant cover, annual primary productivity, and protein and phosphorus content of forage. Wildlife populations also increased on treated areas. The authors state that when sludge, which contains low levels of toxicants, is applied to forest land at appropriate rates, forest productivity is increased and wildlife habitat improved with little risk to groundwater or the food chain.

148. Brodie, G. A., D. A. Hammer, and D. A. Tomjanovich. Man-Made Wetlands for Acid Mine Drainage Control. Paper in Proceedings of the Eighth Annual National Abandoned Mine Lands Conference (Billings, MT, Aug. 10-15, 1986). MT Dep. State Lands, Helena, MT, 1986, pp. 87-105.

A marsh-pond wetland system was utilized to treat seepage from the toe of a coal slurry impoundment dam in northeastern Alabama. Transplanted and volunteer vegetation and fauna within the wetland exhibited rapid growth and expansion. Water quality exhibited significant improvement within 3 weeks after the wetland system was constructed. After 1 year, comparisons between seep and final effluent showed significant reductions in manganese, iron, and total suspended solids and increases in pH and dissolved oxygen. Final discharge values were equal to or better than comparable values from undisturbed natural streams of the area. An additional discharge of 75 to 100 L m^{-1} of pH 3.5 water from the slurry impoundment was initiated in early December. At the end of December, the final discharge pH had fallen, and manganese and iron concentrations had increased. As a result, slurry discharge was terminated. Cessation of inflow resulted in pH and total iron concentration recovery within a month, but manganese levels remained high until late March. Even with the input of a large quantity of acid water during the nongrowing season, the system recovered the functional ability to modify acidic seepage to natural stream water quality.

149. Brown, J. E., R. E. Farmer, Jr., and W. E. Splittstoesser. The Establishment of Mixed Plant Communities on Surface Mined Land for Timber Production, Timber and Wildlife, Wildlife Only, and a Native Mixed Forest. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 27-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 431-435.

This study evaluated the direct-seeding of tree, shrub, forage, and forb species planted in different combinations on surface-mined lands in Campbell and Morgan Counties, TN. Experimental treatments consisted of species mixtures designed for different management objectives: (1) timber production (two combinations), (2) wildlife food and cover (two combinations), (3) timber production and wildlife food and cover, (4) mixed forest with wildlife cover, and (5) a control of Kobe lespedeza (*Lespedeza striata* var. Kobe) and various volunteer species. Of the species planted, the following survived and grew well: (1) trees: Virginia pine (*Pinus virginiana* Mill.) and black locust (*Robinia pseudoacacia* L.); (2) shrubs: indigobush (*Amorpha fruticosa* L.), autumn olive (*Elaeagnus umbellata* Thunb.), bicolor lespedeza (*Lespedeza bicolor* Turcz.), and bush grape (*Vitis rupestris* Scheele.); and (3) forbs: aster (*Aster pilosus* Willd.), bur-marigold (*Bidens frondosa* L.), lambsquarters (*Chenopodium album* L.), fireweed (*Erechtites hieracifolia* (L.) Raf.), small wood sunflower (*Helianthus microcephalus* Torr. & Gray.), and pokeweed (*Phytolacca americana* L.). Depending on the plant community designation, sourwood (*Oxydendrum arboreum* L.), joe-pye-weed (*Eupatorium serotinum* Michx.), and goldenrod (*Solidago altissima* L.) had varying survival rates. All sown forage plants became established and grew well with vegetative ground cover ranging from 21 to 63 pct after the first growing season. Except for the community designed as a native mixed forest, all treatment areas had at least 70-pct ground cover by the end of the second growing season.

150. Brown, J. E., and J. B. Maddox. Mixed Woodchips and Paper as a Mulch for Strip-Mined Land Revegetation. Div. Land and For. Res., TN Val. Auth., Norris, TN, Tech. Note B42, Nov. 1980, 9 pp.

The study reported in this publication tested the effectiveness of combined hammer-milled woodchips and paper mulch in aiding vegetation establishment. The woodchip-paper mulch mix was also compared with a standard mulch (Turfiber). The study was conducted at a surface mine site in Campbell County in east Tennessee. Three rates of application were tested: 1,120, 1,680, and 2,241 kg ha^{-1}. These rates were compared with the standard recommended rate of Turfiber (91,680 kg ha^{-1}). First-season vegetative cover produced with the lowest rate of the woodchip-paper mulch mix was comparable with that obtained with the standard rate of Turfiber at a significant cost savings.

151. Brown, J. E., J. B. Maddox, and G. N. Bartley, Jr. Acrylic Emulsion as a Straw Binder in Reclaiming Coal Surface-Mined Land. TN Val. Auth., Norris, TN, Tech. Note B43, TVA/ONR/LFR-81/2, Jan. 1981, 15 pp.

The effectiveness of acrylic emulsion (AE) as a straw binder was tested and treatment cost comparisons were made between AE and emulsified asphalt. The study was conducted at a strip mine site in Campbell County, TN. Treatments consisted of 0.56 kL ha^{-1} AE plus 2.2 mt ha^{-1} straw, and 1.68 kL ha^{-1} asphalt plus 4.5 mt ha^{-1} straw. No significant difference was found in vegetative cover between the two treatments. Half the recommended rate of straw used in conjunction with AE was as effective as the recommended rates of asphalt and straw. Application costs were slightly higher for the AE treatments.

152. Brown, J. E., J. B. Maddox, and W. E. Splittstoesser. The Effect of Fertilizer and Strip Mine Spoil on Germination and Growth of Legumes. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 27-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 419-422.

This greenhouse study simulated seeding conditions with a hydroseeder using fertilizer slurries and mine spoil. Seeds of alfalfa (*Medicago sativa* L.), hairy vetch (*Vicia villosa* Roth.), Kobe lespedeza (*Lespedeza striata* var. Kobe), Korean lespedeza (*Lespedeza stipulacea* Maxim.), red clover (*Trifolium pratense* L.), sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don.), yellow sweetclover (*Melilotus officinalis* (L.) Lam.), and white clover (*Trifolium repens* L.) were soaked for 20 min in 0, 57 plus 54, or 114 plus 118 kg ha^{-1} N (ammonium nitrate) and P (triple super phosphate), respectively, in 8 kL ha^{-1} water. Seeds and fertilizer were then sown in three different soils: (1) a loamy sand from an area along the Clinch River near Norris, TN (river bottom soil), pH 6.1, as a control (unmined); (2) a silt-clay loam shaley material, pH 6.4, mine soil 1; and (3) a mixture of shale and sandstone, pH 4.1, mine soil 2. The mine soils were obtained from two separate mines located in Campbell County, TN.

Fertilizer did not affect germination on river bottom soil or, at low rates, on mine soils. At higher fertilization rates, however, germination was generally lower on the mine soils. The higher concentration of ammonium nitrate in the fertilizer along with the high levels of toxic ions (manganese, sulfur, iron, and aluminum) in the mine soils apparently reduced the germination of legume seeds. The shoot-root ratios of planted legumes were also affected by the type of soil material they were grown in. Shoot-root ratios were generally higher on river bottom soil and mine soil 1, which supported the best plant growth. Mine soil 2 generally had low shoot-root ratios, reflecting poor overall legume growth when compared with the other two spoil materials.

153. Brown, J. E., J. B. Maddox, and W. E. Splittstoesser. The Use of Trees, Shrubs, and Forbs for Reclamation of Mine Spoils. Paper in Third Annual Conference on Better Reclamation With Trees (co-sponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll., Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 129-134.

The authors report a study conducted on mine spoils in outdoor microplots. Tests were conducted on gray shale (pH 5.5) and brownish sandstone (pH 4.0) from Campbell County, TN, in addition to a silt-loam soil (pH 6.5) from Norris, TN. The objective of the study was to determine which species of trees, shrubs, and forbs could be established via direct-seeding procedures. An extensive list of species were tested including 12 trees, 14 shrubs, and 14 forbs. Stratification or acid treatment was applied to some species prior to planting. The seeds and fertilizer were applied to the plots in a slurry to simulate a hydroseeder operation. Most species had a survival rate greater than 50 pct. Species that performed well with respect to plant height, root penetration, dry weight, and plant survival included black locust (*Robinia pseudoacacia* L.), European black alder (*Alnus glutinosa* (L.) Gaertn.), Virginia pine (*Pinus virginiana* Mill.), wild goose plum (*Prunus hortulana* Bailey), autumn olive (*Elaeagnus umbellata* Thunb.), bristly locust (*Robinia fertilis* Ashe.), bush grape (*Vitus rupestris* Scheele.), indigobush (*Amorpha fruticosa* L.), staghorn sumac (*Rhus typhina* L.), fireweed (*Erechtites hieracifolia* Raf.), flatpea (*Lathyrus sylvestris* L.), partridge pea (*Cassia fasciculata* Michx.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), pokeweed (*Phytolacca americana* L.), tick trefoil (*Desmodium* spp.), and sheep sorrel (*Rumex acetosella* L.). This paper provides a good reference of potential species for direct-seeding operations in reclamation activities.

154. Brown, K. W., J. C. Thomas, and L. E. Deuel, Jr. Physical and Chemical Properties of Gulf Coast Lignite Overburden. Reclam. & Reveg. Res., v. 3, No. 1, 1984, pp. 17-29.

This study measured selected physical and chemical properties of Gulf Coast lignite overburden in Texas, which may affect the potential for successful reclamation. Data on heavy metal content, texture, plant available moisture, and potential acidity are presented. Heavy metal concentrations in the overburden materials tested were not excessive. Water retention in the mixed overburden was

higher than the native surface soils. Texture does not appear to be a problem since most spoils were loam, sandy loam, or clay loam. More samples were acidic than alkaline, which suggest that the greatest limiting factor in the reclamation of these overburdens may be acidity.

155. Brown, K. W., J. C. Thomas, and K. W. Lawnius. Distribution of Bermudagrass Roots in Native Soils and Reclaimed Lignite Spoil. Reclam. & Reveg. Res., v. 2, No. 2, 1983, pp. 139-153.

This study compared the soil pH, electrical conductivity, texture, bulk density, and root growth of bermudagrass (*Cynodon dactylon* (L.) Pers.) on surface mined areas to native soils of unmined areas in eastern Texas. The surface-mined areas had been revegetated 2 years earlier. The results indicated that in all of the overburdens sampled, root biomass and distribution in the 120-cm profile were as great as, and in some cases greater than, those of native soils. The root mass was concentrated in the upper 0.25 m in both soil types. The spoil materials were generally more acidic than the native soils, but that caused no significant effect on root biomass or distribution. The bulk densities of the native soils were lower than those of the reclaimed spoil material. At greater depths in the soil profile, however, bulk densities were similar in both spoil and native soil. The spoil material also had more contained salt than the native soils, but the salt content was not high enough to have a detrimental effect on plant growth. The authors conclude that the salt content and bulk density of the spoil material did not have an apparent adverse effect on bermudagrass root growth. They feel, however, that a continued decrease in spoil pH may have a future impact on root growth.

156. Brown, M. B. Survival of Rhizobium Inoculum in Hydroseeding Slurries. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 681-685.

The viability of *Rhizobium* was studied in fertilizer slurries with differing pH values. Since phosphate was the only fertilizer component to influence the pH of a hydroseeding solution, different concentrations of diammonium phosphate (DAP) and triple superphosphate (TSP) were used to prepare hydromixtures with pH values ranging from 2.9 to 7.7. With slurry pH levels of less than 6.0, inoculum viability was significantly reduced. However, with enough DAP present in the slurry to increase pH levels above 6.0, normal nodulation of sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don.) occurred. The ratio of DAP to TSP should be maintained at 4:6 for nodulation to occur. Hydrated lime can also be used.

157. Brown, R. W., and R. S. Johnston. Reclaiming Disturbed Alpine Lands. West. Wildlands, v. 7, No. 3, 1981, pp. 38-42.

This article contains general information on revegetation treatments that should be used when reclaiming alpine mining disturbances. Examples of treatments used successfully on the Beartooth Plateau in southeastern Montana are given. General revegetation principles such as shaping and contouring, species selection, timing of seeding, soil treatments (amendments), seeding and planting methods, and postrevegetation management are all applicable to disturbed alpine lands. By using these revegetation principles, site stability can be achieved much faster than if natural succession was allowed to proceed alone. The main challenge to reclaiming alpine sites is to link climatic variations, physiological adaptations of plants, and limiting factors of the disturbed site.

158. Brunke, R., P. Alvo, P. Schuepp, and R. Gordon. Effect of Meteorological Parameters on Ammonia Loss From Manure in the Field. J. Environ. Qual., v. 17, No. 3, 1988, pp. 431-436.

Ammonia (NH_3) volatilization from swine and cow manure under field conditions was measured under precipitation-free conditions. Correlation coefficients were calculated between volatilization and the following meteorological parameters: air temperature, net radiation, ground heat flux, horizontal wind speed, and field surface temperature. The trajectory simulation model (TSM) was used to determine volatilization rates. Significant correlations were found between meteorological parameters and NH_3 volatilization; however, since these parameters are not independent under field conditions, the results are inconclusive. The highest correlations were found with horizontal wind speed and net radiation. A strong linear relationship existed between applied total nitrogen or ammoniacal nitrogen and NH_3 fluxes within the meteorological conditions. The results also indicated that the volatile losses of NH_3 were dependent on the method of application (surface applied or incorporated) rather than environmental conditions. The authors suggest that the hay drying index, a composite of meteorological forecasts, be used as a suitable indicator of high volatilization conditions. The spreading of manure should be avoided on days of high drying indices.

159. Brush, L. J., and J. R. Brown. The Use of Lime Stabilized Food Processing Waste on Forages. Am. Soc. Agron., Agron. Abstr., 1986, p. 28.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. The effect of lime

stabilized dairy processing sludge on the growth of tall fescue (*Festuca arundinacea* Schreb.) was evaluated. An application of 84,000 L ha^{-1} waste raised the soil pH and extractable phosphorus levels to recommended levels for a 3-year period. The waste did not contain enough nitrogen and potassium to achieve the yield potential of the site.

160. Buck, J. K. Direct (Soil-Less) Revegetation of Anthracite Waste Using Coal Fly Ash as a Major Amendment. Paper in Proceedings: Eighth International Ash Utilization Symposium, Volume I (Washington, DC, Oct. 28-31, 1987). Electr. Power Res. Inst., Palo Alto, CA, 1987, pp. 28-1—28-26.

The beneficial use of fly ash as the major soil amendment for the direct (soil-less) revegetation of an anthracite waste site in Pennsylvania is demonstrated. Fly ash (type F) was chosen as the major amendment because of its favorable effect on soil physical properties, fertility, and soil pH. A laboratory study was conducted to determine the rate of application. Based on this study, fly ash was applied at a rate of 200 mt $acre^{-1}$ and, along with agricultural limestone and fertilizer, plowed into the anthracite waste to a depth of 10 in. This direct revegetation method was compared with a control plot covered with borrow soil, which was also limed and fertilized. A seed mixture of annual (temporary cover and erosion control) and perennial (permanent cover) species were seeded over the entire area. Postreclamation monitoring included vegetation monitoring (establishment success over a 3-year period, erosion control, and a tree planting trial), chemical monitoring of fly ash amended coal waste and soil (surface and subsurface soil chemistry), water quality monitoring (lysimeters monitoring and surface water quality monitoring), plant tissue analyses, and forage quality. Results show that fly ash can be used successfully as an amendment for direct reclamation of anthracite waste. Vegetative growth on fly ash amended coal refuse was comparable with vegetative growth on borrow soil on the same site. There were no adverse affects of fly ash on water or forage quality. A cost comparison between direct revegetation using fly ash and borrow soil is given.

161. Buck, J. K., and R. J. Houston. Direct Revegetation of Anthracite Refuse Using Coal Fly Ash as a Major Soil Amendment. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 236-245.

The objective of this research was to demonstrate the beneficial use of fly ash (class F) as the major soil amendment in the direct (soil-less) revegetation of an anthracite coal cleaning site (refuse site) in northeastern Pennsylvania. Prior to applying the fly ash onto the refuse site, a laboratory study was conducted to determine the chemical and physical properties of fly ash mixed with coal refuse at various rates and the effects these mixtures would have on vegetative establishment. Based on these studies, an application rate of 200 dry tons fly ash per acre was selected. Fly ash, fertilizer, and lime were incorporated to a 10-in depth at the site. Annual species (to provide erosion control and a quick cover) and perennial species were then planted. A control using limed and fertilized borrow soil was also established on the refuse site.

The physical and chemical properties of the anthracite refuse were improved using the fly ash amendment; the textural class shifted from a sandy loam to a silt loam, the water-holding capacity of the site increased (over fly ash alone, unamended refuse, and the borrow soil), and pH and soil fertility were improved. Fly ash amendments had no significant effect on water quality of an on-site spring, an offsite pond, or a nearby creek. The authors also found that the growth of the vegetation on fly ash amended coal refuse was comparable with the growth on borrow soil. Plant tissue analyses indicated that molybdenum and selenium uptake was high on the fly ash amended coal refuse, compared with the borrow soil; however, all other nutrients and trace elements analyzed had comparable concentrations.

Cost comparisons were also made between using fly ash as the major soil amendment in the direct revegetation of this site or using borrow soil. Based on conservative estimates, the revegetation of this site using fly ash was \$4,053 $acre^{-1}$ and using 6 in of soil cost \$5,272 $acre^{-1}$. Based on their study results, the authors conclude that fly ash can be used successfully as a soil amendment to prepare anthracite refuse for direct revegetation. However, not all fly ash is appropriate for use as an amendment to mine soils. Unique chemical reactions between fly ash and coal refuse or mine soils must be taken into consideration through physical and chemical evaluations of the mixtures of amendment-refuse or soil and each component of the mixture.

162. Buckner, D. L. Grass Root Penetration in TOSCO II Processed Oil Shale. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 173-180.

The root penetration of grass species in TOSCO II processed oil shale was documented utilizing the following treatments: (1) bare processed shale, (2) 6 in of soil over processed shale, (3) 24 in of soil over processed shale, and (4) a native soil control. Of the six grass species studied, there were no significant differences, in terms of rooting depth, between the processed shale and topsoil treatments.

Roots in processed shale were, however, fewer in number, but thicker. Because of the thicker roots, root biomass was equal to or greater than the same species grown in the soil control. Total root numbers were higher in the 6-in topsoil treatment. The results indicate that there are no differences between rooting patterns of test species or any substrate differences.

163. Buford, M. A., and W. H. McKee, Jr. Effects of Site Preparation, Fertilization and Genotype on Loblolly Pine Growth and Stand Structure—Results at Age 15. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 378-383.

The main effects and interaction of five site preparation treatments, four fertilization treatments, and two genotypes on the growth, survival and yield of planted loblolly pine (*Pinus taeda* L.) were reported at age 15. Site preparation treatments were (1) control, (2) v-blade, (3) v-blade and rootrake, (4) v-blade, rootrake, and bed, and (5) v-blade, rootrake, and disk. The fertilizer treatments were (1) control, (2) 50 lb P and 200 lb N, (3) 100 lb K and 200 lb N, and (4) 50 lb P, 100 lb K, and 200 lb N. The two different seed sources were (1) seed production from natural stands (unimproved seedlings) and (2) seed orchards (genetically improved seedlings). Phosphorus treatments increased all stand characteristics studied with the phosphorus-potassium-nitrogen treatments showing the largest response. Heights and diameters increased through age 15. Applications of nitrogen and potassium without phosphorus decreased height and diameter mean values. Site preparation treatment had no significant effect on any of the stand characteristics studied at age 15, but site preparation treatment did significantly affect initial tree survival. At age 15, mean heights and dominant heights were greater for the seed orchard stock than for the seed production area stock.

164. Burger, J. A., S. H. Schoenholtz, R. E. Preve, and J. L. Torbert. Research Progress on the Use of Forest Regeneration Techniques for Surface-Mine Reclamation in Southwestern Virginia. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 171-179.

Four separate, but related southwestern Virginia studies are reported in this paper. The objective of the first study was to identify tree species capable of competing with herbaceous vegetation. Fifteen tree species were planted on a recontoured strip mine in Wise County, VA. Greater than 60 pct of the black locust (*Robinia pseudoacacia* L.), oak (*Quercus* spp.), sycamore (*Platanus occidentalis* L.), and white ash (*Fraxinus americana* L.) survived. The more shade-tolerant white pine (*Pinus strobus* L.) fared the best of the pines tested, with a 62-pct survival rate. A second study was conducted to evaluate the effects of ectomycorrhizal inoculation with *Pisolithus tinctorius* (Pt), chemical weed control, and slow-release fertilization on first-year survival and growth of white pine, Virginia pine (*Pinus virginiana* Mill.), and loblolly pine (*Pinus taeda* L.) on two surface-mined sites. The fertilizer used was Agriform tablets. Glyphosate was used for weed control.

First-year survival was excellent for all pine species with loblolly pine showing the best growth. Pt colonization increased seedling growth for all species. A third study examined the effects of hydroseeding pine-grass-legume mixtures for erosion control and reforestation of mine soils. Nurse crops consisting of perennial ryegrass (*Lolium perenne* L.) and red fescue (*Festuca rubra* L.), as well as birdsfoot trefoil (*Lotus corniculatus* L.), crownvetch (*Coronilla varia* L.), or white clover (*Trifolium repens* L.) were applied in combination with a mixture of white, Virginia, and loblolly pine seeds. Fertilizer treatments were also applied. Ground cover was increased for all nurse crops by nitrogen application. This had an adverse effect on pine establishment. Nitrogen increased the number of pine seedlings when nurse crops were not included in the seed mixture. Early data suggest that at least four times as much spoil erosion may be expected when nurse crops are not used in the reforestation of strip mines. A fourth study compared regeneration success on siltstone and sandstone overburden. This study was conducted in a greenhouse combining surface-seeded white, Virginia, and loblolly pine seeds, sandstone or siltstone spoil, mycorrhizal application, and fertilizer treatment. Spoil type strongly influenced mycorrhizal colonization with seedlings grown on sandstone spoil exhibiting a higher degree of colonization. A spoil-type fertilizer interaction was significant for loblolly pine biomass. The results of these studies are directly applicable to planning activities in this specific area.

165. Burgess, D., and R. L. Peterson. Development of *Alnus japonica* Root Nodules After Inoculation With *Frankia* Strain HFPArI$_3$. Can. J. Bot., v. 65, No. 8, 1987, pp. 1647-1657.

A description of root nodule development from early infection with *Frankia* strain HFPArI$_3$, through prenodule formation, to complex lobe development found in 3-month-old nodules was given for the alder species *Alnus japonica* (Thunb.) Steud. Morphological and anatomical changes that accompany endophyte infection and nodule

development are emphasized. This study was conducted using seedlings grown in a growth chamber. Inoculation was accomplished by applying 0.5 mL of diluted inoculum over the root system as a wash. Information is given on external nodule morphology, infection and prenodule anatomy, nodule structure and anatomy, and histochemistry. Root nodule induction occurs through infection of root hairs. The prenodule developmental stage is characterized by an unorganized, but restricted cell proliferation that took place in response to the invading endophyte. *Alnus japonica* produced a single primary nodule lobe primordium from each prenodule. Endophytic vesicles were first noted in nodules 4 weeks after inoculation, indicating that nitrogen fixation was occurring.

166. Burgess, D., and R. L. Peterson. Effect of Nutrient Conditions on Root Nodule Development in *Alnus japonica*. Can. J. Bot., v. 65, No. 8, 1987, pp. 1658-1670.

The effects of different nitrogen addition rates on root nodule morphology and structure of alder (*Alnus japonica* (Thunb.) Steud.) seedlings grown in a growth chamber were examined. It was assumed that it is the amount of nutrient supplied per unit time and not the nutrient concentration in solution that controls the rate of nutrient uptake and growth. Nutrients were added frequently, in small amounts, in proportions found in plants at maximum growth. Phosphorus and iron stress effects on nodule development were also determined and differences among treatments were shown. Nitrogen addition experiments were conducted using 5, 10 and 15 pct addition rates for uninoculated seedling and 0, 5, 10, and 15 pct for inoculated seedlings. Phosphorus stress was induced by reducing the amount of phosphorus added by 1/3 and iron stress was induced by not adding iron to the nutrient solution. Results are presented on seedling growth and development, nodule growth, morphology, activity, and the variability in nodule structure due to nutrient treatments. Seedling growth improved with inoculation. The exception being at the highest rate of nitrogen addition. Of the treatments used, inorganic nitrogen fertilization of uninoculated seedlings resulted in maximum growth rates for *Alnus japonica* (Thunb.) Steud. The nutritional status of *Alnus* strongly affected root nodule morphology and physiology. Nitrogen and phosphorus stress resulted in the limitation of vascular cylinder branching and apical dominance was expressed by nodule meristems resulting in thin separate nodule lobes. High nitrogen and phosphorus availability promoted vasculature branching, forming thicker nodules within nodule clusters. The size of cortical cells within nodules and the number of endophytic vesicles per infected cell were affected by nitrogen levels. High nitrogen increased cortical cell size, but reduced the number of vesicles per unit area. The numbers of endophytic vesicles were also reduced by iron and phosphorus stress. The authors state that if fixation activity under field conditions is to be stimulated, it is necessary to apply low levels of fertilizer on a frequent basis.

167. Burk, D. G., R. J. Miles, W. D. Broderson, and D. M. Sievers. Monitoring Saturated Zones in Soils Containing Coarse Fragments. Soil Sci. Soc. Am. J., v. 52, No. 5, 1988, pp. 1514-1516.

A simple method of utilizing soil pits, dug lengthwise with the hillslope, to install lateral piezometers constructed of PVC pipe for assessing zones of saturation with appreciable amounts of coarse fragments (up to 60 pct by volume) in dissected hillslope landscapes is described. Field results from 150 lateral piezometers in 36 monitoring sites have shown that matched pairs gave results which correlate well with observations from profile exposures. Although time consuming, lateral piezometers allow for monitoring zones of saturation in soils where vertical piezometers cannot be used, provide accurate water level readings, and can be duplicated at the depth or horizon in question. Additionally, they can be placed in a known morphological horizon, and the soil is left undisturbed in the vertical plane.

168. Burley, J. B., and C. H. Thomson. Multivariate Techniques to Develop Vegetation Productivity Models for Neo-Soils. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 153-161.

Comparing reclaimed land productivity levels with reference areas is an unreliable and expensive method. Several numerical productivity index models have been developed; however, present equations do not address six significant factors. A recently devised and tested methodology to predict, prior to final placement, neo-soil (reconstructed soil profiles) productivity is presented. Step by step instructions for reclamationists to develop their own productivity equations for their region or country are given. The methods presented include information on time and equipment, required baseline data, readying the data for analysis, analysis, regression modeling, model testing, and model description. Model interpretation and model limitations are discussed.

169. Burmester, C. H., J. F. Adams, and J. W. Odum. Response of Soybean to Lime and Molybdenum on Ultisols in Northern Alabama. Soil Sci. Soc. Am. J., v. 52, No. 5, 1988, pp. 1391-1394.

In northern Alabama, the critical soil pH of inherently acid soils for soybean (*Glycine max* (L.) Merr.) growth varies among sites. This suggests that more than one acid-soil infertility factor (aluminum and manganese toxicity or deficiencies of calcium, magnesium, or molybdenum) is limiting yields. A field experiment was conducted to determine which infertility factor was most responsible for yield responses of soybean to liming in northern Alabama. Fifteen test sites were treated with dolomite limestone and a sodium molybdate solution at 0 and 4,500 kg ha^{-1} and 0 and 100 g ha^{-1}, respectively, using a split-plot design (lime as whole plots and molybdenum as subplots). Soil pH at the 15 experimental sites ranged from 4.6 to 5.6 prior to liming. Liming without molybdenum resulted in yield increases at 12 of the sites. The sites unaffected by liming had pH values of 5.2, 5.3, and 5.6. In the abscence of applied lime, molybdenum additions resulted in yield increases at 11 of the experimental sites. Of the 12 sites showing a yield response to liming, 10 showed that all or part of this response was due to increased leaf nitrogen and seed weights. The soil chemical factor best correlated with molybdenum deficiency was the Fe:Mo ratio, the critical ratio being 1,540. Results show that molybdenum was a more common factor of acid soil infertility than aluminum toxicity in northern Alabama Ultisols.

170. Burrows, D. C., G. L. Mullins, and J. W. Odum. Soybean Response to Paper Mill Sludge Applications. Am. Soc. Agron., Agron. Abstr., 1988, p. 36.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The effects of annual paper mill sludge applications on the yield and nutrient content of soybean (*Glycine max* (L.) Merr.) were determined. Sludge was applied at 22, 67, and 134 Mg ha^{-1}. Fall versus spring applications were compared. At the highest rate of application, 97 kg N, 43 kg P, 98 kg K, 2,737 kg Ca, and 125 kg Mg were added to the soil. The calcium carbonate equivalent of the paper mill sludge was 15 to 25 pct. Rates of application, time of application (fall versus spring), and liming application (paper mill sludge versus agricultural limestone) were compared. Soil fertility was improved with sludge additions, particularly calcium concentration and soil pH values. Soybean yield and nutrient content were not adversely affected by annual applications of paper mill sludge.

171. Burton, J. D., and A. E. Tiarks. Available Nutrients and Early Growth of Woody Plants Vary with Overburden Material in Lignite Minesoils of Louisiana. Paper in Proceedings, National Meeting American Society For Surface Mining and Reclamation (Jackson, MS, Mar. 17-20, 1986). Am. Soc. Surf. Min. and Reclam., 1986, pp. 79-85.

The survival and growth of trees and shrubs (after 4 years) on different overburden mixtures and soil properties (after 5 years) were evaluated following a lignite mine operation in northwestern Louisiana. The four overburden treatments used were (1) 2.6 m of mixed overburden containing on A horizon material, 0.3 m overburden consisting of B horizon material, and 0.15 m of A horizon (topsoil); (2) 2.45 m of mixed overburden containing no A horizon material covered with 0.6 m of loamy sand overburden; (3) 3 m of overburden containing 2.5 pct A horizon by volume; and (4) 1.5 m of clay loam overburden cover by 1.5 m of overburden containing 10 pct A horizon by volume. Each treatment was limed and fertilized. Loblolly pine (*Pinus taeda* L.) sawtooth oak (*Quercus acutissima* Carruth.), Yaupon (*Ilex vomitoria* Ait.), Amur honeysuckle (*Lonicera maacki* Maxim.), water oak (*Quercus nigra* L.), blackgum (*Nyssa sylvatica* Marsh.), and white oak (*Quercus alba* L.) were planted. Of the species tested, loblolly pine was the most successful regardless of overburden type. The most successful hardwood species was sawtooth oak. The foliage of all planted species was chlorotic after the first year despite nitrogen fertilization. Soil analyses after 5 years showed that nitrogen and organic matter were low in plots not receiving replaced topsoil (2-4). Soil phosphorus, potassium, calcium, and magnesium did not differ among the overburden treatments.

172. Bussler, B. H., W. R. Byrnes, P. E. Pope, and W. R. Chaney. Properties of Minesoil Reclaimed for Forest Land Use. Soil Sci. Soc. Am. J., v. 48, No. 1, 1984, pp. 178-184.

This study evaluated the physical and chemical properties of reclaimed mine land and unmined reference soil (reference area) in Sullivan County, IN. A second objective was to determine the suitability of mine soils for reforestation with hardwood tree species established concurrently with ground cover. The topography, soils (Typic Fragiudalf and Typic Hapludalf), vegetation (mixed upland hardwood tree and shrub), and geologic formation were similar on both sites prior to mining. The results indicate that the chemical properties of the mine soil were similar to or more favorable for plant growth than those of the unmined reference soils. Plant nutrient availability for the establishment and growth of cover crop and tree species should not be limiting, especially after liming and fertilizing. The physical properties of the mine soils were less favorable than those of the reference soils. Mine soils had higher bulk densities, lower porosity, lower permeability, more coarse fragments, higher clay content, and

lower available water-holding capacity than the reference soils at comparable depths. These physical properties could limit plant growth and survival on reclaimed mine soils.

173. Butterfield, R. I., and P. T. Tueller. Revegetation Potential of Acid Mine Wastes in Northeastern California. Reclam. Rev., v. 3, No. 1, 1980, pp. 21-31.

This research was conducted to evaluate the potential for establishing vegetation on the Leviathan Mine sulfur spoils in Alpine County, CA. Four approaches were used to determine revegetation success on these 14-year-old spoils: (1) a volunteer vegetation study, (2) field trials, (3) greenhouse trials, and (4) soil analysis. The main factors limiting plant growth on sulfur soil materials are acidity and low nitrogen availability. Volunteer plant distribution on the spoils was apparently controlled by seedbed characteristics, soil pH, geologic origin of the spoil material, and seed dispersal methods. No spoil modifications were apparently needed for the survival of planted bare-root tree and shrub species. No consistent relationships were found between liming and geologic origin and the survival rates of planted trees and shrubs. Liming and straw mulch treatments increased both the emergence and survival of seeded grasses and legumes. Fertilization decreased emergence and survival of herbaceous species and is probably not necessary or beneficial on these spoils. The most important factor influencing vegetation establishment on these spoils is the low pH of the soil material.

174. Byerly, D. W., J. B. Maddox, C. S. Fletcher, and D. T. Eagle. Reclamation of Mined Land in the Piney Creek Watershed—An Interim Report. Paper in Symposium on Surface Mining and Fish/Wildlife Needs in the Eastern United States (WV Univ., Dec. 1978). U.S. Fish and Wildlife Serv., FWS/OBS-78/81, 1978, pp. 267-275.

This report presents general information on how reclamation of mined land will improve vegetation and the stream water quality of a 8,900 hectare watershed in Van Buren County, TN. Baseline studies on the water quality and aquatic life of Piney Creek indicated that 174 ha of surface-mined land and two underground mines contributed to the adverse effects on stream water quality. Reclamation treatments to improve cover and water quality included: planting trees and shrubs, seeding grasses and legumes, fertilizing, liming, construction of silt-retaining structures, and sealing the two underground mines. Through these efforts there has been an improvement in the water quality of the watershed.

175. Byrnes, W. R., W. R. Chaney, and P. E. Pope. Changes in Surface Minesoil Properties After Four Years Exposure to Natural Processes. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 159-171.

Changes in soil chemical and physical properties of a reconstructed mine soil and on unmined reference soil were analyzed and compared after 4 years of soil development. Replaced topsoil (0 to 28 cm) and graded cast overburden (28 to 40 cm) on the minesite and the A (0 to 20 cm) and B1 (20 to 33 cm) horizons of the unmined silt loam soil were analyzed before and 4 years after revegetation, and compared. Chemical properties of both soils changed little over the 4 years of this study. The most important changes were in soil physical properties. With time, bulk density decreased and the total and non-capillary porosity increased in the surface layer of the replaced topsoil (mine soil) and the silt loam soil. Changes in physical properties were not evident in the subsurface soils. The physical changes in the surface layers were attributed to freezing-thawing and wetting-drying cycles. The amount of root biomass was greatest in the surface soils of both the mined and reference areas.

176. Byrnes, W. R., W. R. Chaney, and P. E. Pope. Concurrent Establishment of Ground Cover and Hardwood Trees on Reclaimed Mineland and Unmined Reference Sites. BuMines OFR 10-84, 1983, 13 pp.

This research was done to assess reforestation success and productivity for reclaimed mine land and reference sites in Sullivan County, IN. The specific objectives of the study were to: (1) compare the establishment success and productivity of ground cover and commercial hardwood trees planted concurrently and maintained under the same level of management on reclaimed and unmined reference sites; (2) evaluate the survival and growth of bare-root, containerized, and mycorrhizae inoculated hardwood seedlings on both sites; and (3) evaluate chemical plant control (herbicides) as a technique for concurrent establishment of tree species and ground cover vegetation. The woody and herbaceous species used in this study were black walnut (*Juglans nigra* L.), northern red oak (*Quercus rubra* L.), tall fescue (*Festuca arundinacea* Schreb.), and red clover (*Trifolium pratense* L.). The results indicated that ground cover vegetation was readily established on the minesite and exceeded the required 70 percent of the cover present on unmined reference areas. The ground productivity was similar on the minesite and reference area. With herbicide application the survival of both black walnut and red oak was adequate to meet the stocking requirements of Public Law 95-87. Without chemical control, however, stocking results were one-half of the required level. Containerized black walnut and red oak seedlings showed higher survival and height growth than bare-root seedlings

on the minesite; no significant differences were found on the reference site. Finally, mycorrhizal inoculation did not increase seedling survival or growth response.

177. Cabrera, M. L., and D. E. Kissel. Evaluation of a Method To Predict Nitrogen Mineralized From Soil Organic Matter Under Field Conditions. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1027-1031.

Laboratory and field studies were conducted to evaluate the method proposed by Sanford and Smith for predicting the amount of nitrogen mineralized from soil organic matter under field conditions. Soil samples were incubated to determine their nitrogen mineralization potentials and first-order rate constants of mineralization. In all cases of cropped and fallowed plots, the method proposed by Sanford and Smith overpredicted by 67 to 343 pct the amount of nitrogen mineralized. The factors most responsible for the overpredictions were improper soil water content and the use of disturbed samples (drying and sieving) in laboratory incubators.

178. Cabrera, M. L., and D. E. Kissel. Potentially Mineralizable Nitrogen in Disturbed and Undisturbed Soil Samples. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1010-1015.

Current models used to predict nitrogen mineralized in the field sometimes overpredict the amounts of nitrogen mineralized. Overpredictions are related to the treatment of samples before incubation or the physical condition of the samples during incubation. It may be more desirable to incubate undisturbed samples to better depict field conditions. This study measured nitrogen mineralization in disturbed and undisturbed samples to develop models that would describe the data of each type of sample. It was also determined whether the models for disturbed samples could be used to predict nitrogen mineralized under undisturbed conditions. Soil sampling, laboratory incubations, and laboratory analysis procedures are presented. A nonlinear curve-fitting procedure was used to fit one-pool and two-pool models of nitrogen mineralization to the cumulative nitrogen mineralized with time in disturbed and undisturbed samples. For the soils tested, the amount of nitrogen mineralized in disturbed samples was larger than that in undisturbed samples. The two-pool model described the data for disturbed samples, while the one-pool model described the data for undisturbed samples. Models fitted to disturbed samples could not predict nitrogen mineralized in undisturbed samples; however, the models could be used to estimate the parameters of the one-pool model for undisturbed samples. Using this approach, reasonable predictions of the amounts of nitrogen mineralized could be predicted in fallow soils. The parameters of the one-pool model for undisturbed samples could also be estimated from the total nitrogen and clay contents of the soils tested. The results indicate that it may be possible to estimate the nitrogen mineralized in the field by estimating the parameters of the one-pool model for undisturbed samples.

179. Caldwell, C. An Overview of the Establishment and Success of the Ohio Division of Reclamation's Reforestation Program. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 307-310.

An overview of the establishment and success of the Ohio Division of Reclamation's Reforestation Program, established in 1981, is presented. Over a 5-year period, nearly 1.1 million tree seedlings were planted on 809.8 acres of abandoned mined land in Ohio. Information is given on the establishment of the State AML program, the role of *Pisolithus tinctorius* (an endomycorrhizae) in the reforestation program, site selection criteria, and a cost comparison between reforestation and traditional reclamation on AML sites. It is proposed that 1,850 acres of AML sites will be planted with 2.6 million tree seedlings, a large percentage inoculated with *Pisolithus tinctorius*, through the spring of 1990.

180. Caldwell, W. E., D. A. Whitney, R. E. Lamond, and J. S. Hickman. Effects of Replaced Soil Depth of Reclaimed Surface-Mined Soils on Crop Yields in S.E. Kansas. Am. Soc. Agron., Agron. Abstr., 1988, pp. 36-37.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Soil replacement plots were constructed using 30 cm of topsoil and 0, 30, 60, or 90 cm of subsoil over a neutral mine spoil in southeastern Kansas. One-half of each plot was subsoiled to a depth of 50 cm. Wheat (*Triticum aestivum* L.), tall fescue (*Festuca arundinacea* Schreb.), alfalfa (*Medicago sativa* L.), soybeans (*Glycine max* (L.) Merr.), and oats (*Avena sativa* L.) were the test species used. Wheat and tall fescue had a significant yield response to depth of replaced soil, while yields of alfalfa, soybeans, tall fescue, and oats were significantly increased because of subsoiling prior to planting. Yield responses to replaced soil depth have been variable.

181. Call, C. A., and C. M. McKell. Vesicular-Arbuscular Mycorrhizae—A Natural Revegetation Strategy for Disposed Processed Oil Shale. Reclam. & Reveg. Res., v. 1, No. 4, 1982, pp. 337-347.

This study compared the incidence of vesicular-arbuscular mycorrhizae (VAM) associations in disturbed

and undisturbed salt desert shrub communities located in Utah and in Anvil Points, CO. The authors also determined the effects of soil disturbances and surface disposal of processed oil shale on the infection potential of VAM fungi in Paraho processed shale. The majority of plant species examined in the Utah shrub community possessed VAM. In the undisturbed shadscale and sagebrush-greasewood communities, all 17 species were mycorrhizal, while in the disturbed sagebrush-greasewood community 4 of the 5 species present were nonmycorrhizal. Disturbances at the Utah and Anvil Points sites reduced VAM potential of the soils. The mean infection percentages of bioassay plants grown in disturbed soils were about one-half those of bioassay plants grown in undisturbed soils. The bioassay plants grown on the Paraho processed shale showed no signs of VAM infection. The infection percentages were 0, 19 to 26, and 40 to 45 for the processed oil shale, disturbed native soil, and undisturbed native soil, respectively. The authors discuss VAM in terms of their roles in disturbed and undisturbed communities and their potential use in the revegetation of disposed processed oil shale.

182. Campbell, W. F., J. F. Walsh, J. J. Skujins, T. M. Schreeg, and D. Ianson. Utilization of Legumes in the Revegetation of Environmentally Stressed Arid Mine Spoils. Paper in Surface CoalMining and Reclamation Symposium, Coal Conference and Expo V (sponsored by Coal Age, Louisville, KY, Oct. 23-25, 1979). McGraw-Hill, 1979, pp. 227-239.

This article reports the results of laboratory, greenhouse, and field experiments conducted with legumes and their appropriate *Rhizobia* spp. to examine their potential in revegetation of arid western surface-mined soils. Soil pH, moisture content, salinity, available phosphorus and calcium were found to affect germination, emergence, survival, and nitrogen-fixation. The authors concluded that under adequate management, legumes can be successfully grown on mine soils. The results indicate that legumes inoculated with the appropriate *Rhizobia* spp. can supply nitrogen for other non-nitrogen-fixing plants.

183. Campion, P., and D. K. Benner. Establishing Permanent Vegetation on Coal Refuse Without a Four-Foot Layer of Topsoil. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 71-78.

The purpose of this study in Wise County, VA, was to demonstrate a cost-effective method of producing a vegetative cover on coal refuse without the addition of a 4-ft layer of topsoil. Six substrate treatments were utilized and seeded with two different seed mixtures, a standard reclamation mix or a stress-tolerant mix, by two different methods, broadcast seeding or hydroseeding. Two different aspects were tested, a north-facing slope and a south-facing slope. Plant production on a dry-weight basis and percent plant cover were determined. Yield was found to be the highest on the 150-mm replaced mine-soil treatment. Fly ash application decreased yield, and the yield was lower than for the bare refuse alone for the first year. Yield for the stress-tolerant mixture was significantly higher than for the standard reclamation mix. By increasing the depth of applied mulch, the percent vegetative cover also increased. The high yield and dense cover on the refuse material with 150 mm of replaced mine soil indicates that it is possible to establish vegetation on coal refuse without a 4-ft layer of replaced topsoil. The cost-effectiveness of using this method is discussed.

184. Carlstrom, M. G., F. A. Amendola, D. A. Shay, and D. J. Dollhopf. Sodium. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 75-108.

This chapter discusses the physical aspects of sodium pertinent to mine soils, factors affecting mine-soil suitability, and the revegetation and reclamation of sodium-affected western U.S. mine soils. Sodium affects soil material suitability, use, and management. Sodium may affect plant growth through nutritional effects and root growth. Indirectly, excess sodium may affect plant growth through the deterioration of soil structure, resulting in restricted movement, aeration, root elongation, and seedling emergence and development. A literature review on the upward migration of sodium is presented. Amendments used to mitigate sodium-affected soils or sodium migration include soil, gypsum, calcium chloride, or sulfuric acid. The authors state that the best amendment for sodium-affected mine soil is cover soil or soil replacement.

185. Carpenter, S. B., and R. A. Eigel. Reclaiming Surface Mines With Black Locust Fuel Plantations. Paper in Surface Coal Mining and Reclamation Symposium, Coal Conference and Expo V (sponsored by Coal Age, Louisville, KY, Oct. 23-25, 1979). McGraw-Hill, 1979, pp. 301-307.

This article reports results obtained from a study conducted in eastern Kentucky that examined biomass production in black locust (*Robinia pseudoacacia* L.) plantations established for fuel production on reclaimed surface-mined sites. Plantations were established by both

seeding and transplanting. Yields were also determined on coppice production following initial harvest. The study included estimates of the heat content of the wood produced, permitting expression of production in terms of heat content per unit land area (British thermal units per hectare). The authors conclude that fuel plantation systems such as the one studied are economically favorable where costs of site preparation and plantation establishment are part of the reclamation process.

186. Carpenter, S. B., D. H. Graves, and R. A. Eigel. Producing Black Locust for Fuel on Southern Surface Mines. Energy Commun., v. 5, No. 2, 1979, pp. 101-108.

The potential use of black locust (*Robinia pseudoacacia* L.) in establishing fuel plantations on reclaimed mine lands is discussed. Results from field studies indicated that in unmanaged stands from 2 to 13 years old in harsh surface-mined sites, black locust dry weight yields ranged from 2 to 28 tons per acre. The authors feel that with the establishment of fuel plantations and the application of appropriate silvicultural methods, these yields could be increased and the fuel plantation concept become economically feasible. Black locust biomass yield data for 72 sample sites on surface-mined lands are provided, together with an outline of future research directions.

187. Carpenter, S. B., D. H. Graves, and R. R. Kruspe. Individual Tree Mulching as an Aid to the Establishment of Trees on Surface Mine Spoil. Reclam. Rev., v. 1, No. 3/4, 1978, pp. 139-142.

This study investigated the amount of soil surface area that needs to be covered by mulch to significantly raise the survival of tree seedlings. A second objective was to test a variety of mulching materials. American sycamore (*Platanus occidentalis* L.), European black alder (*Alnus glutinosa* (L.) Gaertn.), loblolly pine (*Pinus taeda* L.), and Virginia pine (*Pinus virginiana* Mill.) seedlings were planted on surface mine spoil near Colmar, KY. The mulch treatments consisted of control (no mulch), 0.9- by 0.9-m clear polyethylene plastic, 0.9- by 0.9-m fiberglass mat, 15.2-cm fiberglass disk, 30.5-cm fiberglass disk, latex rubber spray (1:5 rubbery polymer emulsion-water mixture sprayed in a 0.3-m-diameter circle), and bark (0.012 m^3 applied in a circular fashion). Parameters of interest were spoil moisture and temperature and the growth and survival of the tree seedlings after one growing season.

The fiberglass mat and polyethylene plastic raised the level of soil moisture above that of the control, while the bark mulch significantly lowered soil moisture. The highest surface temperatures occurred under the polyethylene plastic and the lowest under the fiberglass mat. Effects of other treatments did not significantly differ from those with the control. The polyethylene plastic and fiberglass mat treatments resulted in a significant increase in seedling survival over that with the control. Survival with latex spray and fiberglass disk treatments did not differ significantly from that with the unmulched control. The bark mulch resulted in a significantly lower survival rate than the unmulched control. The authors conclude that survival, vigor, and growth are increased under conditions that provide more surface area under mulch, such as the polyethylene plastic or fiberglass mats.

188. Carpenter, S. B., R. F. Wittwer, D. H. Graves, and R. E. Daniels. A Comparison of Broadcast Seeding and Spot Seeding of Black Locust on Eastern Kentucky Mine Soil. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 257-260.

This article compares two methods of establishing black locust (*Robinia pseudoacacia* L.) on surface mine spoils in Kentucky, broadcast seeding versus spot seeding. Black locust was chosen as the trial species because of its potential use as a biomass fuel. The experimental design consisted of testing 2 aspects (north and south) and 10 treatments: broadcast seeding at 5 seeding rates and spot seeding at 5 seeding rates. Spot seeding of black locust resulted in better survival, greater growth, and stands with more evenly distributed trees.

189. Carpenter, S. B., R. F. Wittwer, D. H. Graves, and R. A. Eigel. Production of Black Locust Biomass on Appalachian Surface Mines. Sec. in Woodpower: New Perspectives on Forest Usage. Pergamon, 1981, pp. 161-176.

This study was done to determine the biomass production and fuel potential of black locust (*Robinia pseudoacacia* L.) grown on reclaimed surface-mined sites in eastern Kentucky. The study was divided into three phases: (1) sampling biomass produced on previously established black locust stands, (2) establishing two black locust fuel plantations using direct seeding and containerized seedlings, and (3) harvesting a 5-year old stand and measuring coppice (sprout) growth. The biomass produced ranged from an average of 4.7 mt ha^{-1} for 2-year-old stands to 62.1 mt ha^{-1} for 13-year-old stands. These results are comparable to other yields obtained for black locust on surface-mined land. The site factors that influenced black locust growth the most were clay content of the spoil material and slope of the terrain. Biomass was directly related to clay content and inversely related to slope. The heat content of black locust grown on surface-mined land was found to be 33.1 million Btu $cord^{-1}$

(45.3 million Btu acre^{-1}). The authors conclude that the concept of establishing fuel plantations of black locust by direct seeding on reclaimed surface-mined sites appears to be a promising solution to both reclamation problems and the development of an additional renewable energy resource in the Eastern United States.

190. Carrel, J. E., C. L. Kucera, A. P. Harrison, Jr., C. J. Johannsen, and R. W. Blauchar. Strip-Mine Reclamation: Criteria and Methods for Measurement of Revegetation Success (U.S. Dep. Energy contract, Univ. MO—Columbia). U.S. Dep. Energy, DOE/EV/ 02758-8, Sept. 1982, 17 pp.

The purpose of this study was to evaluate and identify suitable methods and criteria for determining revegetation success on reclaimed mine lands in the Midwestern United States. Both direct and remote sensing techniques for measuring plant growth, cover, production, and species composition were tested. Fieldwork was conducted on old abandoned mines in Missouri and newly reclaimed mines in Missouri, Illinois, and Kansas. The authors concluded that direct, ground-level measurements are necessary to obtain statistically valid data on plant performance such as crop and forage yield.

191. Carrel, J. E., C. L. Kucera, C. J. Johannsen, and R. W. Blauchar. Reclamation: Criteria and Methods for Measurement of Revegetation Success, Progress Report for Period Apr. 1, 1980-Mar. 31, 1981 (U.S. Dep. Energy contract DE-AC02-76EV02758.A006). Univ. MO, Prog. Rep. C00-2758-7, Dec. 1980, 71 pp.

The purpose of this study was to find suitable methods and criteria for determining the success of revegetation in midwestern prime agricultural lands strip-mined for coal. Direct and remote sensing techniques are described for measuring plant ground cover, production, and species composition. Digital computer image analysis of color infrared aerial photographs, when compared with ground-level measurements, provided a fast, accurate, and inexpensive way to determine plant ground cover and area. However, the remote sensing approach was inferior to standard surface methods for detailing plant species composition and abundance. This reference is an interim progress report and has been included because it contains extensive data collected during the study that could be of use in comparative studies. Additionally, the authors provide a clear description of their methods in this report.

192. Carter, F. S., K. N. Potter, and E. C. Doll. Effects of Physical Factors on Moisture Relationships in Undisturbed and Reclaimed Soils. Paper in 1987 Mine-Land Reclamation Research Review (sponsored by Land Reclam. Res. Cent., ND State Univ., and North. Great Plains Res. Cent., U.S. Dep. Agriculture, Bismarck, ND, Feb. 24, 1987). ND State Univ., Fargo, ND, 1987, pp. 43-53.

Soil bulk density, total pore space, pore space distribution, and the rate of water movement (saturated hydraulic conductivity) were determined for an undisturbed soil and soils that had been reclaimed for 4 and 11 years. The undisturbed site had lower surface bulk density values, higher total pore space, higher available water capacity, and higher macropore space than the reclaimed soils. Differences in subsurface physical characteristics between undisturbed and reclaimed sites were slight for bulk density, while undisturbed subsurface soil had higher total pores, higher macropore space, but lower available water-holding capacity and micropore space. The results were interpreted to mean that moderate compaction does not result in a decrease in micropore space; it may even increase. Moderate compaction, however, can affect macropore space by decreasing it and influence the movement of water and air and the penetration and expansion of roots. The authors used saturated hydraulic conductivity as an index of the degree of pore continuity. In each case, the saturated hydraulic conductivity of reclaimed soils was lower than that of undisturbed soils. The authors state that the disruption of soil properties that facilitate the entrance and internal movement of air and water is the most drastic effect of mining and reclamation on soil productivity. There is a need to adjust reclamation practices and techniques to facilitate the reestablishment of soil conditions favorable for root growth.

193. Carter, R. P., R. R. Hinchman, and S. D. Zellmer. Land Reclamation Program Annual Report, 1980. Argonne Natl. Lab., ANL/LRP-12, May 1981, 107 pp.

This annual report describes the Argonne Land Reclamation Program and reviews several ongoing or recently completed field and laboratory studies. Preliminary results, accomplishments, and planned future activities are presented for the Jim Bridger Mine Project in southwestern Wyoming; the Kellerman Mine Project in Tuscaloosa County, AL; the Bighorn Mine-Tongue River Project near Sheridan, WY; the Alaska Project considering coal mining impacts throughout that State; the Macoupin County Refuse Reclamation Demonstration Project near Staunton, IL; and the Navajo Mine Project—Plant Breeding and Selection of Plant Materials for Reclamation of Arid Sites (New Mexico), conducted by Brigham Young University. The information presented in these discussions is primarily relevant to the coal mining regions in which the projects are located. Reference to a particular key word used in the evaluation process may not be found in each research project description.

194. Caruccio, F. T., and G. Geidel. Evaluation of Mine Waste-Overburden Analytical Techniques. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 147-153.

Several mine waste-overburden analytical techniques were evaluated to determine which method most closely approximates observed field conditions. Various size fractions of an acid-producing pyrite ore from the Haile Gold Mine, South Carolina, were exposed to rainfall. The samples oxidized under natural conditions, and the volume and quality of leachate produced were related to the weight of a particular size fraction of rock. Splits of these samples were used to compare and evaluate the following analytical techniques: column leaching tests, humidity cell weathering tests, soxhlet reactors, British Columbia Research (BCR) initial and confirmed (bacteria) tests, and acid-base accounting. Results indicated that the finer the particle size of the test material, the greater the amount of acidity produced. Of the techniques tested, the column tests more closely approximated the leachate derived under natural conditions. The humidity cell and soxhlet reactions both overestimated acidity.

195. Castellano, S. D., and R. P. Dick. Distribution of Sulfur Fractions in Soil as Influenced by Management of Organic Residues. Soil Sci. Soc. Am. J., v. 52, No. 5, 1988, pp. 1403-1407.

The long-term effect of organic residues and inorganic nitrogen applications on the distribution of C:N:S ratios, inorganic sulfate sulfur, ester sulfate sulfur, carbon-bonded sulfur, and sulfolipid sulfur in soils under a winter wheat (*Triticum aestivum* L) and summer fallow rotation were studied. Additionally, sulfur additions in the crop and organic residues were compared with the amount of sulfur removed in grain harvest. All treatments were applied biennially over a 55-year period. Treatments used in each 2-year period were (1) straw (control), (2) straw plus nitrogen fertilizer, (3) straw plus 2.24 Mg ha^{-1} of pea vine residue, and (4) straw plus 22.4 Mg ha^{-1} of strawy manure. All residues and wheat straw were incorporated by moldboard plowing to a depth of 20 cm during the fallow year. The strawy manure treatment had 7 to 41 pct more total sulfur than all other treatments, while the straw plus nitrogen fertilizer treatment had the lowest total sulfur values. There were significant decreases in total sulfur with cultivation in the absence of organic inputs other than crop residues. The amounts of organic carbon and total nitrogen in the soil were significantly higher in the strawy manure and pea vine residue treatments than the straw only (control) treatment, which reflects the greater carbon and nitrogen inputs from organic amendments. There were significant treatment effects on all the sulfur fractions. The strawy manure treatment had 9 to 22 pct greater ester sulfate sulfur, and two times more carbon-bonded and sulfolipid sulfur than any of the other treatments. Biennial sulfur budgets show that treatments receiving only straw (control and nitrogen fertilizer treatments) had net inputs (amount of sulfur added in residues minus sulfur removed by crop) of -0.51 and -1.72 kg ha^{-1} S, respectively, and the pea vine residue and straw manure treatments had sulfur inputs of 1.92 and 31.05 kg ha^{-1}, respectively. These results suggest that the sulfur additions from the strawy manure treatment are in excess of crop requirements and that the sulfur mineralized may be lost from the system; however, additions of strawy manure and pea vine residues can maintain sulfur levels in soils. The authors conclude that the ultimate source of sulfur under long-term sulfur depletion may be from the recalcitrant residual sulfur pool.

196. Cech, F. C., and R. N. Keys. Establishment and Early Growth of Sweetgum Planted on Disturbed Land. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 217-228.

Sweetgum (*Liquidambar styraciflua* L.) seedlings from 34 seed sources that represent the natural range of this species were planted on a forest site, a reclaimed deep-mine refuse pile, and a reclaimed surface mine. These sites are in northeastern West Virginia and western Maryland. Height growth and survival differed among sources and sites. Fastest growth was exhibited by seedlings from northern sources; however, these seedlings were the shortest because of susceptibility to winter dieback. The forest site showed the best growth and survival. Low pH contributed to poor growth and survival on the reclaimed refuse pile. Competition and possible allelopathic effects by grasses and other herbaceous cover contributed to poor growth on the reclaimed site.

197. Cerligione, L. J., A. E. Liberta, and R. C. Anderson. Effects of Soil Moisture and Soil Sterilization on Vesicular-Arbuscular Mycorrhizal Colonization and Growth of Little Bluestem (*Schizachyrium scoparium*). Can. J. Bot., v. 66, No. 4, 1988, pp. 757-761.

Although this paper does not discuss soil amendments or soil characterization of surface-mined land, it can serve as a reference to the effects of soil moisture on vesicular-arbuscular (VA) mycorrhizal colonization and the associated growth of little bluestem (*Schizachyrium scoparium*

(Michx.) Nash.) throughout its range. The soil used in this study was obtained from a prairie located in McLean County, IL. The soil was a silt loam. A portion of the soil was used to isolate VA mycorrhizal fungus spores, while the remaining soil was divided into two subsamples. One subsample was sterilized by autoclaving for 90 min, while the second remained unsterilized. Thirty containers each of sterilized and unsterilized soil were used in this experiment, and 8 to 10 caryopses of little bluestem were planted. The seedlings were thinned to one seedling per container after germination. Prior to moisture treatments, five containers from both soil groups were selected for harvest. Root and shoot biomass and the presence or absence of mycorrhizal colonization were noted. Seedlings grown in sterilized soil contained no mycorrhizae, while those grown in unsterilized soil all showed evidence of colonization. The remaining containers of each soil type were divided among five soil moisture treatment groups ranging from saturation for 12 h followed by drainage for 48 h, to allow the soil to dry, to the permanent wilting point (-15 bars tension); the containers were then held for 72 h before the soil was returned to field capacity. All plants were exposed to the experimental condition for 60 days.

At the end of the experiment, the number of flowering culms produced was recorded, soil was washed from the roots, and weights of shoots and roots were recorded. The spores isolated from the soil used were identified. Analysis of variance results indicated that the observed plant responses were due to soil sterilization rather than moisture treatments. Nonmycorrhizal plants (sterilized soil) produced significantly greater root and shoot biomass, had lower root-to-shoot ratios, and produced more flowering culms than mycorrhizal plants. The authors attribute the greater biomass accumulation in these plants to the higher phosphorus levels in sterilized soil. Mycorrhizal plants did have higher concentrations of tissue phosphorus, calcium, zinc, iron, copper, aluminum, and sodium and lower concentrations of potassium and manganese. There was a nonsignificant decrease in percent colonization as soil water availability decreased. The results suggest that little bluestem and its associated mycobionts are adapted to a wide range of soil moisture conditions.

198. Chae, Y. M., and M. A. Tabatabai. Mineralization of Nitrogen in Soils Amended With Organic Wastes. J. Environ. Qual., v. 15, No. 2, 1986, pp. 193-198.

The mineralization of nitrogen in various sewage sludges, animal manure, and plant materials added to five different surface (0 to 15.0 cm) soils was assessed in a laboratory incubation study. All organic amendments were added at a rate equivalent to 50 Mg ha^{-1}. Four sewage sludges, four animal manures (chicken, cow, hog, horse), and four plant materials (cornstalks, soybean residue, alfalfa, sawdust) were added to each soil type and incubated for 26 weeks. Leachate samples were taken every 2 weeks. Nitrogen mineralized ranged from 156 to 668 mg kg^{-1} during the 25-week period. The patterns of nitrogen mineralization in animal-manure-treated soils were similar to those of sludge-treated soils. During the first 4 weeks, little or no mineralization occurred. Between weeks 4 and 12, there was a marked increase in mineralization rates, followed by a constant release of mineral nitrogen during weeks 12 to 26. Total amounts of nitrogen mineralized in the manure-treated soils ranged from 176 to 617 mg kg^{-1} during the 26-week period. Chicken manure contained the greatest percentage of mineralizable nitrogen of the manures examined. All plant materials, with the exception of alfalfa, showed an initial phase of nitrogen immobilization. With cornstalks and sawdust, immobilization continued during the entire period. In alfalfa-treated soils, nitrogen mineralization exhibited a fast initial rate to week 12 and a steady nitrogen release occurred between weeks 12 and 26. Total nitrogen released ranged from 0 to 983 mg kg^{-1} in alfalfa-treated soils. The results of this study indicate that nitrogen mineralization in organic-waste-treated soil is dependent on the compositions of the waste and the chemical and physical characteristics of the soils amended with organic waste.

199. Chambers, J. C., R. W. Brown, and R. S. Johnston. A Comparison of Soil and Vegetation Properties of Seeded and Naturally Revegetated Pyritic Alpine Mine Spoil and Reference Sites. Landscape Urban Plann., v. 14, 1987, pp. 507-519.

The soil physical and chemical characteristics of seeded and naturally revegetated minesites and native undisturbed reference sites on two high-elevation gold and copper mines in Montana were examined. Vegetative cover and peak biomass on each site were also determined. Nitrogen is the nutrient that is often limiting plant growth in alpine ecosystems, and available nitrogen can exhibit large fluctuations during the growing season. Total nitrogen, NH_4-N, and NO_3-N were measured three times during the growing season. Significant differences in soil physical and chemical characteristics were obtained among the reference, seeded, and naturally revegetated sites. Revegetated sites generally had lower levels and smaller fluctuations in NH_4-N and NO_3-N during the growing season than did the reference sites. Fertilization and liming caused high levels of phosphorus, potassium, and calcium on revegetated areas; however, phosphorus was still higher on the reference than on naturally revegetated sites. The authors state that differences in soil and vegetation properties between the revegetated and reference areas indicate that the use

of reference areas as the standard of reclamation success for acidic alpine mine spoils had severe limitations.

200. Chambers, J. C., J. A. MacMahon, and R. W. Brown. Response of an Early Seral Dominant Alpine Grass and a Late Seral Dominant Alpine Forb to N and P Availability. Reclam. & Reveg. Res., v. 6, No. 3, 1987, pp. 219-234.

This greenhouse study was conducted to determine the growth response and uptake characteristics of an early seral dominant alpine grass (*Deschampsia cespitosa*) and a late seral dominant alpine forb (*Geum rossii*) to nitrogen and phosphorus availability. Soil was collected from a gravel borrow pit on the Beartooth Plateau in Montana. This represented a highly disturbed alpine soil. A factorial experimental design was used with four levels of nitrogen (4.2, 38.8, 73.3, and 107.6 mg kg^{-1}), four levels of phosphorus (6.7, 39.5, 72.4, and 105.0 mg kg^{-1}), three replications of each treatment, and two plants per pot. The lowest nutrient additions represented the amounts of nitrogen and phosphorus present in native alpine soils. Species growth responses (shoot and root dry weights, root-to-shoot ratios, nitrogen and phosphorus concentrations, and relative growth rates) were related to changes in nutrient levels as they would occur during succession. *Geum rossii* responded to nutrient additions by exhibiting a lower relative growth rate and a higher root-to-shoot ratio compared with *Deschampsia cespitosa*. *Deschampsia cespitosa* exhibited a greater growth response to added nitrogen, while *Geum rossii* was more responsive to added phosphorus. In disturbed alpine soils, high rates of fertilization, particularly with nitrogen, or repeated fertilization can enhance the competitive ability of early successional species that have high relative growth rates. These species more effectively utilize the available resources. To promote the establishment of late successional species with low relative growth rates it may be necessary to increase their relative seeding density. The use of late successional species, which are adapted to low nutrient conditions and have low relative growth rates, may help to ensure the long-term productivity of nonmanaged reclaimed alpine ecosystems. Field studies are needed to verify the results of this study because the environmental conditions of a greenhouse compared with a natural system and other nutrients may be limiting.

201. Che, M. D., and J. T. Logan. Chemistry and Mineralogy of Water Treatment Lime Sludges and Their Use as Liming Materials. Am. Soc. Agron., Agron. Abstr., 1987, p. 24.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. A laboratory study was conducted to determine the potential of water treatment lime sludges as a substitute for agricultural limestone. The calcium carbonate equivalent and total fineness efficiency of the sludges were comparable to those of agricultural limestone. The dominant mineral in the sludges was calcite, with only trace amounts of silicates and soluble salts. The initial pH of the sludges ranged from 9.6 to 11.0, indicating the presence of unreacted $Ca(OH)_2$ or Na_2CO_3 used in water softening. Lime sludges also gave a faster initial rise in pH compared with agricultural limestone when added to an acid loamy soil; however, the final pH values were similar. Water treatment lime sludges have potential use as substitutes for agricultural limestone.

202. Chichester, F. W. Premining Evaluation of Forage Grass Growth on Mine Soil Material From an East-Central Texas Lignite Site. Soil Sci., v. 135, No. 4, 1983, pp. 236-244.

This paper reports the results of a greenhouse study designed to examine the growth of several warm season forage grasses and a cool season pasture mix of oats (*Avena sativa* L.) and clover (*Trifolium* spp.) on mixtures of soil profile horizon materials. The author concluded that if an adequate supply of water and nutrients is provided, the mixtures of soil profile horizon materials evaluated had the same potential for forage grass production as the generic topsoil at the minesite. The results reported could be applicable to the study or planning of reclamation on sites with thin topsoil.

203. Chichester, F. W., and V. L. Hauser. Revegetation of Minesoils Constructed From Lignite Overburden in East-Central Texas. Reclam. & Reveg. Res., v. 3, No. 2, 1984, pp. 137-152.

Mine-soil profile construction options were evaluated for a proposed lignite surface mine in east-central Texas to simulate reclamation options. Five profiles were used: (1) an undisturbed Axtell soil profile, (2) dragline spoil hauled from a nearby lignite mine, (3) 30 cm of Axtell soil mix over 150 cm of mine spoil, (4) 60 cm of Axtell soil mix over 120 cm of mine spoil, and (5) 120 cm of Axtell soil mix over 60 cm of mine spoil. All profiles had a total depth of 180 cm. Soil for profiles 2 through 5 were backfilled in 30-cm layers, with each layer compacted to an average bulk density of 1.40 g cm^{-3}. Before the final soil layer was added, profiles 2 through 5 were split, with half receiving 12 Mg ha^{-1} dolomitic limestone and the other half receiving no lime treatment. Prior to the establishment of an oat (*Avena sativa* L.) cover crop, all plots were fertilized with 112 kg ha^{-1} N and 197 kg ha^{-1} P, and 2.5 Mg ha^{-1} limestone was applied. The following spring

the oat cover crop was killed and kleingrass (*Panicum coloratum* L.) was seeded into the stubble. Nitrogen was topdressed at 112 kg ha^{-1} after seedling emergence. Grasses were harvested during midsummer and fall for yield and chemical analysis. Plots were fertilized with 150 kg ha^{-1} N and 30 kg ha^{-1} P the following spring when the grass began regrowth. After the first harvest, a second topdress fertilizer application of 74 kg ha^{-1} N was made. All soils were characterized chemically and physically. None of the soil materials used were inherently fertile. Kleingrass was successfully established on the undisturbed Axtell soil and on each of the constructed mine-soil profiles. Plant emergence was significantly greater on bare soil compared with mulched soil for the Axtell soil and mine spoil surface, while a greater number of seedlings emerged on mulched plots than on bare soil for the soil-spoil mixture plots. Nonmulched soil-spoil mixtures tended to form surface crusts when dried, which restricted grass seedling emergence compared with plantings on nonmulched undisturbed soil or mine spoil. Planting kleingrass into the stubble mulch on soil-spoil mixture plots reduced surface temperatures and evaporative water loss, thereby effectively minimizing crust formation. Mulch on the undisturbed soil and spoil reduced rather than enhanced grass seedling emergence in the absence of a crusting problem.

204. Chironis, N. P. Guide to Plants for Mine Spoils. Coal Age, v. 82, No. 7, 1977, pp. 122-130.

This article provides information on 21 species of shrubs, trees, legumes, and grasses that have been grown successfully on different spoil materials across the United States. Included is a short discussion on a few soil factors that affect the success of plantings. For each species described, information is given on growth habit, tolerances (acid and drought), varieties available, and the benefit a particular species may provide to the site. The cover provided for wildlife and the ability to fix nitrogen are examples of such benefits.

205. Chironis, N. P. Reedgrass Greens Slurry Ponds. Coal Age, v. 87, No. 4, 1982, pp. 86-91.

The author discusses the use of reedgrass (*Phragmites australis* Trin.) in revegetating slurry areas at a site in southern Illinois. A new method of establishing vegetation on slurry areas without the use of topsoil is needed because of the high cost of covering the area with 4 ft of borrow material. A good discussion is included on the morphological characteristics and adaptability of reedgrass to differing environmental conditions. The establishment of reedgrass on slurry areas was accomplished by planting sectioned rhizomes, which are similar to root cuttings, using techniques similar to those used for tree seedlings. Results indicate that within 8 days of initial planting, lateral root and vertical shoot development had occurred. By the end of the third growing season, shoot height was over 6 ft with stand densities over 130 stems per square yard on favorable sites. These results indicate that it may be possible to establish vegetative cover on refuse areas without an initial topsoil cover.

206. Chong, S. K., M. A. Becker, S. M. Moore, and G. T. Weaver. Characterization of Reclaimed Mined Land With and Without Topsoil. J. Environ. Qual., v. 15, No. 2, 1986, pp. 157-160.

Several major hydrological and physical soil properties of land reclaimed with and without topsoil were quantified on a southern Illinois surface mine. All hydrologic and physical characterizations were limited to the top 0.2 m of topsoiled (topsoil over B and C horizon mix) and nontopsoiled (B and C horizon mix) plots. The nontopsoiled plot had an average bulk density of 1.5 Mg m^{-3}, which was 15 pct higher than the topsoiled plot. The topsoiled plot had higher hydraulic conductivity, macroporosity, and drainage rates than the nontopsoiled plot; however, the sorptivity and infiltration rates were not significantly different.

207. Christensen, B. T. Effects of Animal Manure and Mineral Fertilizer on the Total Carbon and Nitrogen Contents of Soil Size Fractions. Biol. and Fertil. Soils, v. 5, 1988, pp. 304-307.

This research was conducted using noncoal soils. However, the article contains good background information on the effects of mineral fertilizer and animal manure, compared with unmanured soil, on the organic matter distribution between soil particle fractions. The soil was fractionated according to particle size using ultrasonic dispersion and sedimentation in water. Following fractionation (clay size, silt size, and various solid sizes), fractions were analyzed for total carbon and nitrogen.

Results show that clay and silt fractions accounted for 8.8 to 10.1 pct and 9.3 to 10.2 pct of the soil dry matter, respectively, across all treatments. The largest concentrations of carbon and nitrogen, mean of the treatments, were found in the clay fraction, 8.3 pct C and 0.70 pct N; the concentrations in the silt fraction were 4.2 pct C and 0.30 pct N. This corresponded to 58 pct and 65 pct of the soil carbon and nitrogen, respectively, for the clay fraction and 30 pct and 26 pct of the soil carbon and nitrogen, respectively, for the silt fraction. Sand accounted for 10 pct of the soil carbon across all treatments. Clay, silt, and whole-soil carbon and nitrogen concentrations increased from the unmanured to the N-P-K fertilization

treatment to the animal manure treatment. No consistent patterns were found for carbon concentrations in the sand size fractions in relation to fertilization. These distribution patterns of carbon and nitrogen concentrations were not influenced by fertilization. The carbon-nitrogen ratio of silt organic matter across all treatments (14.1:14.4) was higher than the whole-soil carbon-nitrogen ratio (11.5:12.7), while that of clay (10.4:10.8) was lower across all treatments. Fertilization did not affect the clay and silt carbon-nitrogen ratios. Animal manure caused similar increases (34-pct and 39-pct increases in carbon and nitrogen content, respectively) of clay and silt size fractions, while mineral fertilizer increased the organic matter content of silt by 21 pct and that of clay by 14 pct. The authors state that in soils where similar total contents of organic matter have been reached, either by mineral fertilizer or animal manure, the manure-treated soil will contain a larger proportion of more labile organic matter than will the soil that is fertilized.

208. Ciolkosz, E. J., R. C. Cronce, R. L. Cunningham, and G. W. Petersen. Characteristics, Genesis, and Classification of Pennsylvania Minesoils. Soil Sci., v. 139, No. 3, 1985, pp. 232-238.

Twenty-four nontopsoiled, noncultivated Pennsylvania mine soils ranging in age from 1 to 29 years are described in relation to their genesis and classification. Soil profiles are described using standard USDA Soil Conservation Service definitions. Rock fragment content of the subsoil was >70 pct, while the surface horizons had a rock fragment content 10 to 30 pct lower than the subsoil. The surface horizons had two to three times the 2- to 4.7-mm-size rock fragment content of the subsoil, indicating that weathering (chemical and physical) near the surface had broken the larger fragments into smaller fragments and fine earth material (<2 mm). Particle size data showed that the mine soils studied were primarily medium textured. The texture varied with depth, but variation with elevation was not evident. Morphological descriptions of the surface indicated that only four profiles had a moderate grade of structure; the remaining profiles had a weak grade of structure. The subsurface horizons showed weak development. The morphological data indicated that the solum is developing at a rate of about 1.6 cm yr^{-1}. The organic carbon content of the studied mine soils varied with depth. The free iron oxide content was high and reflected the rapid iron release during acid-sulfate weathering. The pH was variable, but the general trend indicated that the mine soils were acid. Apparently the mine soils have undergone a significant sulfate weathering phase in their initial development. Evidence for this includes the high soluble salt content in which sulfate and cations are produced faster than they can be leached, resulting in the accumulation of salts. The minerals studied showed weak morphological development, with the vast majority having A and B horizon thicknesses of 50 cm or less. The majority of the soils studied (79 pct) would be classified as Entisols (Orthents or Spolents), while the remaining 21 pct would be classified as weakly developed Inceptisols.

209. Clason, T. R. Growth in Thinned Loblolly Pine Plantations. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 429-432.

Productivity of overstocked loblolly pine (*Pinus taeda* L.) plantations can be restored through thinning and nitrogen fertilization. Rather than using inorganic fertilizer sources, leguminous species may provide nitrogen fertilizer growth enhancement in thinned stands. This study was conducted in an overstocked loblolly pine plantation to evaluate the combined effect of thinning and biologically derived nitrogen on residual pine growth. A loblolly pine plantation was thinned to 100 trees per acre, and sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don.) and subterranean clover (*Trifolium subterraneum* L.) were broadcast seeded into the plantation. Seedbed preparation treatments were burned or unburned plots that were either unfertilized or fertilized with 30 and 60 lb $acre^{-1}$ of phosphorus and potassium, respectively. Legume stocking during the first year was greatest on the burned, fertilized seedbed plots. After 5 years, the more persistent legume understory was produced with lespedeza. Lespedeza averaged 2,500 lb $acre^{-1}$ dry matter on burned, fertilized seedbed plots. Clover was not present in any of the treatment plots. Tree growth data (DBH, bark thickness, total height, height to base of live crown, and crown radius) indicated no growth response to the leguminous understory. Soil nutrient concentrations were not significantly altered because of a leguminous cover. The results of this short-term study indicate that there is no justification for establishing a biological nitrogen source in thinned pine plantations because of cost.

210. Cline, J. F., and V. A. Uresk. Revegetation of Disturbed Grounds in the Semi-Arid Climate of South Central Washington. Health Phys., v. 35, 1979, pp. 289-294.

The purpose of this study was to evaluate the effectiveness of various soil treatments in establishing a self-sustaining vegetative cover on soil fill overlying a portion of a former radioactive waste pond. The soil was stabilized sufficiently to resist wind erosion using treatments that incorporated straw, Wyoming bentonite clay, or a

straw-clay mixture. Successful revegetation was achieved in 1 year. Cheatgrass (*Bromus tectorum* L.), a shallow-rooted species, was planted to retard the growth of deep-rooted radionuclide carriers. The cheatgrass maintained itself through three growing seasons. The authors feel that the cheatgrass will probably persist in the study area for several decades.

211. Cline, M. L., R. C. France, and C. P. P. Reid. Intraspecific and Interspecific Growth Variation of Ectomycorrhizal Fungi at Different Temperatures. Can. J. Bot., v. 65, No. 5, 1987, pp. 869-875.

Isolates of four ectomycorrhizal fungal species were examined in pure cultures to determine their response to temperature. Isolates used were *Pisolithus tinctorius*, *Cenococcum geophilum*, *Suillus granulatus*, and *Thelephora terrestris*. Liquid culture plates of geographically distinct isolates of each ectomycorrhizal fungi were placed in incubators without light at 16°, 21°, 27°, 32°, and 38° C. Each of the fungal species isolates exhibited one of six general patterns of mycelial growth in relation to temperature: (1) normal distribution, (2) skewed to the left (higher temperature optimum), (3) skewed to the right (lower temperature optimum), (4) gradual decrease in growth with increased temperature, (5) rapid decrease to zero growth with increased temperature, and (6) constant low level of growth over all temperatures.

Pure-culture growth of *P. tinctorius* was more tolerant of high temperatures than any of the other fungi examined. Optimal pure-culture growth of *P. tinctorius* occurred between 21° and 32° C depending on the isolate considered. Northern U.S. isolates generally have lower temperature optima for mycelial growth, while southern U.S. isolates have higher temperature optima. Growth of *P. tinctorius* followed either general pattern 1, 2, or 3. The temperature optimum for *C. geophilum* occurred at 27° C, with mycelial growth occurring at temperatures between 16° and 27° C, depending on the isolate considered. Isolates of *C. geophilum* exhibited four patterns of growth over the temperature range of 16° to 27° C: 1, 2, 4, or 5. *C. geophilum* is tolerant to water stress, which makes the species competitive in xeric environments. The optimal growth temperature of *S. granulatus* varied with the isolate, with mycelial growth occurring primarily at 21° and 27° C and to some extent at 32° C. The growth patterns of *S. granulatus*, relative to temperature, followed 1, 2, 3, or 4. Isolates of *T. terrestris* exhibited mycelial growth at all treatment temperatures except 38° C. Pure-culture growth of *T. terrestris* was high relative to that of other fungi and varied in response to temperature. Each isolate of *T. terrestris* exhibited a different growth pattern over the temperature range investigated. The results indicated that particular isolates or species may be better suited for certain inoculation programs. The variability in growth optima for fungal species and isolates may reflect the variability of specific fungal species or isolates to colonize root systems.

212. Coal Age. Guide for Revegetation in Eastern U.S. V. 86, No. 7, 1981, pp. 76-79, 82-86.

This article is a good reference to the revegetation of surface-mined land in the Eastern United States. The information provided deals with vegetation establishment, from the time of seedbed preparation through mulching. Included in the discussion are sections on the various seeding techniques available for herbaceous species, recommended varieties and mixtures, and seeding times and rates. There is also a short discussion on tree and shrub plantings. Various soil amendments that aid in vegetation establishment are discussed. The information presented in this article is based on material compiled by B. L. Rafaill, W. G. Vogel, and R. R. Hinchman.

213. Coal Miner. Alaska's Usibelli Coal Mine Expands Into Export Markets. V. 7, No. 5, 1982, pp. 36, 38.

This is a general article that deals with the reclamation efforts at the Usibelli coal mine in Alaska. The entire article contains very little specific information on revegetation and reclamation other than to mention the various research projects that have occurred at the site since 1971.

214. Coaldrake, J. E., and M. J. Russell. Rehabilitation With Pasture After Open-Cut Mining at Three Sites in the Bowen Coal Basin of Queensland. Reclam. Rev., v. 1, No. 1, 1978, pp. 1-8.

Field trials were conducted to develop a method for establishing permanent vegetative cover on three reclaimed areas of the Bowen Coal Basin located in Queensland, Australia. Species trials were made with grasses and tropical legumes. The key to rapid and successful rehabilitation of these areas is the application of superphosphate at a rate of 400 kg ha^{-1}. Large increases in cover and yield resulted for each species at each site because of the application of superphosphate. Response to nitrogen fertilizer application was variable.

215. Cocke, C. L., and K. W. Brown. The Effect of Sewage on the Physical Properties of Lignite Overburden. Reclam. & Reveg. Res., v. 6, No. 2, 1987, pp. 83-93.

The influence of sewage sludge applications on the physical properties and vegetation yields of reclaimed lignite mine spoil in Grimes County, TX, was determined. Four treatments were used to evaluate the effect of

chemical fertilizer and sewage sludge on infiltration, aggregate stability, available water, and yield of bermudagrass (*Cynodon dactylon* (L.) Pers.) on lignite spoil. Treatments were: (1) control, (2) 0.224 Mg ha^{-1} N as NH_4NO_3, (3) 0.112 Mg ha^{-1} N as NH_4NO_3 plus 0.112 Mg ha^{-1} mineralizable nitrogen as sewage sludge (142 Mg ha^{-1}), and (4) 0.224 Mg ha^{-1} mineralizable nitrogen as sewage sludge (284 Mg ha^{-1}). All treatments were applied to adjacent sets of identical plots 1 year apart, and data were collected during the year of application and the year after application to allow for comparisons under similar environmental conditions. Water infiltration, aggregate stability, available soil water, and vegetation yields all increased significantly as a result of sludge application. Sewage sludge increased water infiltration by 38 pct over control plots for both years. Aggregate stability was 16 pct greater on plots that received only sewage sludge compared with those receiving equivalent amounts of fertilizer. Sewage sludge application also increased the available water by 18 pct over that in control plots. Average bermudagrass yield increased significantly from the control (0.5 Mg ha^{-1}), to the fertilizer treatment (2.0 Mg ha^{-1}), to the fertilizer plus sludge treatment (3.2 Mg ha^{-1}), to the sludge alone treatment (4.0 Mg ha^{-1}).

216. Coe, C. A., and J. M. Klopatek. Mycorrhizae in Reclaimed Soils. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 399-405.

Two greenhouse studies were conducted to determine the presence of vesicular-arbuscular mycorrhizae (VAM) in soils of undisturbed (reference area) and disturbed (reclaimed) plant communities in the Black Mesa Coal Region in northeastern Arizona. Soils were taken from four undisturbed plant communities; three reclaimed soils, one prelaw and two postlaw (Public Law 95-87); and three topsoil storage piles ranging from 1 to 3 years in age. All soils were analyzed for pH, electrical conductivity, percent saturation, and textural class. The first study was done to reveal the interaction of VAM with plant roots of sudangrass (*Sorghum sudanense* (Piper) Stapf.). The results of this study showed that mycorrhizal infection was directly related to the different soil types. Plants grown in natural soils had greater mycorrhizal infection and total biomass than plants grown in disturbed soils. The second study consisted of four treatments that were used to determine if different soil substrates had varying capacities to support mycorrhizal fungi and how VAM affects the growth of four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.). The treatments consisted of four-wing saltbush grown in sterile and unsterile soil inoculated and noninoculated with mycorrhizal fungi. Four-wing saltbush grown in disturbed and undisturbed soils inoculated with the mycorrhizal fungi *Glomus mosseae* and *Glomus fasciculatum* had higher percent infection and greater biomass than noninoculated soils. The authors conclude that disturbance has several detrimental effects on the native mycorrhizal populations.

217. Conservation Consultants, Inc., and Zellars-Williams, Inc. Reclamation Methodology Resource Document, Draft EIS, Swift Agricultural Chemicals Corporation, Duette Mine Site, Manatee County, Florida. U.S. EPA, Rep. EPA 904/9-79-044 F, Oct. 1979, 57 pp.

This document provides an excellent description of proposed reclamation and revegetation methods for a phosphate mine in Florida. All parts of the minesite are treated. Revegetation methodology includes separate procedures for improved pasture establishment, reforestation, enhancement of unmined palmetto rangeland, and marsh revegetation. Special reclamation methods are described for wetland restoration, lake creation, and natural revegetation. Although the document was written specifically for a phosphate mine, many of the procedures are applicable to reclamation of surface coal mines.

218. Conwell, C. N., and S. Weston. Reclaiming Mining Lands in Alaska. Paper in Stability in Coal Mining (Proc. 1st Int. Symp. on Stability in Coal Mining, Vancouver, BC, 1978). Miller Freeman Publ., San Francisco, CA, 1979, pp. 459-462.

The authors provide a brief general statement of surface coal mine reclamation in Alaska. The discussion is centered around experience gained from reclamation efforts at the Usibelli coal mine near Healy, AK. Although few actual data are provided for the topics considered, the discussion will be of interest to individuals with limited knowledge of surface coal mine reclamation efforts in Alaska.

219. Conyers, M. K., and B. G. Davey. Observations on Some Routine Methods for Soil pH Determination. Soil Sci., v. 145, No. 1, 1988, pp. 29-36.

Soil pH is one of the more commonly measured characteristics of both coal- and noncoal-mined soils. Although this study was conducted using noncoal-mined soils, the results are directly applicable to coal-mined soils. The soils used in this study were from New South Wales, Australia. The study explored the relationship among several variables that are involved in the determination of soil pH. Some of the variables examined included electrolyte solution, solution-to-soil ratio, and soil-electrolyte shaking time. Regression equations relating

these variables were also determined. Soil pH was determined in three electrolytes: pH in water, pH in 0.01*M* $CaCl_2$, and pH in 0.1*M* KCl, and three solution-to-soil ratios: 2:1, 2.5:1, and 5:1. Additionally, the change in pH with dilution of the solution-to-soil ratio was examined for each electrolyte using 2, 10, 20, 30, 40, 50, 100, 140, and 1,000:1 dilutions. The pH readings were taken after 1 h, 1 day, 1 week, 1 month, and 3 months without inhibition of microbial action. The regression equations for the relationship between methods for pH determination were all highly linear and allowed for the conversion between electrolytes and dilution ratios with precision. Soil pH determinations using water as the electrolyte consistently resulted in the highest pH values, and those using 0.1*M* KCl resulted in the lowest for any given soil. The pH values obtained at the various dilution ratios were highly correlated with each other. The pH in all electrolytes was unaltered between 30 and 60 min of shaking time. Between 1 and 24 h, however, the pH rose approximately 0.1 pH unit, depending on the electrolyte, at all dilution ratios from 2:1 to 100:1. The authors found that the relationship between pH in water and 0.01*M* $CaCl_2$ at a 2.5:1 solution-to-soil ratio was $pH_{Ca} = 1.05\ pH_w - 0.9$ for nonsaline, net negatively charged soils. In the acid soils tested there were large amounts of hydrolyzable acidity, which maintained a fairly constant pH over the solution-to-soil ratios tested. Shaking time for soil pH measurements should be less than 24 h and preferably nearer 1 h. The authors found that longer periods resulted in changes of pH that did not reach equilibrium.

220. Cook, F. Evaluation of the Environmental Effects of Western Surface Coal Mining, Volume I (Mathematica, Princeton, NJ). U.S. EPA, Ind. Environ. Res. Lab. EPA-600/7-79-110, May 1979, 136 pp.

The author presents a general review of methods used for surface mining of coal in the Western United States, the environmental effects of those mining methods, and recommendations to alter or reduce both short- and long-term environmental damage. The overall evaluation of revegetation and erosion control practices is good. Mine spoils in the West can be successfully revegetated to produce at least as good a cover as the premining cover, particularly where topsoil is replaced and proper seedbed preparation, seeding, and amendment procedures are used. Long-term survival, however, is still uncertain.

221. Cordell, C. E., J. H. Owen, and D. H. Marx. Mycorrhizae Nursery Management for Improved Seedling Quality and Field Performance. Paper in Meeting the Challenge of the Nineties: Proceedings, Intermountain Forest Nursery Association (Oklahoma City, OK, Aug. 10-14, 1987). U.S. For. Serv., Gen. Tech. Rep. RM-151, 1987, pp. 105-115.

This article discusses mycorrhizae in terms of key components to root system quality and integrated nursery management. Mycorrhizae infect root systems in one of two forms, ectomycorrhizal and endomycorrhizal (vesicular-arbuscular) fungi. Ectomycorrhizal fungi grow between root cells and cover the root surface with a mantle of fungus hyphae. These mycorrhizae can be identified by their fruiting bodies. Tree species associated with ectomycorrhizal fungi include pine, spruce, fir, alder, beech, oak, and hickory. Endomycorrhizal fungi penetrate cortical cells of infected roots and form nutrient-exchange structures (arbuscules) inside the cells. Vesicles or spores develop in feeder roots. Tree species associated with endomycorrhizal fungi include most hardwood species (including maple, sweetgum, sycamore, ash, walnut, and poplar), some conifers (cypress and redwood), and all agronomic crops. The benefits of both ecto- and endomycorrhizae, both naturally occurring and introduced, in forest plantings are discussed. Most conifer tree species cannot grow without ectomycorrhizae. Methods for identifying and quantifying mycorrhizae are given. Information is presented on nursery management practices that can be modified to increase mycorrhizal infection. These modifications usually include soil or cultural factors. Finally, information is given on ectomycorrhizal fungus inoculum, cost of inoculum, procedures for inoculation, and operational applications, and inoculations using endomycorrhizal fungus.

222. Cordell, C. E, J. H. Owen, D. H. Marx, and M. E. Farley. Ectomycorrhizal Fungi—Beneficial for Mineland Reclamation. Paper In Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 321-326.

Tree seedlings tailored (inoculated) with the ectomycorrhizal fungus *Pisolithus tinctorius* (Pers.) Coker & Couch, have been used to successfully reforest or afforest acid coal spoils, kaolin spoils, borrow pits, and other severely disturbed sites in the Eastern and Central United States. Ectomycorrhizae infections increase root water and nutrient absorption, feeder root longevity, nutrient assimilation, and resistance to root pathogens. There are several types of *P. tinctorius* inoculum that are commercially available, including vegetative mycelium inoculum, spore pellets, spore-encapsulated seed, and bulk spore. The procedures for operational nursery use vary among the commercial inocula used. Vegetative inoculum can be broadcast and incorporated prior to sowing bare-root seedbeds. Vegetative inoculum can be incorporated into the growing medium of container-grown seedlings prior to filling the containers. Bulk spores can be sprayed, drenched, or dusted onto growing medium or seedbeds, while spore

pellets can be incorporated or broadcast on the soil surface. The benefits that *P. tinctorius* provides seedlings planted on disturbed sites are documented. Several studies have shown that the largest gains in tree survival and growth have occurred on sites with high air and soil temperatures, low soil pH values, and high concentrations of calcium, magnesium, and manganese. *P. tinctorius* tailored seedlings have improved the seedlings' tolerance to these conditions as long as soil compaction and high bulk densities are mitigated. Costs of commercially available inoculum are presented. Evidence suggests that reclamation costs can be reduced by utilizing *P. tinctorius* inoculated trees in reforestation and afforestation efforts. Operational application of *P. tinctorius* is also presented.

223. Corkern, C. M., and W. H. Hudnall. Nutrient and Elemental Composition of Domestic Sludge-Amended Bermudagrass. Am. Soc. Agron., Agron. Abstr., 1986, p. 28.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. Vegetative samples of Alicia bermudagrass (*Cynodon dactylon* (L.) Pers.) grown on soils amended with sewage sludge were collected, and elemental analyses were conducted to investigate the potential toxic effects of sludge on bermudagrass. Vegetative mean elemental concentrations were correlated with the mean elemental concentration of the soil. Elemental concentrations increased with increasing levels of sludge application. The authors conclude that sludge application rates of 75 mt ha^{-1} mo^{-1} supplied nutrients at rates that increased yields. Toxic levels of heavy metals were not reached, and heavy metals were not added to the soil in significant quantities.

224. Corkern, C. M., and W. H. Hudnall. Translocation of Selected Elements Through Sludge-Amended Soil, Their Uptake by Alicia Bermudagrass and Effect on Yield. Am. Soc. Agron., Agron. Abstr., 1987, p. 24.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Domestic sewage sludge was utilized as a soil amendment to pasture land. The composition and variability of sludge was monitored to determine its effect on the translocation of nitrogen, phosphorus, potassium and selected trace elements through a silt loam soil profile and to measure the uptake of these elements by Alicia bermudagrass (*Cynodon dactylon* (L.) Pers.). Results show that additions of sewage sludge of 75 mt ha^{-1} mo^{-1} supplied nitrogen, phosphorus and potassium at rates sufficient to increase yields, while maintaining acceptable levels of trace elements in the plants.

225. Creighton, J. L., R. N. Muller, and R. F. Wittwer. Biomass and Nutrient Assimilation of Intensively-Cultured Black Locust on Eastern Kentucky Mine Spoil. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 503-508.

This study evaluated the effects of several cultural treatments (fertilization, irrigation, bark mulch, and competition control) and establishment methods (direct seeding and planting seedlings) on the biomass accumulation of black locust (*Robinia pseudoacacia* L.) planted on surface mine spoil near Middlesboro, KY. A second objective was to examine the patterns of nutrient assimilation in the aboveground portions of the stand. Direct seeding of black locust at a rate of 12.0 kg ha^{-1} resulted in greater total biomass and was more productive than planted seedlings. If seedlings are planted at a closer spacing (0.9 by 0.9 m), they will outproduce direct-seeded black locust planted at a rate of 6.0 kg ha^{-1}. Bark mulching was found to be the minimum cultural treatment needed to ensure successful establishment and increase yields on direct-seeded plots. The other cultural treatments failed to show any significant effects. The concentration of nutrients in a tree was not affected by either cultural treatment or establishment method. The nutrient content of the various components of a tree had the following descending order: leaves > branch > stem > bark for nitrogen, phosphorus, potassium and magnesium. For calcium the order was leaves > branch > bark > stem. Approximately 40 pct of these elements in a stand were found in the foliage and could be saved, from the nutrient cycling standpoint, by dormant season harvesting. Based on soil analyses, the nitrogen, phosphorus, and potassium assimilated in the aboveground portion of these stands amounted to 12.2, 63.3, and 35.7 pct of the sites' nutrient reserves, respectively. The authors conclude that the black locust, surface mine, fuel plantation trio can be successfully merged only through awareness of the interaction of site, treatments, and establishment methods on the productivity and nutrient dynamics of a given site.

226. Cripps, R. W., and J. M. Matocha. Sewage Sludge Application to Calcareous Soils To Ameliorate Grain Sorghum Fe-Deficiency. Am. Soc. Agron., Agron. Abstr., 1988, p. 37.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. In this greenhouse study, three calcareous soils with a history of iron deficiency were planted to grain sorghum (*Sorghum bicolor* (L.) Moench) in separate experiments. To each soil, sewage sludge was added at four rates (0.0, 7.5, 15.0, or 25.0 g kg^{-1} soil), and four nitrogen and iron applications were used (no nitrogen or iron, only nitrogen, only iron,

both nitrogen and iron). Ammonium sulfate (NH_4SO_4) was the nitrogen source and was applied at 60 mg N per kilogram soil, while the iron was applied at 5 mg Fe per kilogram soil as Fe-EDDHA. Sewage sludge applications alone resulted in increased grain sorghum dry matter yield regardless of the soil type tested. Although sewage sludge applications decreased iron chlorosis, resulting in increased plant growth, iron sufficiency was not attained by sludge applications alone. Increased yields resulted if iron chelate was applied with 7.5 g sludge per kilogram soil. In all three soils, additions of 15 and 25 g sludge per kilogram soil to the iron-chelate-amended treatments resulted in decreased grain sorghum yields.

227. Crookston, R. B., and J. H. Merino. Reclamation of Spent Oil Shale. Paper in American Mining Congress, Mining Convention Session Papers, Set No. 5, Environmental Controls I & II (San Francisco, CA, Sept. 11-14, 1977). Am. Min. Congr., Washington, DC, 1977, 31 pp.

This paper reviews the methods that the TOSCO Corp. has developed for the reclamation of processed oil shale. The physical and chemical properties of the spent shale are discussed. The major interest in these studies was to establish the material's engineering properties in relation to embankment stability and water movement through the embankments. Health hazards involved in shale oil production and processed shale exposure are examined. A number of revegetation studies are reviewed. The major problems encountered in establishing vegetation on spent oil shale are low fertility, poor infiltration rate, and high soluble salt content. These problems have been overcome through the application of fertilizer, the addition of topsoil, talus cover, mulch, and supplemental irrigation to leach soluble salts lower in the profile.

228. Cross, E. A., and F. C. Gabrielson. Reclamation of Surface Mine Soil. Sch. Mines and Energy Dev., Univ. AL, Res. Rep., Sept. 1981, 50 pp.

This publication reports ongoing and completed research on revegetation studies on alkaline shale from the Corona Mine in southern Walker County, AL. Results of completed studies are included in this annotation. Greenhouse and field studies to evaluate the effect of *Pisolithus tinctorius* ectomycorrhizal fungi on the growth and survival of southern red oak (*Quercus falcata* Michx.) showed that after one growing season the fungi enhanced neither survival nor growth. Another experiment evaluated the effects of vegetative cover and fertilization on growth, survival, and tip moth damage of loblolly pine (*Pinus taeda* L.) planted in fields of weeping lovegrass (*Eragrostis curvula* (Schrad.) Ness) and Kobe lespedeza (*Lespedeza striata* var. Kobe), common bermudagrass (*Cynodon dactylon* (L.) Pers.) and Kobe lespedeza and sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don.), and in unseeded areas containing sparse native vegetation.

Fertilization improved all aspects of tree development and reduced tip moth damage, but the presence of vegetation retarded tree development. Several greenhouse experiments were designed to evaluate the effects of soil materials and amendments on the germination and growth of weeping lovegrass and perennial ryegrass (*Lolium perenne* L.). Ammonium nitrate treatment inhibited germination and growth of weeping lovegrass, as did acidification of the spoil and addition of coal washings, but superphosphate fertilization yielded the greatest biomass of any treatment. Weeping lovegrass grows best on acid soils, whereas perennial ryegrass prefers more basic conditions. In combination, however, the grasses grew best and were compatible in a mix of 25 pct spoil and 75 pct topsoil at a combined pH of 4.6. Under this condition the ryegrass did not compete with the lovegrass, as is normally the case.

229. Cross, E. A., F. C. Gabrielson, and D. K. Bradshaw. Some Effects of Vegetative Competition and Fertilizer on Growth, Survival, and Tip Moth Damage in Loblolly Pine Planted on Alkaline Shale Surface Mine Spoil. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 59-63.

Growth, survival, and tip moth damage of 1-0 loblolly pine seedlings (*Pinus taeda* L.) were monitored on nontopsoiled alkaline shale in Alabama. Different combinations of herbaceous species and fertilizers were used to assess their effects on loblolly pine growth and survival. Tree survival and diameter growth after 2 years were highest on bare spoil compared with those areas with vegetative cover, but tip moth damage to the main leaders on loblolly pine was greatest on bare spoil. It is suggested that when erosion is not a major concern, herbaceous seeding should be delayed for 1 year on areas planted with loblolly pine seedlings in order to increase tree survival and growth.

230. Cross, E. A., F. C. Gabrielson, D. K. Bradshaw, and S. Beard. Studies on the Effects of *Pisolithus tinctorius* and Acorn Size on the Germination, Growth, and 5-Year Survival of Southern Red Oak (*Quercus falcata* Michx.). Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 237-241.

The effects of acorn size and inoculation with *Pisolithus tinctorius* on the survival and growth of container-grown

southern red oak (*Quercus falcata* Michx.) outplanted on alkaline shale surface mine spoil in Walker County, AL, were evaluated. Large and small acorns were collected and were either inoculated with *P. tinctorius* or left uninoculated. Tree growth and survival data were collected 1, 2.5, and 5.5 years after outplanting. Tree survival at the end of the first year, approximately 64 pct, was not significantly different among treatments. After 2.5 years, however, inoculated trees had a survival percentage that was significantly higher, 52 pct, compared with 35 pct of uninoculated trees. There was no difference in survival due to acorn size. After 5.5 years, survival of inoculated trees versus uninoculated trees had narrowed to 11 pct. Acorn size still had no effect on survival. Tree growth was unaffected by inoculation at the 1- and 2.5-year measurements. After 5.5 years, however, inoculated seedlings were significantly taller than uninoculated seedlings. There was no significant effect on growth due to acorn size. This work indicates that there are no immediate benefits in terms of the survival and growth of southern red oak when seedlings are inoculated with *P. tinctorius*. After a period of years, however, survival and growth are significantly increased because of inoculation with *P. tinctorius*.

231. Cross, E. A., M. C. Rohde, and M. J. Kaliszewski. Seven Year Growth of Loblolly Pine Planted in Topsoiled and Untopsoiled Pottsville Shale in Walker County, Alabama. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 311-314.

A comparison was made of the 7-year growth, height, and diameter at breast height (DBH) of loblolly pine (*Pinus taeda* L.) planted in alkaline Pottsville shale with that of trees planted in the soil shale covered with 1 ft of A-B horizon soil (topsoil). Trees planted in topsoil averaged more than 2 ft taller than those planted in shale and had a diameter averaging 0.4 in larger. There was also a size gradient (height and DBH) related to slope on both the topsoiled and shale sites; trees on the upper slope were largest, while those on the lower third of the slope were smallest. The differences in height and DBH between topsoiled and shale sites are related to the differences in particle size distribution of the growth medium during the first few years of establishment. Survival and growth is greater on the topsoiled site because of its smaller particle size classes, which retain more moisture than larger sized soft shale. After several years, however, the soft shale is broken down into smaller particles and moisture retention is improved. The authors speculate that higher survival and growth rates would occur when seedlings are planted on older weathered shales.

232. Crowder, A. A., B. E. McLaughlin, G. K. Rutherford, and G. W. van Loon. Site Factors Affecting Semi-Natural Herbaceous Vegetation on Tailings at Copper Cliff, Ontario. Reclam. & Reveg. Res., v. 1, No. 2, 1982, pp. 177-193.

This study was conducted to relate the chemical and physical properties of a tailings disposal site to the distribution and elemental content of the herbaceous species growing on the tailings. The location of this study is Copper Cliff, ON, Canada. The area had been intermittently seeded from 1958 to 1962 and was maintained by liming and fertilization. Frequency of occurrence and percentage cover values of herbaceous species were obtained from random locations along three transects. Plant and tailings materials were collected for elemental analysis. Of the species originally seeded, redtop (*Agrostis alba* L.) and Kentucky bluegrass (*Poa pratensis* L.) have become dominant on the site, while the remaining originally seeded species have become rare. Important colonizing species were ticklegrass (*Agrostis scabra* Willd.), quackgrass (*Agropyron repens* (L.) Beauv.), reed canarygrass (*Phalaris arundinacea* L.), and alkali grass (*Puccinellia distans* (L.) Parl.). Microclimatic data indicated that the tailings are comparable to old fields of the area. Concentrations of calcium, manganese, and zinc in the tailings were also comparable to values obtained from agricultural soils. Copper, iron, and nickel values, however, were very high in both the tailings and plants. Except for these high metal concentrations, the tailings provide a satisfactory growth medium with respect to plant nutrients and microclimate.

233. Cundell, A. M. The Role of Microorganisms in the Revegetation of Strip-Mined Land in the Western United States. J. Range Manage., v. 30, No. 4, 1977, pp. 299-305.

This review discusses the role of micro-organisms in the reclamation of spent oil shale wastes in the Piceance Basin of northwestern Colorado and overburden from lignite strip mining in western North Dakota. The revegetation of these areas is limited by low organic matter content, salinity, fine soil texture, lack of nitrogen and phosphorus, and the slow rate of soil formation. Some of these limitations can be alleviated by microbial processes. These processes are responsible for the accretion of soil organic matter, nitrogen fixation, and the modification of adverse soil properties. Strategies to take advantage of microbial activities that encourage plant growth are discussed. These strategies include fertilization, seeding, mulching, inoculating the rhizosphere of perennial grasses with free-living bacteria, and the production of sulfuric acid by sulfur-oxidizing bacteria, thus lowering the pH of the spoil.

The author concludes that soil microorganisms have an important role in the reclamation of spoil material, especially in the creation of soil organic matter and the accumulation of sufficient nitrogen for plant growth.

234. Cunningham, T. R., and R. F. Wittwer. Direct Seeding Oaks and Black Walnut on Minesoils in Eastern Kentucky. Reclam. & Reveg. Res., v. 3, No. 1, 1984, pp. 173-184.

The direct seeding of commercially important species on eastern Kentucky mine soil was evaluated. A split-split plot design was utilized. Blocks were divided into two subplots, with one randomly selected to receive a grass-legume mixture consisting of orchardgrass (*Dactylis glomerata* L.), tall fescue (*Festuca arundinacea* Schreb.), white clover (*Trifolium repens* L.), and birdsfoot trefoil (*Lotus corniculatus* L.). The other subplot in each block was not seeded with the herbaceous mixture. Each subplot was divided in half, creating four sub-subplots per block. Two sub-subplots were divided into five components for the direct seeding of black walnut (*Juglans nigra* L.), bur oak (*Quercus macrocarpa* Michx.), pin oak (*Quercus palustris* Muenchh.), white oak (*Quercus alba* L.), and chestnut oak (*Quercus prinus* L.). The study area was chemically and physically characterized prior to any treatment. The entire study area was mulched with pine bark, chips, and wood fibers mixed with composted sewage sludge (3:1 volume ratio) at 10 Mg ha^{-1}. Seed spot survivals were made 2, 7, 15, and 18 months after establishment. Total height of living seedlings was measured at the end of each growing season, at 7 and 18 months. Foliar analyses were also conducted at 7 and 18 months. Soil temperature and moisture were monitored over the two growing seasons.

Although there were significant differences in mine soil moisture between years, average moisture content was within the available moisture range. No significant differences in soil moisture between treatments were found. The mulching treatment resulted in significantly lower mine-soil temperature during the first growing season, while the grass-legume cover significantly lowered temperature both years. Bur oak was the best performing species, with 90-pct stocking after 2 years across all treatments; chestnut oak, white oak, and pin oak stocking ranged from 52 to 60 pct, and black walnut stocking measured 29 pct 2 years after establishment. Fertilizer application did not have an effect on stocking or height growth.

235. Curry, J. P., and K. E. Boyle. Growth Rates, Establishment and Effects on Herbage Yield of Introduced Earthworms in Grassland on Reclaimed Cutover Peat. Biol. and Fertil. Soils, v. 3, 1987, pp. 95-98.

Earthworms, *Lumbricus terrestris* and *Aporrectodea caliginosa*, growth rates, establishment success, and influence on herbage productivity were studied in a recently reclaimed peat land in central Ireland. Two separate areas were studied: one was managed for silage production and the other was grazed by cattle. In area 1, silage production, juveniles of *L. terrestris* and *A. caliginosa* were confined in soil cores enclosed in nylon 0.5-mesh bags and buried at the soil surface to study earthworm growth rates. In area 2, sods (25 by 25 cm and 10 cm deep) with a good earthworm population were laid down to study earthworm introduction. Results show that *L. terrestris* grew twice as fast (12 mg per worm per day) in area 2 compared with area 1, suggesting that the faster growth rate was due to a more favorable food supply from cattle feces. After 1 year, significant earthworm populations had become established in the vicinity of the soil in area 2. Herbage production was not affected by earthworms during the first year; however, total herbage yield was 25 pct greater in year 2 and 49 pct greater in year 3 in a third area where worms received an annual top dressing of cattle slurry, compared with a similar slurry treatment without worms. The main role of earthworms on herbage yield is to enhance the mineralization of cattle slurry and increase the availability of nutrients to plants.

236. Curtis, R. L., D. K. Fowler, C. H. Nicholson, and L. F. Adkisson. Breeding Bird Populations on Three Contour Surface Mines Reclaimed Under Differing Intensities and Types of Treatment. Paper in Symposium on Surface Mining and Fish/Wildlife Needs in the Eastern United States (WV Univ., Dec. 1978). U.S. Fish and Wildl. Serv., FWS/OBS-78/81, 1978, pp. 369-375.

The authors evaluated the effects of three reclamation techniques on species compositions, diversity, and abundance of avifauna found on three contour surface mines located on the eastern edge of the Cumberland Plateau. As the amount of vegetation increased, breeding-bird density, diversity, and number of species also increased. The authors suggest that there was a high degree of habitat diversity on the sites where the vegetation had been present the longest, i.e., the older narrow bench contour mines. This resulted in the recovery of avian species diversity and composition. The authors conclude that biological productivity can be restored to surface-mined areas more rapidly through intensive wildlife-oriented reclamation techniques. With multilayer vegetative structure, avian successional patterns can be increased beyond that which would occur with standard reclamation techniques.

237. Dahl, B. E., P. F. Cotter, D. B. Wester, and C. M. Britton. Range Plant Establishment in the Southern Plains Region. Paper in Impacts of the Conservation Reserve Program in the Great Plains, ed. by J. E. Mitchell (Symp. Proc., Denver, CO, Sept. 16-18, 1987). U.S. For. Serv., Gen. Tech. Rep. RM-158, 1988, pp. 42-46.

Questions relative to revegetating marginal and eroded cropland in west Texas are answered. Successful range seedings depend on climate (rainfall) and timing of seeding, soils, planting method, seedbed preparation, requirements of planted species, and weed control during establishment. The most useful species for seeding in west Texas were Blackwell switchgrass (*Panicum virgatum* L.), El Reno side-oats grama (*Bouteloua curvula* (Michx.) Torr.), Morpa weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees), and four old-world bluestems (*Andropogon* spp.). Information is also given on the use of preparatory crops and mulches in aiding vegetation establishment in the Southern Plains. This article contains good background information on range grass establishment in the Southern Plains region.

238. Dancer, W. S. Nutrition: A Mechanism Behind Yield Increases From Subsoil-Loess Blending. Reclam. & Reveg. Res., v. 4, No. 1, 1985, pp. 49-62.

A series of greenhouse experiments were conducted using west-central and southern Illinois soils to assess the importance of nutritional factors in subsoil replacement or blending when reclaiming prime farmland disturbed by coal surface mining. Soybeans (*Glycine max* (L.) Merr.) and corn (*Zea mays* L.) were grown on unlimed subsoil and subsoil-loess mixtures, and growth was compared with that using a limed subsoil in order to confirm phosphorus deficiency in southern Illinois subsoils. In a second experiment, subsoils of southern Illinois were mixed with the underlying loess in six overburden treatments. Soybeans were used as the test crop. Other experiments were conducted to compare the growth of tall fescue (*Festuca arundinacea* Schreb.), alfalfa (*Medicago sativa* L.), and field corn on major overburden strata obtained from a west-central Illinois coalfield. Results show that subsoils from southern Illinois contain little phosphorus available for crop uptake. Subsoil-loess blending of southern Illinois soils is beneficial in that the subsoil is the best source of potassium, while the loess material tends to supply phosphorus. Since the subsoil is acid, phosphorus solubility is assured. Replacing or blending of subsoil from west-central Illinois had a negative effect on crop growth. Corn became phosphorus-deficient when grown in the alkaline loess or glacial till. Topsoil replacement, required by law for prime farmland reclamation, is more effective in amelioration of nutrient deficiencies in west-central Illinois topsoil, which is more fertile than southern Illinois topsoil.

239. Dancer, W. S. Prime Agricultural Land Restoration After Surface Coal Mining in Midwestern USA, Chemical and Nutritional Considerations. Paper in Reclamation: A Multifaceted Activity (Proc. 7th Annu. Meet., Sydney, NS, Canada, Aug. 29-Sept. 1, 1982). Can. Land Reclam. Assoc., Guelph, ON, Canada, 1982, pp. 207-222.

Nutritional imbalances in field corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) grown on newly reclaimed land were indicated by the results of plant leaf analyses and soil tests used in greenhouse and field experiments. This nutrient imbalance is characterized by low concentrations of potassium in plant leaves and by high metal concentrations that can become toxic. Ephemeral phosphorus deficiency symptoms were observed, probably induced by temporarily high levels of soluble aluminum from rapid initial weathering of overburden. Potassium deficiencies were eliminated in 3 or 4 years with good fertilizer management.

240. Dancer, W. S., and I. J. Jansen. Greenhouse Evaluation of Solum and Substrate Materials in the Southern Illinois Coal Field: I. Forage Crops. J. Environ. Qual., v. 10, No. 3, 1981, pp. 396-400.

The objective of this study was to identify overburden materials that could be used in construction of postmining soils. Four bulk soil samples (one each from the topsoil Ap, claypan B_2, lower B_3 and upper C_1, and IIIC Illinoisan glacial till) were taken from an abandoned highwall located on the Captain Mine in southwestern Perry County, IL. The B_3 and C_1 were combined into one sample because both layers were relatively thin. Four different greenhouse experiments were conducted to compare the growth of three forage crops (perennial ryegrass (*Lolium perenne* L.), red clover (*Trifolium pratense* L.), and sudangrass (*Sorghum sudanense* (Piper) Stapf.)) on the four materials. Mixtures of subsoil and overburden were also evaluated, along with different fertility treatments. The results show that all overburden material responded to lime and fertilizer treatments. Topsoil produced the highest yields, but with additions of nitrogen, phosphorus, potassium, and lime to the other materials, yield differences were not that great. It was also shown that the C_1 materials were superior to the native subsoil and should be considered when constructing postmining soils. The authors conclude that there is evidence that replacement or alteration of the claypan subsoil of southern Illinois would increase crop growth by enhancing the chemical and physical properties of the soil.

241. Dancer, W. S., and I. J. Jansen. Minespoil Acidity and Rowcrop Productivity. J. Environ. Qual., v. 16, No. 3, 1987, pp. 242-246.

The importance of soil acidity as a parameter for evaluating mine land reclamation success in Illinois was established. Soil pH was assessed as a criterion for

evaluating the suitability of newly reclaimed land for crop production. Additionally, the contribution or interaction of mine-soil acidity with drought stress on reclaimed mine land was studied. Grain yields of corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) grown on reclaimed land, without topsoil replacement, and with 20 cm of topsoil replaced, were higher in years with above-normal precipitation and cool temperatures, while below-normal rainfall and unusually hot, dry weather contributed to lower yields. Grain yields were also correlated with mine-soil pH and the spoil underlying the topsoil. Corn yields correlated most highly with pH in dry years, while soybean yields correlated more strongly in wet years. Lower corn yields during drought years were due to poor pollination. This, along with high temperatures, caused water stress during anthesis, resulting in barren plants. Soil acidification increased the impact of the drought on corn yields by increasing barrenness; 77 pct of the corn plants were barren on mine soil without topsoil, and 89 pct were barren where topsoil had been replaced. In wet years, corn plants produced a second ear when grown on replaced topsoil.

Barren corn plants were observed in mine soils with excessive acidity (pH values of 3.4 to 5.0). Metal composition of corn ear leaves showed that when corn was grown on extremely acid mine soils, concentrations of aluminum, iron, manganese, and copper were consistently higher than concentrations in ear leaves grown on less acid mine soils. Soybean plants grown on acid mine soils were stunted and chlorotic compared with those grown on topsoiled plots. These results demonstrate that strongly acid mine soils increase the susceptibility of corn to drought stress and decrease soybean yields. Mine soils that are extremely acid are not suitable for row-crop production. The authors state that spoil-handling techniques should be developed to minimize the presence of strongly acid mine spoil on lands reclaimed for row-crop production in Illinois.

242. Daniels, W. L., and D. F. Amos. Generating Productive Topsoil Substitutes From Hard Rock Overburden in the Southern Appalachians. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 38-57.

This paper summarizes research projects conducted in West Virginia and Virginia to determine the suitability of overburden strata as topsoil substitute materials. Objectives of the studies included (1) determination of the physical, chemical, and mineralogical properties of overburden strata that are critical to reclamation success, (2) identification of mine-soil properties that have limited reclamation success in the past and determining how these problems can be avoided in current mining operations, and (3) determination of which combinations of rock type and surface treatments are optimal for long-term reclamation success. The local geology of the study sites is discussed, along with the mining techniques used. Factors limiting reclamation success include (1) pyrite oxidation (1 of 10 sites), (2) compacted traffic pans within 30 cm of the surface (9 of 10 sites), and (3) phosphorus fixation by iron oxide (which is a widespread problem in southwestern Virginia mine soils). Soil factors affecting selection of topsoil substitute materials and overburden handling and placement techniques to optimize soil potential are discussed.

243. Daniels, W. L., and D. F. Amos. Generating Productive Topsoil Substitutes From Hard Rock Overburden in the Southern Appalachians. Environ. Geochem. Health, v. 7, No. 1, 1985, pp. 8-15.

This paper summarizes research conducted to determine or identify (1) the physical, chemical, and mineralogical properties of southern Appalachian overburden strata that are critical to reclamation success, (2) the mine-soil properties that have limited reclamation success in the past and how to avoid these problems in current mining practices, and (3) which combinations of rock type and surface treatment are optimal for long-term reclamation success. Mine spoil is defined as the blasted strata placed at the final reclaimed surface, while mine soil is mine spoil exposed to the soil-forming factors (climate, vegetation, and time). The proper selection and management of a productive topsoil substitute is based on an understanding of initial spoil chemical, physical, and mineralogical characteristics and how they change with time. Factors that limit reclamation success in the southern Appalachians include pyritic spoil materials, iron oxide content, and soil compaction. Pyritic materials result in excessive soil acidity and soluble salt content. Iron oxides fix phosphorus, resulting in phosphorus deficiencies. The total amount of iron and the ratio of Fe^{3+} to Fe^{2+} in a given rock type controls its phosphorus-fixing potential. Compaction reduces the downward penetration of roots and water, resulting in limited water availability. A potential topsoil substitute can be evaluated using the following criteria: (1) strata thickness, (2) acid-base balance, (3) pH, (4) soluble salts, and (5) plant-available nutrients. Premining planning and on-site coordination are needed to ensure that the topsoil substitute selected is actually placed on the final reclaimed surface. The major goals of revegetation include the prevention of erosion and the establishment of a self-sustaining plant community. The latter goal requires the development of efficient nutrient cycles. A revegetation strategy for nonacidic mine soils is presented. All revegetation strategies must by planned around anticipated nutrient availability over time.

244. Daniels, W. L., and D. F. Amos. Mapping, Characterization and Genesis of Mine Soils on a Reclamation Research Area in Wise County, Virginia. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 261-266.

The objectives of this research were to accurately map and characterize the soil, identify soil-related factors influencing reclamation success, and evaluate rates and processes of soil genesis on spoil materials. Methodologies used to characterize the mine soil are given. It was found that soil chemical properties are variable from sampling point to sampling point. The mapping legend that was used is based on the USDA Soil Conservation Service legend. Because of the extreme variability of the soil material, 22 different mapping units were delineated. By the time the soil was 29 years old, deep A horizons and weak cambric B horizons had developed. Approximately half of the soils described had a compacted layer (1.8 g cm^{-3}) within 70 cm of the surface. These layers limit vegetative growth and soil genesis. The authors conclude that pedogenic horizons do develop on mine soils and should be described by conventional soil taxonomic methods.

245. Daniels, W. L., J. C. Bell, D. F. Amos, and G. D. McCart. First Year Effects of Rock Type and Surface Treatments on Mine Soil Properties and Plant Growth. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 275-282.

This study evaluated the effects of rock type and surface treatments of topsoil, sawdust, and sewage sludge on the revegetation of southwestern Virginia coal mines. The rock mixes available were pure sandstone (SS), pure siltstone (SiS), 2:1 SS to SiS, 1:1 SS to SiS, and 1:2 SS to SiS. For the establishment and production of Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) a mixture that is greater than 1:1 SS to SiS appears to be superior. Fescue establishment and growth were inhibited by high-siltstone spoils. Inhibition was due to rockiness, low water-holding capacity, high pH, and the soluble salts present in the siltstone strata. The surface treatment experiments were constructed using a 2:1 SS-to-SiS mix, and the following treatments were used: (1) a fertilized control (120 kg ha^{-1} 15-30-15 N-P-K), (2) a topsoil plus lime (7.8 Mg ha^{-1}) plus fertilizer (1,120 kg ha^{-1} 15-30-15), (3) sawdust (112 Mg ha^{-1}) plus fertilizer (1,120 kg ha^{-1} 15-30-15 and 336 kg ha^{-1} slow-release nitrogen), and (4-7) sewage sludge (22.4, 56, 112, and 224 Mg ha^{-1}, respectively). Fescue yield was found to be the same on control, topsoiled, and limed plots. Plots receiving 56 Mg ha^{-1} sewage sludge or greater outyielded plots receiving all other surface treatments and were the only plots with significant phosphorus. Sewage sludge was also superior to sawdust as an organic amendment because the plots receiving sawdust were deficient in nitrogen, owing to nitrogen immobilization. The authors conclude that care-ful overburden selection and placement, along with the proper surface treatment, can create a hard-rock-derived mine soil that is superior to locally occurring natural soils.

246. Daniels, W. L., J. A. Burger, J. A. Roberts, and S. A. Moss. The Effects of Controlled Overburden Placement on Mine Spoil Properties, Revegetation and the Growth of Pitch x Loblolly Pine Hybrid Seedlings as Demonstrated on an Abandoned Strip Bench (U.S Off. Surf. Min. contract J5140102). Final Report, Aug. 15, 1986, 91 pp.

This report summarizes the findings of an experiment to determine the suitability of rock mine spoils as a topsoil substitute, to gain knowledge of nutrient cycling in this material, and to determine the ability of the rock mine spoil to support vegetative growth. All experiments were conducted in southwestern Virginia. There were two parts, a rock mix experiment and a surface treatment experiment. The rock mix experiment consisted of five spoil mixes ranging from pure sandstone (SS) to pure siltstone (SiS) with intermediate treatments of 2:1 SS to SiS, 1:1 SS to SiS, and 1:2 SS to SiS. The surface treatment experiment consisted of a 2:1 SS-to-SiS rock mix that was fertilized with N-P-K (control), a limed (7.8 Mg ha^{-1}) and fertilized replaced topsoil treatment (30 cm) that was fertilized with N-P-K, a 112-Mg ha^{-1} sawdust treatment fertilized with N-P-K and 336 kg ha^{-1} slow-release nitrogen fertilizer, and four municipal sewage sludge application rates (22, 56, 112, and 224 Mg ha^{-1}) without fertilizer. All soil and soil substitutes were characterized physically, chemically, and mineralogically. Both experimental areas were mulched with 900 kg ha^{-1} straw and hydroseeded with a slurry containing 170 kg ha^{-1} Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) seed and 840 kg ha^{-1} paper fiber mulch. The following spring, half of each plot was treated with herbicide and planted with 4 loblolly pine (*Pinus taeda* L.) and 12 pitch and loblolly pine hybrid (*Pinus rigida* x *taeda*) seedlings. Soil physical properties summarized include coarse fragments, fine-earth fraction, and water-holding capacity. Soil chemical properties summarized include soil pH and exchangeable calcium, magnesium, potassium, and aluminum. The major mineral constituents in the clay fractions are identified.

Tall fescue yields were greatest in the surface amended treatments, particularly the sludge-amended plots. Fescue yields increased linearly as sludge application rates were

increased. Yields on organically amended plots were higher compared with yields from topsoiled and control treatments. In the rock mix experiment, yields decreased as siltstone content increased. Tissue macronutrient, micronutrient, and heavy-metal concentrations of tall fescue were also monitored. Additionally, changes in soil chemical relationships in each experiment were monitored over time. Parameters measured include soil organic matter, total soil nitrogen, nitrogen mineralization, inorganic nitrogen levels, effects of nitrogen on pine seedling growth, changes in soil potassium using quantity-intensity (Q/I) relationships, and changes in the form of phosphorus using fractionation data. Results show that in the mine soils studied, topsoil substitutes outperform replaced topsoil in terms of ability to support fescue growth. Also, all treatments in both experiments equal or exceed the topsoiled treatment in terms of fescue growth. The physiochemical properties that limit plant growth on the mine soils are available water, nitrogen, and phosphorus availability. Organic amendments helped to ameliorate these conditions on the mine soils studied.

247. Daniels, W. L., C. J. Everett, and J. A. Roberts. Factors Governing Uptake of Mn From SW Virginia Mine Spoil Materials. Paper in Proceedings 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 2-7, 1984). Univ. KY, Lexington, KY, 1984, pp. 421-425.

The amounts of exchangeable, easily reducible, and manganese-oxide-bound manganese were determined in a wide variety of sandstone and siltstone derived mine spoil materials in Virginia. The relationship, if any, among rock type, redox potential (Eh), pH, and forms of manganese were determined. Sixteen southwestern Virginia mine soils were studied in two separate evaluations of manganese uptake by plants. In the first experiment, five mixes of sandstone (SS) and siltstone (SiS) were evaluated along with four rates of sewage sludge addition and one rate of sawdust addition. The area was seeded to Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.). Vegetation samples were taken for foliar manganese analysis in mid-July, and total yields were determined at the end of October. A greenhouse study was conducted to determine the effects of biological weathering on mine-soil genesis. Sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don) was grown on fertilized and unfertilized oxidized and unoxidized sandstone and siltstone materials. Foliar analysis and yields were determined. In both experiments, soils were sampled prior to treatment.

The level of manganese in weathered soil is governed by the parent material. The majority of reducible manganese comes from manganic oxides, while the higher values of exchangeable manganese are associated with low pH values. No consistent relationship was found between rock type and exchangeable manganese in the fresh sandstone and siltstone mine soils. The lowest tissue manganese concentrations in tall fescue were associated with the high sewage sludge treatments. Manganese concentration in sericea lespedeza varied by rock type. There were no consistent relationships between manganese form and plant uptake even though oxidized sandstones and siltstones contained more oxide manganese. The redox potential (Eh) of all mine soils was low compared with that of natural, weathered, oxidized soils. Redox potential appears to fluctuate independently of pH and exchangeable manganese. Redox potentials for the soils are at or below the critical values for manganese reduction at their respective pH values. The overall levels of extractable manganese in the soils studied are controlled by the initial levels in the parent material and the degree to which the material has been leached and oxidized. Soil pH appears to control the overall manganese availability of these materials.

248. Danielson, R. M. Mycorrhizae and Reclamation of Stressed Terrestrial Environments. Ch. in Soil Reclamation Processes: Microbiological Analyses and Applications, ed. by R. L. Tate III and D. A. Klein. Marcel Dekker, 1985, pp. 173-201.

This article reviews previous research and, based on published research, determines if mycorrhizae are successful at overcoming the variety of stresses encountered by plants being established or functioning on mine wastes. Mechanisms by which mycorrhizae may alleviate stress on plants on mine sites may include (1) improved phosphorus and nitrogen uptake, (2) accumulation or exclusion of toxic elements in the roots, (3) improved water relations, including drought tolerance, (4) improved seedling vigor, (5) tolerance to extreme temperatures, and (6) adaptations to a wide range of soil pH. Fungal symbionts reported to occur on mine spoils are presented. Mycorrhizal development on mine spoils and tailings (naturally occurring, inoculated seedlings, topsoil replacement, or amendments containing inoculum) is discussed. The source or quality of inoculum can influence the rates of mycorrhizal development on roots. The beneficial aspects of mycorrhizal associations on mine wastes are given for warm and cold climates. In general, mycorrhizal associations benefit and enhance the establishment of plants on mine wastes by improving mineral nutrition and possibly increasing tolerance to toxic metals.

249. Danielson, R. M., J. C. Zak, and D. Parkinson. Plant Growth and Mycorrhizal Development in Amended Coal Spoil Material. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for

Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 912-919.

The purpose of this study was to evaluate the effects of inorganic and organic amendments of coal mine spoil on the growth of a variety of plants and the development of endomycorrhizae and ectomycorrhizae on these plants. Plant species used in this study included white spruce (*Picea glauca* (Moench) Voss), willow (*Salix glauca* L.), slender wheatgrass (*Agropyron trachycaulum* (Link) Malte), and alsike clover (*Trifolium hybridum* L.). The treatments tested included none; a 14-cm layer of fibrous peat; mineral fertilizer equivalent of 113 kg ha^{-1} N, 113 kg ha^{-1} P_2O_5, and 91 kg ha^{-1} K_2O; and anaerobically digested liquid sewage sludge applied at a rate of 243 L m^{-2}. Application of mineral fertilizer or sewage sludge resulted in substantial first-year growth responses for willow, slender wheatgrass, and alsike clover. Ectomycorrhizae were absent on spruce in the sewage-treated spoil. Sewage sludge adversely affected the rate of endomycorrhizal infection in both slender wheatgrass and alsike clover. For both plant species, fertilizer produced the largest lengths of roots containing vesicles of endomycorrhizae. This research was conducted in Canada; however, the results and methods described could find application throughout the United States.

250. D'Antuono, J. R. Some Aspects of Natural Vegetation Establishment on Abandoned Underground Coal Mine Refuse Areas in Illinois. IL Inst. Nat. Resour. Doc. 79/18, June 1979, 84 pp.

The author reports the results of a study designed to characterize sites used for disposal of refuse from abandoned underground coal mines in Illinois. These sites were categorized as (1) well vegetated or (2) sparsely vegetated and/or barren. The revegetation occurring at both types of sites was the result of natural processes. The sites were characterized, and selected physical and chemical parameters of the spoil material were related to the occurrence of vegetation. Feasible reclamation procedures using alternatives to classical reclamation practices were evaluated. This publication offers an excellent review of the pertinent literature and extensive vegetation, soil characterization, and statistical data that could be of use for comparisons and planning revegetation programs.

251. Darby, S. P. A Look at Trees and Reclamation in Georgia. Paper in Trees for Reclamation (Lexington, KY, Oct. 27-29, 1980). U.S. For. Serv., Gen. Tech. Rep. NE-61, 1980, pp. 11-14.

Two loblolly pine (*Pinus taeda* L.) plantations, established by two different companies, were compared to assess the silvicultural techniques used to establish the plantations and the reclamation requirements when rehabilitating mine lands in Georgia. The techniques used to establish the plantations were different. For example, vegetative ground cover was established prior to planting by company B, but not A; subsoiling was used by company B, but not A; fertilization was used by company B at planting, but not A. After 11 years, the average diameter at breast height (DBH) and height for plantation A were 6 in and 31 ft, respectively. After 8 years, the average DBH and height for plantation B were 5 in and 28 ft, respectively. These comparisons raised several important issues that, if resolved, could result in increased tree planting and lower land reclamation costs.

252. Darling, A. P., and S. A. Young. The Effects of Native Hay Mulch on Soil Stabilization and Introduction of Native Species on Strip Mined Lands in Southeastern Montana. Paper in Third Biennial Symposium of Surface Coal Mining and Reclamation on the Great Plains (co-chaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S Off. Surf. Min., 1984, pp. 296-306.

This paper describes a study conducted on direct haul topsoiled mine spoils near Colstrip, MT, to evaluate the use of native hay mulch for soil stabilization and establishment of native species on coal strip-mined lands. A factorial combination of two variables was tested: mulching using native hay and wheat straw, and seeding with a native seed mix. Soil erosion and vegetation density, cover, and biomass were evaluated. Native hay was found to be at least as effective as wheat straw in reducing erosion and, depending upon its seed content, perhaps more effective. Native hay mulch may be used to successfully introduce needlegrass (*Stipa comata* Trin. & Rupr.). It was shown that, compared with unmulched sites, both straw and native hay mulch can improve plant community diversity, evenness, and floristic richness by introducing additional species. Undesirable species introduced by native hay may limit the growth of seeded species. Consequently, it is recommended that hay free from seed of aggressive weedy species be used to optimize the establishment of desirable species.

253. Darling, A. P., and S. A. Young. The Effects of Native Hay Mulch on Stabilization and Native Species Establishment on Mined Lands in Southeastern Montana. Proc. MT Acad. Sci., v. 43, 1984, pp. 165-173.

The effectiveness of using native hay as a mulch and seed source on mined lands was evaluated on a Montana surface mine. A Latin square experimental design was used to test mulching (native hay, wheat straw, and no

mulch) and seeding (seed and no seed) with a native seed mix in a factorial combination. Mulch was applied at a rate of 907 kg ha^{-1} and incorporated into the mine soil. Relative soil erosion was estimated on each treatment plot. Plant density, canopy cover, and aboveground biomass were determined. Diversity, evenness, and species richness were calculated using the canopy cover data. Erosion occurred on all nonmulched sites, with less erosion on the native hay- and straw-mulched plots. Native hay mulch was more effective in reducing erosion than straw mulch because of the dense vegetative cover that developed. Plant density in the hay-mulched plots was 105 and 92 pct greater than in control and straw plots, respectively. The density, biomass, and cover of needleandthread grass (*Stipa comata* Trin. & Rupr.), a desirable grass, and of cheatgrass (*Bromus tectorum* L.) and Japanese brome (*Bromus japonicus* Thunb.), undesirable grasses, were significantly higher on the native hay plots. Needleandthread grass was successfully reestablished using the native hay mulch. Diversity, evenness, and species richness were greater on seeded than on nonseeded plots because of the species introduced by the mulches.

254. Darlington, A. B., and W. E. Rauser. Cadmium Alters the Growth of the Ectomycorrhizal Fungus *Paxillus involutus*: A New Growth Model Accounts for Changes in Branching. Can. J. Bot., v. 66, No. 2, 1988, pp. 225-229.

Although this research is not concerned with surface mine soil amendment use or the characterization of mine soils, the information presented on the effect of cadmium on the growth of the ectomycorrhizal fungus *Paxillus involutus* serves as a good reference on the subject. Since sewage sludge, a common amendment used on surface-mined sites, generally contains high levels of cadmium, the effect of cadmium on the mycorrhizae associated with the vegetation used in reclamation is an important consid-eration when mine soils are amended with sewage sludge. In this study the authors present a new growth model of an ectomycorrhizal fungus in order to accommodate changes in mycelial development caused by cadmium. In a liquid culture, using 1 mmol m^{-3} Cd, cadmium reduced the specific growth rate (dry mass) by 45 pct, from 0.509^{ln} mg d^{-1} in the controls to 0.277^{ln} mg d^{-1} in the treated cultures. In agar cultures, increasing cadmium concentrations from 0 to 3.0 mmol m^{-3} resulted in decreased radial growth of *Paxillus involutus*. The authors state that the degree to which cadmium reduces the specific growth rate of *Paxillus involutus* is the same whether based on mycelial length, from agar plates, or on mycelial mass, from liquid cultures. The biological importance of this study is the prediction, based on the growth model, that cadmium causes an increase in the hyphal density around mycorrhizal roots. This results in a change in the cadmium supply to the higher plant symbiont.

255. Darmody, R. G., J. S. Stevens, I. J. Jansen, and S. B. Carmer. Agricultural Impacts of Coal Mine Subsidence: Evaluation of Three Assay Methods. J. Environ. Qual., v. 17, No. 3, 1988, pp. 510-513.

A method to determine the impact of subsidence on agricultural production in Illinois was developed and evaluated. A 64-point grid overlay adjusted to fit a township section on each aerial photograph was used to mark individual sampling points. Topographic, soils, and mine maps were used in conjunction with the aerial photographs. The information recorded at each grid point was mine name, township, section, grid point, land use, subsidence impact, mine type, mine panel orientation to slope, soil type, and soil slope. The 64-point regular grid method proved to be as accurate in the estimation of the extent of land use and subsidence classes as a random point method; however, the 64-point grid method is less expensive and is flexible, easy to learn and use, and applicable to other land use or environmental studies.

256. Dave, N. K., and T. P. Lim. Effects of Various Tailings Covers on Radon Gas Emanation From Pyritic Uranium Tailings. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 99-104.

The effects of various existing dry and wet covers on pyritic uranium tailings were evaluated by monitoring radon gas emanation at a site near Elliot Lake, ON, Canada. Activated charcoal cartridges were used to measure radon gas fluxes from the following surface tailings covers: (1) compacted crushed rock and gravel, (2) terrestrial vegetation, (3) semiacidic acidophilic moss, (4) sewage sludge, (5) water-saturated tailings, and (6) snow cover during the winter months. At a given sampling site there were no significant differences in radon emanation rates between a given cover and bare tailings. Of particular interest was an increase in radon emanation rates from vegetated areas compared with emanation from bare areas. The highest attenuation of radon flux was found on sites characterized by high moisture saturation or where the water table or capillary fringe was close to the surface. Radon emanation rates from tailings were moisture dependent. Emanation rates increased as the moisture saturation increased from a few percent to between 20 and 70 pct. There was no attenuation in radon fluxes for the crushed rock and gravel (0.6 m) or winter snow (0.5 m) covers. Radon fluxes increased with certain meteorological conditions, such as falling barometric pressure, and

after precipitation events. Movement of radon gas through the tailings pore spaces is by molecular diffusion or by transport of the interstitial fluid induced by temperature and pressure gradients.

257. Dave, N. K., T. P. Lim, R. Swik, and R. Blackport. Geophysical and Biohydrogeochemical Investigations of an Inactive Sulphide Tailings Basin, Noranda, Quebec, Canada. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 13-19.

This paper describes geophysical and biohydrogeochemical investigations conducted at an inactive copper-zinc tailings site located near Noranda, PQ, Canada. The geophysical methods used include seismic refraction, electromagnetic terrain conductivity measurements, and electrical resistivity measurements. The hydrogeological investigations involved installation of piezometers. By monitoring piezometric pressure heads, ground water flow and hydraulic gradient can be established. Tailings solid core and water samples were taken for geochemical investigations to characterize physical and chemical parameters in mineralogical composition. Biological investigations were conducted to analyze solid core samples of iron-oxidizing *Thiobacillus ferrooxidans* and sulfate-reducing organisms. Preliminary results are presented.

258. Davidoff, B., and H. M. Selim. Correlation Between Spatially Variable Soil Moisture Content and Soil Temperature. Soil Sci., v. 145, No. 1, 1988, pp. 1-10.

The spatial variation, relation, and correlation between surface soil moisture measured gravimetrically and surface temperature measured by thermocouple sensors (point measurements) and infrared thermometer (area measurements) were studied along an 80-m transect with regular sampling points at 0.68 m. This study was conducted on a bare, silty loam, nonmined soil. The paper contains useful reference information for the same types of measurements and study on mined land soils. Along the transect, both soil temperature and moisture exhibited cyclic patterns with maximum and minimum values occurring at approximately the same locations along the transect. High soil moisture corresponded to low soil temperature measurements. The authors attribute this cyclic behavior to differential soil compaction along the transect. Using semivariograms and autocorrelation analyses, they hypothesize that the means and the sphere of spatial influence are similar for temperatures obtained by the two methods used. These analyses indicated that regardless of the method of measurement, the sphere of spacial influence was similar. As a result, the authors recommend the infrared method for estimating mean soil surface temperature, because it is simple to use and it is less time consuming than using thermocouple sensors. The authors conclude that both surface soil moisture and temperature exhibit significantly spacial structure along an 80-m transect, with a cyclic pattern. When the cyclic pattern was removed from the data, the spatial variations in soil moisture and temperature were reduced. Removing cyclic patterns by transforming the observations and treating cyclic patterns as trends is not recommended.

259. Davidson, W. H. A Renewed Interest in White Pine. Greenlands, v. 16, No. 2, 1986, pp. 32-33.

This article gives reasons as to why white pine (*Pinus strobus* L.) should be used for reclamation of and planting on abandoned mined lands. The species survives and grows well over a range of site pH's (3.6 to 5.9) and climatic conditions, is aesthetically pleasing, provides wildlife food and cover, and supplies a market demand for high-grade white pine logs.

260. Davidson, W. H. Excess Moisture Decreases Survival and Retards Growth of Hybrid Pine Seedlings. Paper in Proceedings of the Fourth Annual Better Reclamation With Trees Conference (Owensboro, KY, June 7-8, 1984). Madisonville Community Coll., Madisonville, KY, 1984, pp. 135-139.

An evaluation was made of a small plantation of pitch-loblolly pine hybrids (*Pinus rigida* x *taeda*) established on a reclaimed mountaintop removal surface mine in West Virginia. The site was originally reclaimed with Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don), and birdsfoot trefoil (*Lotus corniculatus* L.). A moderately dense stand resulted. A total of 456 seedlings were planted, 216 pitch and hybrid pine and 24 loblolly pine. First year survival was nearly 100 pct; only four seedlings died, and three of these were located in moist depressions. After 3 years, overall survival was 92 pct. Total mortality was 8 pct or 40 seedlings, 33 of which were planted in the moist depressions, and death was attributed to excess moisture. Of the pines planted on the favorable part of the site, the survival of pine hybrids was 99 pct after 3 years.

261. Davidson, W. H. Hybrid Poplar Cutting Production and Plantation Establishment. U.S. For. Serv., State and Private For., NE Area, NA-FB/M-6, Rectec, No. 3, 1981, 2 pp.

The author discusses the establishment of hybrid poplar (*Populus* spp.) on surface-mined land in the Eastern

United States. Information is presented on site preparation, soil amendments, establishment procedures and spacing of the hybrid poplar plantings, and maintenance of the stand. The author states that after 8 to 10 years the entire plantation should be ready for firewood and pulpwood cuttings, with trees having a DBH ranging from 6 to 8 in. An alternative to complete harvesting would be to leave approximately 100 trees per acre for sawlog production.

262. Davidson, W. H. Performance of Ponderosa Pine on Bituminous Mine Spoils in Pennsylvania. U.S. For. Serv., Res. Paper NE-358, 1977, 6 pp.

The author discusses the results of a 5-year field trial on the feasibility of establishing ponderosa pine (*Pinus ponderosa* Laws.) on bituminous mine spoils in Pennsylvania. Seedlings from numerous ponderosa pine provinces were used. The author concludes that selected sources of ponderosa pine can be planted on bituminous strip mine spoils in Pennsylvania.

263. Davidson, W. H. Pitch x Loblolly Pine Performance on a West Virginia Minesoil. Paper in Proceedings of the Thirtieth Northeastern Forest Tree Improvement Conference (Orono, ME, July 22-24, 1986). Univ. ME, Orono, ME, 1987, pp. 96-101.

Five-year height and survival data of a pitch pine (*Pinus rigida* Mill.), loblolly pine (*Pinus taeda* L.), and a pitch-loblolly pine hybrid (*Pinus rigida* x *taeda*) plantation established on a reclaimed surface mine are reported. On the favorable portion of the site the survival of hybrid and pitch pine was 97 and 96 pct, respectively, while loblolly pine survival was 83 pct. Average height of the hybrids was 55 in, while pitch pine had an average height of 50 in. Loblolly pine had an average height of 80 in after 5 years. The results indicate that the pitch-loblolly pine hybrid had potential for planting on reclaimed surface mines in the East.

264. Davidson, W. H. Potential for Planting Hardwoods in the Appalachians. Paper in Guidelines for Regenerating Appalachian Hardwood Stands, ed. by H. C. Smith, A. W. Perkey, and W. E. Kidd, Jr. (Proc. Workshop WV Univ., Morgantown, WV, May 24-26, 1988). Soc. Am. For. Publ. 88-03, 1988, pp. 255-268.

The author reviews research that had been conducted on the artificial regeneration of hardwoods on both mined and nonmined lands. Included are interpretations of current research guidelines for regeneration, and areas where further research on artificial hardwood regeneration is needed. Establishment techniques (types of seedlings used, direct seeding, and season of planting), techniques to improve seedling establishment (use of mycorrhizae, fertilization, pruning, mulching, and site selection), cultural treatments to improve seedling survival and growth (control of competing vegetation, fertilizer, seedling protection, and other release treatments), and establishment costs are discussed. Based on the experience and available information, general guidelines are presented for regenerating hardwoods artificially. Artificial hardwood regeneration techniques that are not specifically defined or lacking information are presented as areas where additional research is necessary.

265. Davidson, W. H. Results of Tree and Shrub Plantings on Low pH Strip-Mine Banks. U.S. For. Serv., Res. Note NE-285, 1979, 5 pp.

The author presents the 11-year results of a study to evaluate the survival and growth of 16 species of trees and shrubs established on 10 acid strip mines in the bituminous region of Pennsylvania. Species used in the evaluation included five species of European alder (*Alnus* spp.), four birch species (*Betula* spp.), black locust (*Robinia pseudoacacia* L.), sycamore (*Platanus occidentalis* L.), scotch pine (*Pinus sylvestris* L.), autumn olive (*Elaeagnus umbellata* Thunb.), sawtooth oak (*Quercus acutissima* Carruth.), and Japanese fleeceflower (*Polygonum cuspidatum* Sieb. & Zucc.). First-year results indicated that mortality was very high; mortality by species ranged from 48 to 94 pct. After 11 years, two birches, gray birch (*Betula populifolia* Marsh.) and European white birch (*Betula pendula* Roth.), had the highest survival rates and best growth of all the species tested. These species had survival rates of 50 pct or better at 8 of the 10 sites. Other species that performed well on a few of the sites were European alder from a German seed source and scotch pine. The author recommends that the birch species be used for reforestation of Pennsylvania bituminous spoils when the pH is 3.5 or higher.

266. Davidson, W. H. Rooting Characteristics of Topsoiled Surface Mines. Paper in 1981 Symposium of Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 267-270.

Evaluations of five reclaimed surface mines in the bituminous region of Pennsylvania were made to determine the effectiveness of replacing topsoil as a technique to enhance the establishment of herbaceous plants. A total of 390 random sampling points were chosen, and percent ground cover, root penetration, and topsoil depth were examined at each point. Soil samples were also collected to determine selected soil chemical properties for

each site. The results indicate that herbaceous species can be successfully established on topsoiled surface mines. Root growth, however, is primarily dependent on topsoil depth. Soil chemical analysis of the sites indicates that there are large variations in soil chemical properties among the five sites.

267. Davidson, W. H., W. C. Ashby, and W. G. Vogel. Progressive Changes in Minesoil pH Over Three Decades. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 89-92.

Changes in mine-soil pH are documented over a 30-year period for several sites in the Eastern and Interior Coal Provinces. The nature of these changes is also evaluated. Initial pH values of the sites ranged from extremely acid to moderately alkaline. Comparisons of soil pH's at each site over a period of years indicate that there is a convergence of pH values toward those more typical of the regional soils, particularly for sites where the initial soil pH values were extremely acid. Increased plant productivity on these sites with time, together with an increase in organic matter quantity and quality, may be responsible for these soil pH changes. Organic matter additions through the vegetation improve the physical and chemical characteristics of a site. The authors state that organic matter inputs from the vegetation present may, over time, increase base nutrient cycling and microbial transformations of acid-producing materials, such as sulfate.

268. Davidson, W. H., and D. H. Graves. Opportunities for Forestry Practices on Reclaimed Surface Mines. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 327-330.

This article discusses the opportunities for forestry practices on reclaimed surface mines in the Eastern United States. The influence of State and Federal regulatory policy on tree plantings, the need for long-range planning, reclamation practices and case studies of successful forest plantations on mine soils, and the economics of forest plantings are discussed. Factors that favor or oppose woody plants are listed. Since the factors favoring tree and shrub plantings outweigh opposing factors, the authors recommend tree and shrub plantings as the reclamation technique to use on all sites except those that will be used for intensive agriculture or will be developed for other purposes.

269. Davidson, W. H., R. J. Hutnik, and R. A. Bauman. Ponderosa Pine—A Reclamation Species for the East? Paper in Fourth Biennial Symposium on Surface Mining and Reclamation on the Great Plains and Fourth Annual Meeting of the American Society for Surface Mining and Reclamation. Reclam. Res. Unit, MT State Univ., Bozeman, MT, Rep. 8704, 1987, pp. H-8-1—H-8-7.

Seedlings from 49 seed sources of ponderosa pine (*Pinus ponderosa* Laws.) were planted on a surface mine site in Pennsylvania to determine if any of these seed sources would result in satisfactory survival and growth and the resistance of the provenances to western gall rust (*Endocronartium harkenssii*). Soil amendments were not used in this study; however, some physical and chemical characteristics of the mine soil are given. Additionally, the performance of seed sources at age 17 by survival, growth (DBH), and disease rating are given. The results of this study indicate that ponderosa pine can be planted successfully in the East if the appropriate seed source is used. Additional research is necessary to make recommendations concerning the use of ponderosa pine on surface mines in the East with topsoil replacement and a vegetative cover of grasses and legumes as required by current reclamation rules and regulations.

270. Davidson, W. H., R. J. Hutnik, and D. E. Parr. Reforestation of Mined Land in the Northeastern and North-Central U.S. North. J. Appl. For., v. 1, 1984, pp. 7-12.

The state-of-the-art surface mine reclamation for forestry in portions of the Eastern and Interior Coal Mining Regions is reviewed. Legislative constraints, socioeconomic issues, limiting factors to successful reforestation, species selection, tree establishment techniques, postmining land use trends, and applications of reforestation are discussed.

271. Davidson, W. H., and E. A. Sowa. Conifers Growing on Anthracite Minesoils Respond to Fertilization. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY. Lexington, KY, 1982, pp. 115-118.

Two separate studies were conducted on Pennsylvania anthracite mine soils to evaluate the growth response of established conifers to slow-release and granular fertilization. In the first study, six plantations ranging in age from 3 to 8 years were used. At each site, every other tree in a row received one fertilizer tablet per 30 cm of average height. Agriform planting tablets (21 g) having an analysis of 20-15-5 were used. The tablets were placed in a hole 10 to 15 cm deep. Over the 4 years of the study, all fertilized trees showed a positive response to fertilizer

tablets except for white spruce (*Picea glauca* (Moench) Voss). Japanese larch (*Larix leptolepis* (Sieb. & Zucc.) Gord.) responded the first year, while red pine (*Pinus resinosa* Ait.), white pine (*Pinus strobus* L.), and Austrian pine (*Pinus nigra* Arnold) did not respond until the second year after treatment. These responses lasted for a 2-year period. By the end of the fourth year there were no significant differences between fertilized and nonfertilized trees except at one site on coalbreaker refuse where Austrian pine had a significant growth response to fertilization over the 4 years of the study. In the second study, a plantation of scotch pine (*Pinus sylvestris* L.) and red pine were treated as follows: (1) 100 kg ha^{-1} N and 90 kg ha^{-1} P, (2) 100 kg ha^{-1} N and 180 kg ha^{-1} P, and (3) a control. There were no growth responses to granular fertilization until the third year, and even then the response was short lived. Only red pine responded to both phosphorus fertility rates. The authors conclude that the growth rates of most conifers on anthracite mine soils can be increased by fertilization. The fertilizer tablets produced a growth response more quickly than granular fertilizer and the response was longer lasting.

272. Davidson, W. H., and W. G. Vogel. Hybrid Poplar for Reclamation. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 99-109.

This article provides a brief literature review of the use of hybrid poplar (*Populus* spp.) for mine-soil reclamation. Much of the literature and results reviewed in this article are from research conducted by the U.S. Forest Service in the Eastern Coal Mining Region. Included in the article is a list of hybrid poplar clones that have been reported as performing well, their lineage, and the area where research on them was conducted. This article provides a good reference for this subject and is pertinent to potential land use considerations and to planning reclamation.

273. Day, A. D., and K. L. Ludeke. Reclamation of Copper Mine Wastes With Shrubs in the Southwestern U.S.A. J. Arid Environ., v. 3, 1980, pp. 107-112.

This article reports the results of a study that examined the effects of desert soil, copper mine overburden, overburden plus copper mine tailings, and tailings on the germination, seedling establishment, and growth of five shrub species. The study was conducted at the Cyprus Pima Mining Co. copper mine near Tucson, AZ. A sidewinder and a sheepfoot roller were used to prepare the seedbed on each soil material. The five shrub species included four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.), quailbush (*Atriplex lentiformis* (Torr.) Wats.), creosote-bush (*Larrea divaricata* Cav.), Australian saltbush (*Atriplex semibaccata* R. Br.), and desertbroom (*Baccharis saraothroides* Gray). The desert soil was most productive, followed by overburden, overburden plus tailings, and tailings, in decreasing order of productivity. Second-year growth produced taller plants, more vegetation, and more ground cover for all species tested.

274. Day, A. D., and K. L. Ludeke. Stabilization of Copper Mine Wastes in a Semi-Arid Environment With Perennial Grasses. J. Arid Environ., v. 5, 1982, pp. 285-290.

This study examines the effects of desert soil, copper mine overburden, overburden plus copper mine tailings, and tailings on the germination, seedling establishment, and growth of six perennial grass species. The study was conducted at the Cyprus Pima Mining Co. mine in Arizona. The six grass species included perennial ryegrass (*Lolium perenne* L.), crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.), Lehmann lovegrass (*Eragrostis lehmanniana* Nees), weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees), Wilman lovegrass (*Eragrostis superba* Peyr.), and blue panicgrass (*Panicum antidotale* Retz.). The desert soil was found to be most productive, followed by overburden, overburden plus tailings, and tailings, in decreasing order of productivity. Second-year growth produced taller plants, more vegetation, and more ground cover for all the species tested.

275. Day, A. D., K. L. Ludeke, G. O. Amaugo, and T. C. Tucker. Copper Mine Wastes: Good Potential as Medium for Growing Livestock Forage. Ch. in Engineering and Mining Journal Operating Handbook of Mineral Surface Mining and Exploration, ed. by R. Hoppe. McGraw-Hill, v. 2, 1978, pp. 128-129.

The purpose of this study was to compare the growth and the fiber, protein, and amino acid contents of barley (*Hordeum vulgare* L.) grown on soil materials in copper mine wastes in Arizona. The four soil materials used were tailings, tailings-overburden, overburden, and desert soil. The results presented in this paper are qualitative; no quantitative data are give. The greatest height growth and largest amount of tillers per area for barley forage were obtained on the desert soil, followed by overburden, overburden-tailings, and pure tailings. The fiber content and protein content of barley forage were similar for the desert, overburden, and tailings material. The barley forage on mixture of tailings and overburden had less fiber, but more protein. This indicates a higher nutritional value for livestock feed on a mixture of tailings and

overburden than on the other three soil materials. These differences in amino acid concentration may be explained by the differences in the availability of nutrient to barley plants from the soil materials studied. The authors conclude that with improved cultural practices, barley forage grown on copper mine wastes may produce high yields of quality forage for livestock feed.

276. Day, A. D., B. B. Taylor, and L. L. Pepper. Agricultural Potential of Municipal Sewage. Am. Soc. Agron., Agron. Abstr., 1987, p. 36.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Information is presented on the average quantity and fertilizer value of nitrogen, P_2O_5, and K_2O produced in treated municipal waste water and digested liquid sewage sludge from 1,000 people in Arizona. It is estimated that municipal waste water from 1,000 people per year contains 5,395, 4,648, and 2,988 lb of nitrogen, P_2O_5, and K_2O, respectively, while sewage sludge from 1,000 people per year contains 4,130, 2,082, and 200 lb, respectively. Based on an estimated cost of \$0.30, \$0.20, and \$0.10 per pound for nitrogen, P_2O_5, and K_2O, respectively, the fertilizer value of municipal sewage from 1,000 people per year is \$2,858, \$1,346, and \$319, respectively. This amounts to a total fertilizer value of \$4,523.

277. Day, A. D., T. C. Tucker, and J. L. Thames. Response of Plant Species to Coal-Mine Spoil Materials. Miner. and Environ., v. 5, No. 1, 1983, pp. 10-14.

The growth and establishment of seven plant species in undisturbed soil and coal mine soil (spoil) was investigated in this 2-year study conducted on the Black Mesa Coal Mine near Kayenta, AZ. Natural rainfall (20 cm yr^{-1}) and rainfall plus sprinkler irrigation (50 cm yr^{-1}) were the irrigation treatments applied to each soil material. Better plant growth was obtained on undisturbed soil. Supplemental irrigation resulted in improved plant growth on both soil materials. When supplemental irrigation was applied, effective ground cover was produced on both soil materials with alfalfa (*Medicago sativa* L.) and all the native grasses used, except Indian ricegrass (*Oryzopsis hymenoides* (Roem & Schult.) Ricker). During the first year of growth, four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) had low germination, seedling establishment, and stem production. During the second year of growth this species produced a dense ground cover on coal mine soil when supplemental irrigation water was applied. Harlan II barley (*Hordeum vulgare* L.) and Super X wheat (*Triticum aestivum* L.) were used to provide initial protective cover until the perennial species could be permanently established. The results of this study indicate that supplemental irrigation is essential during seedling establishment for effective revegetation of coal mine soils in a semiarid environment.

278. Day, A. D., T. C. Tucker, and J. L. Thames. Russian Thistle for Soil Mulch in Coal Mine Reclamation. Reclam. Rev., v. 2, No. 1, 1979, pp. 39-42.

Two greenhouse experiments were conducted to compare Russian-thistle mulch (*Salsola kali* L. var. *tenuifolia* Tausch.) with barley (*Hordeum vulgare* L.) straw mulch in reducing soil moisture loss from a coal mine spoil and two unmined soils. The coal mine spoil material was collected from the Black Mesa Coal Mine near Kayenta, AZ. Each of the soils was observed using the Russian-thistle mulch, barley straw mulch, or no mulch. The two greenhouse environments utilized in this study were (1) 27° C and 5-pct relative humidity and (2) 21° C and 75-pct relative humidity. Soil moisture loss was calculated as a percentage of the initial 50 mL of water added to the soil. Barley straw and Russian-thistle mulches significantly reduced moisture loss from the soil materials studied in both environments. Moisture loss was lower in environment 2 than in environment 1 for all soils, but the moisture loss patterns were similar in both environments. The authors concluded that Russian-thistle is as effective as barley straw, as a soil mulch, in reducing moisture loss from the three soils studied.

279. Dean, K. C., L. J Froisland. and M. B. Shirts. Utilization and Stabilization of Mineral Wastes. BuMines B 688, 1986, 46 pp.

This report reviews problems encountered in stabilizing mineral waste accumulations (including surface mine reclamation and coal wastes), suggests means of utilizing mineral wastes, and outlines laboratory and field research conducted on the various methods of stabilization utilized. Suggested means of utilizing mineral waste materials include ceramic purposes (copper mill tailings for bricks, steam-cured bricks, and phosphorus furnace slag for making ceramic tile) and metal value recovery (zinc and lead from foundry flue dust, sponge iron from dry and oily mill scale, recyclable iron from iron hydroxide sludge, and vanadium and uranium values from uranium tailings). Physical, chemical, and vegetative stabilization methods were evaluated for reclamation potential on copper, uranium, lead-zinc, and asbestos tailings and at a coal surface mine site in Wyoming. Details and results of several field studies utilizing chemical and vegetative stabilization techniques are presented. Cost comparisons of the various stabilization methods, based on 1974 prices, are made. This report provides a good summary of laboratory and field studies conducted to reduce the environmental problems associated with mineral wastes.

280. Del Rosario, M. S., and S. E. Feagley. Reclamation of Louisiana Lignite Mine Using Papermill Sludge. Am. Soc. Agron., Agron. Abstr., 1988, p. 38.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. This greenhouse pot study investigated the effect of papermill sludge and fertilizer amendments on the growth of subterranean clover (*Trifolium subterraneum* L.) grown in Louisiana mine spoil. Sludge was applied at 0, 56, 112, and 224 Mg ha^{-1} in combination with twice the recommended phosphorus and potassium fertilizer or none. All amendments were thoroughly mixed with the spoil prior to seeding. Fertilizer application enhanced yield, while sludge applied alone had a detrimental effect on yield. This negative effect decreased with time and was reversed when papermill sludge and fertilizer were added in combination. Phosphorus and nitrogen concentrations in plant tissue decreased with sludge application, whether or not fertilizer was added. As sludge levels increased, plant tissues from unfertilized pots accumulated more potassium, calcium, sulfur, iron, copper, aluminum, zinc and sodium than tissues from fertilized pots.

281. Dell'Agnola, G., and S. Nardi. Hormone-Like Effect and Enhanced Nitrate Uptake Induced by Depolycondensed Humic Fractions Obtained From *Allolobophora rosea* and *A. caliginosa* Faeces. Biol. and Fertil. Soils, v. 4, 1987, pp. 115-118.

The separation of two fractions from humic extract by depolycondensation using acetic acid at pH 2.5 is described. The hormone-like activity and the effects of the isolated fractions on oat (*Avena sativa* L.) nitrate-nitrogen uptake are compared. The two fractions separated had apparent molecular weights greater (HSp) and less (HEf) than 3,500. When present in suitable concentrations, HEf is the more active fraction. HEf induced nitrate-nitrogen absorption in oats because of the higher affinity of carrier HEf toward nitrate-nitrogen in the absorption phase. The HEf fraction also has auxin-, gibberellin-, and cytokinin-like activity that is approximately 3.2, 1.2, and 3.4 x 10^4 greater than HSp, respectively. The HSp fraction is almost inactive, while the HEf fraction is physiologically very active. Evidence suggests that HSp acts as a support for HEf and regulates its activity on plant metabolism.

282. Demchak, K., R. D. Morse, D. D. Wolf, and J. L. Neal. Phosphorus Availability of Minesoils as Influenced by Phosphorus and Lime Rates and Organic Residues. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 423-429.

Red clover (*Trifolium pratense* L.) and tall fescue (*Festuca arundinacea* Schreb.) were established on a surface mine site in Wise County, VA, to evaluate the long-term effects of different rates of applied fertilizer and lime and various sources of incorporated organic residues on plant growth, tissue phosphorus content, and extractable soil phosphorus. Phosphorus fertilization rates were determined by the isotherm method, and the amounts needed to establish the mine solution phosphorus levels at 0, 0.025, 0.05, 0.1, and 0.2 ppm were applied. The organic amendments used were high lime and wood fines (passed through a 0.6-cm mesh), lime and papermill sludge, and lime and composted sewage sludge.

Based on 1 year of data, improvements in phosphorus availability were achieved by adding lime with either sewage sludge or phosphate fertilizer. Lime alone, however, did not significantly increase yields. Adding phosphorus without lime also failed to maximize yields even though yields increased as the soil solution phosphorus content was increased. The optimum initial soil solution phosphorus level for red clover and tall fescue was between 0 and 0.025 ppm. Sewage sludge produced excellent first-year yields, even without supplemental phosphorus. Sewage sludge could be an excellent amendment for improving the long-term availability of phosphorus on mine soils if mineralization keeps pace with phosphorus demands. The potential for papermill sludge and wood fines to directly supply phosphorus is not sufficient to maintain adequate growth on mine soils. Across all treatments, the total yield obtained was highly correlated with tissue phosphorus concentrations. Of the soil tests that were compared (Bray I, sodium bicarbonate, and dilute double acid) for extractable phosphorus, the sodium bicarbonate test had the highest correlation with yield and tissue phosphorus concentration across all treatments.

283. DePuit, E. J. Recent Progress in Mined Land Revegetation Research in Montana. Paper in Symposium on Adequate Reclamation of Mined Land? (Billings, MT, Mar. 26-27, 1980). Soil Conserv. Soc. Am., 1980, pp. 19-1—19-23.

The author presents a brief description of the history and scope of past mined land revegetation research in Montana, summarizes recent and current revegetation research being conducted in Montana, and presents a bibliography of coal mined land revegetation studies produced by Montana-based research. Results and/or conclusions from recent or current research specific to native species establishment, irrigation, fertilization, and grazing management are presented and discussed.

284. DePuit, E. J., and J. G. Coenenberg. Methods for Establishment of Native Plant Communities on Topsoiled Coal Stripmine Spoils in the Northern Great Plains. Reclam. Rev., v. 2, No. 2, 1979, pp. 75-87.

This study evaluated seeding method (drill versus broadcast), number of species in a seeded mix, and rate of seeding on a topsoiled coal strip mine near Colstrip, MT. Broadcast seeding was found to be superior in terms of productivity, stand composition, and diversity if the seeding rates were twice that of drill seeding. If equal seeding rates were used, drill seeding was superior to broadcast seeding in terms of perennial grass productivity. Broadcast seeding at equal rates with drill seeding still resulted in a higher stand diversity and development of smaller seeded species. By increasing the numbers of species in a seed mix, community diversity increased without having a detrimental effect on productivity. This indicates the value that a broad seeding mixture has on both diversity and productivity. The heavy seeding rates evaluated (42, 56, and 84 kg ha^{-1} PLS) generally yielded good stands of vegetation in terms of productivity, native species dominance, and diversity. Above 56 kg ha^{-1}, however, there was a reduction in perennial grass productivity. Stand diversity also declined when seeding rates were increased. It may be necessary to use the higher seeding rates to ensure rapid vegetative stabilization on semiarid mined lands.

285. DePuit, E. J., J. G. Coenenberg, and W. H. Willmuth. Research on Revegetation of Surface Mined Lands at Colstrip, Montana: Progress Report, 1975-1977. MT Agric. Exp. Stn., MT State Univ., Bozeman, MT, Res. Rep. 127, Aug. 1978, 165 pp.

This report describes progress on a number of revegetation research projects conducted by the Montana Agricultural Experiment Station at the Western Energy Co.'s Rosebud Mine at Colstrip, MT, from 1975 through 1977. The major phase of reclamation addressed by this report is the revegetation of mine spoils. The results of each study are presented, with particular emphasis on the amounts of fertilizer applied, the species and seeding rates used, and the resulting cover and biomass produced.

286. DePuit, E. J., C. L. Skilbred, and J. G. Coenenberg. Effects of Two Years of Irrigation on Revegetation of Coal Surface-Mined Land in Southeastern Montana. J. Range Manage., v. 35, No. 1, 1982, pp. 67-74.

This report summarizes the data obtained on the responses of seeded vegetation to 2 years of summer irrigation on a topsoiled sodic site at the West Decker Coal Mine in southeastern Montana. A sprinkler irrigation system was used for the application of supplemental water. The objectives of the study were (1) to evaluate the effects of supplemental irrigation on vegetation establishment, structure, composition, diversity, and productivity, and (2) to define the effects of irrigation on root biomass and distribution. One year of supplemental irrigation significantly stimulated the productivity of seeded perennial grasses, increased warm-season perennial grass development, and increased stand diversity. Species that were significantly stimulated by 1 year of irrigation were thickspike wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.), slender wheatgrass (*Agropyron trachycaulum* (Link) Malte), smooth bromegrass (*Bromus inermis* Leyss.), and blue grama (*Bouteloua gracilis* (H.B.K.) Lag.). Total stand productivity after 1 year was similar for irrigated and nonirrigated plots; the first year was characterized by above-average precipitation. First-year irrigation also decreased the productivity of annual weed species. Irrigation in the second year, a drier year, resulted in a total irrigated stand productivity that was three times higher than that of nonirrigated plots Plant species stimulated by 2 years of irrigation were all cool-season species and included slender wheatgrass, western wheatgrass (*Agropyron smithii* Rydb.), smooth bromegrass, and yellow sweetclover (*Melilotus officinalis* (L.) Lam.). The growth of warm-season species was retarded by 2 years of irrigation, with more shallow root systems and lower belowground-to-aboveground biomass ratios than in nonirrigated areas. Total root biomass was significantly higher in nonirrigated plots than in irrigated plots.

287. Derby, G. K., and R. D. Perry. Economic Considerations of Reclaiming Abandoned Tailings Ponds and Dams. Paper in Conference on the Economics of Mined-Land Reclamation (cosponsored by Land Reclam. Prog., Argonne Natl. Lab., and U.S. Dep. Energy; Chicago, IL, Sept. 1-2, 1981). Argonne Natl. Lab., ANL/LRP-TM-20, Sept. 1981, pp. 243-257.

The authors discuss methodologies that can be used to develop reclamation plans specific to an abandoned or inactive mine tailings deposit. Two representative case studies, one from the Southwestern United States and the other from the Northwestern United States, are included as examples. Semidetailed reclamation plans were developed that contain information on methods, procedures, and cost estimates to reclaim each site. The authors feel that a basic reclamation plan cannot be developed to cover all the circumstances involved in reclamation costs; the reclamation requirements are site specific, and engineering studies and comprehensive plans should be developed on an individual basis.

288. Dewar, S. W. Direct Seeding of Jack Pine on Waste Rock Dumps. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 148-154.

The effectiveness of direct seeding jack pine (*Pinus banksiana* Lamb.) on waste rock mine dumps for afforestation was evaluated on the Mesabi Iron Range in

northern Minnesota. Jack pine germination and survival response was measured at seven mine dump sites under three fertility treatments: 19-19-19 fertilizer applied at two rates (200 and 400 lb acre^{-1}) plus a control (no fertilization), for three consecutive years. Seedling germination, establishment, and survival were significantly affected by site. Vegetative competition was the primary factor affecting seedling germination and survival among sites. There were no significant fertilizer effects at any of the waste rock mine dumps studied.

289. Dewar, S. W., and E. R. Berglund. First-Year Survival and Growth of Willow and Poplar Cuttings on Taconite Tailings in Minnesota. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 141-147.

This study evaluated the effectiveness of crack willow (*Salix fragilis* L.) and balsam poplar (*Populus balsamifera* L.) cuttings for afforestation of a taconite tailings basin near Keewatin, MN. Survival and growth responses were measured according to tailings texture and fertilization treatments. The fertilizer treatments used were (1) a control—no fertilizer, (2) surface application of 150 lb acre^{-1} of 46-0-0 and 150 lb acre^{-1} of 0-46-0 fertilizer, and (3) a rototilled fertilizer treatment using the same fertilizer application rate as in treatment 2. The overall survival of crack willow (94 pct) was not significantly affected by either texture or fertilization treatments. The average growth of crack willow, however, was significantly greater on rototilled-fertilized and surface-fertilized plots than on control plots. The overall survival of balsam poplar (30 pct) was significantly lower than that of crack willow. Growth of balsam poplar was significantly affected by texture; as the tailings material became coarser, the average growth decreased. Fertilization was found to have no effect on the growth on balsam poplar. The results of this study indicate that crack willow cuttings have a higher survival and higher growth response to fertilization and are more promising than balsam poplar for establishing woody vegetation on taconite tailings.

290. Dick, W. A., J. V. Bonta, and F. Hagiri. Chemical Quality of Suspended Sediment from Watersheds Subjected to Surface Coal Mining. J. Environ. Qual., v. 15, No. 3, 1986, pp. 289-293.

The chemical quality of suspended sediments was determined for three small east-central Ohio watersheds that had experienced 78- to 99-pct disturbance due to coal surface mining activities. Samples were collected prior to surface mining, during mining and reclamation, and after reclamation was completed. The concentrations of measured parameters in the suspended sediment samples varied depending on location, time of sampling, and parameter measured. The differences in sediment quality were related to the composition of the overburden material. At one watershed, the overburden contained substantial amounts of limestone, which resulted in higher pH values and calcium and strontium concentrations compared with watersheds composed on sandstone and shale. The large variations in concentrations were due to changing topography and surface conditions at the minesites. At two of the watersheds studied, the concentrations of measured chemical parameters collected after reclamation were not significantly different from concentrations measured prior to mining. Organic carbon concentrations were the exception; concentrations after reclamation were lower than prior to mining. Pyrite oxidation did occur at all three watersheds; SO_4 concentrations increased during the active mining and reclamation phases. Once reclamation was completed, however, SO_4 concentrations returned to premining levels.

291. Dicke, S. G., and J. R. Toliver. Response of Cherrybark Oak Families to Different Soil-Site Conditions. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1988). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 260-263.

The survival and height growth of cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.) during the first 5 years of development, as influenced by soil series and drainage, were determined. Poor drainage and poor soil aeration reduced the survival and growth of cherrybark oak. There were, however, differences in height and survival among cherrybark oak families, indicating that height growth and survival could be improved on bottom lands through proper family selection.

292. Dickerson, J., T. Kelsey, and R. Godfrey. The Use of Warm Season Grasses for Revegetating Sands and Gravels in New Hampshire, Vermont, and New York. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 2-8.

Species and cultivars of C_4 grasses that were best suited for reclamation of sand and gravel spoils were identified. Additionally, information on the agronomic practices that promote rapid establishment and effective cover are presented. Although this research was not conducted on coal mine soil, it would apply to coal mine soils that are droughty and low in organic matter. Field sites located throughout the Northeastern United States were studied. Information is given on the C_4 grass species tested at each

of the sites, the species and cultivars that performed best based on percent cover, the types and rates of fertilizer, lime, and mulch used at a particular site, and the method of incorporating the seed and amendments into the soil material. One of the ten sites was used specifically for a fertility trial in order to evaluate fertilizer treatments. Based on this study, the authors recommend that slow-release nitrogen fertilizers be used when establishing C_4 grass species on droughty sites.

293. Dickson, K. L., and D. Vance. Revegetating Surface Mined Lands for Wildlife in Texas and Oklahoma (U.S. Fish and Wildl. Serv. contract FWS 14-16-009-80-045, Inst. Appl. Sci. and Dep. Biol. Sci., N. TX State Univ.). U.S. Fish and Wildl. Serv., FWS/OBS081/25, Aug. 1981, 120 pp.

This publication is designed as a guide for reclaiming surface coal mined lands in Texas and Oklahoma. Guidance is provided for the development and implementation of revegetation plans that will create a diversity of habitats capable of attracting and supporting wildlife. Possible considerations of wildlife habitat where agricultural production is the primary goal in postmining land use are also presented. Excellent vegetation information, including planting spacing, planting dates, adaptability, wildlife value, and seed or plant stock sources, is provided for numerous species.

294. Dixon, J. B., H. S. Arora, F. M. Hons, P. E. Askenasy, and L. R. Hossner. Chemical, Physical, and Mineralogical Properties of Soils, Mine Spoil, and Overburden Associated With Lignite Mining. Ch. in Reclamation of Surface-Mined Lignite Spoil in Texas. TX Agric. Exp. Stn., College Station, TX, Rep. RM-10, 1980, pp. 12-21.

The authors briefly summarize the physical and chemical properties of unmined soils, mine spoil, and selected overburden strata from Freestone and Milam Counties, TX. Mine spoil has a more favorable texture than unmined soils, although it does form crusts that can reduce seedling emergence and oxygen diffusion. The spoil is deficient in nitrogen, phosphorus, and organic matter, all of which can be corrected with proper fertilization. This is a good article on soil properties of the Texas lignite mining areas.

295. Dixon, R. K., and C. A. Buschena. Response of Ectomycorrhizal *Pinus banksiana* and *Picea glauca* to Heavy Metals in Soil. Plant and Soil, v. 105, No. 2, 1988, pp. 265-271.

Seedlings of jack pine (*Pinus banksiana* Lamb.) and white spruce (*Picea glauca* (Moench) Voss) were grown in an acid-washed sandy loam soil that had been sterilized. Six metal treatments (cadmium, copper, nickel, lead, and zinc applied at 2, 5, 10, and 20 ppm, and a control) and two mycorrhizal treatments (*Suillus luteus* inoculated and noninoculated) were used for each tree species. Seedlings were grown in the greenhouse for 12 weeks. The number of lateral roots, percent ectomycorrhizal infection, root dry weight, shoot dry weight, and soil and tissue concentrations of nutrients and added heavy metals were determined following the 12-week growth period.

The additions of heavy metals significantly reduced mycorrhizal colonization on the seedlings tested, particularly nickel and cadmium at concentrations above 10 ppm. The needle tissue concentrations of heavy metals were lower in ectomycorrhizal seedlings at low soil concentration than in noninoculated seedlings. At higher soil concentrations, heavy-metal tissue concentrations were similar in both ectomycorrhizal and nonmycorrhizal seedlings. Heavy metals also resulted in reduced growth in nonmycorrhizal seedlings compared with ectomycorrhizal seedlings. At low or intermediate soil concentrations of cadmium, copper, nickel, lead and zinc, ectomycorrhizal colonization apparently ameliorates heavy-metal toxicity in the species tested by forming a protective fungal mantle that binds the metal to roots or fungal structures. This article serves as a good reference on the effects of heavy metals, particularly in sewage sludge, on the growth of species used for the revegetation of coal surface-mined lands. Additionally, based on the results of this study, it may be possible to ameliorate the heavy-metal toxicity by ectomycorrhizal inoculation. This study may be of particular interest to those conducting research on reforestation of surface-mined sites where sewage sludge has been used as a soil amendment.

296. Doerge, T. A., and E. H. Gardner. Comparison of Four Methods of Interpreting the Shoemaker-McLean-Pratt (SMP) Lime Requirement Test. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1057-1059.

This methods comparison study was conducted under field conditions to test the accuracy of four methods of interpreting the Shoemaker-McLean-Pratt (SMP) lime requirement (LR) test and to quantify random, constant, and proportional error associated with these four methods. Lime applications, 0 to 14 Mg ha^{-1}, were applied to two acid soils. Soil samples (0 to 15 cm) were taken prior to liming and analyzed using the following four methods of interpreting the SMP lime requirement tests: (1) SMP single buffer (original SB), (2) modified SB, (3) SMP double buffer (DB), and (4) modified SB plus initial pH_{Ca}. Statistical models were developed for each method to predict the quantity of calcium carbonate required to adjust the pH of amended soil to the desired level. The models were algebraically solved to predict the pH

values measured 1 and 2 years after application. Proportional, random, and constant errors were calculated. The proportional errors associated with original SB, modified SB, DB, and modified SB plus initial pH_{Ca} were 1.2, 0.19, 1.3, and 0.06, respectively. The constant and random errors associated with the same methods were 7.8, 0.64, 8.6, and 0.26 pH units, and 0.83, 0.19, 0.77, and 0.25 pH units, respectively. When not calibrated under field conditions, all four methods underpredicted soil pH values resulting from lime applications by 0.5 to 0.7 pH units. This suggests that the calibration of LR tests is needed to reduce the errors associated with each method, particularly for soils from the same geographical region. The inclusion of additional parameters in an LR statistical model may improve the accuracy of a method if the initial soil pH is included rather than soil texture, CEC, or organic matter content.

297. Doerr, T. B., and E. F. Redente. Seeded Plant Community Changes on Intensively Disturbed Soils as Affected by Cultural Practices. Reclam. & Reveg. Res., v. 2, No. 1, 1983, pp. 13-24.

This study examined the effects of irrigation, fertilization, seed mixture, seeding method, and interactions on successional trends of seeded grass and forb species on intensively disturbed soils near Rifle, CO. The soils were disturbed by removing, mixing, and replacing the A, B, and C horizons. Initially, fertilization and irrigation increased grass production, but after 4 years there was no increase in aboveground production due to either treatment. Irrigation favored forb production during the first 2 years, but fertilization reduced forb biomass during the entire time the study was conducted. The aboveground biomass of native and introduced species was significantly different for only 1 year. After that time little difference in biomass production was found. Forb production, however, was found to be greatest when introduced species were used. Alfalfa (*Medicago sativa* L.) was the species that contributed the most to the difference found between introduced and native forbs. Aboveground biomass of the grass species was not significantly affected by seeding method (drill versus broadcast). Forb biomass was generally greater on broadcast-seeded plots than on drill-seeded plots. The conclusions drawn by the authors were (1) depending on land use and importance of soil stabilization, irrigation and fertilization may or may not be useful for vegetation establishment, (2) there are no apparent reasons for not using adapted introduced species for revegetation at appropriate rates, and (3) broadcast seeding was as effective in establishing diverse and productive stands as drill seeding.

298. Doll E. C., S. D. Merrill, and G. A. Halvorson. Soil Replacement for Reclamation of Stripmined Lands in North Dakota. ND Agric. Exp. Sta., ND State Univ., Fargo, ND, Bull. 514, July 1984, 24 pp.

This bulletin reviews published and unpublished North Dakota research related to the depth and quality of topsoil and subsoil needed for successful reclamation of North Dakota coal surface-mined lands. Soil properties that are important in determining optimum depth of topsoil and subsoil to be replaced include sodium content, salinity, clay content, and kinds of minerals present. The early work done on revegetation in North Dakota compared topsoil replacement with applications of chemical amendments and straw mulch. This initial work demonstrated that topsoil depths needed for optimum yields were related to the quality of the underlying soil. Greater depths of quality topsoil were needed to restore the productivity on poor-quality spoil. These experiments led to a series of wedge experiments to determine depths of soil replacement using topsoil and subsoil materials over spoil. Areas where further research is needed are identified.

299. Doll, E. C., and N. C. Wollenhaupt. Use of Soil Parameters in the Evaluation of Reclamation Success in North Dakota. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 91-94.

A procedure for evaluating the productivity of reclaimed soils in North Dakota is proposed. Successful reclamation is dependent on the development of favorable root zone conditions for optimal plant growth. When the root zone materials have favorable chemical and physical characteristics, topographic position becomes an important influence on productivity. The relative production capacity of different soils can be compared using morphological characteristics. Soils with productivity indexes (PI's) of 100 are the most productive, with lesser values indicating less productive soils. There is a need to develop criteria for evaluating measurable soil characteristics to calculate the PI of reclaimed soils. The potential productive capacity of reclaimed soils is determined by topographical position and by the amount and properties of the soil and spoil. The authors modified existing PI models to calculate the PI of reclaimed soils: $PI = 100\ Topo\ Sum\ n, i = 1\ (AWC_i x SAR_i x EC_i x\ Db_i x HC_i x WF_i)$. The topographic location (Topo) adjusts the PI to reflect the moisture status as affected by slope steepness and position in relation to runoff and run-on water. Available water capacity (AWC), sodium adsorption ratio (SAR), and electrical conductivity (EC) are fixed properties. Bulk density (D_b) is a measure of the total pore space in the soil, while hydraulic conductivity (HC) is a measure of the rate of water movement through the soil and is a measure of the continuous pore space. The authors feel

that HC gives the most critical evaluation of the reestablishment of productivity in reclaimed soils. Root depth weighing factor (WF) is a measure of the relative contribution of various depths within the root zone to the potential productive capacity of the soil. The potential postmine PI for reclaimed areas should be calculated before mining begins, using premine inventory data and the proposed postmine topographic plan.

300. Doll, E. C., N. C. Wollenhaupt, G. A. Halvorson, and S. A. Schroeder. Planning and Evaluating Cropland Reclamation After Stripmining in North Dakota. Paper in Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ. and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 88-101.

The authors offer an excellent review of pertinent literature and personal experience related to planning and evaluating cropland reclamation following strip mining in North Dakota. The authors stress that reclamation planning based upon duplication of premine conditions is not always the most efficient and cost-effective way to utilize the available soil and overburden materials. Topics discussed in the paper include the importance of topography, soil and overburden characterization, premine land use, soil replacement, and prime soil reclamation and its evaluation.

301. Dollhopf, D. J. Acid Minesoil Problems in the Northern Plains States. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 292-301.

This paper discusses acid production problems encountered on surface-mined land in the Northern Great Plains. The source of the acid production is the oxidation and hydrolysis of exposed sulfur-heavy rocks. Most of the sulfur in these rocks is not in the form of pyrite, as is the case in the Eastern United States. The residual sulfur is thought to be organic sulfur, which constitutes 50 to 80 pct of the total sulfur in the overburden material. There is uncertainty, however, of whether organic sulfur is the source of the acid problem. Weathering experiments indicated that acid production from sulfur-containing materials may persist for long periods of time.

302. Dollhopf, D. J., and E. J. DePuit. Chemical Amendment and Irrigation Effects on Sodium Migration and Vegetation Characteristics in Sodic Mine Spoils in the Northern Great Plains. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 481-485.

The purpose of this study was to determine the causes of topsoil sodication in Montana and to develop methods that would reduce sodication in order to establish diverse vegetation for grazing purposes. Soil physical properties such as particle size distribution, clay mineralogy, and soil water movement govern whether sodium will migrate from the spoil to the topsoil. In this study, chemical amendments had no effect on plant growth or soil chemistry. Irrigation increased aboveground biomass of planted grasses and legumes and reduced the annual weed production. Root biomass was decreased in irrigated plots. The key to grazing-land productivity in the Northern Great Plains is the construction of mine soils that have suitable physical characteristics.

303. Dollhopf, D. J., C. J. Levine, and B. J. Bauman. Reclamation Advances in Selective Placement of Overburden. Paper in Symposium on Adequate Reclamation of Mined Land? (Billings, MT, Mar. 26-27, 1980). Soil Conserv. Soc. Am., 1980, pp. 15-1—15-16.

This paper reports the results of a study conducted near Colstrip, MT, to examine the extent and effects of overburden material mining during the spoiling process and to evaluate the feasibility of two methods of selective placement of toxic overburden material. Selective handling of a saline overburden zone followed either of two treatments: (1) segregation and burial or (2) segregation, burial, and covering with a relatively water-impermeable clay cap. The tests found that these treatments were technically feasible with a minimum of operational delays. Costs of these methods, however, were about 1.1 to 1.5 times the normal operational costs. Of particular significance was that a borehole sampling pattern approaching a 30- by 60-m grid was necessary to allow sufficiently accurate delineation of inhibitory overburden materials in order to implement selective overburden handling.

304. Dollhopf, D. J., and L. J. Russell. Assessment of Acid Producing Materials in the Northern Plains. Paper in Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 201-210.

This paper contains a review of the sources of mine-soil acid production and evaluates the use of laboratory weathering methods as an alternative to lime requirement determinations. The authors primarily examine mine-soil acid production in the Northern Great Plains, where the

coal overburden and hard-rock mine waste material tend to contain mostly unoxidized sulfur in the organic form, rather than as sulfides. Stoichiometrical analysis of these complex sulfur-containing compounds is discussed.

305. Donnelly, K. C., and K. W. Brown. Mutagenic Potential of Municipal Sludge Amended Soil. Am. Soc. Agron., Agron. Abstr. 1988, p. 38.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The fate and mobility of organic mutagens in municipal-sewage-sludge-amended soils using the Salmonella-microsome assay (strain TA98) were measured. Soil lysimeter samples were extracted using methylene chloride and methanol, following the application of sewage sludge. The specific activity of sludge-amended soil 154 days after sludge application (150 Mg ha^{-1} total) was 416 net revertants per 10 mg induced by the methanol fraction. The mutagenic potential of sludge-amended soils did decrease slowly with time; however, after 207 days a positive response was still observed for several of the extracted fractions. This indicates that municipal sludge may contain a persistent mutagenic residue.

306. Drake, L. D. Recommendations for Rural Abandoned Mine Program in Iowa, USA. Miner. and Environ., v. 5, No. 1, 1983, pp. 15-19.

Observations made on a 10-year-old test plot designed with a wedge of loess over acid spoils are related to orphan (abandoned) coal surface mines in Iowa that have been reclaimed under the Federal Rural Abandoned Mine Program (RAMP) by smoothing highly acid spoils, covering with a thin topsoil layer, and planting a cover crop. These observations suggest that acidified throughflow and discharge of shallow soil moisture and ground water will eventually kill the vegetation in the lower valleys, and erosion will proceed up the valley as a migrating knickpoint on the RAMP sites. A suggestion to eliminate this problem is redirection of the acidified throughflow below the cover material in sand underdrains or tile lines in the main drainages. If adequate flow is available, the discharge could be diluted in a nearby creek or it could be neutralized in a basin paved with limestone riprap. Native prairie grasses, crownvetch (*Coronilla varia* L.), and cattails (*Typha* spp.) were found to be especially well adapted to thin cover sites.

307. Drake, L. D. Survival and Growth of Conservation Shrubs and Trees, With Thin-Cover Reclamation on Acid Substrate, Iowa, USA. Environ. Geochem. Health, v. 8, No. 3, 1986, pp. 62-67.

The survival and growth of 22 shrub and tree species were evaluated for 6 years on acidic, abandoned mine land covered with a silt loess wedge ranging in thickness from 0.0 to 0.75 m. Seedling growth and survival were evaluated near the end of each growing season. The survival and growth of each species were outlined. The performance of each species was categorized into one of three groups: (1) consistent survival, (2) irregular survival and growth, and (3) little suitability for survival. The most favorable survival and growth were not on the thickest loess cover, owing to competition from weedy species. Shrub species had the best survival when weed competition occurred on the thickest loess cover.

308. Drake, L. D., and G. T. Ririe. A Low-Cost Method of Reclaiming Strip-Mined Land in Iowa to Agriculture. Environ. Geol., v. 3, 1981, pp. 267-279.

A loess terrace method for reclaiming Mahaska County, IA, strip-mined cropland as mining progresses was designed and tested by the authors. This article provides an excellent analysis of this method of reclaiming strongly acidic spoils. Methodology and yields are clearly presented, as is a logical cost analysis. The article is recommended for review and planning of methods for reclaiming mine spoils that have toxic levels of acidity.

309. Dressler, R. L., G. L. Storm, W. M. Tzilowski, and W. E. Sopper. Heavy Metals in Cottontail Rabbits on Mined Land Treated With Sewage Sludge. J. Environ. Qual., v. 15, No. 3, 1986, pp. 278-281.

The levels of heavy metal in soils, vegetation, and tissues of cottontail rabbits (*Sylvilagnus floridanus*) on a Pennsylvania strip mine treated with municipal sewage sludge were compared with those from a site reclaimed using standard methods (fertilizer and lime) and a nonmined site to determine sludge treatment effects. All vegetation, soil, and animal tissue samples were analyzed for seven heavy metals (cadmium, chromium, cobalt, copper, lead, nickel, and zinc) based on dry weight. Heavy-metal concentrations in surface soil samples from sludge-treated and untreated sites were not significantly different. Concentrations of cadmium, copper, and zinc were significantly higher in vegetation on the sludge-treated sites than on the nontreated sites. The concentrations in plant tissues were, however, below the EPA and Pennsylvania Department of Environmental Resources recommended limits of metal loading. Concentrations of zinc in cottontail rabbit femurs from the sludge-treated site were significantly higher than in those from the untreated sites, reflecting the increased zinc levels in the vegetation on the sludge-treated site. Muscle and liver samples from

mineralization indices of the soil microbial communities utilizing the two litter fractions.

In all the soils tested, the microbial communities had similar potential to decompose the labile fraction. There were, however, significant differences among the five treatments in the potential for microbial communities to decompose the recalcitrant fraction. The soil mineralization potential of the recalcitrant fraction would be less when the segregated topsoil is mixed with the overburden than when it is spread on the site as segregated topsoil. Following reclamation, it may take up to 4 years for the mineralization potential of the overburden material to recover to levels similar to that found for segregated topsoil. Spoil factors did not affect the potential of microbial communities to decompose the labile litter fraction; however, the potential to decompose the recalcitrant litter fraction was influenced by the soil microbial biomass, soil organic matter, and soil nitrogen.

316. Durall, D. M., W. F. J. Parsons, and D. Parkinson. Decomposition of Timothy (*Phleum pratense*) Litter on a Reclaimed Surface Coal Mine in Alberta, Canada. Can. J. Bot., v. 63, No. 9, 1985, pp. 1586-1594.

The behavior of timothy (*Phleum pratense* L.) litter decomposition on three reclaimed subalpine coal mine sites in Alberta, Canada was described using single and double exponential functions. Time since reclamation was 1, 3, and 7 years. Mass losses were best described using the double exponential decay function, which showed a trend of decreasing mass-loss rate for labile and recalcitrant litter fractions with increasing time following reclamation. Abiotic factors controlled the release of the labile fraction during the initial phase of decomposition, while biotic factors controlled the decomposition of the recalcitrant fraction.

317. Dwyer, L. M., D. W. Stewart, and D. Balchin. Rooting Characteristics of Corn, Soybeans and Barley as a Function of Available Water and Soil Physical Characteristics. Can. J. Soil Sci., v. 68, No. 1, 1988, pp. 121-132.

Rooting depths of corn (*Zea mays* L.), soybeans (*Glycine max* (L.) Merr.), and barley (*Hordeum vulgare* L.) were monitored as functions of soil water on four physically contrasting soils: sand, clay, loam, and till. Since these agronomic species are commonly used in prime farmland reclamation, the relationship among rooting depth of each species, available soil water, and soil texture in this study can be used as a reference for similar studies on coal surface-mined lands. Root depths varied with soil type; roots were deepest in sand, shallower in clay and till textures, and shallowest in the loam. An inverse relationship was found between maximum rooting depth and available water within the limits imposed by each species' rooting habit and the soil physical characteristics. Available water, however, accounted for most of the annual variability in maximum root depth. The results also indicate that root depth or density measurements made at or near physiological maturity approximate the maximum root development for each species. The authors conclude that in general, root depth and distribution of the species studied are influenced by available water and soil physical characteristics.

318. Dyer, K. L., W. R. Curtis, and J. T. Crews. Response of Vegetation to Various Mulches Used in Surface Mine Reclamation in Alabama and Kentucky—7-Year Case History. U.S. For. Serv., Gen. Tech. Rep. NE-93, 1984, 11 pp.

The long-term effects of six mulches on the growth of selected grasses and legumes, runoff, and erosion were evaluated on two different types of mine spoil located in northern Alabama and western Kentucky. This study was conducted over a 7-year period. Each site was limed and fertilized utilizing standard reclamation practices. The seven mulch treatments were applied at each site within 4 days of seedling. The mulches and rates at which they were applied are (1) Petroset SB emulsion at 40 gal $acre^{-1}$ plus hydromulch at 500 lb $acre^{-1}$, (2) hardwood chips at 40 to 50 yd^3 $acre^{-1}$, (3) straw at 3,000 lb $acre^{-1}$, (4) a control, (5) hydromulch at 1,500 lb $acre^{-1}$, (6) bark at 40 to 50 yd^3 $acre^{-1}$, and (7) hay at 3,000 to 3,500 lb $acre^{-1}$. Vegetative cover was evaluated at the end of the first four growing seasons, while yield was determined over the last three growing seasons. Soils were characterized for chemical and physical properties during the first, second, and seventh growing seasons. Appreciable differences in vegetative cover and yield could be attributed to the mulch treatments. In general, the bark, hay, and straw mulches produced the best vegetative cover during the first 4 years. These same treatments also resulted in the least amount of erosion.

319. Dyer, K. L., and J. C. Sencindiver. Bark Mulch Promotes Establishment of Vegetation on Minesoils With South and West Exposures. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 151-156.

This paper showed the need to consider both slope and aspect when selecting a mulch or when assessing whether any mulch should be applied. Two separate studies were conducted in southeastern Kentucky on a head-of-hollow

area and a mountaintop removal area. At the head-of-hollow area, hardwood bark mulch was applied at a rate of 48 yd^3 $acre^{-1}$. The area was also fertilized and seeded. South- and west-facing slopes were either mulched or left unmulched. Neither site was topsoiled. At the head-of-hollow area, hardwood bark resulted in a nearly fully sodded slope regardless of aspect, while unmulched areas were poorly vegetated. At the end of the second growing season, the entire head-of-hollow fill area was well vegetated regardless of aspect on mulched treatments. On the mountaintop removal area, cover and yield were greater on mulched plots on both slopes. Hardwood bark mulches facilitated the establishment of grasses and legumes seeded during the summer on south- and west-facing mine soils in central Appalachia. The mulch protected exposed mine soils from erosion during the first year.

320. Ebelhar, M. W., R. I. Barnhisel, G. W. Akin, and J. L. Powell. Effect of Lime, N, P, and K Amendments to Surface-Mined Coal Spoils on Yield and Chemical Composition of Common Bermudagrass. Reclam. & Reveg. Res., v. 1, No. 4, 1982, pp. 327-336.

This study evaluated common bermudagrass (*Cynodon dactylon* (L.) Pers.) as an alternative to cool-season grasses on acid sandstone surface mine spoils in Muhlenberg County, KY. The objectives of the study were to evaluate the effects of lime, nitrogen, potassium, and phosphorus amendments on the growth and development of common bermudagrass, and to evaluate the effects of the amendments on the chemistry of acid surface mine spoils. Lime applications were effective in raising the pH from 3.4 to 4.6, 5.7, and 6.3 for the 18, 36, and 72 mt ha^{-1} applied, respectively. The lime applications, however, may have reduced the availability of soil potassium. Nitrogen additions had the most influence on bermudagrass production. Significant increases in dry matter production were observed with each additional increment of nitrogen (0, 50, and 100 kg ha^{-1}). Deficiency symptoms were observed where nitrogen was not applied. Applications of phosphorus and potassium increased the elemental concentrations in the bermudagrass, but did not cause a significant increase in total dry matter production. Phosphorus and potassium did, however, increase the winter hardiness and survivability of bermudagrass. The authors conclude that bermudagrass offers an alternative to the cool-season grasses now used on reclaimed coal spoils in the humid regions of the Eastern United States. It may serve as a nurse crop to allow the establishment of longer lived grasses and legumes.

321. Eddleman, L. E. Survey of Viability of Indigenous Grasses, Forbs, and Shrubs: Techniques of Initial Acquisition and Treatment for Propagation in Preparation for Future Land Reclamation in the Fort Union Basin (U.S. Dep. Energy contract EY-76-S-06-2232). U.S. Dep. Energy, RLO-2232-T2-18, DE 82-018880, Prog. Rep., Feb. 1980, 87 pp.

This publication reports interim results of a study examining the dispersal, phenology, and germination requirements of numerous species of grasses, forbs, and shrubs indigenous to southeastern Montana. The final report for this study is listed below. This report has been reviewed and included because it contains extensive germination and seed treatment data for many of the species considered in the study. These data were not specifically presented in the final report; however, they may be of interest and useful in land reclamation activities or research.

322. Eddleman, L. E. Survey of Viability of Indigenous Grasses, Forbs, and Shrubs: Techniques of Initial Acquisition and Treatment for Propagation in Preparation for Future Land Reclamation in the Fort Union Basin. Final Report (U.S. Dep. Energy contract DE-AT06-76EV77002). U.S. Dep. Energy, RLO-2232-T2-18, DE 82-018880, June 1982, 29 pp.

This report contains information on the dispersal, phenology, and germination requirements of 151 species of grasses, forbs, and shrubs indigenous to southeastern Montana. A classification scheme based on the germination requirements of these species was devised and subsequently applied to rating each species for inclusion in revegetation procedures. Based on the results of this study, the author reports that less than 50 pct of the common indigenous species will easily and rapidly reestablish on mine spoils. It is reported that the probability of establishment success will be enhanced significantly by selection of those species that rapidly germinate a large percentage of their seed and that produce seedlings capable of maintaining growth through short drought periods. Dormancy-breaking requirements are reported for numerous species.

323. Edgar, R., W. J. Ruzzo, B. Bailey, C. Berry, and F. Samson. Development of Revegetation Success Standards for LaPlata Coal Mine in Northwestern New Mexico. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 77-83.

This paper describes the process of using the technical guideline approach to develop a set of revegetation standards for the proposed LaPlata coal mine in northwestern New Mexico. The standards were developed using on-site baseline vegetation data, published SCS range site descriptions, published wildlife management guidelines,

and other detailed vegetative data on good-quality grazing areas and wildlife areas relevant to the site. Seventy-five percent of the mined areas will be reclaimed with primary emphasis on livestock grazing, while the remaining 25 pct will be reclaimed to wildlife habitat.

324. Eivazi, F., and K. Schmidt. Nitrogen Fixation of Soybeans and Alfalfa on Sludge Amended Soils. Am. Soc. Agron., Agron. Abstr., 1986, p. 29.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. Two soil types and two sewage sludge sources were used in a greenhouse experiment. Alfalfa (*Medicago sativa* L.) and soybeans (*Glycine max* (L.) Merr.) were grown on soils amended with sludges with low and high heavy-metal contents at 0, 35, and 70 Mg ha^{-1}. Dinitrogen fixation was estimated using the acetylene reduction procedure. Root and shoot dry weights were increased by sludge applications on both kinds of soil. Dinitrogen fixation was not significantly affected by sludge application. Plant tissue heavy-metal concentrations increased significantly with increasing levels of sludge to soils amended with high heavy-metal sludge.

325. Elkhatib, E. A., and J. L. Hern. Kinetics of Potassium Desorption From Appalachian Soils. Soil Sci., v. 145, No. 1, 1988, pp. 11-19.

The surface and subsurface horizons of five major hill land soils of the Appalachian Region were used in this study to investigate the rate of potassium desorption. Each of the soils and horizons studied was characterized as to its physical, chemical, and mineralogical properties. Prior to the kinetic desorption studies, subsamples from each horizon were incubated at five different concentrations of potassium. The Elovich, modified Freundlich, parabolic diffusion, and first-order equations were tested by least squares regression analysis to determine which equation best described the potassium desorption data. Based on these tests, the first-order equations best described the data, owing to the low standard error values over most of the soils and initial potassium concentrations used. The remainder of the paper discusses the relationship between first-order equation constants and selected soil properties of the soils studied. Simple correlation coefficients were calculated between the first-order equation constants and selected soil properties for unfertilized and fertilized soil horizons. Most of the correlation coefficients between these variables were low; however, significant correlation coefficients were found for organic carbon and exchangeable potassium. It was found that the ratio of organic carbon to exchangeable potassium was a strong contributor in the first-order constants model.

The authors conclude that the close correlation between measured and predicted values of potassium desorbed indicate the potential that first-order equation and regression models derived from soil properties have in modeling potassium desorption in soils. Analysis of soil for organic carbon and exchangeable potassium in conjunction with the first-order equation may aid in a more accurate prediction of the release of potassium from soils. The ability to make proper potassium fertilizer recommendations may be improved. Soil fertility is one factor that is of major concern in the reclamation process. The information presented in this paper may aid in making proper potassium fertilizer recommendations for areas disturbed by surface mining.

326. Elkins, N. Z., L. W. Parker, E. F. Aldon, and W. G. Whitford. Responses of Soil Biota to Organic Amendments in Stripmine Spoils in Northwestern New Mexico. J. Environ. Qual., v. 13, No. 2, 1984, pp. 215-129.

The effects of organic amendments and topsoiling on soil biota and organic matter decomposition were evaluated to determine the efficiency of organic amendments in restoring soil biological processes. Three treatments were imposed on a northwestern New Mexico coal mine spoil: (1) 0.5-ha deep-contour (20-cm) furrow amended with bark (10 Mg ha^{-1}), (2) barley straw (5 Mg ha^{-1}), and (3) reclaimed spoil utilizing standard topsoiling procedures. The control was an undisturbed (unmined) pinyon-juniper woodland. Decomposition rates and soil biota were determined by burying 10 g of straw placed in fiberglass mesh litterbags at a depth of 10 cm within each treatment area. A total of 30 litterbags were buried per treatment in early June. Periodically during the growing season, 10 litterbags were removed for estimation of decomposition rates, nematode and microbial populations, and soil microarthropod populations.

After 1 month, bacterial numbers were low in all treatments, protozoan numbers were significantly higher in the bark- and straw-amended treatments, and total fungal hyphal lengths were similar among all treatments. After 3 months, all microbial components showed an increase in all treatments. Bacterial, protozoan, and fungal estimates were highest in litterbags on the bark-amended site and lowest in litterbags on the unmined site. On the final sampling date, bacterial numbers were identical between the bark and straw amendments and significantly higher than those for the unmined soil. No significant differences existed between treatments in protozoan or fungal numbers. The density and diversity of microarthropods were highest and similar in unmined soil and bark-amended spoil. The lowest diversity and density were found in topsoiled spoils. Treatments were grouped based

on decomposition rates; topsoil- and straw-amended spoils had similar rates, as did the unmined and bark-amended spoils. The unmined and bark-amended spoils had greater loss of straw at the final two sampling dates than did the topsoil and straw treatments. The decomposition rate of burned straw on bark-amended spoil was not significantly different from that on the unmined area. Spoils with organic amendments yielded consistently higher population parameter estimates than did nonamended spoils, with the bark amendment providing higher decomposition rates and population parameter estimates than straw amendments.

327. Elliot, H. A. Land Application of Municipal Sewage Sludge. J. Soil and Water Conserv., v. 41, No. 1, 1986, pp. 5-10.

This general article discusses the option of land application of municipal sewage sludge in terms of impacts on soil fertility, environmental and health effects, alternative land-based options, and management guidelines, and the future outlook of land application. The growing preference for land application, 42 pct of all municipal sludge disposal, is due to economic, environmental, and regulatory constraints on alternative methods. Mined land may provide an excellent opportunity for disposal of large quantities of sewage sludge. Based on current disposal methods, the use of land application for municipal sludge disposal will continue to increase.

328. Ellis, J. E., and W. J. Parton. Impact of Strip-Mine Reclamation Practices: A Simulation Study (U.S. Fish and Wildl. Serv. contract 14-16-0008-2107 and Interagency Agreement EPA IAG-D6-E685, Natl. Res. Ecol. Lab., CO State Univ.). U.S. Fish and Wildl. Serv., W/Coal-78/W5, Mar. 1977, 329 pp.

A computer simulation model is described that replicates, in a reasonable fashion, the response of a strip-mined site to a variety of reclamation procedures and changes in the environment. The model was developed and tested using soil abiotic and biotic data from undisturbed plant communities around Colstrip, MT. The major components of the model include abiotic, producer, decomposer, ruminant, and sediment production submodels. The flow of water in the system, the temperature profile in the plant canopy and soil, and loss of soil due to wind and water erosion are simulated in the abiotic submodel. The producer submodel simulates the flow of carbon in the plant shoot-root system for a variety of plant species. The biomass dynamics of the microbes, nitrogen cycling in the soil-plant system, and decomposition of litter and dead roots are simulated by the decomposer submodel. The ruminant model simulates the flow of carbon and nitrogen through the grazing animals. The sediment production model is concerned with sediment load in the runoff water. The model was used in computer simulation runs, which showed that the ecosystem studied is extremely responsive to nitrogen. The simulations indicate that nitrogen may be the major factor limiting the rate at which ecosystem processes occur. Topsoil is critical to all other aspects of reclamation as a source of nitrogen and organic matter. The authors stress that the reclamation simulation model presented in their report should be considered preliminary and not directly applicable to regions with climate and soil characteristics different from those in the Colstrip, MT, area for which it was developed. Additionally, it should be pointed out that, at the time of their report, the authors had not tested the model with data other than those used to initially develop the model. The program may be applicable to reclamation efforts in the Colstrip area and could provide an excellent starting point for reclamation studies and planning in the Northern Great Plains and Rocky Mountain Coal Mining Regions. Since this report deals with a computer model and not actual field studies, the ratings represent the apparent treatment of these subject areas by the simulation model and the conceptual basis for the model.

329. Emerson, L. D. A Substitute Topsoil Plan for Reclamation of a Mountaintop Removal Mine in Southern West Virginia. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 274-276.

Overburden materials, mudstone and sandstone, were identified as having physical and chemical characteristics conducive to plant growth. A reclamation plan was developed that utilized these materials as a topsoil substitute at a surface mine site in southern West Virginia. The site was distinguished by its steep topography and thin native soils. Nutrient and texture analyses of the substitute and native soil materials show that with the exception of phosphorus and clay content, the substitute soil material is superior to the native soil. Using the substitute topsoil material, a soil management plan was developed to remedy the limiting factors of the topsoil substitute to plant production, water-holding, and nutrient-exchange capabilities. The area was fertilized, and an annual grass-legume cover crop was established.

After one growing season the mixture was tilled into the substitute material as a green manure. The action resulted in increased nutrients, water-holding capacity, and organic matter. Through weathering, the green manure helped to break up the larger stones in the topsoil substitute material. The area was again fertilized and reseeded in a permanent hay-and-pasture mix. One deficiency of this study is that soil testing was not used to verify that the

cation-exchange capacity or water-holding capacity of the topsoil substitute material had been improved through the organic additions. This study does, however, demonstrate that topsoil substitutes, in this study mudstone and sandstone overburden, can be used as a growth medium capable of supporting vegetative growth and are an alternative to native topsoils that are thin or highly weathered.

330. Emrich, S. L. Methods for Evaluating Diversity. Paper in Symposium on Western Coal Mining Regulatory Issues: Land Use, Revegetation, & Management (West. Reclam. Group, Denver, CO, Apr. 1982). Range Sci. Dep., CO State Univ., Fort Collins, CO, Sci. Ser. 35, Aug. 1983, pp. 43-46.

The author examines the concept of establishing a diverse, effective, and permanent vegetative cover and discusses general methods of establishing species diversity. A method for evaluation of species diversity that has been proposed by the Colorado Mine Land Division is described. The method is a species composition approach utilizing premine, baseline data. Consequently, it circumvents some of the problems sometimes encountered using the reference area approach.

331. Energy and Mineral Resources Research Institute, Iowa State University. Iowa Coal Project, Report to the Legislature. IA State Univ., Ames, IA, Rep. IS-ICP-57, July 1977, 18 pp.

This publication provides a brief synopsis of the numerous research studies conducted under a program called the Iowa Coal Project. The major objective of the project was to demonstrate state-of-the-art economic coal mining, coal processing, and mineland reclamation methods. To that end, a full-scale demonstration mine, beneficiation plant, and reclamation project were instituted. Agricultural row-crop production was the targeted postmining land use. The agronomic studies examined the growth of corn (*Zea mays* L.), soybeans (*Glycine max* (L.) Merr.), and tomatoes (*Lycopersicum esculentum* Mill.) under different tillage systems. The results of these studies indicated that deep tillage of replaced soil is necessary to obtain the greatest possible yields. Tomatoes were used as an indicator crop. No nutrient deficiencies or toxicities were observed. Compaction, however, increased moisture deficiency during drought periods and restricted rooting. This report, together with earlier and later progress reports, is an excellent reference for reclamation of surface-mined land for agricultural row-crop production. Water quality, crop production, and overburden characterization data are contained in the progress reports.

332. Energy Resources Co., Inc. Low-Rank Coal Study, National Needs for Resource Development, Volume 4—Regulatory, Environmental, and Market Analysis. U.S Dep. Energy contract DOE/FC/10066-TI (v. 4), Nov. 1980, 224 pp.

This document is volume 4 of a six-volume study. The purpose of this portion of the study was to formulate scenarios for low-rank coal development, characterize the resource, evaluate existing and required technology, review the regulatory requirements and constraints, analyze environmental impacts, and provide a market analysis. The document provides a good review of Federal and State regulations affecting coal mining and mine-land reclamation. Factors affecting mine-land reclamation are treated in a relatively general manner. The scope of the document is designed for nationwide applications.

333. Erazo, F. Superabsorbent Hydrogels and Their Benefits in Forestry Application. Paper in Meeting the Challenge of the Nineties: Proceedings, Intermountain Forest Nursery Association (Oklahoma City, OK, Aug. 10-14, 1987). U.S. For. Serv., Gen. Tech. Rep. RM-151, 1987, pp. 14-17.

The possible uses of superabsorbents, cross-linked polymers that absorb and retain fluids hundreds of times their own weight, in forestry applications are presented. A brief history of the development of superabsorbents and types of superabsorbents available are given. In horticulture and agriculture, propenoate propenamide copolymers have been used as soil additives to increase water-holding capacity, improve aeration and drainage in soils, reduce irrigation frequency, increase shelf life, and maintain moisture equilibrium. In forestry, root dipping in a superabsorbent may help to improve field survival of bare-root seedlings by keeping roots in a moist condition, thereby preventing roots from drying out during storage and shipping.

334. Erickson, A. E., L. W. Jacobs, and P. E. Sierzega. Improving Crop Yield Potentials of Coarse Textural Soils With Coal Ash Amendments. Paper in Proceedings: Eighth International Ash Utilization Symposium, Volume 1 (Washington, DC, Oct. 28-31, 1987) Electr. Power Res. Inst., Palo Alto, CA, 1987, pp. 26-1—26-11.

Fly ash was applied to droughty coarse-textured agricultural soil as an amendment to study its effect on water-hold capacity and corn (*Zea mays* L.) yields. Methods of incorporation and effects of high fly ash additions on crop growth, yield, and potential environmental problems were evaluated. Experimental treatments included an unplowed

control, plowed control, and 2 in (270 mt acre^{-1}), 3 in (410 mt acre^{-1}), and 4 in (540 mt acre^{-1}) of fly ash plowed into the soil. Yield and chemical composition of the planted corn, soil moisture content, leachate, and soil chemical composition were monitored. Fly ash incorporated in bands increased infiltration and water storage capacity of the sandy and sandy loam soils studied, thereby decreasing percolation through the soil. Corn yield response to fly ash additions was variable. First-year results show that plowing and fly ash additions had similar effects on corn yield; there were increases over the yield obtained for unplowed controls. Second-year field data, however, show that fly ash additions resulted in higher corn yields, which may not be sustained in succeeding years. Plant tissue analysis showed that boron and molybdenum were the only nutrients that were significantly increased by fly ash additions. Concentrations of other macro-, micro- and nonessential elements were not significantly different among the various treatments. Soil analysis indicates that pH was increased because of ash additions, but the solubility of iron and manganese decreased. In some cases, extractable molybdenum increased significantly because of fly ash amendments. All boron levels were, however, below detection limits. Corn yields and soil moisture content were significantly increased with fly ash amendments.

335. Erickson, P. M. Oxygen Content of Unsaturated Coal Mine Waste. Paper in Control of Acid Mine Drainage. BuMines IC 9027, 1985, pp. 19-24.

Oxygen availability in coal refuse and spoil was determined to gain an understanding of oxygen's potential to control acid production. The rate of acid production is controlled by the rate-limiting step in the chemical reactions of pyrite. Laboratory investigations indicated that pyrite oxidation was dependent on the partial pressure of oxygen. This study characterized gas composition profiles in coal mine refuse and spoil. Soil gas probes were installed in four inactive coal refuse disposal areas. Atmospheric oxygen levels were found only in the upper 30 cm of refuse. The concentrations were low at times, which restricted pyrite oxidation. The refuse showed a strong seasonal dependence in gas composition. The oxygen profile was sharp and exhibited the greater change in the upper 15 cm of refuse during the summer, while during the winter oxygen was found at significant concentrations at greater depths. Pore gas composition was also monitored at three regraded surface mines. Oxygen profiles were distinctly different from those found in the coal refuse. Oxygen concentrations of 5 to 20 pct occurred to depths of several meters, but oxygen usually decreased with depth.

Results show that gas composition monitoring can provide information on the location of pyritic oxidation zones. The results also suggest that inert cover materials may not be useful as diffusion barriers to reduce pyrite oxidation. Covering refuse or spoil with an oxygen-containing layer is a better pyrite oxidation control strategy. This layer may be vegetation, an active microbial population, or decaying organic matter.

336. Erickson, P. M., R. W. Hammack, and R. L. P. Kleinmann. Prediction of Acid Drainage Potential in Advance of Mining. Paper in Control of Acid Mine Drainage. BuMines IC 9027, 1985, pp. 3-11.

The potential for acid mine drainage is commonly determined using one of two techniques, acid-base account or weathering tests. Both tests have their limitations. This article discusses research to improve acid drainage prediction. Research is being conducted that addresses the validity of using available overburden analysis techniques to predict postmining drainage quality and focuses on the development of empirical predictive schemes that encompass mining-related variables.

337. Erickson, P. M., R. L. P. Kleinmann, and S. J. Onysko. Control of Acid Mine Drainage by Application of Bactericidal Materials. Paper in Control of Acid Mine Drainage. BuMines IC 9027, 1985, pp. 25-34.

A review is presented of anionic surfactant solutions as a technique for controlling acid mine drainage through the control of *Thiobacillus ferrooxidans*. Sodium lauryl sulfate (SLS) is the active bactericidal ingredient. Progress on two alternative procedures to the surfactant solution technique is reported. The first procedure involves the use of slow-release surfactants, each containing SLS as the active ingredient. Results of laboratory, pilot-scale, and field experiments on the controlled or slow-release concept are presented. These results indicate that controlled release is a feasible means of extending the bactericides' effectiveness in controlling acid production. Organic acid inhibitors were tested as alternative controls of *T. ferrooxidans*. The bactericidal effectiveness of potassium sorbate and sodium benzoate were tested. Both organic inhibitors were as effective as the surfactant solution in controlling acidification and acid mine drainage in pilot-scale tests. A field test is being conducted to evaluate potassium benzoate in reducing acid mine drainage.

338. Erickson, P. M., K. J. Ladwig, and R. L. P. Kleinmann. Acid Mine Drainage From Inactive Eastern Coal Operations. Environ. Geochem. Health, v. 7, No. 1, 1985, pp. 16-25.

The results of several field studies to determine the location of pyritic oxidation and the migration pathways of oxidation products at inactive spoil and refuse sites are presented. Pore space gas composition within unsaturated refuse and spoil was sampled to identify probable zones of active pyrite oxidation. Hydrologic studies monitored the acid loading of saturated spoils and the migration of pyrite oxidation products toward discharge points. Gas composition surveys were conducted at three sites. Gas probes were installed at depths ranging from 15 to 91 cm. Oxygen concentration in the upper 20 cm of refuse was slightly lower than the nominal concentration of air, while below 60 cm the refuse was poorly oxygenated. Atmospheric monitoring of regraded surface mine spoils indicated that oxygen concentrations decrease with depth, but the spoil atmosphere is well oxygenated to a greater depth than is the refuse. Varying particle size distributions and moisture retention properties may be responsible for the higher diffusion rates in spoil materials. Series of observation wells were established to monitor water quality and water levels at the three reclaimed surface-mined sites. At each site there was extreme spatial variability in water quality. Water quality near the bedrock seepage areas was significantly better than the quality at the discharge points. Degradation of influent water occurred as it flowed through the spoil.

339. Erickson, W. R. McKinley Mine: Vegetation Bond Release Criteria Based on Soil Conservation Service Technical Guide Range Site Descriptions. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surface Min. and Reclam., 1985, pp. 114-116.

This article describes the approach taken by the Pittsburg and Midway Coal Mining Co. to have its permanent program permit application for its McKinley Mine in New Mexico accepted by the U.S. Office of Surface Mining Reclamation and Enforcement (OSMRE). After several attempts, OSMRE and the New Mexico Mining and Mineral Division accepted the Technical Guideline Range Site Descriptions as revegetation success standards (criteria) developed locally by the Soil Conservation Service (SCS). These site descriptions were used with Order III soil survey information to develop revegetation standards. The development of revegetation success criteria involved four phases: (1) all soil types identified by the Order III baseline soil inventory were listed, (2) a aerobic soil profile for reclaimed lands was established, (3) the generic reclaimed soil description was compared with the nine Range Site Descriptions, and (4) the Loamy Range Site Description was used to establish the revegetation success criteria. The specific standards for cover, productivity, and diversity for revegetation success are presented.

340. Evangelou, V. P., and R. I. Barnhisel. Sampling Surface Mine Lands Before and After Mining. Dep. Agron., Univ. KY, Lexington, KY, AGR-41, July 1981, 7 pp.

This extension service publication provides an excellent outline for the procedures to be followed in collecting representative soil samples for fertility analysis of natural soil and surface-mined lands.

341. Evangelou, V. P., and J. H. Grove. Evaluation of Changes in the Chemical Equilibria of Soils/Spoils During Wetting-Drying Cycles Using a Computer Model (REC-1). Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 381-386.

This research was conducted to explain why the solution composition is needed in planning the reclamation of gypsiferous soils and to show how a computer model might be used to answer questions pertinent to the mechanics of reclamation. The solution composition of gypsiferous soils is needed because plant growth will be depressed if soluble salts are too high. The computer model developed (REC-1) used three major factors that control spoil solution composition and concentration: (1) the thermodynamic solubility product constant of gypsum, (2) selectivity coefficient for calcium-magnesium exchange on colloid surfaces, and (3) ion pair stability constants for $CaSO_4$ and $MgSO_4$ monomers. Data from the literature were used to test the model. The model can be used for soils and spoils that have a pH greater than 5, or a pH below 5 if the iron and aluminum concentrations in solution are negligible. This model can be used to (1) predict the actual calcium-magnesium ratio of limed coal spoils, (2) predict the sulfate concentration of limed coal spoils, and (3) predict solution compositions at low soil-water ratios between field capacity and permanent wilting point.

342. Evangelou, V. P., and J. H. Grove. Salts in Eastern U.S. Coal Spoils. Coll. of Agric., Coop. Ext. Serv., Univ. KY, Lexington, KY, Reclam. News and Views, v. 1, No. 5, Apr. 1982, 7 pp.

The source and significance of soluble salts in the Eastern United States are identified. Salt compounds and problems are generally associated with the original geologic strata or with pyritic oxidation, which contributes to the disintegration of relatively unstable minerals, resulting in salt formation that occurs when these strata are exposed. The various effects of salts on plant growth are presented, along with the methods used to evaluate salt-affected spoils. Five permanent practices to alleviate salt-affected spoils are presented.

343. Evangelou, V. P., J. H. Grove, and F. D. Rawlings. Rates of Iron Sulfide Oxidation in Coal Suspensions. J. Environ. Qual., v. 14, No. 1, 1985, pp. 91-94.

The relative reactivity of pyrite according to spoil particle size fraction was determined in order to facilitate the control of acidity in sediment ponds where spoil materials are segregated and trapped. Western Kentucky pyritic spoil samples were collected, and the role of spoil particle size (<0.5 mm and 0.5 to 2.0 mm) on pyritic oxidation was evaluated. Each size fraction was treated with reagent-grade $CaCO_3$ at 0, 14.4, and 28.8 g kg^{-1}. Microbial growth was inhibited in another treatment by adding toluene to unlimed spoil particles. Electrical conductance (EC) measurements were taken after samples were incubated; increases in EC values represented the oxidation of pyrite. Suspension pH values remained stable in all treatments during the incubation period. Electrical conductivity values ranged from 0.9 to 1.5 dS m^{-1}; pyrite oxidation was most evident in suspensions of large soil particles. The solution phase of the large particle size suspensions was dominated by sulfates, mainly those of calcium and magnesium. Lime application at 14.4 g kg^{-1} to the small particle size fraction enhanced the oxidation-dissolution process during the initial phase of the reaction. Lime additions to the large particle size fraction at 28.8 g kg^{-1} resulted in three rates of oxidation-dissolution. These rates represent three stages of solid-phase and solution interaction.

344. Evangelou, V. P., L. W. Murdock, and F. J. Coale. Oil Well Salt Brine Contaminated Soils: Their Chemistry and Reclamation. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 443-446.

This study was conducted to determine the sodium threshold contamination points of soil contaminated by brine discharge from oil wells located in McLean County, KY. Soil samples were taken from an agricultural field across a salt gradient and analyzed for extractable calcium, magnesium, sodium, and potassium and electrical conductivity (EC). A greenhouse pot experiment was conducted with the most contaminated sample alone and amended with four rates of gypsum: 5, 114, 12,000, and 25,520 lb $acre^{-1}$. The pots were continuously leached until the EC of the leachate was below 3 mmho cm^{-1}. Three types of problems are generally recognized when soils are contaminated by oil well salt brines: (1) the sodium buildup in the soil solution is toxic to plants, (2) the salt buildup causes high osmotic pressures, and (3) an unbalanced solution is produced that causes soil dispersion due to sodium dominance.

This study demonstrates how the degree of sodium contamination can be predicted. If the sodium concentration in a saturation extract exceeds 4 meq L^{-1}, then a sodium adsorption ratio (SAR) should be calculated. If the SAR approaches 10, then the amount of sodium present should be determined in an ammonium acetate extract, and the amount of gypsum needed can be estimated. The greenhouse pot experiments demonstrated that gypsum applications and leaching are effective treatments for reclaiming sodium-contaminated soils. Soybeans (*Glycine max* (L.) Merr.) seeded in the pots grew normally only if gypsum was applied. When no gypsum was applied, high EC's and pH's resulted, compared with the other treatments, and water did not move through the soil.

345. Evangelou, V. P., K. Roberts, and G. W. Szekeres. The Use of an Automated Apparatus for Determining Coal Spoil Carbonate Types Content and Reactivity. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 163-166.

Quantification of carbonates in disturbed geologic systems is necessary to predict processes and the degree of influence on the natural environment. Carbonate minerals may have different effects due to differences in solubility and reactivity. The type of carbonate present and the degree of armoring are important in determining its neutralization effectiveness. This study demonstrates that carbonates do have different rates of reactivity. The carbonates studied were siderite, calcite, and dolomite present in the geologic strata. The different rates of carbonate acid reactivity were based on the type and degree of armoring. A manometric technique was utilized. This technique is based on the different rates of dissolution of each carbonate species when reacted with excess 5-mol-L^{-1} HCl. The decomposition of carbonates in the HCl acid is a pseudo-first-order reaction. The rate constants for the three minerals were 27.64, 6.75, and 0.23 h^{-1} for calcite, dolomite, and siderite, respectively. These rate constants show the effectiveness of calcite and dolomite in neutralizing acid drainage. The technique used in this study can be utilized as a means of quantifying the reactivity of residual spoil carbonates. The effectiveness of carbonates in neutralizing or controlling acid mine drainage can be predicted using this technique.

346. Evangelou, V. P., and W. O. Thom. Coal Spoil Chemistry Interpretations and the Effect of Spoil Chemical Changes in the Continuity of Nutrient Availability. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue

Univ, South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 55-67.

This paper provides a discussion of the physical and chemical factors limiting tree establishment and growth on surface-mined lands and how they may be expected to shift with time. The authors stress that establishment of trees or any other type of vegetation is subject to solution-phase chemistry. Problems with vegetation establishment may be due to high salinity levels and/or magnesium dominance of the spoil water system. The results used in the discussion originate from research conducted in southern Ohio and eastern Kentucky. The paper provides a good reference for understanding nutrient availability based on soil solution-phase chemistry in the soils of this area.

347. Evans, R. K., E. C. Varsa, B. P. Klubek, and P. Baskins. The Effects of Refuse-Sewage Sludge Compost on Field Crops and Selected Soil Properties. Am. Soc. Agron., Agron. Abstr., 1987, p. 25.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. A commercially processed municipal refuse-sewage sludge compost was evaluated as a soil amendment over a 3-year period on farmland in southern Illinois using a corn-soybean-corn rotation. Compost was applied at 0, 12, 24, 48, and 96 Mg ha^{-1} (dry), with supplemental nitrogen, phosphorus, and potassium fertilizers added alone or in combination with the first three rates of compost. During the first growing season severe nitrogen deficiencies were observed at the highest compost rate. Where no fertilizers had been used, when compared with controls, yields were reduced by 15 to 40 pct on the high-compost plots. When fertilizers were added, the highest yields were obtained. Compost additions had little effect on yield during the second 2 years of the study; however, compost did increase the levels of soil organic matter and available phosphorus and potassium and reduced soil bulk density.

348. Everett, C. J. Effects of Biological Weathering on Mine Soil Genesis and Fertility. Ph.D. Thesis, VA Polytech. Inst. and State Univ., Blacksburg, VA, 1981, 125 pp.

This study was conducted to understand the role of biological weathering in mine soils derived from overburden rock from Buchanan County, VA. The objectives of the study were (1) evaluate plant-available phosphorus and potassium in fractured overburden rock, (2) identify the effects of biological weathering on fractured overburden rock and describe the processes involved, and (3) assess the impact of biological weathering on the availability of phosphorus and potassium to plants. Two separate greenhouse experiments were conducted to determine plant-available phosphorus and potassium and to identify the effects of biological weathering on soil properties. The results of these experiments indicate that plant-available phosphorus and potassium are influenced by biological weathering. By removing bases and producing acids, the plants caused acidification of the soil material. This process solubilized the phosphorus and increased the amount available for plant uptake. As the apatite dissolves, however, the amount of phosphorus available declines and becomes limiting. Potassium was described as adequate for plant growth. Since there were considerable amounts of mica present in the soil material, the author feels that the biological weathering process will constantly replenish the soil solution with potassium from mica.

349. Everett, H. W., D. S. Henry, and S. A. Sanders. Establishment of Some Forage Species on Mine Spoil in Kentucky. Paper in Fifth Symposium on Surface Mining and Reclamation (NCA/BCR Coal Conf. and Expo IV, Louisville, KY, Oct. 18-20, 1977). Natl. Coal Assoc. and Bitum. Coal Res., 1977, pp. 12-15.

This paper provides a brief description of two studies conducted on mine spoil in both eastern and western Kentucky. The purpose of these studies was to evaluate methods of establishing several potentially useful forage species on mine spoil. Eight different grasses and legumes were planted alone or in mixtures with five different methods of establishment. The preliminary results reported indicate that when fresh mine spoil has the proper pH and nutrients available, several species can be established for erosion control and for forage production without the use of straw mulch. Rating for ground cover 6 months after seeding, however, showed that woodbark and straw mulch produced more cover. Percent ground cover due to seeded species only (biomass) was less with straw mulch treatments.

350. Fairbanks, B. C., G. A. O'Connor, and S. E. Smith. Mineralization and Volatilization of Polychlorinated Biphenyls in Sludge-Amended Soils. J. Environ. Qual., v. 16, No. 1, 1987, pp. 18-25.

Sewage sludge addition is a potential route of polychlorinated biphenyls (PCB's) entry into soil. This may limit the use of sewage sludge on agricultural lands as a fertilizer and soil conditioner source because of the potential hazard and toxicity of PCB's. The effects of sewage sludge amendments on the mineralization and volatilization of PCB's (^{14}C-Aroclor 1254) were monitored for 240 days in three calcareous New Mexico soils: a clay soil and two

sandy loam soils. Rate constants were used to describe mineralization and volatilization and to compare the treatment effects of sludge addition (45 or 90 Mg ha^{-1}), PCB concentration (5, 50, or 500 mg kg^{-1}), soil textural class, and the length of sludge incubation with soils prior to experimentation. Volatilization of organics, including the original PCB's, was the major means of ^{14}C loss in unamended soils and all 500-mg-kg^{-1} PCB treatments. Volatilization of organics ranged from 5 to 31 pct, with the total loss of PCB's ranging from 8 to 33 pct. The predominant treatment effect on ^{14}C-organic volatilization was the rate of sludge addition. Volatilization rates were reduced with sludge addition, especially in the sandy loam soils treated with 5 and 50 mg kg^{-1} PCB's. Soil factors such as clay and organic matter content increased ^{14}C-Aroclor 1254 mineralized in the soils studied. Of the added ^{14}C-Aroclor 1254, 1 to 11 pct was evolved as $^{14}CO_2$ after 240 days. Carbon-14 evolution and detoxification increased with sewage sludge addition and decreased with increasing PCB concentration. At 5 mg kg^{-1} PCB, mineralization exceeded volatilization in sludge-amended soils. Sewage sludge may have increased the chance of contact between bacteria and PCB's. The results show that sewage sludge applications did not increase the environmental hazard of Aroclor 1254 in the soils studied.

351. Farina, M. P. W., and P. Channon. Acid-Subsoil Amelioration: I. A Comparison of Several Mechanical Procedures. Soil Sci. Soc. Am. J., v. 52, No. 1, 1988, pp. 169-175.

This study was concerned with subsoil acidity of noncoal mined lands. Subsoil acidity, particularly high levels of exchangeable aluminum, is recognized as a limiting factor to plant productivity, through restricted root development. Several mechanical procedures and conventional gypsum applications were evaluated in a field experiment, with corn (*Zea mays* L.) as the test crop, to assess the practicalities of ameliorating strongly acidic subsoils. Conventional moldboard incorporation of gypsum (0.25 m) was compared with the following mechanical procedures: (1) gypsum incorporation using a deep moldboard plow (0.50 m), (2) gypsum incorporation using a Wye-double-digger (0.50 m), (3) a modified subsoiler that incorporated ameliorated topsoil to depths of 0.45 and 0.90 m, and (4) a deep limer designed to ameliorate vertical bands of soil at similar depths. All of the mechanical procedures tested were found to be superior to conventional application procedures. Results show that there was poor root growth outside of the zones where gypsum or ameliorated topsoil had been placed. Roots that grew into unlimed soil exhibited symptoms of aluminum toxicity. Yield responses to mechanical treatments were related to increases in rooting volume and changes in root configuration. This research has practical application for gypsum amendments applied to coal surface-mined lands. Recent studies have been conducted on acid-subsoil amelioration on replaced coal mine soils in the Eastern United States. This study on mechanical profile modification serves as a good reference to the research conducted on coal mine soils.

352. Farina, M. P. W., and P. Channon. Acid-Subsoil Amelioration: II. Gypsum Effects on Growth and Subsoil Chemical Properties. Soil Sci. Soc. Am. J., v. 52, No. 1, 1988, pp. 175-180.

The effects of gypsum (10 Mg ha^{-1}) on corn (*Zea mays* L.) yield, root development, and nutrient uptake, the possible mechanisms of soil amelioration by gypsum, and the economic considerations when gypsum is used as a soil ameliorant were assessed on noncoal soils over a 4-year period. The soil studied was strongly acidic to 1 m. Grain yields were increased by gypsum application, which reflects an improvement in subsoil chemical properties in those plots that were treated. During the first growing season, gypsum had little effect on rooting depth, which the authors attribute to low rainfall. In years of normal rainfall, root development and density were greater on gypsum-treated plots than on conventionally limed plots (15 Mg ha^{-1}). The movement of calcium and magnesium through the soil profile is evident, and further accumulation of calcium and magnesium in the subsoil horizons is expected in gypsum-treated plots. No movement of potassium was detected. Extractable and exchangeable sulfate sulfur and exchangeable aluminum and percent aluminum saturation on gypsum-treated plots were reduced by gypsum application and movement through the soil profile. Subsoil pH (water) increased as a result of gypsum application. The authors conclude that surface applications of gypsum, under suitable soil and environmental conditions, reduce the negative growth effects of subsoil aluminum on corn. This study serves as a good reference to the possible use of gypsum as a acid-subsoil ameliorator on coal mined soils.

353. Farmer, E. E., and B. Z. Richardson. Acid Mine Waste Revegetation: Influence on Soil-Water Quality. U.S. For. Serv., Intermt. For. and Range Exp. Stn., FSRP/INT-266, Jan. 1981, 12 pp.

This publication summarizes the results of a 5-year study of soil-water ionic concentrations of copper, iron, and sulfate at the Blackbird copper-cobalt mine near Salmon, ID. Soil-water samples were collected using ceramic cup samplers installed in an acid-producing overburden waste dump. Part of the waste dump was treated with lime, topsoil, and fertilizer and then reseeded to establish a heavy stand of grass. Another portion of the

waste material remained untreated. Both areas exhibited decreasing soil-water ionic concentrations of copper, iron, and sulfate. The revegetation procedures used in this study did not affect the concentrations, compared with those in the untreated portion of the waste material. The authors stress that the major purpose and importance of revegetating spoils and waste dumps is to control surface erosion. They suggest that in the case of this mine, the vegetation established also controls dust.

354. Farmer, E. E., and G. E. Schuman. Reclamation of Uranium Mining and Milling Disturbances. Ch. in Environmental Consequences of Energy Production: Problems and Prospects, ed. by S. K. Majumdar, F. J. Brenner, and E. W. Miller. PA Acad. Sci., 1987, pp. 182-197.

This chapter discusses the problems associated with reclaiming uranium mining and milling wastes and the reclamation techniques available. Past efforts to reclaim uranium wastes have been unsuccessful because of operator attitude, the nature of the waste material, the arid or semiarid climate of most site locations, and the demands of uranium reclamation. Wastes left from mining and milling, such as overburden, acid-leach piles, and tailings, are radioactive and potentially hazardous. Additionally, wastes may have a variety of chemical and physical characteristics that make them difficult to reclaim, including (1) pH values greater than 9 or less than 5.5, (2) textural problems, both fine and coarse, (3) high bulk-density values, (4) surface crusting, and (5) low saturated hydraulic conductivities. If vegetative stands are to be permanent, it is necessary to reestablish nutrient cycles on revegetated lands. It may be necessary to develop a long-term fertilization program to maintain nutrient cycling on reclaimed land. The goal of uranium waste reclamation is to isolate all radioactive materials and take measures to ensure that they stay on-site. Methods and technologies developed for coal mined land reclamation in semiarid and arid areas are applicable to uranium reclamation. The authors assert that the current reclamation technology is adequate for the revegetation of uranium mined lands; however, before any reclamation operation, the tailings, overburden spoils, topdressing soils, and other disturbed soils should be sampled to determine their radiological, chemical, and physical properties. The authors state that the most important points regarding reclamation of uranium mining and milling wastes are the management implications of the current technology.

355. Farmer, R. E., Jr., M. Cunningham, and M. A. Barnhill. First-Year Development of Plant Communities Originating From Forest Topsoil Placed on Southern Appalachian Minesoils. J. Appl. Ecol., v. 19, No. 1, 1982, pp. 283-294.

The authors evaluated the revegetation potential of forest topsoil from mixed deciduous stands spread over mine soil in the Cumberland Mountains of eastern Tennessee. Forest topsoil from three sites near the mining operation was collected and spread over mine soils to a depth of 2 to 3 cm. Ammonium nitrate (168 kg ha^{-1}) and triple superphosphate (280 kg ha^{-1}) were broadcast on the site after the topsoil had been spread. An average of 286 plants per square meter, representing 134 taxa, had emerged by late May, and over 90 pct of these plants survived the entire growing season. The number of plants did not significantly change with either topsoil or mine soil as substrate. At the end of the growing season, shoot and root weight was approximately 8.4 mt ha^{-1}. The authors conclude that forest topsoils found in the areas being mined in the Cumberland Mountains can provide diverse plant communities capable of quick, effective cover that has the potential for developing into forests.

356. Farr, W. A., and E. W. Ford. Site Quality, Forest Growth, and Soil-Site Studies in the Forests of Coastal Alaska. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, April 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 49-54.

Studies are described that are designed to obtain information on site quality, forest growth, and soil-site relationships in southeastern Alaskan forests. These studies will eventually provide forest managers with information necessary to make reliable estimates of future productivity and yields from managed even-aged stands of western hemlock (*Tsuga heterophylla* (Ref.) Surg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.). The studies are concentrating on the development of height growth and site index equations for even-aged stands and on soil properties in Alaskan coastal environments.

357. Fedkenheuer, A. W., and J. Browne. Reclamation Research for the Future at Syncrude Canada Ltd.: Soil Simulation Revegetation Studies on Tailings Sand. Syncrude Canada Ltd., Edmonton, AB, Canada, Dec. 1979, 8 pp.

This is a very general article concerning Syncrude's efforts to return vast acreages of spent oil sands to a vegetative cover having a productivity at least equal to premine conditions. The location is northeastern Alberta, near Fort McMurray, and the material is the Athabasca tar sands. Syncrude's objective was to return its disturbed areas to forest and wildlife areas, and the field studies include soil building simulations, fertilization, seeding with grasses and legumes, and planting woody seedlings. No

results are given; however, more details can be obtained from the sources listed in the paper.

358. Fedkenheuer, A. W., H. M. Heacock, and D. L. Lewis. Early Performance of Native Shrubs and Trees Planted on Amended Athabasca Oil Sand Tailings. Reclam. Rev., v. 3, No. 1, 1980, pp. 47-55.

The early results are reported of an attempt to establish woody plants on Athabasca oil sand tailings located in northeastern Alberta, Canada. The tailings sand was treated with 10 cm of native sand, 10 cm of lean tar sand, 10 cm of mineral fines, or 20 cm of mineral fines applied over tailings sand. Fifty kilograms per hectare of nitrogen, phosphorus, and potassium fertilizer, along with 15 cm of peat, was applied to each plot and rototilled to a depth of 30 cm. All plots were seeded with a grass-legume mixture at a rate of 11 kg ha^{-1}, followed by tree and shrub plantings. The tree and shrub species utilized in this study were propagated and container grown. The plot treatment that resulted in the highest tree and shrub survival rates was the lean tar sand amendment. The authors feel that the reduced grass-legume cover on this treatment resulted in more moisture being available to the woody species, hence higher survival rates. Preliminary results indicate that the following tree and shrub species had the highest survival rates over the range of treatments used: Saskatoon serviceberry (*Amelanchier alnifolia* Nutt.), jack pine (*Pinus banksiana* Lamb.), lodgepole pine (*Pinus contorta* Dougl.), shrubby cinquefoil (*Potentilla fruticosa* L.), Canada buffaloberry (*Shepherdia canadensis* (L.) Nutt.), and snowberry (*Symphoricarpos albus* (L.) Blake).

359. Fehrenbacher, D. J., I. J. Jansen, and J. B. Fehrenbacher. Corn Root Development in Constructed Soils on Surface Mined Land in Western Illinois. Soil Sci. Soc. Am. J., v. 46, No. 2, 1982, pp. 353-359.

This study compares corn root development in soils constructed after mining and in undisturbed soil (reference area) on experimental plots constructed at the Sunspot Mine in Fulton County, IL. The objectives of the study were (1) to compare corn root systems in four different constructed soils and one undisturbed soil and (2) to relate differences in root system development to measurable differences in the physical and chemical properties of the soils. The soil treatments were (1) topsoil (A horizon) over replaced B horizon (A/B), (2) topsoil over graded dragline cast overburden spoil (A/spoil), and (3) replaced B material only, (4) graded dragline spoil only, and (5) an undisturbed soil as a control. Root penetration and length were recorded for all samples. Based on first-year corn root data, the undisturbed site was most favorable, the A/B intermediate, and the A/spoil least desirable as rooting material. This relationship is consistent with observed differences in pH, bulk density, and soil structure. This suggests that when B horizon soil material is replaced with minimal compaction, it is a more favorable rooting material than dragline spoil.

360. Felipo, M. T., and M. A. Garau. Comparison of Biological and Chemical Methods To Determine Available Nitrogen in Sewage Sludge Amended Soil. Biol. and Fertil. Soils, v. 5, 1987, pp. 26-30.

Sewage sludge application rates are calculated by considering the crop's nitrogen requirement, the total nitrogen content of the sewage sludge applied, and residual soil nitrogen. Two biological and two chemical laboratory methods to determine potentially available nitrogen were compared to quantify the available nitrogen in two sewage sludges (aerobic and anaerobic) incorporated into two different soils. Quantified available nitrogen is defined as the sum of whole-crop total nitrogen and inorganic nitrogen of aerobically treated sludge-amended topsoil (0 to 25 cm). The mean quantified available soil nitrogen increased with sludge additions regardless of test method. The biological methods (leaching and nonleaching incubation procedures) efficiently estimated the potentially mineralizable nitrogen and mineralization rates of sludge-soil mixtures. There was a significant correlation between the amounts of available nitrogen determined by the biological methods. There was no significant relationship between the results of the chemical procedures (acid hydrolysis and 2*N* KCl extraction). There were good correlations between quantified available nitrogen in a field experiment and laboratory methods for aerobic sludge for all methods except acid hydrolysis. The highest coefficient was obtained when the chemical method based on NH_4-N released by KCl was taken into consideration. This method was also correlated with the biological procedures. The NH_4-N released by KCl represents a constant proportion of the total added organic nitrogen. The authors conclude that the NH_4-N released by 2*N* KCl may be used to estimate the available nitrogen in sewage sludge. The available nitrogen determined by this method is less dependent on the rate than the sludge type, and the available nitrogen or sewage sludge is a function of the treatment process. The KCl chemical method gives a good estimation, is easy to use, and is a time-saving procedure in the determination of available nitrogen in sewage sludge, which can be mineralized under field conditions through the growing season.

361. Fenn, L. B., and E. Wu. Effect of Ammonium Fertilizer on NH_3 Loss and Ca, Mg, Ammonium and Nitrate Content in a Calcareous Soil Solution. Biol. and Fertil. Soils, v. 5, 1987, pp. 171-174.

The influence of ammonium (NH_4) fertilizers on calcium, magnesium, NH_4, and nitrate (NO_3) concentrations in the soil solution has not been previously documented. This study examined the effects of NH_4 fertilizers on leachable calcium plus magnesium contents, ammonia (NH_3) losses, and the effect of changes in solution calcium plus magnesium content on nitrification of added NH_4. All experiments were conducted in soil columns (10 cm ID and 30 cm high). Nitrogen sources used were ammonium hydroxide (NH_4OH), ammonium carbonate ($(NH_4)_2CO_3$), ammonium sulfate ($(NH_4)_2SO_3$), ammonium nitrate (NH_4NO_3), and diammonium phosphate ($(NH_4)_2HPO_4$). Ammonium sulfate additions resulted in significantly higher NH_3 losses than did $(NH_4)_2CO_3$ or NH_4OH additions. The $(NH_4)_2SO_4$ treatment reacted with $CaCO_3$ to produce an equal molar amount of $CaSO_4$, thereby increasing the mobility of NH_4. The $(NH_4)_2CO_3$ and NH_4OH treatments resulted in calcium precipitation and decreased ammonium mobility. Leaching each system with 160 cm of water after fertilization resulted in no NH_4 loss in the $(NH_4)_2SO_4$ system. Nitrate content in the leachate, however, was significantly higher, and it appeared faster and in greater quantities in the $(NH_4)_2SO_4$ system than in the $(NH_4)_2CO_3$ or NH_4OH systems. Surface placement of $(NH_4)_2CO_3$, $(NH_4)_2SO_4$, NH_4NO_3, and $(NH_4)_2HPO_4$ immediately leached with 20 cm of water resulted in variable leachate contents of calcium plus magnesium. Again, $(NH_4)_2SO_4$ reacted with $CaCO_3$ to solubilize calcium plus magnesium or it replaced exchangeable calcium plus magnesium with NH_4, resulting in higher leachate contents of calcium plus magnesium. Ammonium nitrate had similar effects on leachate content. Ammonium carbonate and $(NH_4)_2HPO_4$ had lower leachate calcium and magnesium contents, owing to the precipitation of equivalent molar amounts of soluble and absorbed calcium plus magnesium.

362. Ferguson, R. B., and N. C. Frischknecht. Reclamation on Utah's Emery and Alton Coal Fields: Techniques and Plant Materials. U.S. For. Serv., Res Paper INT-335, 1985, 78 pp.

Techniques that could be used in revegetating lands disturbed by mining in the Emery and Alton Coal Fields, UT, are discussed. Since no large-scale surface mining of coal has occurred on these sites, research was limited to treatments that could be applied following severe disturbance with heavy equipment. At the Emery site, soils were prepared for revegetation by gouging, harrowing, or cultipacking in conjunction with alfalfa hay (incorporated) or composted conifer bark (incorporated) as the soil amendments. At the Alton site, soils were prepared for revegetation by using gouging in conjunction with topsoil replacement, grass hay (incorporated), or composted conifer bark (incorporated). Plant species tested at both sites consisted primarily of grass and shrub species adapted to semiarid conditions, along with selected forb and tree species. Physical and chemical properties of topsoil and subsoil by soil amendment are presented for the Alton site. Data were collected on plant establishment, productivity (yield), and survival and growth rates (height and diameter) for shrubs, forbs, and trees. The major findings at both sites are reported along with conclusions and recommendations for reclamation at each site based on 5 years of data on the Emery and 6 years of data on the Alton Coal Fields.

363. Ferguson, R. B., and N. C. Frischknecht. Revegetating Processed Oil Shale in the Upper Mountainbrush Zone of Colorado. U.S. For Serv., Res. Paper INT-321, 1983, 9 pp.

This study was conducted to provide information on methods used to establish vegetation on processed shale disposal areas, located in Garfield County, CO, without using large volumes of water to leach salts from the processed shale. A second objective was to evaluate 14 species on their adaptability to the soil material and climatic conditions of the site. Three amendments were used on the unleached TOSCO II processed oil shale: (1) 15 to 25 cm of topsoil covering, (2) 5 to 10 cm of covering rock fragments, and (3) barley straw (applied at a rate of 0.73 mt ha^{-1} incorporated to a depth of 15 to 20 cm). All of the species used in this study (13 shrubs and 1 forb) were container grown and then transplanted onto the site. After 6 years, the overall survival was four times greater on topsoiled shale than on the straw-mulched shale, and 1.5 times greater on topsoiled shale than on the rock-mulched shale. Plots on north-facing slopes were the most favorable for plant growth. Four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) and prostrate summer-cypress (*Kochia prostrata* (L.) Schard.) grew well on all amended plots. Rubber rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Britt.), mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana* Rydb.), green ephedra (*Ephedra viridis* Coville.), four-wing saltbush, and prostrate summer-cypress were the only species that showed adaptability to topsoil-covered processed oil shale. The authors recommend that processed oil shale be covered with a minimum of 20 cm, or preferably 30 cm, of topsoil before attempting revegetation.

364. Fiedler, D. A., K. W. Brown, and K. C. Donnelly. Mutagenicity of Plants Fertilized With Mutagenic Municipal Sewage Sludge. Am. Soc. Agron. Abstr., 1987, p. 26.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. The mutagenicity of

solvent extractable organics from alfalfa (*Medicago sativa* L.) and coastal bermudagrass (*Cynodon dactylon* L.) grown on a fine sand amended with municipal sewage sludge was evaluated. The Salmonella-microsome bioassay was used to assess mutagenic activity. Sludge was applied at 0, 22.4, 112, and 223 Mg ha^{-1}. Plant extracts did not have a positive response to the bioassay.

365. Fisher, J. T., J. B. McRar, and E. F. Aldon. Methods for Establishing Containerized Native Juniper on Surface Disturbed Sites in the Southwest. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 76-88.

A review of methods for woody plant establishment in the Southwest is provided, in addition to a discussion of current research. Containerized native junipers (*Juniperus monosperma* (Engelm.) Sarg.) were planted on three northern New Mexico mine spoils. Depending on the treatments applied, good to excellent success was obtained. Preliminary results indicate that irrigation and the application of triple superphosphate (0-46-0) are beneficial to seedling survival, whereas slow-release fertilizer (Osmocote 18-6-9) caused mortality. On some sites rodent protection is absolutely necessary. the importance of time of planting is also discussed. Information very useful to reclamation planning is provided.

366. Fisher, S. E., Jr., and F. F. Munshower. Extremely Acid Soils, Overburden and Minesoils in the Great Plains. Paper in Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 186-200.

Extremely acid soils (pH less than 4.5) developing from parent materials high in pyrite and marcasite were recently identified in the Western United States. Mine soils containing significant quantities of acid-forming materials have also been identified in this region. Analytical data are presented on overburden materials from several Western States, containing high concentrations of acid-forming materials. The authors discuss the impact of spoil materials derived from these overburden strata on the formation and characteristics of mine soils and on the establishment of a permanent, effective, and diverse vegetative cover.

367. Fisher, S. E., Jr., F. F. Munshower, and F. E. Parady, III. Selenium. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 109-133.

The importance of selenium in surface mine reclamation and regulation involves the potential contamination of mine soils from the addition of selenium-bearing materials. Such materials may be taken up by crops, forages, or native plants, resulting in potential toxicities to animals, and may affect the quality of ground water and surface water after reclamation. This chapter discusses the metabolic role of selenium for plant growth (not considered essential) and animal nutrition (essential), the distribution and geochemical relationships of selenium, the availability and uptake of selenium by plants, and the various analytical methods for selenium determination. An outline for evaluating existing and potential toxicities to selenium and for surface coal mine reclamation planning is given, along with future research needs.

368. Flint, A. L., and S. Childs. Physical Properties of Rock Fragments and Their Effect on Available Water in Skeletal Soils. Ch. in Erosion and Productivity of Soils Containing Rock Fragments, ed. by J. D. Nichols, P. L. Brown, and W. J. Grant (Proc. Symp., Anaheim, CA, Nov. 28-Dec. 3, 1982). Soil Sci. Soc. Am., Madison, WI, SSSA Spec. Publ. 13, 1984, pp. 91-103.

Available water supply and other soil physical properties were quantified for 40 soils in southwestern Oregon. Field and laboratory techniques for measuring water supply of skeletal soils for specific sites were also identified. The results indicated that the bulk density of rock fragments is a significant factor in the measurement of total bulk density and water content of the skeletal soils studied. Rock fragment porosity was also an important measurement in the determination of water retention and total available water of the soils studied. The authors state that in skeletal soils, measurements of water content should be expressed on a whole-soil basis.

369. Follet, R. H., L. S. Murphy, and R. L. Donahue. Fertilizers and Soil Amendments. Prentice-Hall, 1981, 557 pp.

This book contains 11 chapters on the science and technology of fertilizers and soil amendments. Although written for agronomists and soil scientists interested in increasing crop production, the book contains information on several topics dealing directly with fertilizers and soil amendments that would be of interest to those involved in reclamation. The first chapter of the book is devoted to a general overview of fertilizer use, soil and plant nutrition, and soil-fertilizer-plant relationships.

Chapters 2 to 7 deal directly with fertilizers; separate chapters are included on the following fertilizers: nitrogen, phosphorus, potassium, secondary nutrients (calcium, magnesium, and sulfur), and micronutrients (zinc, iron, copper, manganese, boron, molybdenum, and chloride). Within each of these chapters information is presented on the soil chemistry and reactions in the soil of each nutrient and reactions of the soil when that nutrient is applied as a fertilizer; the role of each nutrient in plant nutrition and the deficiency symptoms when the nutrient is limiting; crop responses to added nutrients; and comparisons among forms (sources) and types of each fertilizer nutrient. Chapter 7 discusses the application and addition of fertilizers to the soil environment by various methods, including gaseous forms, through irrigation water, as solids or liquids, in combination with pesticides, and in foliar applications, and the use of fertilizers in tillage systems. Within this chapter, a section deals directly with the calibration of the various types of equipment used to apply fertilizers and soil amendments in order to optimize the utilization of the added chemical or amendment by the crop under production. The rates of application are discussed in a generalized fashion since they are dependent upon the soil requirement for nutrient or amendment addition. These rates are determined based on soil testing. The efficient plant use of fertilizers and other soil amendments is based on the soil test.

Chapter 8 discusses the use of lime and liming materials. Included in this chapter is information on the benefits of plant response to requirements, types, and applications of lime. Additionally, information is presented on the origin of soil acidity, plant tolerance of soil pH, and the relative productivity of acid soils.

The chapter on the reclamation of saline and sodic soils (chapter 9) should be of particular interest to those involved in the reclamation of surface-mined lands in the Western United States. Included in this chapter are sections on the characterization of saline and sodic soils, the effects of salts on plant growth, the reclamation of salt-affected soils, saline seeps, managing saline and sodic soils, and sampling soils and waters for salinity analysis. The authors state that the reclamation of salt-affected soils requires an assessment of the situation: how bad the situation is, the factors involved, how the affected area can best be reclaimed, and the expense involved. The authors recommend that when sodic or saline-sodic soils are reclaimed, the following procedures be utilized: initially, the soil surface should be reclaimed, followed by the addition of amendments, such as gypsum, to reclaim the soil to greater depths.

Organic amendments, both plant and animal residues, are discussed in chapter 10. The following types of organic amendments are discussed in relation to their beneficial use and possible detrimental effects: crop residues, animal manures, sewage sludges (solid and liquid), composts, green manures, and peat and wood products. The final chapter in this book is devoted to the economic and efficient use of fertilizers and lime. This book is an excellent reference on the use of fertilizers, particularly their sources and applications and their influence on soil and plant nutrient relationships, and other soil amendments used to improve soil fertility and plant nutrition.

370. Ford, E. W., W. A. Farr, and C. Lu-Ping. Preliminary Analysis of Four Soil Variables and Their Relationship to Site Index of Sitka Spruce in Southeast Alaska. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 84-89.

The relationship of site index of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in southeastern Alaska to depth of mineral soil, soil drainage, organic carbon content, and coarse fragment content was examined. No relationship was found between site index and depth of mineral soil; however, significant differences in site index and coarse fragment content were found. The nonskeletal soils tend to be more highly weathered with more available nutrients and greater rooting volume than skeletal soils. Mean site index also declined with decreased drainage. Organic carbon content differences caused only slight changes in the mean site index of Sitka spruce. The authors state that soil taxonomic factors alone may not be reliable predictors of site index; soil physical and chemical properties need to be used in various combinations to reliably predict site index.

371. Fowler, D. K., and L. F. Adkisson. Survival and Growth of Wildlife Shrubs and Trees on Acid Mine Spoil. TN Val. Auth., Div. Land and For. Res., Tech. Note B37, 1980, 49 pp.

This study assessed the survival and growth of selected wildlife plants over a range of acid mine spoil conditions in Campbell and Scott Counties, TN. A second objective was to identify species suitable for surface mine reclamation. Seventeen tree and shrub species were evaluated to assess the effects of soil pH on plant establishment and growth; plots were grouped into seven pH categories ranging from 2.50-2.99 to 5.50-5.99. Tree and shrub performances were determined by assigning minimum acceptable growth and survival criteria in each pH category. Once the species were judged to be acceptable for reclamation use, they were rated as to their short- and long-term suitability for wildlife habitat improvement. Autumn olive (*Elaeagnus umbellata* Thunb.), elaeagnus

cherry (*Elaeagnus multiflora* Thunb.), Arnot bristly locust (*Robinia fertilis* Ashe), sawtooth oak (*Quercus acutissima* Carruth.), red maple (*Acer rubrum* L.) and Toringo crabapple (*Malus sieboldii* (Reg.) Rehd.) were found to be species most useful for quick improvement of surface mine habitat over the range of spoil pH in Appalachian coalfields. Even though this study was conducted before Public Law 95-87 was enacted, the results are useful for selecting species that can be used in a postmining land use design for wildlife habitat.

372. Fowler, D. K., L. J. Turner, and L. J. Slaski. Surface Mine Reclamation for Wildlife: A Model Reclamation Plan for Southern Appalachia (U.S. Fish and Wildl. Serv. contract 14-16-0009-78-908, Off. Nat. Resour.). U.S. Fish and Wildl. Serv., FWS/OBS-80/09, June 1981, 30 pp.

This publication presents a reclamation plan for use on surface coal mines in southern Appalachia. Suggestions for the establishment of ground cover and trees, as well as the retention of surface water on the minesite, are included. The plan presented has been implemented cooperatively by the Tennessee Valley Authority (TVA) and the Fish and Wildlife Service on a minesite in Campbell County, TN. The reclamation techniques discussed in the plan benefit wildlife and can aid a mine operator in achieving bond release. The costs of reclamation at the study site are compared with the costs of a more traditional forestry (monoculture) option. The economic analysis indicates that the costs of reclamation for wildlife were less than the cost associated with the forestry option.

373. Fox, C. A., R. Trowbridge, and C. Tarnocai. Classification, Macromorphology, and Chemical Characteristics of Folisols From British Columbia. Can. J. Soil Sci., v. 67, No. 4, pp. 765-778.

Folisols, as defined by the Canadian soil classification system, are organic soils that have L, F, and H horizons. These horizontal are composed of leaf litter, twigs, branches, and moss that occur over rock or fragmented material with interstices filled or partially filled with organic matter, or organic horizons that are more than twice as thick as the mineral soil above the lithic or fragmented material. The macromorphology and chemical characteristics of the subgroups Hemic, Humic, Lignic, and Histic Folisols are documented. This article was included in the review because of the information presented on sampling, physical characteristics, and chemical analyses used in soil classification.

374. Frame, R. C., and R. R. Hicks, Jr. Propagation of Aspen and Woody Shrubs on Reclaimed West Virginia Surface Mines. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 37-47.

The effects of three site preparation treatments on the survival and growth of several woody species were studied on two reclaimed surface mines in north-central West Virginia. These treatments included the use of Dalapon and Atrazine herbicides or black plastic mulch to control competition from herbaceous cover. Root suckers from bigtooth aspen (*Populus grandidentata* Michx.) and trembling aspen (*Populus tremuloides* Michx.), as well as seedlings of Washington hawthorne (*Crataegus phaenopyrum* (L.) Medic.), gray dogwood (*Cornus racemosa* Lam.), European black alder (*Alnus glutinosa* (L.) Gaertn.), and pink spiraea (*Spiraea billiardi* Herincq.), were used in the study. The best overall results were obtained using Dalapon herbicide to control herbaceous competition. Washington hawthorne and gray dogwood had significantly better survival than the other species tested.

375. Franklin, J. W. Simulation of the Revegetation Potential of Coal Mines in Semi-Arid Climates. M.S. Thesis, Univ. AZ, Tucson, AZ, 1981, 87 pp.

The author presents a computer model that predicts the success or failure of revegetation of coal mine spoils in the semiarid Southwest, as typified by the Black Mesa Mine in northeastern Arizona. The model consists of a stochastic rainfall model coupled to a soil moisture model. For a 1-year period only, the most limiting factor is the amount of soil moisture available for the germination process. An irrigation model was also run to evaluate the addition of moisture during the first year of establishment. Very little additional moisture (via irrigation) would be necessary to greatly improve establishment; however, evaluation of a 10-year period after the year of establishment showed that without first-year irrigation there was very little chance of successful vegetation. The author concludes that Federal law governing revegetation of arid and semiarid mined lands can be met if proper species are selected, the soil moisture holding capacity is increased through mulch addition, and irrigation is applied during the first year of establishment. Since plant death will generally occur early in the cycle, Federal law need only require a 5-year waiting period to determine if revegetation is successful, rather than the 10-year period now established.

376. Fransway, D. F., and R. J. Wagenet. Salt Release and Movement in Processed Oil Shale. J. Environ. Qual., v. 10, No. 1, 1981, pp. 107-113.

This paper deals with the reduction of saline minerals, such as dawsonite, nahcolite, and halite, contained in Paraho processed oil shale from Colorado, Utah, and Wyoming. These salts are not removed in the normal processing of oil shales and, if excessive, could cause adverse effects on plant establishment and growth if concentrated in the root zone. Properly managed, the addition of excess water could leach the salts below the root zone without affecting ground water.

377. Fresquez, P. R., and E. F. Aldon. Distribution of Fungal Genera in Stockpiled Topsoil and Coal Mine Spoil Overburden. U.S. For. Serv., Res. Note RM-447, 1984, 4 pp.

The abundance and diversity of fungal genera in stockpiled topsoil and spoil overburden are described for a New Mexico coal strip mine. These values are compared with those of an undisturbed soil. Soil samples were collected from a topsoil stockpile (3 to 4 years old), a spoil overburden pile (2 to 3 years old), and an adjacent undisturbed site. Soil chemical and physical properties were characterized. Fungal numbers were estimated using a dilution and plating technique, and a pairwise comparison was made between the materials sampled. Four indices of diversity were calculated to compare the distribution pattern of each genera group isolated: (1) Shannon's index of species diversity (richness), (2) evenness, (3) an estimate of similarity using Sorensen's presence community coefficient, and (4) similarity in the relative abundance of genera between samples using Sorensen's quantitative similarity coefficient.

Numbers of fungal propagules were not significantly different among the materials sampled. The overburden did contain the lowest numbers of fungal propagules. The undisturbed soil was characterized by higher fungal genera diversity and evenness. A high diversity index indicates a stable and well-balanced soil ecosystem. The stockpiled topsoil had a higher diversity index than the spoil material. Sorensen's community and similarity coefficients indicated that the stockpiled topsoil was microbially more similar to the undisturbed soil than was the spoil material. This suggests that the topsoil material is more biologically active than is the overburden material.

378. Fresquez, P. R., E. F. Aldon, and G. L. Dennis. Carbon Dioxide Evolution From an Organically Amended Rio Puerco Soil. U.S. For. Serv., Res. Note RM-480, 1988, 3 pp.

This preliminary study determined the effects of four organic amendments on soil microbial activity in a degraded rangeland soil in New Mexico and the best suited organic amendment for further study in this environment. The amendments used were anaerobically digested sewage sludge (22.4 Mg ha^{-1}), composted dairy cattle manure (22.4 Mg ha^{-1}), wheat straw (11.2 Mg ha^{-1}), and wood chips (1 cm at 11.2 Mg ha^{-1}). All amendments were applied, and microbiological activity was compared with that of an unamended control.

Composted manure had the highest organic matter content; however, it also had a high electrical conductivity (EC) and sodium adsorption ratio (SAR), which may limit microbial activity and plant growth. Sewage sludge had a lower EC and SAR than the manure, but had the highest total nitrogen (106.00 μg^{-1}) content of any of the amendments. As a result, sewage sludge had the lowest carbon-nitrogen ratio (6) compared with the other amendments. When carbon-nitrogen ratios are above 30, nitrogen immobilization is favored. All of the other soil amendments tested had carbon-nitrogen ratios above 30 and are expected to decay slowly. Compared with the unamended control, organic treatments had significantly higher carbon dioxide (CO_2) production, indicating a higher level of microbial activity. Soil microbiological activity increased in all plots as soil moisture content increased to 11 pct (-2 bars). With further increases in soil moisture content to 32 pct (-1/3 bar), decomposition of the organic amendments doubled; however, there was no increase in the microbial activity of unamended plots above a soil moisture content of 11 pct. This indicates that microbial activity in this soil is limited by organic matter, not soil moisture. Of the organic amendments tested, sewage sludge had the most desirable effects on soil microbial populations. This paper is a good reference on the effects of organic amendments on soil microbiological populations in degraded semiarid soils. The results are applicable to the use of organic soil amendments on coal mined semiarid soil in the Southwestern Region.

379. Fresquez, P. R., E. F. Aldon, and W. C. Lindemann. Changes in Microbial Populations and Enzyme Activities Resulting From Coal Mine Spoil Reclamation. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 63-70.

Reclamation success should be judged not on the basis of vegetation reestablishment only, but also by the development of the belowground system including the soil biota. In this study, microbial parameters were used as ecological indicators of changes resulting from coal mine reclamation. Emphasis was placed on the distribution of selected microbial populations, the diversity and composition of fungal groups, and enzyme activities in three nontopsoiled and five topsoiled reclaimed areas varying in age. The microbial parameters of these mined areas were compared with

those of an undisturbed area. Both the nontopsoiled and topsoiled areas were reclaimed using mulch, fertilizer, and native species.

At first, soil chemical characteristics of topsoiled areas were found to be similar to those of nontopsoiled areas; however, soil chemical and physical properties of topsoiled areas after 4 years were more similar to those of undisturbed soil than to those of the nontopsoiled areas, indicating a stabilization of chemical characteristics with time. Micro-organism populations changed with site age in the topsoiled areas; with time there were statistically significant declines in bacteria, Streptomyces, ammonium oxidizers, and fungal populations. Higher populations in the early reclamation stages reflect the addition of carbon from hay amendments and plant establishment. At the oldest topsoiled site microbial populations had declined to levels approximating those in undisturbed soil. Age had less effect on nontopsoiled areas, and no trend in microbial populations was apparent. Species diversity and evenness of fungal groups were greater in the undisturbed soil than in nontopsoiled or topsoiled areas. Of the reclaimed sites, topsoiled sites had higher diversity and evenness indices than did nontopsoiled sites. The oldest nontopsoiled site had the lowest diversity and evenness index. Enzyme activities of topsoiled areas were found to be equal to or surpass those of nontopsoiled areas. Enzyme activity generally increased 1 to 2 years after reclamation, followed by a decline to activity levels similar to that in undisturbed soil. These results emphasize the importance of topsoiling and revegetation to the recovery of mine spoil microbial populations and enzyme activity. The authors state that the return to a natural state should be more rapid with topsoil application, owing to the presence of a more diverse microbial inoculum.

380. Fresquez, P. R., E. F. Aldon, and W. C. Lindemann. The Distribution of Fungal Genera in Reclaimed Coal Mine Spoils in the Arid Southwest. Paper in Proceedings 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 2-7, 1984). Univ. KY, Lexington, KY, 1984, pp. 215-219.

The degree of microbial reestablishment and stability of eight reclaimed sites varying in age and an undisturbed soil were estimated for a New Mexico coal surface mine. Three of the disturbed sites were reclaimed by grading the overburden material, mulching with 4.5 Mg ha^{-1} of grass hay, fertilizing with 16-20-0 fertilizer, and seeding with four native plant species. These sites were 6, 7, and 8 years old. The more recently disturbed sites were reclaimed using the same amendments, but stockpiled topsoil was placed (20 to 30 cm deep) over the recontoured spoil. These sites were 0.25, 1, 2, 3, and 4 years old. Soil was sampled from each area: nontopsoiled, topsoiled, and unmined sites. All soils were characterized physically and chemically. Numbers of fungi were estimated by a dilution and plating technique, and variations in numbers between sites were analyzed using analysis-of-variance log-transformed data. Four indices of diversity were used to compare the distribution patterns for each of the genera isolated: (1) Shannon's index of species diversity (richness), (2) evenness, (3) an estimate of similarity using Sorensen's presence community coefficient, and (4) an estimate of the similarity in the relative abundance of species between samples using Sorensen's quantitative similarity coefficient.

Numbers of fungal propagules were significantly higher in the oldest nontopsoiled site than in the oldest topsoiled and the undisturbed sites. The oldest topsoiled site contained the lowest number of fungal propagules, but numbers were similar to those for the undisturbed site. Diversity and evenness were greatest in the undisturbed soil. The topsoiled sites had higher diversity and evenness indices than did any of the nontopsoiled sites. The oldest nontopsoiled site had the lowest diversity and evenness of genera. Sorensen's community and similarity coefficients showed that the more recently topsoiled minesites were microbially more similar to the undisturbed soil than were any of the older nontopsoiled sites. This study shows that for the soils studied, fungi are reestablished rather quickly in reclaimed topsoil areas. The edaphic conditions of the nontopsoiled site may still be changing and are not stable after 8 years.

381. Fresquez, P. R., E. F. Aldon, and W. C. Lindemann. Enzyme Activities in Reclaimed Coal Mine Spoils and Soils. Landscape Urban Plann., v. 14, 1987, pp. 359-367.

Topsoiling and reclamation age may affect dehydrogenase, nitrogenase, phosphatase, arylsulphatase, amylase, invertase, and urease enzyme activity. The activity of these enzymes was evaluated in three reclaimed nontopsoiled areas and five topsoiled areas in New Mexico. These reclaimed areas were compared with an undisturbed reference soil. Reclaimed areas generally had higher clay, sodium, calcium, magnesium, NO_3-N, total nitrogen, CEC, organic matter, EC, and SAR values than undisturbed soils.

Soil chemical values were similar for topsoiled and nontopsoiled areas soon after reclamation. After 4 years, the soil chemical and physical properties of topsoiled areas were more similar to those of undisturbed soils than to those of nontopsoiled areas, indicating stabilization of chemical characteristics with time. Significant differences were found among the undisturbed soil and the reclaimed nontopsoiled and reclaimed topsoiled areas for all enzyme

assays. Three months after topsoiling and revegetation, the activities of most enzymes were not significantly different from those found in undisturbed soil. During the first 2 years following reclamation, the enzyme activities in topsoiled areas increased above those of undisturbed soils. This was followed, however, by a decline in activity, so that by 4 years, the topsoiled enzyme activity was similar to that in undisturbed soil. Older nontopsoiled areas had lower enzyme activities than did the younger topsoiled areas. It is apparent that many enzyme activities important to nutrient cycling are quickly reestablished in topsoiled areas. Physiochemical properties of nontopsoiled areas, particularly salinity and high clay content, may influence the development of enzymatic activities by reduction or prevention. The results of this study emphasize the importance of topsoiling and vegetation establishment in the recovery of soil enzymatic activity. The observed return to a natural state may have been hastened by the presence of a more diverse microbial inoculum in the replace topsoil. In untreated spoils, microbial populations or the enzymatic state is not expected to return as quickly because of the lack of an established, active, or diverse microbial population.

382. Fresquez, P. R., E. F. Aldon, and W. C. Lindemann. Litter Decomposition on Reclaimed Coal Mine Spoils and Soils in the Arid Southwest. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 157-161.

The degree and rates of plant litter and cellulose decomposition on three graded nontopsoiled areas, five topsoiled areas, and an undisturbed soil at a New Mexico surface minesite were evaluated. Each disturbed site was graded, mulched, fertilized, and seeded; the only differences were age (the three nontopsoiled area were older) and the fact that stockpiled topsoil was respread (20 to 30 cm deep) over the five graded, younger sites. Fiberglass litterbags were filled with stripped alfalfa (*Medicago sativa* L.) stems on flat sheets of Whatman No. 1 filter paper. At each site, 20 bags were randomly buried at a depth of 6 cm, while 20 other bags were randomly placed on the soil surface. Weight loss of the litter was measured at 3, 6, 9, and 12 months. Weight loss at the 6-cm depth during the first 6 months was lower in the older nontopsoiled areas than weight losses of litter in the younger topsoiled areas or undisturbed soil. At 9 and 12 months, weight losses for reclaimed soil and spoil areas, at 6 cm, appeared to equalize for each litter type. After 1 year of decomposition there were significantly greater weight losses for both litter types when they were buried than when surface placed. The oldest topsoiled areas had comparable or higher decomposition rates than did undisturbed soil.

383. Fresquez. P. R., E. F. Aldon, and W. C. Lindemann. Microbial Re-establishment and the Diversity of Fungal Genera in Reclaimed Coal Mine Spoils and Soils. Reclam. & Reveg. Res., v. 4, No. 3, 1986, pp. 245-258.

Eight reclaimed sites (three nontopsoiled and five topsoiled areas) varying in age and one undisturbed reference soil were sampled to estimate the degree of soil microbial development. Populations of aerobic heterotrophic bacteria, streptomyces, fungi, aerobic symbiotic nitrogen-fixing bacteria (*Azotobacter*), and ammonium oxidizers were determined. Soils at each of the sites were characterized chemically. Four indices of diversity were used to compare the distribution patterns for each of the fungal genera isolated: (1) Shannon's index of species diversity (richness), (2) evenness, (3) Sorensen's presence community coefficient (estimates of similarity in genera composition among sample populations), and (4) Sorensen's quantitative similarity coefficient (estimates of similarity in relative abundance of genera between samples). The oldest topsoiled site was similar to the undisturbed soil, while the chemical properties of the oldest nontopsoiled sites were least like those in undisturbed soil. Changes in microbial populations with site and age are presented and compared with those of the undisturbed site. The results of this study indicate that microbial populations are quickly reestablished and that they change with time.

384. Fresquez, P. R., E. F. Aldon, and D. L. Sorensen. Microbial and Soil Enzyme Activities in Stockpiled Topsoil and Coal Mine Spoil Materials. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 340-345.

The biogeochemical quality of stockpiled topsoil and coal mine spoil overburden materials was determined for a coal surface mine in northwestern New Mexico. These values were compared with those of an adjacent undisturbed soil. Five composite soil samples were collected from a spoil overburden pile, a topsoil stockpile, and an adjacent undisturbed area. The chemical and physical properties of the spoil and soil materials were determined. Enzymes measured included dehydrogenase, nitrogenase, urease, invertase, amylase, phosphatase, cellulase, arylsulphatase, and protease. The stockpiled topsoil and overburden material generally had higher EC, SAR, calcium, magnesium, sodium, potassium, SO_4, NO_3-N, total

nitrogen, organic matter, CEC, and clay contents than did the undisturbed soil, while soil pH and phosphorus were higher in the undisturbed soil than in the stockpiled topsoil or spoil overburden materials. The stockpiled topsoil and spoil overburden materials were characterized by low microbial populations and a low diversity of microorganisms.

385. Fresquez, P. R., L. T. Campbell, and E. F. Aldon. Response of Soil Fungi and Soil and Plant Parameters to Sewage Sludge and Sawdust Amended Coal Mine Spoils. U.S. For. Serv., Res. Note RM-444, 1984, 6 pp.

Changes in the distribution of fungal genera in a New Mexico mine spoil material as a result of organic amendments were evaluated, along with the influence of the organic amendments on spoil chemical properties and sorghum (*Sorghum bicolor* (L.) Moench.) growth. In the field, tubes (11 cm in diameter and 100 cm long) were inserted into the spoil material in holes dug into the center of twenty-four 1-m-square plots. The spoil was amended with anaerobically digested sewage sludge, or sawdust (10 Mg ha^{-1}), or was untreated as a control. Each treatment was replicated eight times. After 1 year the tubes were removed and divided into increments of 0 to 30 cm and 30 to 100 cm. Variations in occurrence of fungal genera among treatments and soil depth were analyzed. The indigenous spoil fungal populations were not significantly influenced by organic treatment. A significant interaction did occur between the number of isolates and soil depth. The application of organic amendments was beneficial in terms of supplying NO_3-N, chlorine, and potassium.

386. Fresquez, P. R., and W. C. Lindemann. Greenhouse and Laboratory Evaluations of Amended Coal-Mine Spoils. Reclam. & Reveg. Res., v. 2, No. 3, 1983, pp. 205-215.

The authors describe the effects of spoil treatment on the growth potential and nutrient content of blue grama (*Bouteloua gracilis* (H.B.K.) Lag.) and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.). The spoil material and stockpiled topsoil used in this greenhouse study were taken from the San Juan coal mine in northwestern New Mexico. The chemical and physical properties of the spoil and topsoil materials were determined. In the greenhouse studies only the spoil material was amended, using one or a combination of the following materials: alfalfa (*Medicago sativa* L.), gamma irradiated sewage sludge, stockpiled topsoil, fertilizer (nitrogen and phosphorus), and gypsum. It was found that alfalfa mulch plus fertilizer increased the yields and phosphorus and potassium content of blue grama more than any other treatment. Organic amendments were found to increase the yields of four-wing saltbush more than any other treatment including fertilizer. Incorporating topsoil into the spoil, as opposed to topsoiling, did not stimulate plant growth. The increased yields found for both species can be attributed to the addition of organic matter and essential plant nutrients, along with an improved biological environment. There was an increase in microbial activity due to the spoil amendments, which resulted in the mineralization and solubilization of calcium, magnesium, potassium, and phosphorus; increased nitrification; and the lowering of the sodium adsorption ratio (SAR). Gypsum applications also increased the yields of both species under optimum moisture conditions over most nongypsum treatments, whether organic matter was present or not. Gypsum application stimulated plant growth by lowering the SAR. The authors concluded that increased plant yields were due to the addition of plant-available nutrients contained in the amendments and increased microbial activity.

387. Fresquez, P. R., and W. C. Lindemann. Soil and Rhizosphere Microorganisms in Amended Coal Mine Spoils. Soil Sci. Soc. Am. J., v. 46, No. 4, 1982, pp. 751-755.

This research compared soil microbial numbers, dehydrogenase activity, and fungal genera distribution of spoil with those of the original and stockpiled soil. A greenhouse study was conducted, using spoil and stockpiled topsoil material, to determine the effect of spoil amendments on the microbial parameters given above. The treatments used were (1) spoil, (2) spoil and topsoil plus inoculant, (3) spoil plus alfalfa (*Medicago sativa* L.) plus fertilizer, (4) spoil plus alfalfa plus fertilizer plus topsoil, (5) spoil plus sewage sludge, and (6) spoil plus sewage sludge plus topsoil. The soil and spoil material used in this study were collected at the San Juan coal mine near Farmington, NM. The results show that microbial numbers, dehydrogenase activity, and fungal genera distribution were greater in the undisturbed soil and reclaimed area than in the stockpiled topsoil or nonvegetated spoil. This indicates that if sites are reclaimed without topsoil or if topsoil is stored before use, steps should be taken to ensure that the material remains biologically active. The use of alfalfa or sewage sludge as an organic amendment generally increases microbial numbers, dehydrogenase activity, and fungal distribution over those in the non-amended and topsoil-inoculant treatments. The authors conclude that organic amendments are more critical to the stimulation of spoil microflora than the additions of topsoil inoculants. It must be remembered, however, that the results were obtained under greenhouse conditions.

388. Fresquez, P. R., B. R. Sabey, and D. A. Klein. Soil Fungal Community-Plant Rhizosphere Interactions

During the Early Stages of Ecosystem Development on Reclaimed Coal Mine Soils. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 9-14.

The microfungal community and soil chemical properties were assessed in the rhizosphere and nonrhizosphere zones of galleta (*Hilaria jamesii* (Torr.) Benth.), alkali sacaton (*Sporobolus airoides* (Torr.) Torr.), and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.). These species were established and had been growing for 0.25, 1.25, and 2.25 years on a reclaimed coal mine soil in New Mexico. Microbial populations help to accelerate revegetation by increasing the biological activity and nutrient cycling processes in the rhizosphere of the plant species used in the reclamation of coal mine soils. In both the rhizosphere and nonrhizosphere soil zones of the species studied there were significant decreases in soil nutrient concentrations with reclamation age. The authors speculate that this decline reflects the depletion of added fertilizer and hay amendments, decreased plant productivity due to termination of irrigation, and reduced nutrient cycling.

After 2.25 years, most soil chemical properties were significantly higher in the rhizosphere soil than in the nonrhizosphere soil for all three species. Prior to this time, there were not many differences in soil chemical properties. Organic matter was the only soil property that was consistently higher in the rhizosphere of all three species after 2.25 years. In the grasses, phosphorus concentration was significantly higher in the rhizosphere than in the nonrhizosphere. Four-wing saltbush had significantly higher rhizosphere fungal populations than did the rhizosphere of galleta and alkali sacaton. Additionally, the fungal populations in the rhizosphere and nonrhizosphere zones of the grasses, and the nonrhizosphere soil zone in four-wing saltbush, tended to decrease with time. The significantly higher microbial component in the rhizosphere of four-wing saltbush was attributed to the carbon released as exudates rather than to differences in soil chemical properties between the two zones. In general, the diversity of fungal groups increased with time in both rhizosphere zones in all three species. The diversity in nonrhizosphere soil, however, was greater than the diversity in the rhizosphere soil.

The authors relate the higher fungal populations and lower fungal diversities to the higher concentration of nutrients in the rhizosphere. In contrast, the lower fungal populations and higher fungal diversity in nonrhizosphere soil are related to the lower concentration of nutrients in this zone. With changes in time, the overall composition of the fungal component changes between the rhizosphere and nonrhizosphere zones and among and within the plant species studied. The interaction between the soil fungal community and the rhizosphere of four-wing saltbush resulted in greater decomposition and soil aggregation deeper into the soil profile than the interactions in the grass species. The rhizosphere, and fungal community interaction of the two grass species, however, results in a greater cycling of nutrients near the soil surface than does the rhizosphere of four-wing saltbush.

389. Fu, M. H., X. C. Xu, and M. A. Tabatabai. Effect of pH on Nitrogen Mineralization in Crop-Residue-Treated Soils. Biol. and Fertil. Soils, v. 5, 1987, pp. 115-119.

The mineralization of nitrogen in crop-residue-treated soils as affected by pH was assessed. Additionally, the effect of soil type and pH on mineralization of nitrogen in plant materials was evaluated. Three soils were treated with four different crop residues. Each soil was adjusted to pH values of 4, 6, and 8 using dilute H_2SO_4 or KOH. The crop residues used were corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), sorghum (*Sorghum vulgare* Pers.), and alfalfa (*Medicago sativa* L.). A sample of each pH-adjusted soil (20 g) was treated with 0.488 g of each plant material mixed with 20 g silica sand, which was adjusted to the pH of the soil and packed into a leaching tube (3.5 cm in diameter and 15 cm in length). The soil-sand mixture was leached with 100 mL 5m*M* $CaCl_2$, adjusted to the same pH as the treated soil, to move initial soil mineral nitrogen. Each tube was incubated at 30° C. This leaching procedure was repeated every 2 weeks for 20 weeks. All leachates were analyzed for NO_3-N, NO_2-N, and NH_4-N.

Depending on the soil treatment and the nature of the organic nitrogen, the manner in which nitrogen was mineralized during the incubation periods followed one of four patterns. Nitrogen mineralization increased as the soil pH increased in all three soils. There was, however, an initial lag period in nitrogen immobilization for all crop residues except for alfalfa residues. This lag period was followed by a rapid increase in mineralization except for corn- and soybean-residue-treated soils where nitrogen immobilization continued through the entire incubation period, particularly at pH 4. Nitrogen mineralization was least in corn-residue-treated soil at pH 4 and greatest in alfalfa-residue-treated soil at pH 8. Most of the mineral nitrogen produced under neutral or slightly alkaline conditions was in the form of NO_3. No significant amount of NO_2 was found in any of the soils at any pH, while NH_4 was detected only at pH 4. The percentages of organic nitrogen added to the soil from residues ranged from 7.7 pct (pH 4) to 37.0 pct (pH 6) for sorghum, 17.8 pct (pH 4) to 30.1 pct (pH 8) for alfalfa, -86.7 pct (pH 4) to -15.2 pct (pH 8) for corn, and -21 pct (pH 4) to

18.3 pct (pH 8) for soybean. The negative values indicate nitrogen immobilization. The authors conclude that nitrogen mineralization in crop-residue-treated soil is highly dependent on the composition of the crop residue, soil pH, and chemical and physical makeup of the soil.

390. Fuchs, M. R., and G. R. Cox. Factors Affecting Choice of Plant Species for Revegetation on the Hanford Site (U.S. Dep. Energy contract DE-AC06-77RL01030, Rockwell Int., Richland, WA). Informal Rep. RHO-LD-155P, Apr. 1983, 29 pp.

The principal objectives of this study were to determine whether soil conditions influenced the establishment of selected native perennial grass species, the extent of these species as members of the vegetative community on the Hanford site prior to human influences, and whether these perennial grasses could be established on other sites to be reclaimed. Three sites were evaluated. The dominant perennial grass species in the vegetative communities at each of these sites were Siberian wheatgrass (*Agropyron sibiricum* (Wild.) Beauv.), thickspike wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.), Indian ricegrass (*Oryzopsis hymenoides* (Roem & Schult.) Ricker), and Sandberg bluegrass (*Poa secunda* Presl.). The authors conclude that these species, along with needlegrass (*Stipa comata* Trin. & Rupr.) and sand dropseed (*Sporobolus cryptandrus* (Torr.) Gray), may be successfully established for revegetation purposes on the Hanford site. Addition of nitrogen is necessary to increase the fertility of the soil. Faster stand establishment may be achieved on disturbed sites by reducing competition for moisture and nutrients through the control of invading species such as Russian-thistle (*Salsola kali* L. var. *tenuifolia* Tausch.) and tumble mustard (*Sisymbrium altissimum* L.). The use of selective herbicides has been shown to help reduce this competition. Factors reported to influence the choice of revegetation species include (1) the level of exchangeable magnesium in the soil, (2) soil textural class, gravel percentage, and depth to coarse sediments, (3) the presence of an indicator plant species that defines a habitat, and (4) the soil fertility level.

391. Fullerton, S., and S. Pawluk. The Role of Seasonal Salt and Water Fluxes in the Genesis of Solonetzic B Horizons. Can. J. Soil Sci., v. 67, No. 4, 1987, pp. 719-730.

Seasonal salt and water fluxes of two Solonetzic soils were evaluated in Alberta, Canada. Both soils were monitored over a 2-year period for soil salinity, temperature, moisture, and ground water levels. Moisture movement into each soil was by capillary flow of water upward from the water table. The salts responsible for solonization in the B_{ntj} horizons were $NaHCO_3$ and Na_2SO_4. Below this horizon the concentrations of $NaCHO_3$ decreased, while the concentrations of $CaSO_4$ and $MgSO_4$ increased. Seasonal salt and water fluxes were identified and shown to be dependent upon soil temperature. When soils were above 0° C, capillary movement and evaporation were mechanisms responsible for salt transport, concentration, and deposition. When soil temperatures were below 0° C, water moved upward from the water table toward the freezing zone, depositing salts upon freezing. This article was included in the review process because of the information it contains on the processes of soil genesis.

392. Gabrielson, F. C., E. A. Cross, and D. K. Bradshaw. The Effects of Fertilizer and Acid Treatment on Plant Growth in Alkaline Spoil. Abstr. of paper pres. at Meet. Am. Counc. Reclam. Res. (Univ. AL, Sept. 19-20, 1979). Reclam. Rev., v. 3, No. 1, 1980, p. 62.

The experiments described by the authors were designed to determine the response of lovegrass (*Eragrostis* spp.) and Kobe lespedeza (*Lespedeza striata* var. Kobe) to acid and fertilizer treatments of alkaline mine spoil. Although parts of the abstract were difficult to follow, it was clear that lovegrass responded well to 13-13-13 fertilizer and to NH_4NO_3 treatment.

393. Gabrielson, F. C., E. A. Cross, D. K. Bradshaw, and O. L. Carter, Jr. Seed Size Influence on Germination and Plant Growth of Kobe Lespedeza and Other Species Used for Surface Mine Revegetation. Reclam. & Reveg. Res., v. 1, No. 3, 1982, pp. 271-281.

This article describes a series of pilot and expanded greenhouse experiments that used various spoil-soil substrates and plant species commonly used to revegetate coal surface mines in Alabama. In the pilot experiments, seeds of soybean (*Glycine max* (L.) Merr.), Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), Kobe lespedeza (*Lespedeza striata* var. Kobe), and crimson clover (*Trifolium incarnatum* L.) were divided into three weight classes (small, medium, and large) and grown on greenhouse soil, acid mine spoil (pH 4.8), pine stand topsoil, and calcareous shale mine spoil (pH 7.8). No soil amendments were used in the pilot study.

The results of the pilot study showed that survival and aboveground biomass were always greater when produced by large seeds compared with small seeds. Biomass and survival of plants from medium-sized seeds were also greater than for plants from small seeds, but not significantly greater. The authors suggest that some of the differences found may have been due to seed size-substrate interactions. A germination experiment was conducted with different-sized seeds of Kobe lespedeza,

weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees.), and crimson clover. The seeds were divided into two groups per plant species: lovegrass, larger and smaller than 42 mm; Kobe lespedeza, larger and smaller than 1.3 mm; and crimson clover, larger and smaller than 1.5 mm. For the species tested, the larger seed class always had significantly higher germination percentages.

Because Kobe lespedeza is an important legume component of reclamation seed mixtures, three experiments using Kobe lespedeza were conducted on various mine substrates (ranging from acid sand with a pH of 4.4 to calcareous shale with a pH of 7.5) to evaluate the advantages of using large seeds relative to spoil-soil characteristics and fertilizer and lime treatments. Seed size effects were found to differ with substrate and amendment treatment, but overall the larger seeds increased plant density and biomass. On spoil material with low cation-exchange capacities (CEC's), the 13-13-13 fertilizer treatment was excessive and caused a significant reduction in plant density. Lime plus fertilizer on low-CEC spoils was found to modify the effect of fertilizer alone. This article contains a great deal of useful information; however, field results may be different from the results obtained in the greenhouse experiments.

394. Gale, P. M., and J. T. Gilmar. Mineralization of Carbon and Nitrogen Under Aerobic and Anaerobic Conditions. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1006-1010.

The kinetics of carbon and nitrogen mineralization during the decomposition of alfalfa (*Medicago sativa* L.) under aerobic and anaerobic conditions were evaluated. Dried and ground alfalfa was mixed with a silt loam soil and incubated either aerobically at optimum water in a CO_2-free atmosphere or anaerobically (flooded to 1 cm) in a N_2 atmosphere for 30 days at 25° C. Decomposition was followed by measuring the CO_2 and CH_4 evolved, water-soluble organic carbon, and inorganic nitrogen. Three phases of decomposition were observed under aerobic conditions: rapid, intermediate, and slow. Rate constants (K) for each phase were calculated, with the rapid, intermediate, and slow phases having rate constants of 0.123, 0.059, and 0.0095 per day, respectively. The distribution of the substrate carbon among phases was 23, 20, and 57 pct in the rapid, intermediate, and slow phases, respectively. During the 30-day incubation, 55 pct of substrate carbon was converted to CO_2. During the first 2 days of decomposition, there was an initial flush of nitrogen mineralization which continued throughout the intermediate phase of decomposition (a high carbon-nitrogen ratio). Net nitrogen mineralization began again during the slow phase and continued through the rest of the experiment. CO_2 evolution was small and constant under anaerobic conditions; the rate constant for substrate decomposition was 0.006 per day.

Carbon mineralization estimates were made using CO_2, CH_4, and water-soluble organic carbon summations. Three phases of decomposition were recognized. The rate during the first 2 days was similar to that of the aerobic experiment, which was attributed to the respiration by aerobes and facultative anaerobes before the system became anaerobic. From day 2 to day 14, water-soluble organic carbon was produced. The rate constant during this period was 0.024 per day, which is less than the rate under aerobic conditions. After 2 weeks, carbon mineralization appeared to stop. There was a decline in the water-soluble organic carbon pool; however, this was offset by the production of CH_4 and CO_2. There was a shift in the predominant microbial population from facultative to obligate anaerobes. Under anaerobic conditions, nitrogen mineralization proceeded more rapidly, which was attributed to the lower metabolic efficiencies of the anaerobic microbial populations. A computer simulation model to predict net carbon and net nitrogen mineralization under both aerobic and anaerobic conditions resulted in linear relationships between predicted and observed mineralization data. Linear regressions resulted in a slope of 1.1 for carbon mineralization and 1.0 for nitrogen mineralization, with R^2 values of 0.961 and 0.946, respectively.

395. Gale, P. M., J. M. Phillips, D. C. Wolf, and M. L. May. Variability of Nutrient Concentrations in Hen Manure. Am. Soc. Agron., Agron. Abstr., 1988, p. 38.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The nutrient content of hen manure was assessed. Comparisons were made between total Kjeldahl nitrogen, inorganic nitrogen, and phosphorus and potassium for fresh wet and dry manure. Total Kjeldahl nitrogen was reduced from 5.65 to 4.01 pct upon drying, and ammonia-nitrogen was reduced from 1.93 pct wet to 0.20 pct dry. The cause of the loss of inorganic nitrogen was NH_3-N volatilization. Phosphorus and potassium concentrations were not significantly affected by the moisture content of the manure. These results show that samples should not be dried prior to estimating the nitrogen content of hen manure.

396. Gambrell, R. P., S. Landes, C. N. Reddy, and W. H. Patrick, Jr. Soil Physiochemical Parameters Affecting Metal Availability in Sludge-Amended Soils (Project Summary). U.S. EPA, Water Eng. Res. Lab., EPA/600/52-85/123, Jan. 1986, 4 pp.

Soil pH and oxidation-reduction (redox) conditions are two physiochemical parameters that affect metal mobilization and immobilization. This paper summarizes experiments conducted to study the effects of soil pH and redox

conditions on the soil chemical form and availability of trace and toxic metals to plants grown on agricultural soils receiving municipal sludge applications. Additionally, the effects of pH and redox conditions on trace metal complex formation with soluble and insoluble organic matter were studied. Four different studies are summarized. Under controlled pH and redox potentials, results indicate that the organic phases of sludge retain copper under reduced conditions; however, as the redox potential is increased, transformation occurs so that potentially available copper becomes associated with reducible phases under well-oxidized conditions. Dissolved and exchangeable zinc increased with increasing redox potential and decreasing soil pH. Plant zinc levels increased with increasing redox potential. A large proportion of the total cadmium extracted was recovered in readily available forms. Cadmium was not immobilized by high-molecular-weight organics and is weakly bound to hydrous iron oxides. Plant cadmium concentrations increased as the redox potential increased. Lead was strongly associated with the residual organic phase. Exchangeable lead was pH dependent, and the greatest levels were found at pH 5.0. Soil oxidation status had little effect on plant levels of chromium, nickel, and arsenic. This study showed the importance of soil redox potential in regulating the chemical mobility and availability of zinc and cadmium to plants. Wet or poorly oxidized soils would be more effective in immobilizing zinc and cadmium.

397. Garcia, F., R. M. Cruse, and A. M. Blackmer. Compaction and Nitrogen Placement Effect on Root Growth, Water Depletion, and Nitrogen Uptake. Soil Sci. Soc. Am. J., v. 52, No. 3, 1988, pp. 792-798.

Plant root growth can be altered by zones of compaction or high nutrient concentrations that result from certain tillage systems. Additionally, these changes in plant root growth may affect water and nutrient uptake. This greenhouse study evaluated the effect of three compaction treatments and nitrogen fertilizer placement on corn (*Zea mays* L.) root growth, soil water depletion, and nitrogen fertilizer uptake. Compaction treatments were a simulated plowpan with horizontal orientation in one or both interrows, a simulated plowpan with vertical orientation in one or both interrows, and uncompacted soil. Nitrogen placement treatments consisted of ^{15}N-enriched NH_4NO_3 point injected, 0.1 m deep, at a rate of 80 kg ha^{-1} N under the plant, and in the simulated interrow, and a control (no nitrogen added). Corn plants were grown 26 days without rewatering. At day 26, measurements taken included shoot and root growth, plant ^{15}N content, and soil water content and distribution. Compaction treatments did not significantly affect the dry weight of corn roots. Nitrogen fertilization, particularly below the plants, resulted in smaller average root systems compared with the control. The reduction in total root dry weight was not significant. The distribution of roots with depth and lateral spread were affected by the various compaction and nitrogen treatments utilized. Root growth was redirected in the compaction zones, but not reduced. Redirection or compensation of root growth resulted in shallower growth and lateral spread (simulated plowpan) or deeper growth (simulated wheel tracks). Point application of nitrogen fertilizer stimulated growth in the application zone, but resulted in an overall reduction in total root growth. Compaction zones resulted in greater plant shoot weight than did uncompacted zones, which had the first visible plant response to water stress. Apparently, the uncompacted treatment resulted in less efficient water use or less available water than did the compacted conditions. There was, however, greater water depletion in the compaction treatments, and the greater the proportion of compaction, the greater the water depletion. There was less water depletion when nitrogen fertilizer was placed below plants, owing to a smaller and shallower root system. Total water extraction and the spatial water extraction patterns were both affected by compaction and nitrogen treatments. Nitrogen fertilizer uptake was related to the presence of roots in the application zone. Root densities were always greater below the plants than in the interrows, and density was greatly increased below the plants when the sides (vertical orientation) were compacted. Root growth compensation, both enhancement in zones of favorable nutrient supply and redirection to zones of favorable physical conditions, can be used to enhance the uptake of fertilizer-applied nutrients. The authors state that the application of fertilizer nutrients in zones most favorable for root growth will result in the greatest efficiency in nutrient uptake. Although this study is concerned with corn production on non-coal-mined soils, the information presented on water and nutrient use efficiencies, compaction, and fertilizer amendments have direct applications to coal mined lands. This paper contains good reference material on similar problems encountered in the reclamation of coal surface-mined land.

398. Gavande, S. A. Selecting Cover-Soil for Use in Surface Mine Reclamation in East Texas. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 541-545.

This greenhouse study was conducted to compare the revegetation potential of surface soil and underlying overburden materials sampled from a proposed lignite surface-mined area in east Texas. Four composite surface soil samples and 16 mixed overburden samples representing 4 depth intervals were taken. All soil samples

were analyzed for major chemical and physical parameters. Common bermudagrass (*Cynodon dactylon* (L.) Pers.) was selected as the test plant. All soil and overburden samples were limed to obtain a pH level of 6.5. Three fertilizer treatments were used: (1) a control, (2) 90-60-60 lb $acre^{-1}$ N, P, and K, and (3) 180-60-60 lb $acre^{-1}$ N, P, and K. The results of the soil analysis indicate that the overburden mixtures had a more favorable texture, which resulted in a greater water- and nutrient-holding capacity, than unmined surface soils. Plant growth on unamended overburden material indicated that the mixed overburden was equal to or a little less fertile than the surface soil material. When amended, the overburden material from all depths produced greater forage yields than surface soil under the same conditions. The author concludes that the establishment of vegetation on disturbed land in east Texas, with or without topsoil, should present no major problems.

399. Gebhart, E. J. Trees for Ohio. Paper in Trees for Reclamation (Lexington, KY, Oct. 27-29, 1980). U.S. For. Serv., Gen. Tech. Rep. NE-61, 1980, pp. 51-52.

The author discusses the use of trees for reclaiming Ohio surface-mined land. Three areas of revegetation that could utilize tree plantings are (1) planting trees on replaced topsoil with erosion-control grass cover, (2) revegetation of unreclaimed lands mined prior to 1972 (before Ohio's strip mine law), and (3) reforestation of barren lands that once had grass cover. The following recommendations were given: (1) the grass species and seeding rates that should be used when grasses are planted in combination with trees, (2) the spacing and number of trees planted per acre, (3) type of stock, season of planting, and method of planting trees, and (4) tree mixtures for acid and alkaline spoils.

400. George, M. R., C. M. McKell, and S. G. Richardson. The Establishment of Cheatgrass (*Bromus tectorum* L.) on Spent Oil Shale From the Paraho Process. J. Environ. Qual., v. 10, No. 2, 1981, pp. 166-169.

Establishment and growth of cheatgrass (*Bromus tectorum* L.) was evaluated in a greenhouse study on oil shale from northwestern Colorado that had been treated by the Paraho retorting process. The objectives were to (1) study the emergence and growth of cheatgrass in soil, in soil mixed with untreated Paraho spent oil shale, and in spent shale that was either leached, treated with 10 pct H_2SO_4, covered with soil, or mixed with soil, and (2) study the emergence and seedling growth of cheatgrass on Paraho spent oil shale that was fertilized with ammonium nitrate and triple superphosphate. Fertilizer rates were 0, 28, and 56 kg ha^{-1} N and 0, 24.4, and 48.8 kg ha^{-1} P. Cheatgrass emerged sooner, had greater height, produced more biomass, and survived to produce seed when the treatment was soil alone or when the spent shale had been covered with soil material. Cheatgrass establishment was more successful when soil and spent shale were mixed than with spent shale alone. The authors conclude that, by covering spent shale with a soil layer or by mixing soil and shale together, successful cheatgrass establishment is possible. Field studies are needed to verify these results.

401. Gerber, D. W., J. E. Burris, and R. W. Stone. Removal of Dissolved Iron and Manganese Ions by a Sphagnum Moss System. Paper in Wetlands and Water Management on Mined Lands, ed. by R. P. Brooks, D. E. Samuel, and J. B. Hill (Proc. Conf. PA State Univ., State College, PA. Oct. 23-24, 1985). PA State Univ., State College, PA, 1985, pp. 365-372.

Laboratory experiments were conducted to determine the long-term (23-month) adsorption of iron and manganese by sphagnum moss and to identify the possible role of bacteria in metal depletion from acidic mine drainage. Artificial sphagnum wetlands were constructed using *Sphagnum recurvum* and tap water. Solid ferrous sulfate and manganese sulfate were added at 15 ppm in 44 L of water. Both iron and manganese ions were removed through the physical adsorption of metal cations by the moss; iron was preferentially absorbed. Observations, however, indicated that there was a greater capacity for metal cation removal than could be explained by a purely physical mechanism. It was found that iron- and manganese-oxidizing heterotrophic bacteria made up a large percentage of the total heterotroph population in the sphagnum system. These bacteria facilitate metal precipitation. With the loading of metal cations into the sphagnum system, there was a corresponding increase in the percentage of iron and manganese oxidizing bacteria. The removal of metal cations by sphagnum-dominated wetlands may involve two processes: (1) physical adsorption by the moss, and (2) oxidation of the metal cation and regeneration of adsorption sites, with subsequent utilization of the cations by bacteria.

402. Gessel, S. P., D. W. Cole, and H. N. Chappell. Assessing Soil Properties Which Limit Forest Productivity. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 29-36.

Soil physical, chemical, and biological properties that affect forest productivity are identified. Research conducted on the soil-productivity relationships of Alaskan forests and similar environments are reviewed. Soil properties that have a distinctive function or dominant role in

Alaskan forest productivity are (1) soil temperature relationships, especially low temperatures, (2) soil moisture relationships, especially excess moisture, (3) soil depth and texture, since they affect water drainage and nutrients, (4) soil biology, especially processes affecting decomposition, elemental turnover, and the release of elements in available forms, and (5) available soil nitrogen supply.

403. Ghazi, H. E., D. K. Bhumble, R. F. Keefer, and R. N. Singh. Utilization of Fly Ash for Reclaiming Abandoned Mine Spoils for the Production of Agricultural Crops. Paper in Proceedings: Eighth International Ash Utilization Symposium, Volume 1 (Washington, DC, Oct. 28-31, 1987). Electr. Power Res. Inst., Palo Alto, CA, 1987, pp. 27-1—27-18.

Fly ash and rock phosphate mixtures alone and in combination were used as amendments on abandoned acid mine soil to test their effect on plant growth and nutrient composition in greenhouse and field experiments. In the greenhouse study, bulk soil samples were collected from three sites in West Virginia, and mixed with fly ash at three rates (0, 33, and 67 pct) and rock phosphate at four rates (0, 10, 20, and 40 g P per kilogram soil). Treatments used in the field study consisted of a control of lime (22.2 Mg ha^{-1}) plus triple superphosphate (112 kg ha^{-1}), two rates of rock phosphate (15 and 30 Mg ha^{-1}), and three rates of fly ash (0, 400, and 800 Mg ha^{-1}). Corn (*Zea mays* L.) and alfalfa (*Medicago sativa* L.) were used as the test species in the greenhouse study, and alfalfa was used as the test species in the field study.

Fly ash inhibited or reduced corn growth in the greenhouse study because of the high boron concentrations in the fly ash, even when rock phosphate was added to fly ash treatments. Alfalfa, which is tolerant of high boron concentration, grew better on fly ash amendments alone than on 10 g kg^{-1} of rock phosphate alone. Fly ash alone, however, could not provide sufficient phosphorus to meet the phosphorus nutrient requirements of alfalfa. As a result, on acid mine spoils it may be necessary to add supplemental phosphorus if fly ash is to be used as a soil amendment. Field studies confirmed this result; plots that received fly ash in combination with rock phosphate gave statistically higher yields of alfalfa than plots that received fly ash with lime and triple superphosphate or plots that received rock phosphate and no fly ash. Rock phosphate applied in combination with either 400 or 800 Mg ha^{-1} fly ash produced higher alfalfa yields than rock phosphate applied alone.

404. Gibson, D. J., F. L. Johnson, and P. G. Risser. Revegetation of Unreclaimed Coal Strip Mines in Oklahoma. II. Plant Communities. Reclam. & Reveg. Res., v. 4, No. 1, 1985, pp. 31-47.

The species composition and plant communities of abandoned coal strip mines in eastern Oklahoma are presented, along with community types in relation to possible controlling influences. Forty-nine unreclaimed strip mines ranging in age from 10 to 70 years were studied. Initial colonization of a site was affected by the dissemination efficiency of propagules. The major factors determining the overall community composition were site latitude and its components, mean annual temperature and the precipitation-evaporation ratio. Edaphic factors (soil texture, pH, calcium) were also important in overall community development. Natural revegetation of abandoned coal strip mines in Oklahoma is multifactorial in nature; no one factor is of overall importance. Reclamation and revegetation programs can be planned by assessing the surrounding natural vegetation and environmental characteristics, particularly the substrate conditions of the mine sites.

405. Gifford, G. F., and G. E. Hart. A Classification of Utah Mine Wastes. Edge: Nat. Resour./People, v. 3, No. 1, 1980, pp. 8-14.

The article presents a preliminary system of classification for Utah mine wastes based on surface hydrologic characteristics. The principal types of mining considered in the study include gold, silver, lead, zinc, fire clay, brick clay, limestone, fluorspar, phosphate, coal, copper, tungsten, uranium, vanadium, and beryllium mining. The classification system developed is intended for use in rating mine spoils for potential surface hydrologic limitations to revegetation.

406. Giles, R. H., Jr. A Sugarbush System: A Post-Mining Land Use Alternative. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 421-429.

This article discusses the establishment of sugar maple (*Acer saccharum* Marsh.) in one or more groves at high-elevation sites in the Appalachian coalfields for use in sugar and syrup production as a postmining land use alternative. Information is presented on the suggested design and management system including sites, tree spacing for planting and the recommended spacings as trees grow, grove size, fertilization, protection, and syrup collection and processing. Reasons as to why this postmining alternative is suggested are given.

407. Gilley, J. E. Runoff and Erosion Characteristics of a Revegetated Surface Mined Site in Western North Dakota. ND Farm Res., v. 37, No. 6, May 1980, pp. 17-20.

This article reports the results of a study in which a rainfall simulator was used to measure runoff and soil loss from undisturbed, harvested, and bare and surface-mulched treatments on a revegetated surface-mined site near Zap, ND. The greatest soil losses were measured on the bare-soil treatment. The least soil loss was experienced on the undisturbed plots. Applications of 0.5 mt $acre^{-1}$ surface straw mulch reduced erosion by 66 pct over the bare-soil condition.

408. Gilley, J. E., G. W. Gee, A. Bauer, W. O. Willis, and R. A. Young. Runoff and Erosion Characteristics on Surface-Mined Sites in Western North Dakota. Trans. ASAE, v. 20, No. 4, 1977, pp. 697-700, 704.

This study was conducted to measure runoff and erosion from native rangeland, spoil, and topsoil sites in North Dakota. The rangeland served as a premine condition and was compared with cultivated and noncultivated spoil and topsoiled minesites. Rainfall events were simulated. Sediment production averaged 74,000 kg ha^{-1} for the bare topsoil sites, 18,000 kg ha^{-1} for the bare spoil sites, and 200 kg ha^{-1} for the rangeland. By applying wheat straw mulch at a rate of 4,500 kg ha^{-1}, soil losses were reduced by 84 pct on the spoil and 93 pct on the topsoil sites. Runoff averaged 60 and 70 pct of the simulated rainfall applied on the bare topsoil and spoil treatments, respectively. Runoff averaged only 12 pct on the rangeland site. These results indicate the need for suitable management practices on bare topsoil and spoil material to keep erosion and runoff levels within acceptable limits.

409. Girts, M. A., and R. L. P. Kleinmann. Constructed Wetlands for Treatment of Acid Mine Drainage: A Preliminary Review. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 165-171.

The preliminary results of a survey conducted to determine acid mine drainage treatment by constructed wetlands are reported. Information was requested on design, construction techniques, efficiency, and maintenance of constructed wetlands in Pennsylvania, West Virginia, Ohio, and Maryland. Waterflow rate was the primary factor determining wetland design. Treatment efficiency of wetlands varied with season, design, and length of time that the wetland had been established. Maintenance was limited to application of fertilizer or agricultural limestone. Difficulties encountered with constructed wetlands were related to waterflow and depth control. The major cost associated with the wetlands is the initial cost of construction.

410. Girts, M. A., G. E. Lang, and R. W. Wieder. Hydraulic Flow Rates in a Sphagnum-Dominated Appalachian Wetland. Paper in Wetlands and Water Management on Mined Lands, ed. by R. P. Brooks, D. E. Samuel, and J. B. Hill (Proc. Conf. PA State Univ., State College, PA, Oct. 23-24, 1985). PA State Univ., State College, PA, 1985, p. 383.

A method for measuring the rate of waterflow in an undisturbed sphagnum-dominated wetland is described. Bromide and chloride were injected into the wetland and used as chemical tracers to identify vertical and horizontal flow in the surface and deep peat. Information is given on injection and sampling depths and times. This information is critical in determining the use of natural and constructed wetlands for water treatment.

411. Gitts, M. J., and D. J. Dollhopf. Abandoned Coal Refuse Reclamation in the Northern Plains. Reclam. Res. Unit, MT State Univ., Bozeman, MT, Reclam. Res. Publ. 87-02, Feb. 1987, 61 pp.

This study compared the effects of agricultural lime ($CaCO_3$) and cement plant kiln dust (CaO) as liming agents on acid coal waste piles in Montana. The Computerized Automatic Rapid Weathering Apparatus (CARWA) was used to determine the lime requirements on the coal waste piles studied. In addition to liming agents, topsoil replacements of 0, 15, and 30 cm were used as treatments. Grass and forb species were seeded, and aboveground cover, density, and biomass were determined, along with the characterization of root distributions. Changes in mine-soil pH due to liming agents and changes in water availability and surface temperature, as influenced by topsoil replacement and vegetation establishment, were monitored. Treatments used were (1) control, (2) $CaCO_3$ at CARWA rate, to a depth of 35 cm, 0 cm topsoil, (3) CaO at five times CARWA rate, to a depth of 35 cm, 0 cm topsoil, (4) CaO at CARWA rate to a depth of 35 cm, 0 cm topsoil, (5) CaO at CARWA rate to a depth of 100 cm, 0 cm topsoil, (6) CaO at CARWA rate to a depth of 35 cm, 15 cm topsoil, and (7) CaO at CARWA rate to a depth of 35 cm, 30 cm topsoil. The chemical and physical properties of the acid coal mine wastes studied are presented.

Incorporation of the applied CaO and $CaCO_3$ to a depth of 35 cm at CARWA recommended rates neutralized coal acidity in the surface to 10 cm. Acidity was neutralized to 30 cm when CaO was incorporated to 100 cm. Although no reacidification occurred after 2 years, further monitoring is necessary to confirm that liming agents provided sufficient neutralization for permanent reclamation. Both topsoil replacement and liming

affected seedling density, plant canopy cover, and aboveground biomass. Soil replaced to 30 cm had a significantly greater density of seeded grass and total vegetation than did the other treatments, while the 15-cm soil cover treatment had a significantly greater density of seeded grasses and total vegetation than did treatments not receiving replaced topsoil. Soil replacement provided a more suitable medium for germination and vegetation establishment than coal refuse alone. Percent canopy cover of all vegetation (seeded and volunteer) was significantly greater on soil treatments than on treatments not receiving replaced soil. Canopy cover was not significantly different between the 15- and 30-cm soil treatments.

Soil replacement also resulted in significantly greater aboveground biomass of all vegetation compared with treatments not receiving soil, with the 30-cm soil replacement depth having a significantly higher biomass than the 15-cm soil replacement treatment. Of the limed no-soil treatments, the aboveground biomass of the vegetation on the $CaCO_3$ treatment incorporated to 35 cm and on the CaO treatment incorporated to 100 cm were significantly higher than on the other limed, no-cover soil treatments. Maximum rooting depth was near the base of the zone of intended lime incorporation. The CaO treatment incorporated to 100 cm and the CaO treatment incorporated to 35 cm with 30 cm cover soil had the greater maximum root penetration statistically. All other lime and cover treatments did not produce statistically significant differences in maximum root penetration depth. The unamended coal refuse tended to have the lowest water content compared with limed and soil replacement treatments. Surface temperatures were related to treatment and vegetative cover.

412. Glauser, R., H. E. Doner, and E. A. Paul. Soil Aggregate Stability as a Function of Particle Size in Sludge-Treated Soils. Soil Sci., v. 146, No. 1, 1988, pp. 37-43.

The effects of massive additions of sludge over several years on changes in the stability of soil aggregates and morphological changes in aggregates were examined. Aggregate stability and morphology of soils amended with 72 Mg ha^{-1} yr^{-1} and control soils were compared. After water dispersion, sludge-amended soils showed a 5.7 pct higher soil-sized fraction, 2.2 pct lower silt-sized fraction, 2.0 pct lower coarse clay-sized fraction, and 1.4 pct lower fine clay-sized fraction. On a weight basis these changes are subtle; however, 47 pct of the increased sand-sized material was organic matter. This helped to reduce soil bulk density of sludge-amended soil. Ultrasonic dispersion resulted in a net reduction of sand- and silt-sized aggregates and a buildup of clay-sized particles in both the control and sludge-amended soils. Soil bulk density changed from 1.27 to 0.88 Mg m^{-3} on treated soils, indicating a substantial increase in porosity and in water stable aggregation. In fact, 85 pct of the sludge-treated soil aggregates were stable, while 45 pct of the control soils were stable. Water repellency, however, became a problem as a result of sludge application in the soils tested. Scanning electron microscopy showed the surface features of sludge-treated and control soils. The micrographs of sludge-treated soils showed their porous nature.

413. Glenn-Lewin, D. C. Natural Revegetation of Acid Coal Spoils in Southeast Iowa. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 568-575.

Descriptions and quantitative analyses are given for natural revegetation of abandoned coal strip mine spoils in southeastern Iowa. Vegetation reestablishment by natural means resulted in a complex of vegetation characteristics rather than a uniform successional sequence. Substrate acidity was an important factor controlling initial colonization. Approximately 40 to 50 pct of the oldest spoils studied remain unvegetated because of low substrate acidity.

414. Gok, M., and J. C. G. Ottow. Effect of Cellulose and Straw Incorporation in Soil on Total Denitrification and Nitrogen Immobilization at Initially Aerobic and Permanent Anaerobic Conditions. Biol. and Fertil. Soils, v. 5, 1988, pp. 317-322.

This study examined the influence of cellulose and straw on nitrate immobilization and denitrification in a sandy loam soil under both initially aerobic and permanently anaerobic conditions in controlled laboratory experiments. Each soil sample was mixed with 300 μg g^{-1} nitrate-nitrogen (NO_3-N) and cellulose (at 0.5 pct), oat straw (at 1.0 pct), or neither (control). Samples were incubated in the dark for 45 days at 30° C under conditions that changed from aerobic to anaerobic, or in the permanent absence of oxygen (O_2). At regular intervals, gas samples were taken and analyzed for O_2, CO_2, N_2, N_2O, NO, and CH_4 by gas chromatography. Soils were extracted and analyzed for nitrate, nitrite, ammonia, total nitrogen, and cellulose at the end of the incubation period.

Under both anaerobic and originally aerobic conditions, as the amounts of straw and cellulose used increased, CO_2 production increased, ammonia formation diminished, nitrate immobilization increased, and denitrification decreased. Under aerobic conditions, however, cellulose hydrolysis and mineralization were more intensive than

under anaerobic conditions, resulting in greater nitrogen turnover. The increased mineralization of available substrates resulted in a greater demand for O_2, forcing the micro-organisms to use nitrate as an electron acceptor. The parallel decreases in O_2 and nitrate substrates, however, suggest that both electron acceptors are used simultaneously. The major product in all denitrification experiments was N_2. Methane formation was more rapid in the anaerobic than in the initially aerobic condition. Methane formation is inhibited by nitrate; as a result, the release of CH_4 may indicate nitrate depletion. Nitrate must have been depleted more rapidly under the anaerobic conditions since CH_4 was released earlier than under the initially aerobic conditions.

The results of this study support the observation that straw addition to soil is a means of immobilizing soil nitrogen. Additionally, nitrate reduction and ammonia formation were more intensive under anaerobic conditions than under aerobic conditions. The rapid release of methane from cellulose products left by nitrate respiration under anaerobic condition reflects an unfavorable condition for seed germination and root growth. The authors state that the incorporation of cellulose-rich compounds into well-structured soil will be less harmful than incorporating the same compounds into compacted soils. Aerobic conditions appear to increase denitrification losses from the soil used in this study. In the field it is common for soils to have an initially aerobic condition, with a progressively restrictive O_2 supply following summer and fall rains. Under these conditions, micro-organisms use the trapped O_2 for hydrolysis and respiration and change to nitrate respiration (denitrification) in order to continue ATP synthesis. In aerated soils, the rapid mineralization of straw when nitrogen fertilizer has been added may lead to O_2 depletion by micro-organisms through respiration and nitrification. This could result in anaerobic microsites with high denitrification rates. The higher the microbial activity the greater and more intensive will be the demand for electron acceptors, leading eventually to the denitrification process. The authors state that it is likely that denitrification losses from microbiologically active soils that have been organically amended and are considered fertile soils may be more intensive than those from poorly structured and compacted soils. This paper is a good reference on the soil microbiology and biochemical reactions of straw-amended soils. The information presented in this paper has direct application to coal surface-mined soils and the use of straw as a soil amendment.

415. Golden, D. M. EPRI Coal Ash Utilization Research. Paper in Proceedings: Eighth International Ash Utilization Symposium, Volume 1 (Washington, DC, Oct. 28-31, 1987). Electr. Power Res. Inst., Palo Alto, CA, 1987, pp. 1-1—1-24.

A program directed toward increasing fly ash utilization is described. It is estimated that over 71 million tons of solid combustion byproducts is produced by coal utilities in the United States each year, with 80 pct being in the form of fly ash. The program is divided into three principal areas: (1) high-volume uses, (2) medium-technology uses, and (3) high-technology uses. High-volume uses are fly ash products that contain a large quantity or percentage of fly ash. These include fills, embankments, backfills, highway base courses, soil stabilization, and soil amendment. Medium-technology uses include cement pozzolans and bituminous fillers. High-technology uses are directed toward the extraction of minerals from the fly ash. Research in each of these areas is described.

416. Goldner, W. R., F. M. Hoffman, and R. J. Medve. Allelopathic Effects of *Cladonia cristatella* on Ectomycorrhizal Fungi Common to Bituminous Strip-Mine Spoils. Can. J. Bot., v. 64, No. 8, 1986, pp. 1586-1590.

The potential allelopathic effects of the lichen *Cladonia cristatella* on four ectomycorrhizal fungi were determined. The ectomycorrhizal fungi studied were *Cenococcum graniforme*, Pisolithus tinctorius, *Suillus luteus*, and *Thelephora terrestris*. *Cladonia cristatella* was collected from two bituminous coal spoils located in western Pennsylvania. *Cladonia cristatella* thalli were extracted with acetone and toluene; residues left after solvent evaporation were impregnated into the growth medium. The bioassay was conducted for a 30-day period. Thin-layer chromatography was used to identify potential allelopathic components.

Thelephora terrestris was dead after 17 days when the mycelium was placed on the extract-impregnated medium. Growth of *Pisolithus tinctorius* and *Suillus luteus* was inhibited by the extract-impregnated medium. *Cenococcum graniforme* mycelium growth was not affected by *Cladonia cristatella* extracts. D-Usnic acid, which is a major secondary compound of the *Cladonia cristatella* extract, inhibited the growth of *Pisolithus tinctorius*. D-Usnic acid did not, however, account for the total inhibition of *Pisolithus tinctorius*. Synergistic or summation effects by other extract components may account for the complete inhibition of *Pisolithus tinctorius* mycelial growth. Other extract components present with antimicrobial properties include barbatic acid, didymic acid, condidymic acid, squamatic acid, and rhodoclandonic acid. Lichen-dominated bituminous strip mines may affect succession on these sites. Lichens are early invaders of disturbed areas; with their allelopathic capacity to suppress ectomycorrhizal formation, succession is limited to nonmycorrhizal plants or those associated with ectomycorrhizae that are tolerant to lichen leachate. As the lichens are eventually shaded out, succession can resume.

417. Goodman, S. D., T. F. Koppe, and R. J. Hutnik. Revegetation of Strip-Mine Spoils With Containerized Tree Seedlings. Paper in Fifth Symposium of Surface Mining and Reclamation (NCA/BCR Coal Conf. and Expo IV, Louisville, KY, Oct. 18-20, 1977). Natl. Coal Assoc. and Bitum. Coal Res., 1977, pp. 16-19.

The study reported in this paper evaluated the survival of eight species of 1-year-old conifer seedlings grown in various types of containers. Noncontainerized 2-year-old nursery stock were planted in a bare-root condition as a control. Three types of mine-land sites were used in the study: Pennsylvania toxic sites, Pennsylvania current reclamation sites, and Appalachia current reclamation sites (West Virginia, Ohio, Kentucky, and Tennessee). Based on the results obtained from the first growing season, the 2-year-old commercial bare-root stock was superior to 1-year-old containerized conifer seedlings on a variety of surface-mined sites. Severe weather conditions hampered the study and complicated evaluation of the results. Continued superiority of the 2-year-old bare-root stock was uncertain because of the short time period of the study and weather problems.

418. Gordon, J. A., and J. L. Burr. Manganese Treatment by Two Methods at Abandoned Coal Sites in North Alabama. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 383-392.

Two methods of treating seepage or drainage from abandoned coal mine sites are discussed. This drainage may contain appreciable quantities of iron, manganese, and other cations. The methods described are low in initial cost, require minimal maintenance, and operate without electrical power. The first method utilizes packed columns submerged in an upflow manner to remove manganese from mine water. The active substance in the columns was a slimy, black precipitate that coated chert stones. This material was shown to have the ability to colonize inert glass marbles and native sandstone. The packed columns oxidized and removed the dissolved manganese originating from a reclaimed strip mine area. These columns can be used if the water pH is above 6.0 and iron is removed prior to manganese removal. The second method described is a constructed wetland. This wetland system reduced aluminum, manganese, iron, and other cations through biological and chemical oxidation and precipitation, while pH and dissolved oxygen increased.

419. Gosz, J. R., L. Barton, L. D. Potter. An Evaluation of New Mexico Humate Deposits for Restoration of Mine Spoils. Ch. in Reclamation of Disturbed Arid Lands. Univ. NM Press, 1978, pp. 180-188.

The effects of humate and mulch applications were evaluated at the Jackpile uranium mine near Laguna, NM. The specific objectives were to evaluate the microbial and mineral nutrient qualities of humates and their effects on mine spoils, and to evaluate the effects of humates on plant growth and quality of forage of both native and introduced plants. Four humate application rates were used: 0, 714, 3,569, and 7,138 kg ha^{-1}. On a second set of plots, barley mulch (1,695 kg ha^{-1}) was added along with humate. Chemical analyses showed that organic matter, nitrogen, zinc, and phosphorus contents were higher in the humate than in the native soil (Tres Hermanos Sandstone), which had a higher calcium concentration than humate. Humate had both a stimulatory and an inhibitory effect on soil microbes. Soil fungi were stimulated by humate application rates of 714 to 3,569 kg ha^{-1}. Soil bacteria and fungi had their highest counts when humate was applied at 714 kg ha^{-1}. Application rates higher than this reduced microbe counts. The application of mulch on humate did not have a statistically significant effect on plant growth. Potassium was the only element affected by humate application; barley tissue analysis showed a marked decrease in potassium concentration. The authors conclude that there is a need to continue to evaluate the effects of humate on plant growth, particularly for the potential accumulation of metals by plants.

420. Gough, L. P. Regional Investigations of Soil and Overburden Analysis and Plant Uptake of Metals. Paper in Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 156-171.

This paper reports the results of regional studies on the bioavailability of metals at native and disturbed sites in the Fort Union, Powder River, and Green coal regions. Correlations between copper, iron, and zinc in plants and extractable and total levels in native A and C horizons of soil were occasionally significant. A simple linear model generally did not provide an adequate representation of element uptake by plants. Stepwise linear multiple-regression analysis, incorporating several soil chemical and physical parameters, improved the predictive capabilities of the models and accounted for more than 54 pct of the variability in the data. Soil pH was the most important variable relating soil chemistry to plant chemistry.

421. Gozon, J. S., C. J. Konya, S. S. LuKovie, R. G. Lundquist, and J. Olah. Mined Land Reclamation by Biological Reactivation. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 19-26.

The authors describe a new method of reclamation developed in Europe that restores land to full productivity within 2 years without topsoil replacement. The technique is called biological reactivation (BR), and it reestablishes within 1 year following mining the required biological balance between microbes, enzymes, and trace elements. The feasibility of using the BR process in the United States was evaluated. The physical and chemical parameters of 140 spoil samples from 10 surface mining operations were characterized. Results indicate that BR technology could be effectively applied to areas tested in Ohio, Indiana, and Kentucky. There are several advantages to the BR system; for instance, there is no need to use conventional reclamation techniques such as selective stripping, storage of material, replacement of topsoil, or the use of pioneer plant species. Another advantage is that the BR technique reduces reclamation costs on prime farmland by 90 to 95 pct compared with conventional U.S. reclamation techniques. The authors state that the second year after the BR technique has been used, a grain or vegetable yield identical with the original agricultural lands can be expected.

422. Grandt, A. F. Prime Farmland—Is Restoration a Reality? Min. Congr. J., v. 68, No. 9, 1982, pp. 25-30.

The author provides the results of several studies that reveal some row-crop yields comparable to those from relevant reference areas on prime farmland. The studies reported were conducted in the Interior coal region. The results reported are of value for comparative studies and planning.

423. Grandt, A. F. Problems in Reclaiming Farmland in Illinois. Min. Eng. (N.Y.), v. 33, No. 9, 1981, pp. 1347-1350.

This article offers excellent reviews of the salient points of the Surface Mining Control and Reclamation Act of 1977 and the 1971 Illinois Surface Land Conservation and Reclamation Act, as well as the definition of prime farmland by the U.S. Soil Conservation Service in 7 CFR 657 (Federal Register, v. 4, No. 21). Additionally, the author relates the results of a study designed to measure the effects of topsoil on graded surface-mined land and to compare corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) yields on original soil and graded surface-mined lands through the incorporation of a reference area that meets the criteria developed by the Rules and Regulations of Public Law 95-87. An initial settling period for newly reclaimed land is recommended, during which legume-grass mixtures can be used to facilitate the stabilization of the chemical, physical, and biological factors of the soil prior to rotational cropping systems.

424. Grandt, A. F. Reclaiming Mined Land In Illinois for Row Crop Production. J. Soil and Water Conserv., v. 33, No. 5, 1978, pp. 242-244.

The author discusses the feasibility of reclaiming Illinois surface-mined lands for row-crop production. Data are presented from studies conducted on nontopsoiled sites from the late 1940's to early 1960's. The yields obtained from these studies equaled or exceeded the county averages at the time the experiments were conducted. A study is described in which a topsoiled and graded spoil was continuously cropped with corn (*Zea mays* L.), and the yields obtained were compared with the yields of an unmined Muscatine silt loam (prime farmland) in Knox County, IL.

The results of this study suggested that continuous row crops should not be grown on recently reconstructed mine land. Corn yields on the topsoiled area remained constant for 3 years and exceeded the yields for the Muscatine silt loam under basic levels of management. Under high levels of management, however, the topsoiled corn yields were 15 to 20 pct short of the yields on unmined land. On the graded spoil, corn yields dropped substantially over the 3 years and never equaled the yields obtained on the topsoiled or unmined areas. Again, the corn yields obtained were above that predicted for a basic level of management, but below that predicted for a high level of management. The author concludes that newly mined lands should not be immediately planted to corn. A legume-grass mixture should be seeded the first few years to allow the chemical, physical, and biological aspects of the replace topsoil to stabilize. Following this period, row crops, such as corn and soybeans, can be grown successfully on land that has been strip mined for coal.

425. Grandt, A. F. Selection, Establishment, and Utilization of Plant Materials for Multiple Postmining Land Use. A Study Guide for a Mini-Course Taught at the 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, 85 pp.

This manual contains information on the reestablishment of vegetative cover on mined land in the Eastern United States for multiple postmining land use. Information is given on vegetation types (grasses, forbs, and woody plants), selection of plant materials, establishment of vegetation (soil testing and soil amendments needed), planting, and maintenance. Most of the manual contains useful information on grass, forb, and shrub species characteristics.

426. Graney, D. L. Ten-Year Growth of Red and White Oak Crop Trees Following Thinning and Fertilization in the Boston Mountains of Arkansas. Paper in Proceedings of the Fourth Biennial Southern Silvicultural

Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 445-450.

A thinning and fertilization study of 50-year-old overstocked stands of northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam.), and white oak (*Quercus alba* L.) was initiated, and the 10-year growth responses of each species were summarized. Nitrogen and phosphorus fertilizer treatments were (1) no fertilizer, (2) 200 lb acre^{-1} N plus 45 lb acre^{-1} P, and (3) 400 lb acre^{-1} N plus 45 lb acre^{-1} P. All trees produced an immediate positive response to thinning, with the rate of annual diameter growth increasing through the 10-year period. Response to thinning was greatest during the 5th through 10th year, as the response to fertilization declined for all species. Red oaks that were thinned produced the greatest overall response to fertilization. Mean diameter growth of thinned, fertilized red oaks averaged 28 pct more than growth of thinned, nonfertilized red oaks at the 200-lb N treatment and 42 pct more at the 400-lb N treatment over the 10-year period. Maximum response to fertilization occurred during the first 2 years after treatment. Thinned white oak was less sensitive to nitrogen fertilization. Both nitrogen treatments produced about a 30-pct increase during the 10-year period. Maximum growth response for white oak occurred during the first 2 years after treatment. Results of this study indicate that diameter growth of overstocked pole-sized red and white oaks can be significantly increased by thinning or fertilization. The authors doubt, however, that the 10-year cumulative increase in diameter (0.3 to 0.5 in) would justify the cost of a single commercial application of fertilizer in intermediate-aged stands. Management of stand density in younger stands should have first priority.

427. Graves, D. H., and S. B. Carpenter. Use of Hardwood Bark in Stripmine Reclamation. Paper in Organic and Fuel Uses for Bark and Wood Residues (Bark and Residue Tech. Sess., For. Prod. Res. Soc., Annu. Meet., San Francisco, CA, 1979, and Boston, MA, 1980). For. Prod. Res. Soc., Madison, WI, Proc. P-80-27, 1980, pp. 6-12.

The authors review a number of studies being conducted by the University of Kentucky that compare various mulching systems with the use of bark mulch to evaluate vegetative responses and microclimate modification. Bark mulching resulted in higher soil moisture content compared with straw or waterborne fiber mulches. Bark mulch was the warmest mulch during the winter and was only slightly warmer than straw during the hot portion of the growing season. Mixtures of bark and organic material were superior mulches for the development of total ground cover. Bark-based mulches resulted in rapid establishment of legumes. Alternatively, water-based mulches resulted in greater establishment of grass. Direct seeding of heavy seed species such as oaks (*Quercus* spp.), yellow buckeye (*Aesculus octandra* Marsh.), and Chinese chestnut (*Castanea mollissima* Blume) responded favorably to bark and bark-mixture mulches. Interim results indicates that bark mulch improves the initial survival of both bare-root and containerized seedlings. A brief discussion of recent economic analyses indicates that bark mulching compares favorably with hydromulching or with hay or straw mulching and is less expensive than mulching with composted municipal waste.

428. Graves, D. H., S. B. Carpenter, and R. F. Wittwer. Direct-Seeding of Commercial Trees on Surface Mine Spoil. U.S. EPA, Rep. EPA-600/7-80-073, Apr. 1980, 14 pp.

The potential for direct seeding of small-seeded and large-seeded tree species on mine spoils in eastern Kentucky was evaluated. The study combined three directional aspects, four types of mulch application, two levels of fertilizer application, and two herbaceous vegetation seeding rates as treatments. The small-seeded species used were paulownia (*Paulownia tomentosa* (Thunb.) Steud.) and European black alder (*Alnus glutinosa* (L.) Gaertn.). The three large-seeded species used were northern red oak (*Quercus rubra* L.), pin oak (*Quercus palustris* Muenchh.), and bur oak (*Quercus macrocarpa* Michx.). Survival of the large-seeded species was better than that of small-seeded species. Initial germination of all five species was significantly higher on the warmer, south-facing aspect of the spoil. Mulching increased the survival rate and growth for all species. The best survival rates were obtained with composted municipal sewage sludge. The most height increase was obtained with bark-manure mulch. Fertilizer decreased survival and increased height growth. Competition from herbaceous ground cover reduced germination more than any other variable. Ground cover also reduced height growth.

429. Greater Egypt Regional Planning and Development Commission (Carbondale, IL). Erosion Potential of Reclaimed Agricultural Lands in Perry County (U.S. EPA grant P00 5623-01). Rep. GERPDC-82-617, July 1982, 66 pp.; NTIS PC A04/MF A01.

The commission assigned soil loss estimates via the Universal Soil Loss Equation to 1,300 acres of land reclaimed by four mining companies using row crops. Tables were prepared indicating the level of compliance obtained with nine hypothetical crop rotation and tillage method combinations, based on the Perry County, IL, erosion control standards for 1995. State-of-the-art soil

management methods applied to reclaimed soils were shown to be adequate for acceptable sediment and erosion control.

430. Green, B. B. Biological Aspects of Surface Coal Mine Reclamation, Black Mesa and San Juan Basin. Argonne Natl. Lab., ANL/AA-10, Aug. 1977, 56 pp.

This report discusses case study reclamation data from the Black Mesa Mine in Arizona and the Navajo Mine in the San Juan Basin in New Mexico. Edaphic factors, such as soil characteristics, soil amendments, and topsoil storage and handling, are discussed, along with data on the soils and their characteristics. The vegetative communities at the minesites are described, as well as cover and production data. Previous reclamation practices at the mines are briefly outlined, as is ongoing research.

431. Green, J. E., and C. Franz. Mined Land Reclamation for Wildlife Habitat. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 29-33.

This paper discusses the development of wildlife habitat as a reclamation option. The recreational and aesthetic values associated with wildlife areas, and the relatively low cost required for reclaiming to this land use, make it a popular reclamation alternative. Wildlife reclamation studies, and reclamation studies in general, are concerned with soil replacement, revegetation, and the development of early plant and animal communities. Examples of wildlife habitat are given.

432. Groenewold, G. H., and B. W. Rehm. Instability of Contoured Surface Mined Landscapes in the Northern Great Plains: Causes and Implications. Reclam. & Reveg. Res., v. 1, No. 2, 1982, pp. 162-176.

The focus of this research was on the stability characteristics of postmining landscapes at the Indian Head Mine in western North Dakota. Three types of instability have been observed in reclaimed postmining landscapes: (1) areawide settling, (2) localized subsidence or collapse, and (3) piping. The instrumentation of this study was designed to monitor the movement of surface materials and the hydrologic conditions at the site. Concrete survey markers were utilized to monitor both horizontal and vertical displacements. Water levels in piezometers were monitored to determine the hydraulic conductivity of the spoils. Gamma-gamma and gamma-density logs were obtained for each piezometer to delineate blocky and poorly consolidated zones in the spoils. Monitoring of the markers indicated that very little spoil movement had occurred; maximum vertical displacement did not exceed 5 in, and no significant horizontal displacement was found. The authors state that areawide settlement occurred prior to instrumentation. Piezometer data indicated that the base of the spoils was saturated over 70 pct of the site. The results of this study indicate that the design of stable postmining landscapes requires the integration of the following factors: (1) detailed knowledge of the distribution of overburden materials, with emphasis on the delineation of highly sodic sediments, (2) proper equipment selection, and (3) consideration of climatic factors.

433. Grogan, S., C. L. Caldwell, O. J. Estrada, and W. Skeet. Conventional Wisdom in 1975 and the Real World in 1978 in Surface Mine Reclamation at the Navajo Mine. Paper in Ecology and Coal Resource Development, Volume 1 (based on the Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 427-430.

The authors describe the evolution of the reclamation program at the Navajo Mine operated by Utah International, Inc., in northwestern New Mexico on the Navajo Indian Reservation. The conventional wisdom of 1975, under which the original mine plan including the reclamation program was devised, is compared with the reclamation process as it existed in 1977. Revegetation problems and their potential solutions are discussed. Much of the information is covered in a cursory manner. The paper may be of interest, however, to individuals concerned with reclamation planning in the Southwestern Coal Mining Region.

434. Grossnickle, S. C. Ectomycorrhizae: A Viable Alternative for Successful Mined Land Reclamation. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 306-313.

This paper reviews the factors affecting ectomycorrhizal development and occurrence on tree roots and the use of ectomycorrhizal fungi on reclamation and reforestation sites. The literature shows that the rate of ectomycorrhizal development is directly related to soil nutrient levels, pH, soil moisture, soil temperature, oxygen availability, and substances (vitamins, amino acids, carbohydrates, etc.) derived from roots. Research has shown that the introduction of ectomycorrhizae with tree seedlings on disturbed sites is critical if successful establishment is going to occur. Several examples of successful tree establishment studies using ectomycorrhizae-inoculated seedlings are presented.

435. Grossnickle, S. C., and C. P. Reid. The Use of Ectomycorrhizal Conifer Seedlings in the Revegetation

of a High Elevation Mine Site. Can. J. For. Res., v. 12, 1982, pp. 354-361.

This article reports the results of a combined greenhouse and field study that evaluated the potential use of ectomycorrhizal-fungi-inoculated conifers in high-elevation minesite revegetation. Lodgepole pine (*Pinus contorta* Dougl.), limber pine (*Pinus flexlis* James), and Engelmann spruce (*Picea engelmannii* Parry) were inoculated with the ectomycorrhizal fungi *Pisolithus tinctorius* (Pers.) Coker & Couch., *Suillus granulatus* (L.) Kuntze, and *Cenococcum geophilum* Fr. These seedlings, along with uninoculated control seedlings, were grown in a greenhouse for 8 months. Top height, diameter, and seedling total dry weight were greatest for those conifers inoculated with *S. granulatus* and for the control. These were then outplanted on a high-elevation molybdenum tailings pond covered with deep-mine waste rock at a site near Empire, CO. Four fertilizer treatments, together with sewage sludge and wood chips, were incorporated into the study. After 4 years in the field, *S. granulatus*-inoculated seedlings showed greater height growth. Greater height growth was obtained with the sewage sludge and wood-chip treatment than with the three treatments of combined inorganic nitrogen and phosphorus, phosphorus alone, and no fertilization. Although this article is not directly related to revegetation of coal surface mines, the results may find application in the reclamation of coal surface mines.

436. Grove, J. H., and V. P. Evangelou. Colloid Exchange Phase Dynamics and Saline Spoil Management. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 387-390.

The value of added colloid exchangers in reducing soluble salt levels in limed, formerly acid, pyrite coal spoil from western Kentucky was evaluated. Two different experiments were conducted using the limed spoil. In the first experiment, 1 g each of sand, topsoil, subsoil, aluminum-saturated soil clay, calcium-saturated soil clay, and hydrogen-saturated cation-exchange resin (AG 50W-X10) and 0.5 g each of wheat straw, corn stalks, aluminum-saturated peat, and calcium-saturated peat were added to 10 g of limed spoil material. In the second experiment, 5 g of each of the above exchangers (except for wheat straw and corn stalks) was mixed with 5 g of the limed spoil material. In each experiment (amendment-to-spoil ratios of 1:20, 1:10, and 1:1), the mixtures were suspended in water and changes in solution chemistry (pH, calcium, magnesium) were determined relative to an inert sand control mixture. In experiment 1, the corn stalks and wheat straw caused solution calcium and magnesium to rise above control levels. This is probably due to a chelating action of soluble organic anions released from these materials. All other amendments reduced soluble magnesium levels, with aluminum-saturated exchangers being more effective than the calcium-saturated materials. The ion-exchange resin was the most effective at controlling soluble salts. By increasing the ratio of amendment to spoil from 1:10 to 1:1, the average solution calcium and magnesium removed increased from 5.6 to 34.9 pct. Even though the exchanger materials may not reclaim the entire soil profile, they do bring about a better seed zone chemical environment, which should accelerate vegetation establishment.

437. Grove, J. H., and V. P. Evangelou. Modeling Water Quality During Salty Spoil Suspension Events. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 349-353.

The authors describe a model used to predict the solution-phase chemistry of sulfate-dominated colloid systems; it had been tested on pyritic spoil from western Kentucky that had been amended with calcitic and magnesitic liming materials. Liming produced spoils with a wide range of sulfate chemistry. Lime and unlimed spoil response to wetting was determined using water-to-spoil ratios of 1:1, 2:1, 5:1, and 20:1. Soluble cations (calcium and magnesium) in the solution phase were then determined. The suspensions ranged widely in their solution-phase composition and properties. An evaluation was made of the ability of the model to predict solution composition upon dilution (wetting) or concentration (drying) of the solution. It was found that predicting the magnesium concentration was dependent on an estimate of the expansion of the exchange phase on clay colloid surfaces or changes in the selectivity of adsorption between calcium and magnesium with increasing salt strength. The authors conclude that the modeling of the three-phase system (solution, adsorbed, and solid) with salts of different solubilities is dependent on the interaction of the colloid-exchange phase with the surroundings.

438. Grove, J. H., and V. P. Evangelou. The Role of Lime in Salty Spoil Genesis. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 1-4.

This incubation study was conducted to determine the quantity, type, and rate of sulfate salt release from acid pyritic spoil from western Kentucky, as affected by lime rate and source. The study was conducted with 500-g

portions of spoil and both calcitic and dolomitic lime sources. The lime rates used were 0, 14.4 meq per 100 g (one-half the lime requirement for potential acidity control), and 28.8 meq per 100 g (full lime requirement for potential acidity control). Amended spoils were maintained at 30° C and 100 cm moisture tension. Spoils were sampled 1, 9, and 16 weeks after liming, and air dried; soluble-salt formation was determined by suspending a sample in water at a soil-solution ratio of 1:20 for 2 h. The pH of unamended spoils dropped quickly, from 4.8 to 3.2 after 9 weeks of incubation. Of the other treatments, only dolomite applied at half the lime requirement failed to maintain the initial pH level. Soluble magnesium sulfate doubled in the unlimed spoils between weeks 1 and 16. All lime-amended soils, except that with the highest rate of calcitic lime, released larger quantities of soluble salts than did unamended spoil material. Dolomite-amended spoils generated twice as much magnesium salt as calcite-amended spoils. Calcite lime, therefore, was the most effective at reducing the soluble magnesium release. When used at the recommended rate, calcite lime reduced salt genesis. The authors recommended that dolomite not be used on sandy spoils with high pyrite content.

439. Gruhn, C. M., R. W. Roncadori, and P. P Kormanik. Interaction Between Vesicular-Arbuscular Mycorrhizal Fungus and Phosphorus Fertilization on Sweetgum Growth in Loamy Sand and Kaolin Spoil. Reclam. & Reveg. Res., v. 6, No. 3, 1987, pp. 197-206.

This pot study evaluated the effect of the vesicular-arbuscular (VA) fungus *Gigaspora margarita* Becker & Hall and phosphorus fertilization on sweetgum (*Liquidambar styraciflua* L.) growth and development in a loamy sand soil and in kaolin mine spoil. Sweetgum biomass, growth, vigor, foliar nutrient content, and mycorrhizal development in both growth mediums were compared 161 days after planting. Growth of sweetgum seedlings was enhanced by either mycorrhizal colonization or phosphorus additions. Nonmycorrhizal seedlings grew best in the loamy sand when the soil was amended with 100 $\mu g\ g^{-1}$ P. The kaolin-spoil-grown seedlings did not respond to fertilization unless they were mycorrhizal, owing to the effective phosphorus-fixation capacity of the kaolin spoil. In the spoil material, plant growth was increased to a greater degree by mycorrhizae than by phosphorus additions. As phosphorus stress was increased in both growth mediums, mycorrhizal colonization increased. Foliar levels of phosphorus, magnesium, and calcium were enhanced by mycorrhizal colonization and phosphorus fertilization. The successful and economic establishment of sweetgum on kaolin spoil may be possible only if VA mycorrhizae are present. The fertilization of soil and spoil materials with phosphorus inhibits mycorrhizal colonization and sporulation, which suggests that reclamation and reforestation involving phosphorus fertilization may reduce VA mycorrhizal structures, having an adverse effect on VA mycorrhizae and host development.

440. Guernsey, J. L., L. A. Brown, and A. O. Perry. A Case Study of Surface Mining and Reclamation Planning: Georgia Kaolin Company Clay Mines, Washington County, Georgia. Integrated Mined-Area Reclamation and Land Use Planning, v. 3C. Argonne Natl. Lab., ANL/EMR-1, Feb. 1978, 122 pp.

This report is one in a 10-volume series prepared by the Energy and Environmental Systems Division of Argonne National Laboratory and the Resource and Land Investigations (RALI) Program of the U.S. Department of the Interior under the sponsorship of the U.S. Geologic Survey. The reclamation practices of Georgia Kaolin's American Industrial Clay Co. division, a kaolin producer in Twiggs, Washington, and Wilkinson Counties, are examined in this case study. The mining of kaolin in Georgia illustrates the effects of mining and reclamation of lands disturbed by surface mining typical of this area. Reclamation of these mined lands is regulated in accordance with the Georgia Surface Mining Act of 1968. The environmental disturbances and procedures used in reclaiming the mined lands are reviewed, and implications for planners are noted. Several aspects of the reclamation work are reviewed, including spoil characterization, vegetative species performance, operational cost, and the development of a reclamation plan.

441. Guernsey, J. L., M. E. Tiller, and J. R. LaFevers. A Case Study of Surface Mining and Reclamation Planning: Area Strip Coal Mining, Peabody Universal Mine, Universal, Indiana. Integrated Mined-Area Reclamation and Land Use Planning, v. 3D. Argonne Natl. Lab., ANL/EMR-1, Feb. 1977, 54 pp.

This study is concerned with land reclamation at Peabody Coal Co.'s Universal Mine near Terre Haute, IN. This site was chosen because it possesses many of the characteristics common to both midwestern and western coal mines. Included in the paper are sections on the physiographic setting, climate, hydrology, soil, and land use of west-central Indiana. There is also a section on the history of mining and reclamation, along with operational procedures used at Universal Mine. The objectives of the reclamation operation at Universal Mine are grading the topsoil, providing water impoundments and access roads, and reestablishing a vegetative cover. Restoring the land to row-crop production is the most common form of interim and future land use in the area. Grasses and

legumes are the plant species most often used; no tree plantings have been included in the reclamation efforts at Universal Mine. Estimated reclamation costs are included in this paper. Long-range higher uses for the area include the possible development of the area for housing and recreation sites because of the demand for these types of land uses in the Terre Haute area. The authors feel that a well-designed reclamation plan should include both interim and long-range plans. If the two are linked in an orderly manner, disturbed land would be out of production for a minimum period before it is brought to its highest possible long-term use.

442. Guidi, G., A. Pera, M. Giovannetti, G. Poggio, and M. Bertoldi. Variations of Soil Structure and Microbial Populations in a Compost Amended Soil. Plant and Soil, v. 106, No. 1, 1988, pp. 113-119.

Changes in soil structure and microbial population in a compost-amended soil are described. Treatments used were mineral fertilizer (100 kg ha^{-1} N), manure (200 kg ha^{-1} N), and three rates of compost that added 100, 200, and 300 kg ha^{-1} N. Corn (*Zea mays* L.) was seeded in each of the treatment plots. Seasonal variability in the stability of soil aggregates, total porosity, and pore size distribution were observed, along with changes in mycorrhizal infection and aerobic micro-organism populations. The differences that were observed in soil structural parameters were dependent on the presence of different amounts of organic amendments. The physical characteristics were not affected at any one time by the organic treatments. The organic amendments were ineffective in significantly increasing total porosity, the stability of soil aggregates, or pore size distribution. Microbiological populations were, however, influenced by the addition of compost; plants that were treated with low and medium rates of compost had the highest incidence of mycorrhizal infections. Manure additions inhibited mycorrhizal infection, while fertilizer and the highest rate of compost addition tended to lower incidence of mycorrhizal infection. A significantly higher number of cellulolytic micro-organisms were found in the medium- and high-compost treatments than in any of the other treatments. This research shows the importance of organic additions on the number of micro-organisms found in a soil.

443. Guillaume, M., W. A. Berg, and J. T. Herron. Performance of Native and Introduced Species Seven Years After Seeding on Alpine Disturbances. Paper in Proceedings of the High Altitude Revegetation Workshop No. 7, ed. by M. A. Schuster and R. H. Zuck. CO Water Resour. Res. Inst., CO State Univ., Fort Collins, CO, Inf. Ser. 58, 1986, pp. 131-141.

Native and introduced species for seeding into alpine disturbances were evaluated on sites that have winter snow cover. Monocultures of 23 native species were seeded in topsoil, and a mixture of 16 native species were seeded in subsoil and mine rock waste. Ten introduced species, seeded in monocultures and as a mixture, were also evaluated. Evaluation took place after two and seven growing seasons. Species frequency trends over time as affected by site were reported.

444. Guldin, R. W., and J. P. Barnett (eds.). Proceedings of the Southern Containerized Forest Tree Seedling Conference (Savannah, GA, Aug. 25-27, 1981). U.S. For. Serv., Gen. Tech. Rep. SO-37, June 1982, 160 pp.

This publication contains numerous research papers specifically dealing with the use of containerized tree seedlings for reestablishment of trees in the Southeastern United States. Major topics covered by these papers include (1) the selection of appropriate containers, (2) nursery production practices, (3) planting methods and stand establishment techniques, and (4) field performance of container-grown seedlings. Individuals concerned with the reestablishment of tree species on land disturbed by surface coal mining will find this publication a valuable reference.

445. Hajjar, L. M., and L. D. King. Cd Content of Tobacco and Peanut Grown on Sludge-Amended Soil. Am. Soc. Agron., Agron. Abstr., 1985, p. 25.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. The cadmium content of tobacco (*Nicotiana tabacum* L.) and peanut (*Arachis hypogaea* L.) grown on sludge-amended soil was determined in a series of greenhouse studies. Sewage sludge had been applied to the soil used in this study at rates of 0, 9, 18, and 27 Mg ha^{-1} for 3 years. Soil was adjusted to pH >6.5 (high), pH 5.7 to 6.0 for tobacco and 5.8 to 6.2 for peanut (medium), or pH <5.5 (low). Increases in cadmium concentration of tobacco leaves and peanut tops due to sludge loading rate was highest at the low pH. Loading rate did not affect cadmium concentration at the medium or high pH.

446. Hale, A. M. Reclamation in the Eastern U.S. Dames & Moore Eng. Bull., No. 52, Aug. 1980, pp. 33-40.

The author provides a general and relatively nontechnical review of reclamation and revegetation efforts on surface coal mined lands in the Eastern and Interior Coal Mining Regions. Postmining land use defines the direction that all other factors in the reclamation program must take. Topics considered in the article include (1) the

importance and use of overburden analyses, (2) surface and ground water analyses, (3) soil analyses and vegetation inventories, (4) topsoil stockpiling and treatment, (5) consideration of localized climatic conditions, and (6) the establishment and maintenance of vegetation. The article provides good background information that could be helpful to individuals with little or no experience in mine-land reclamation.

447. Hall, A., and W. A. Berg. Prediction of the Sodium Hazard in Coal Mine Overburden. Reclam. & Reveg. Res., v. 2., No. 3, 1983, pp. 191-204.

This research was conducted to determine the relationships of sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) in samples of fresh and weathered overburden collected from North Dakota and Colorado. These relationships were then compared to the SAR-ESP relationship commonly used to predict possible sodium problems in soils. The overburden samples collected were subjected to four different weathering treatments for 16, 64, or 224 days. The weathering treatments used consisted of (1) air-dry, (2) field capacity, (3) wet-dry, and (4) cropped. With weathering there were statistically significant decreases in the ESP and SAR, with corresponding increases in soluble calcium. The most effective treatment in reducing sodicity was the wet-dry weathering treatment. It was found that the ESP in most of the samples taken was overestimated from measured SAR values when the SAR-ESP relationship (developed by the U.S. Salinity Laboratory) was used. The authors recommend that ESP should be determined on overburden samples that have SAR values approaching problem levels.

448. Hall, G. F. Classification of Five Types of Strip Mine Spoil and Implications for Reclamation. Paper in Fifth Symposium on Surface Mining and Reclamation (NCA/BCR Coal Conf. and Expo IV, Louisville, KY, Oct. 18-20, 1977). Natl. Coal Assoc. and Bitum. Coal Res., 1977, pp. 1-3.

This paper describes five soil series proposed during soil mapping in Belmont and Noble Counties, OH, that are made up of strip mine spoil material with lithology ranging from limestone to acid sandstone and shale. Recognition of distinct soil series representing spoil materials through the application of mapping and descriptive methods employed in the National Cooperative Soil Survey Program will allow for the identification, classification, delineation, and interpretation of distinctly different types of spoil material. Once soils are identified and delineated, information gained from reclamation research and experience can be transferred to other areas with similar soil.

449. Hall, R. B. Land Reclamation With Trees in Iowa. Paper in Trees for Reclamation (Lexington, KY, Oct. 27-29, 1980). U.S. For. Serv., Gen. Tech. Rep. NE-61, 1980, pp. 45-47.

The author reviews the findings of studies done on old spoil areas and current research being conducted on surface mine spoils in Iowa. Several potential determinants of what tree species could be planted were identified, which included soil, pH, soil moisture availability, soil compaction, nutrient cycling, and mycorrhizal establishment. The tree species found to be adapted to a variety of site conditions were green ash (*Fraxinus pennsylvanica* Marsh.) and cottonwood (*Populus deltoides* Marsh.). When soil moisture and pH were not limiting tree establishment, nitrogen and phosphorus were. The following tree species were recommended under nitrogen-deficient conditions: European black alder (*Alnus glutinosa* (L.) Gaertn.), black locust (*Robinia pseudoacacia* L.), and Arnot bristly locust (*Robinia fertilis* Ashe). Phosphorus deficiency problems could be reduced if trees were inoculated with the appropriate mycorrhizal fungus species. A current study is being conducted using European black alder and hybrid poplar (*Populus alba* x *Populus grandidentata*). The establishment of tree plantations on surface-mined land is an alternative to the reclamation of sites for row-crop production.

450. Halvorson, G. A. Neutron Moisture Meter Calibration for Minespoils Containing Coal. Soil Sci. Soc. Am. J., v. 50, No. 2, 1986, pp. 496-498.

Coal fragments, made up of hydrocarbons containing high concentrations of H^+, are commonly found in recontoured mine soils. Neutron moisture measurements record the presence of H^+ in soils. The structural H^+ of coal will change the moisture meter readings to give erroneous soil-water measurements on mine soils where coal fragments occur. In this study, the effect of coal in mine soils on soil-water determinations, using the neutron meter method, was determined using clay loam and loamy sand mine soils from western North Dakota. Calibration curves were developed for both soil types with and without coal fragments by taking neutron readings at 0.20, 0.25, and 0.30 m below the surface and determining the volumetric water content at the same depths. Coal, at 8 pct by weight, added the equivalent of 3.7 pct water to the clay loam; at 9 pct by weight, coal added 4.7 pct water to the loamy sand. The calibrations for both soil types corrected for coal were not significantly different from calibrations for soil without coal. The equivalent water corrected for coal accounted for the difference in loamy sand and clay loam soil calibration curves with and without coal.

Neutron moisture meter measurements of absolute water content can be done successfully following coal surface mining when the content of coal in the mine soil is known.

451. Halvorson, G. A. Soluble Salt Movement in Reclaimed Mine Soils in Western North Dakota. Am. Soc. Agron., Agron. Abstr., 1984, p. 27.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. Salt movement in mine-soil profiles that had been reclaimed in the early 1970's was determined for 43 nontopsoiled and 34 topsoiled sites to a depth of 1.8 m. Sodium had leached out of the upper profile in both the nontopsoiled and topsoiled sites. Sodium was concentrated at 0.4 m below the surface for the nontopsoiled sites, and at 0.4 m below the topsoil-spoil interface of the topsoiled sites.

452. Halvorson, G. A. Spatial Variability of North Dakota Mine Spoil. Am. Soc. Agron., Agron. Abstr., 1985, p. 25.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. The variability in the physical and chemical characteristics of regraded spoil in North Dakota was determined. An expanding-square technique at two locations was utilized to sample the soil. Variability from different areas can be measured using this technique. Results indicated that there was considerable mixing of the spoil material during the mining operation. The least variable characteristic of regraded spoil was pH, while the most variable characteristics were SAR and soluble calcium, magnesium, and sodium.

453. Halvorson, G. A., A. Bauer, S. A. Schroeder, and S. W. Melsted. Corn and Wheat Response to Topsoil Thickness and Phosphorus on Reclaimed Land. J. Environ. Qual., v. 16, No. 1, 1987, pp. 73-76.

The thickness of topsoil needed to restore wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.) production on moderately sodic spoil material to optimum levels was determined. Additionally, the yield responses of corn and wheat to phosphorus placement and water were studied. A nonsodic sandy loam topsoil was replaced on a clay loam spoil at thicknesses of 0.05, 0.15, 0.30, and 0.60 m. Prior to topsoil replacement, a one-time broadcast application of fertilizer phosphorus was applied on the leveled spoil at rates of 0, 34, and 100 kg ha^{-1} P. Then, over a 6-year period, phosphorus fertilizer was applied annually using a variety of methods and rates. Using a drill attachment, phosphorus was applied to seeded wheat at rates of 0, 11, and 34 kg ha^{-1} for a 4-year period. The same phosphorus rates were used for seeded corn, but the phosphorus fertilizer was banded. In the last 2 years of the study, phosphorus was broadcast at rates of 0, 12, and 12 kg ha^{-1} P on wheat and 0, 18, 18 kg ha^{-1} P on corn.

Corn silage yields were higher on the 0.3- and 0.6-m replaced topsoil than on the 0.05-m thickness. In general, topsoil thicknesses greater than 0.15 m did not significantly increase corn silage yields. Wheat grain yields responded similarly to topsoil thickness. Wheat and corn silage yields were consistently higher on plots with 0.30 m of replaced topsoil; however, these yields were not significantly different from yields obtained on plots with 0.15 m of replaced topsoil. Profile soil-water loss during the growing season tended to be greater on plots with 0.15, 0.30, or 0.60 m of replaced topsoil than on plots with 0.05 m. The magnitude of this seasonal water loss was dependent on the water content at planting time and the distribution of rainfall during the growing season. The authors attribute the lack of response of both corn silage and wheat yields to topsoil thicknesses greater than 0.15 m to the ability of the clay loam to provide a more constant supply of water at topsoil thicknesses of less than 0.15 m. As the thickness of the sandy loam topsoil increases, the ability of the soil profile to supply the growing crop with water is decreased, leaving the plants more susceptible to drought stress. Yield increases of corn silage and wheat from broadcast, drilled, or banded applications of phosphorus were small and inconsistent from year to year.

454. Halvorson, G. A., and E. C. Doll. Topsoil and Subsoil Replacement on Stripmined Land in North Dakota. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 232-241.

This article reviews and evaluates published and unpublished research relating to the depth and quality of topsoil and subsoil needed for successful reclamation of North Dakota surface-mined lands. The depth of soil replacement needed to restore soil productivity is dependent on the chemical and physical properties of the underlying spoil, while the potential capacity of reclaimed soils is related to the chemical and physical properties of the root zone. For maximum production capacity, reclaimed soils should have a minimum effective root zone depth of 1.2 m. Several topsoil and subsoil depth experiments are discussed, along with suggested guidelines for soil depth replacement.

455. Halvorson, G. A., S. W. Melsted, S. A. Schroeder, M. W. Pole, C. M. Smith, and E. Deibert. Root Zone Soil Management in North Dakota Coal Mine Reclamation. Paper in Symposium on Adequate Reclamation of Mined Lands (Billings, MT, Mar. 26-27, 1980). Soil Conserv. Soc. Am., 1980, pp. 26-1—26-13.

First-year results of a field study conducted at the Falkirk Mine near Underwood, ND, are reported. The study is designed to examine variations in wheat yields (*Triticum aestivum* L.) with varying depths of topsoil, addition of a lift composed of low-salt material, and compaction. Subsidence was also measured. Wheat yields were improved by greater depth of topsoil and addition of low-salt second-lift material. Compaction of the overburden by scrapers reduced wheat yields. After 1 year, subsidence was almost equal on compacted and noncompacted plots. The initial data presented indicate that land reclaimed with sandy overburden may require deeper topsoil or the addition of low-salt second-lift material to achieve maximum yields in western North Dakota.

456. Halvorson, G. A., S. W. Melsted, S. A. Schroeder, C. M. Smith, and M. W. Pole. Topsoil and Subsoil Thickness Requirements for Reclamation of Nonsodic Mined Land. Soil Sci. Soc. Am. J., v. 50, No. 2, 1986, pp. 419-422.

Simulated reclamation experiments were conducted to determine topsoil and subsoil thickness requirements of nonsaline, nonsodic spoil material in west-central North Dakota. Eight trenches were excavated to a depth of 4.6 m and filled with one of three different textured spoils. Two trenches were filled with loams and spoil, two with clay loam spoil, and two with silty clay loam spoils to within 0.23, 0.46, and 0.69 m of the surface. The remaining two trenches were filled with loamy sand spoil to within 1.5 m of the surface. Clay loam subsoil was placed on the loamy sand spoil in the last two trenches to within 0.23, 0.46, and 0.69 m of the surface. Topsoil (loam) was placed on all trenches at thicknesses of 0.23, 0.46, and 0.69 m. Tractor scrapers were used to fill and compact the soil in one trench for each spoil and subsoil treatment. In the other trenches, each spoil and subsoil treatment was placed with front-end loaders without compaction to simulate dragline conditions. Topsoil treatments were further divided into two replications, each of which was subdivided into three fertility treatments: (1) 0 kg ha^{-1} N and 0 kg ha^{-1} P (low), (2) 34 kg ha^{-1} N and 22 kg ha^{-1} P (medium), and (3) 67 kg ha^{-1} N and 45 kg ha^{-1} P (high). Wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and corn (*Zea mays* L.) were grown in rotation (wheat-barley-corn-wheat-corn) on each treatment over a 5-year period. Grain and silage yields were obtained for each crop.

Thickness of topsoil significantly increased crop yields except for barley and corn silage. Trenches filled with loamy sand spoils exhibited significant yield increases with increasing topsoil thickness. Crop yields were greater when subsoil was replaced than when no subsoil was replaced on loamy sand spoil at a given topsoil thickness. The addition of nitrogen and phosphorus fertilizer did not affect crop yields. Native soil fertility is sufficient to supply the nutrients for maximum crop yields under the existing climatic conditions. The authors recommend that topsoil and/or subsoil thicknesses of at least 0.7 m should be spread for highest yields on coarse-textured nonsodic spoil.

457. Hamon, W. R., and R. R. Kruspe. Preliminary Research on Potential Reclamation of Oil Shale Mined Lands in Kentucky. Paper in 1981 Eastern Oil Shale Symposium Proceedings (Lexington, KY, Nov. 15, 1981). Inst. Min. and Miner. Res., Univ. KY, Lexington, KY, 1982, pp. 55-81.

This study investigated the reclamation potential of oil shale mined land in Kentucky. Assessments were made on the potential for establishing vegetation using the available soil and overburden, the use of processed oil shales to improve the physical properties of soil high in clay materials, and the treatments and species needed to establish an adequate vegetative cover. The physical and chemical properties were determined for the materials studies: soil, overburden, and oil shale. Macronutrients and micronutrients found in the raw shales were generally within the limits of those found in soils. A growth chamber study was used to test vegetative response on soils, overburden, oil shale, and admixtures (one-half soil plus one-half oil shale and one-half overburden plus one-half oil shale). Perennial ryegrass (*Lolium perenne* L.) was the species chosen for this part of the study. The vegetative responses (biomass) to the two admixtures were not significantly different. The yields obtained from the admixture treatments were, however, generally larger than yields from either the overburden or the soil alone. Admixtures apparently improve infiltration and water retention properties of the soil and overburden, while retaining nutrients, pH, and soluble salts at desirable levels.

458. Hargis, N. E., and E. F. Redente. Soil Handling for Surface Mine Reclamation. J. Soil and Water Conserv., v. 39, No. 5, 1984, pp. 300-305.

This article discusses the current regulation regarding soil handling or replacement for surface mine reclamation in the West. Soil overburden properties that affect revegetation are discussed, and recommendations are made concerning maximum clay content, minimum organic matter content, and maximum salinity levels. A review of the literature concerning the thickness of replaced soil is presented. The thickness of replaced soil depends on (1) quality of the overburden to be covered, (2) annual average effective precipitation, and (3) soil quality. When overburden has properties that may retard plant growth,

the soil must be managed so that most of the plant root system is not exposed to the harmful material. Overburden without potentially adverse properties does not need to be covered with as much soil material. A discussion of mixing and segregating soil and overburden is presented. Three possible results occur when soil and overburden are mixed: (1) mixing makes no difference in plant productivity compared with segregated soil horizons, (2) mixing increases productivity, and (3) mixing reduces productivity. Mixing topsoil into subsoil or overburden will usually improve the quality of the subsoil or overburden; however, rarely is a mixture better than topsoil replaced on top of the subsurface materials. Topsoil storage or stockpiling procedures are presented. Recommendations to maintain desirable characteristics are given.

459. Harper, W. S., D. E. Baker, and L. H. McCormick. A Dual-Buffer Titration Method for Lime Requirement of Acid Minesoils. J. Environ. Qual., v. 17, No. 3, 1988, pp. 452-456.

A new lime requirement test developed for very acid mine-soil material is described. The dual-buffer titration (DBT) stoichiometrically accounts for H^+ contributions to soil acidity to a pH of 7.0, including those from the hydrolysis of aluminum. The first buffer at pH 3.17 is used to lower the pH of the soil and dissolve Al-OH polymers, amorphus coatings, and interlayer species. The second buffer, when mixed with the first, raises the pH to 8.2. A titration of buffers-soil mixture with standardized base to a pH of 8.2 provides a direct measure of lime requirements. The DBT method was compared with a 5-month $CaCO_3$ incubation using 31 soils from Pennsylvania acid minesites and acidic forest soils. The results of the comparison showed that the two methods were high correlated.

460. Harrison, J. E. Summer Soil Temperature as a Factor in Revegetation of Coal Mine Waste. Paper in Report of Activities, Part A. Geol. Surv. Can., Ottawa, ON, Paper 77-IA, 1977, pp. 329-332.

This article reports the results of field studies conducted in the Crowsnest Pass area of Alberta and British Columbia, Canada. Cursory observations seemed to indicate that high summer soil temperatures were an important factor in revegetation. The investigations examined the composition of coal waste to be revegetated; the variation of surface temperature with time, aspect, slope elevation, and depth; moisture conditions in the coal waste; thermal properties; and the implications of these data to revegetation efforts. The author recommends establishment of grasses prior to the planting of trees and shrubs to reduce thermal injury.

461. Harrison, W., and A. Van Luik. Suitability of Dredged Material for Reclamation of Surface-Mined Land. Argonne Natl. Lab., ANL/ES-73, Dec. 1979, 138 pp.

The main objective of this study was to demonstrate the feasibility of using dredged material to reduce acid surface runoff and drainage from coal mine spoils near Ottawa, IL. A second objective was to promote the use of dredged material in enhancing land degraded by surface mining. Four test plots were constructed, consisting of a control and three treatment plots that received a 0.9-m covering of dredged material. Two of the treated plots received lime. All plots were seeded to grass species. The migration of chemical compounds and metals, present in the dredged material, and their effects on water quality were monitored. Appendixes contain detailed information on climatic conditions, spoil characterization, and spoil monitoring. This detailed study found that the dredged material did not adversely affect the water quality of the area. The dredged material supported plant growth, decreased ground water contamination, and controlled acid runoff. One problem with the study was that no measurement of the vegetation was made; only visual evaluations were employed.

462. Harvey, K. C., and D. J. Dollhopf. Development of a Computerized Automated Rapid Weathering Apparatus for Determining Total Lime Requirements for Acid Minesoils. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 54-60.

A need exists for a rapid and reliable method to determine a one-time total lime requirement for acid mine soils. A computerized automated rapid weathering apparatus was developed and tested; this apparatus could weather a sample in days rather than weeks. This method was compared with manual laboratory weathering and acid-base accounting, which are more laborious and time consuming, as a means of determining total lime requirements. Total acid production determined by the computerized method was a measure of both available and potential acidity. The computerized method determined the total lime requirements within 24 h, and the results were similar to or more precise than those obtained using the other two methods.

463. Hatchell, G. E. Nursery Cultural Practices, Seedling Morphology and Field Performance of Longleaf Pine. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 61-65.

Preliminary results of a nursery study and an outplanting on a sandhills site of longleaf pine (*Pinus palustris* Mill.), as affected by nursery cultural practices and seedling morphology, are presented. Prior to sowing longleaf pine seed, seedbeds were fertilized and inoculated with *Pisolithus tinctorius* mycelium. Seedbed density and lateral root pruning altered the morphological attributes of the 1-0 bare-root seedlings. Lateral root pruning increased the abundance of fibrous roots and ectomycorrhizae infection. Both attributes improved seedling survival and vigor during the first growing season on the droughty sandhills site.

464. Hatchell, G. E., and D. H. Marx. Response of Longleaf, Sand, and Loblolly Pines to *Pisolithus* Ectomycorrhizae and Fertilizer on a Sandhills Site in South Carolina. For. Sci., v. 33, No. 2, 1987, pp. 301-315.

The responses of longleaf pine (*Pinus palustris* Mill.), Choctawhatchee sand pine (*Pinus clausa* var. *immuginata* D.B. Ward), and loblolly pine (*Pinus taeda* L.) to specific ectomycorrhizae and fertilizer treatments applied at planting on a deep sandy soil in the South Carolina sandhills were compared. Bare-root seedlings were produced in nursery beds specifically for this study. Six nursery beds were fumigated, three were treated with vegetative inoculum of *Pisolithus tinctorius* (Pers.) Coker & Couch (Pt) and three were naturally inoculated (NI) by airborne spores of ectomycorrhizal fungi. Following inoculation, nursery beds were fertilized, and two beds (one Pt-inoculated and one NI) were seeded with each test species. A factorial experiment was used in the field; it consisted of three pine species x two ectomycorrhizal conditions x three fertilizer treatments applied during planting. Fertilizer treatments were tablet, sludge, or control (no fertilizer) applied in the closing hole made with the planting dibble. Seedling survival, root-collar diameter (D), and height (H) measurements were taken after one, two, three, four, and seven growing seasons. Seedling volume index (D^2H) and plot volume index (PVI = sum of D^2H divided by plot area) were calculated as measures of seedling biomass and plot biomass, respectively. Roots were assessed for ectomycorrhizal development after the first growing season, and foliar samples were collected during the first 2 years for nutrient analyses. Ectomycorrhizal assessments of planting stock and of 1-year-old seedlings are presented.

The overall mean survival for each pine species was significantly different. Survival of loblolly, sand, longleaf pines was 97, 85, and 77 pct, respectively, after 1 year, and 89, 80, and 72 pct, respectively, after 2 years. Subsequent reductions in survival through the seventh year were small; less than 1.0 pct for loblolly and longleaf pines and 3.7 pct for sand pine. Survival of longleaf pine was significantly higher for Pt-inoculated and NI, 83 and 70 pct after 1 year and 78 and 64 pct after 7 years, respectively. First-year survival of sand pine was not significantly affected by ectomycorrhizae. There were, however, significant interactions between ectomycorrhizae and fertilizer treatments in years 2 through 7, indicating that fertilizer increased survival of Pt-inoculated seedlings and decreased survival of NI seedlings. The authors speculate that this is a chance occurrence. The Pt treatment significantly improved the survival of loblolly pine during the first growing season only. Longleaf and sand pine survival was not significantly affected by fertilizations. Survival of loblolly pine, however, was significantly affected during the second through seventh growing seasons. Rankings based on 3-, 4-, and 7-year D^2H and PVI data were significant, with sand pine > loblolly pine > longleaf pine. Height and diameter data of sand, loblolly, and longleaf pines were also significantly different after 7 years; overall means were 4.2, 3.3, and 2.5 m H and 9.9, 8.8, and 6.6 cm D, respectively.

Ectomycorrhizal treatments significantly affected D^2H and PVI of longleaf pine after 3 years; for Pt-inoculated and NI seedlings, the mean values were 199 and 98 cm^3 for D^2H and 41 and 17 $cm^3 \times 10^{-2}$ for PVI, respectively. At age 3, the increase in response of Pt-inoculated over NI longleaf pine was 103 pct for D^2H and 141 pct for PVI; after 4 years it was 95 pct for D^2H and 126 pct for PVI, and after 7 years it was 35 pct for D^2H and 58 pct for PVI. Sand pine seedlings showed the same significant response of Pt-inoculated over NI, after 1, 2, 3, and 4 years; D^2H values were 111, 105, 70, and 44 pct, and the values for PVI were 100, 111, 90, and 65 pct, respectively. Increases in loblolly pine D^2H and PVI due to Pt treatment were significant only in the first year. Loblolly pine was, however, the only species that exhibited a significant growth response to fertilization after 2 or more years.

465. Hatton, T. J., and N. E. West. Early Seral Trends in Plant Community Diversity on a Recontoured Surface Mine. Vegetatio, v. 73, No. 1, 1987, pp. 21-27.

Early successional changes in plant composition and diversity in relation to topographic position and cultural practices were examined on a southwestern Wyoming surface mine. The planting pattern and density of shrubs and the storage of topsoil were evaluated on the basis of the treatment's ability to divert successional trajectories of the developing vegetation and to increase species diversity. The changes in composition similarity along topographic gradients were also monitored.

Topographic position and assemblage type were statistically independent during the first 3 years of this study; however, by the fourth year this relationship was one of dependency. Assemblage types were dependent on topsoiling treatments over the 4 years of this study. Species

richness of planted, nonsteroid topsoil was greater than that of planted, stored topsoil treatment each year. Evenness among the species growing on the planted, nonsteroid topsoil decreased, leading to no significant difference between the two topsoil treatments. The unplanted, nonsteroid topsoil treatment was richer and more diverse than the unplanted, stored topsoil treatment during the second and third years. In the fourth year, however, these two treatments had equal species richness and no significant difference in diversity. The attempts to direct succession through species composition and structure were short lived. Treatments resulted in convergent, monotonic successional trajectories. Any differences in species richness or diversity are a result of chance processes and are not expected to persist.

These results suggest that species composition following surface mining will be characterized by floristic patterns reflecting chance establishment of colonizing species. Even though the site will gain new species with time, species composition will become increasingly uniform and predictable. Succession at this site follows Margalef's model of succession; however, the rate at which a site reaches some successional stage may be affected by the initial composition.

466. Hayhoe, H. N., A. Bootsam, and L. M. Dwyer. Monitoring and Analysis of Soil Temperature Regimes for Soil Climate Classification. Can. J. Soil Sci., v. 67, No. 3, 1987, pp. 667-678.

Soil temperature influences plant growth as well as soil chemical and physical processes. This study assessed the effects of the length of sampling period on the estimation of soil climatic parameters based on data obtained from published records of soil temperature at two depths, 0.1 m and 0.5 m, from two locations in Canada—Saskatchewan and Ontario. Soil climatic parameters that were calculated included mean annual soil temperature, mean summer soil temperature, and length of season and accumulated degree days above 5° and 15° C for both locations. Normal annual soil temperature cycles were fitted as a function of time with Fourier series curves with one or two harmonics. A sampling period of 3 years should be adequate for determining soil climatic parameters with reasonable accuracy.

467. Haynes, R. J., and R. S. Swift. Effects of Lime and Phosphate Additions on Changes in Enzyme Activities, Microbial Biomass, and Levels of Extractable Nitrogen, Sulphur, and Phosphorus in an Acid Soil. Biol. and Fertil. Soils, v. 6, 1988, pp. 153-158.

This study investigated the effects of lime and phosphate additions to an acid (initial pH of 4.3), phosphate-deficient soil on the microbial activity, enzyme activities, and levels of biomass and extractable nitrogen, sulfate, and phosphate under laboratory conditions. Lime was added at three rates and phosphate at two rates. Soils were incubated for 1, 2, 4, 8, and 16 weeks at 25° C with a moisture content of 60 pct field capacity. Both lime and phosphate additions caused an initial flush in microbial growth and activity. Additions of lime and phosphate resulted in large increases in CO_2 evolution, microbial nitrogen, sulfur, and phosphate, and accumulation of extractable mineral nitrogen and sulfate in the soil. Carbon, nitrogen, and sulfur mineralization was also stimulated by lime and phosphate additions. During the 4 weeks there was an accumulation of ammonium-nitrogen first, followed by an increase in nitrification and a decrease in soil pH. Additions of phosphate decreased the activity of the enzymes assayed in the study, while additions of lime increased protease and sulfatase activities. Lime and phosphate additions had significant effects on nitrogen and sulfur mineralization and on the biochemical properties of the soil studied. This paper contains good reference information on the effects of lime and phosphate on soil microbiological and biochemical properties.

468. Heckman, J. R., J. S. Angle, and R. L. Chaney. Residual Effects of Sewage Sludge on Soybean: I. Accumulation of Heavy Metals. J. Environ. Qual., v. 16, No. 2, 1987, pp. 113-117.

The residual effect from sludge application on heavy-metal uptake by soybean (*Glycine max* (L.) Merr.) with respect to different processing technologies, metal concentrations, application rates, and soil pH at two locations was examined. At the first site (1), digested sludge was applied in 1975 at 0, 56, and 112 Mg ha^{-1}. At the second site (2), the sludge treatments used represented different processing methods and metal concentrations. Lime-digested sludge was applied at 0, 56, 112, and 224 Mg ha^{-1}, lime-raw at 0, 56, 112, and 224 Mg ha^{-1}, lime-compost at 0, 56, 112, 224, 448, and 672 Mg ha^{-1}, heat-treated at 0, 56, 112, and 224 Mg ha^{-1}, and Nu-Earth (Chicago, IL) at 0, 50, and 100 Mg ha^{-1}. All sludges at site 2 were applied in 1976, except the Nu-Earth sludge. Calcium chloride and control treatments were established at high or low pH regimes by adding lime or sulfur. Nodulating plant shoots were harvested from each plot at the R4 pod development stage.

The concentrations of metals in soybeans at this growth stage varied by sludge type, application rate, and soil pH. At site 1, plant concentrations of zinc, cadmium, copper, and nickel exhibited significant linear increases with increasing rates of sludge application. After 9 years, soybean zinc concentration increased from 24 to 165 Mg ha^{-1} and cadmium concentrations increased from 0.06 to 0.25 Mg ha^{-1} at the application rates of digested sludge

of 0 and 112 Mg ha^{-1}, respectively. At site 2, plant tissue concentrations of manganese, zinc, cadmium, and nickel were not significantly increased over controls when plants were grown on plots amended with lime-digested, lime-raw, or lime-composted sludge, even at the highest applications rates. When grown on heat-treated or Nu-Earth sludge, soybeans had significantly higher tissue concentrations of zinc, cadmium, and nickel than did soybeans grown on control plots. Soil pH was an additional factor that affected metal uptake by soybeans. On pH-adjusted plots, tissue concentrations of zinc, cadmium, and nickel were higher then in soybeans on low-pH plots. Soybean zinc and cadmium concentrations in the 100 Mg ha^{-1} of Nu-Earth sludge were 59 and 1.75 mg kg^{-1} at pH 6.4, and 84 and 2.54 mg kg^{-1} at pH 5.8, respectively. This study shows the residual effects of sewage sludge on the metal contents of soybean for at least 9 years after the original application. Of particular concern when applying sludge as a soil amendment are sludge composition and soil pH.

469. Heckman, J. R., J. S. Angle, and R. L. Chaney. Residual Effects of Sewage Sludge on Soybean: II. Accumulation of Soil and Symbiotically Fixed Nitrogen. J. Environ. Qual., v. 16, No. 2, 1987, pp. 118-124.

The effects of different sludge processing technologies, metal concentrations, application rates, and soil pH on symbiotic N_2 fixation in two isolines of Clark soybean (*Glycine max* (L.) Merr.) on soils previously amended with sludge were examined. The sites of the field experiments, sludges used, rates applied, and experimental treatments utilized are described in the previously referenced paper by Heckman and others (reference 468). Nonnodulating and nodulating isolines were grown on the sludge plots, using various sludge rates and pH regimes. No rhizobia inoculant was used, in order to obtain nodulation by indigenous rhizobia. Nodulation was confirmed visually. Plants were harvested at the R4 growth stage. Nonnodulating soybeans had a general increase in dry matter production, shoot nitrogen concentration, and total nitrogen accumulation due to the greater nitrogen availability in sludge-amended plots. Sludge applications increased dry matter production and N_2 fixation of nodulating soybeans under conditions of moisture stress. Under normal moisture conditions, dry matter production and N_2 fixation were moderately higher on sludge plots than on the controls. The results suggest that sludge-amended soils may benefit soybean growth, but this beneficial effect may be limited to sewage sludges low in heavy metals.

470. Heckman, J. R., J. S. Angle, and R. L. Chaney. Soybean Nodulation and Nitrogen Fixation on Soil Previously Amended With Sewage Sludge. Biol. and Fertil. Soils, v. 2, 1986, pp. 181-185.

A greenhouse experiment was conducted to determined the impact of a soil previously amended with sludge on soybean (*Glycine max* (L.) Merr.) nodulation and nitrogen fixation. Nodulating and nonnodulating isolines of Clark soybeans were grown in pots to the R2 state (early pod stage) using soils treated previously with sludge at rates equal to 0, 56, 112, and 224 Mg ha^{-1}. Two soil pH regimes were established using $CaCO_3$-high (pH 7.0) and low (pH 6.2). Heavy-metal concentrations in soybeans were strongly influenced by soil pH and sludge rate. Uptake of manganese, zinc, cadmium, and nickel was significantly greater for soybeans grown at low soil pH. Residual nitrogen due to sludge application significantly affected dry matter production, shoot nitrogen concentration, and total nitrogen accumulation by nonnodulating Clark soybeans. Total nitrogen accumulation exhibited a significant linear increase with sludge rate, but was not significantly affected by soil pH. Total nitrogen accumulation, shoot nitrogen concentration, and dry matter production by nodulating Clark soybeans exhibited a significant linear increase with sludge rate. Nitrogen fixation and nodulation were significantly increased on sludge-amended soils and by higher soil pH. Sewage sludge had a beneficial influence on soil properties several years beyond the initial application as evidenced by increased soybean growth, nitrogen fixation, and nodulation, especially at the higher soil pH value.

471. Hedin, R. S. Ecological Recovery of Minimally-Reclaimed Strip Mines in Northwestern Pennsylvania. NJ Acad. Sci., Bull., v. 31, No. 1, 1986, p. 7.

Abstract of a presented paper. General vegetative and soil quality conditions of 24 minimally reclaimed strip mines were evaluated. Minesites 35 to 40 years old were woodlots with soil surface (A horizon) pH values of 4.1 and greater. Minesites 12 to 20 years old were barren or sparsely vegetated with aspens (*Populus* spp.), lichens (*Cladonia* spp.), mosses (*Polytrichum* spp.), and grasses. Soil pH values were variable; the lowest measurements ranged from 3.3 to 3.8. Results of this survey indicate a recovery period of 30 to 35 years for sites abandoned between 1945 and 1950.

472. Hedin, R. S. Treatment of Acid Coal Mine Drainage With Constructed Wetlands. Paper in Tenth Annual Coal Conference (Wilkes-Barre/Poconos, PA, Oct. 10-14, 1988). Assoc. Abandoned Mine Land Prog., Salt Lake City, UT, 1988, 20 pp.

This article discusses the history of the constructed wetland concept for acid mine drainage treatment, along with the construction and performance of systems, chemical and biological processes that affect acid mine drainage chemistry within constructed wetlands, and the future of

this technology. Long-term performance characteristics, maintenance needs, and costs associated with current designs of constructed wetlands have not been established.

473. Hedin, R. S. Volunteer Revegetation Processes on Acid Coal Mine Spoils in Northwestern Pennsylvania. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 111-117.

The vegetation of 20 abandoned strip mine sites in northwestern Pennsylvania is described. Sites varied in age from 12 to 41 years. Although the major goal of this paper was to describe the general revegetation patterns, emphasizing the importance of volunteer vegetation, soil pH measurements were taken at each site. Relationships were developed between ground cover, tree density, and soil pH for a 12-year-old site. At sites that were classified as having an open canopy, bare soils typically had pH values of less than 4.0. Soil pH and exchangeable aluminum were found to be strongly related to spoil age. In quadrats with lichen and moss mats of greater than 50-pct coverage, the pH was 4.4, while the average pH of quadrats with greater than 50-pct bare soil was 3.8. Trees did not colonize the area dominated by the mosses and lichens, owing to a biochemical product that inhibits both tree seed germination and mycorrhizal infection. There is evidence that liming and fertilization may stimulate the colonization of aspen (*Populus* spp.) on acidic spoils. Sites that had been limed and fertilized prior to abandonment had higher tree-stem densities. The author states that if methods to stimulate the colonization of these abandoned sites by volunteer trees could be developed, a low-cost reclamation option may be available for thousands of poorly vegetated sites in the Eastern Coal Mining Region.

474. Heil, D. M., and K. A. Barbarick. The Influence of Water Treatment Sludge on Sorghum-Sudangrass Growth. Am. Soc. Agron., Agron. Abstr., 1988, p. 39.

Abstract of a paper presented at the 1988 Annual Meeting of ASA, CSSA, and SSSA. This greenhouse study was conducted to determine the effects of three water treatment sludges on the growth of sorghum sudangrass (*Sorghum bicolor* (L.) Moench). Sludges were applied to a forest soil (pH of 5.2) and a calcareous soil (pH of 7.5) at rates of 0, 11, 22, 33, 44, and 55 Mg ha^{-1}. At low application rates all sludges increased the growth of sorghum sudangrass. Iron fertility was improved in the calcareous soil, and potassium fertility was improved in the forest soil.

475. Hendrix, J. W., C. S. Hunt, and D. M. Maronek. Relationship Between the Ectomycorrhizal Fungus *Pisolithus tinctorius* Associated With Loblolly Pine and Acid-Generating *Thiobacillus* spp. on an Acidic Strip Mine Site. Can. J. Microbiol., v. 31, No. 9, 1985, pp. 878-879.

Loblolly pine (*Pinus taeda* L.) seedlings transplanted onto an acid coal mine spoil were examined for infection by *Pisolithus tinctorius* to test the hypothesis that *Pisolithus tinctorius* adapts loblolly pine to acid pyritic spoil by inhibiting the growth and activities of *Thiobacillus* spp. The pines had been transplanted 5 years prior to measurement, and all infection of seedling roots was by natural colonization. Trees associated with *Pisolithus tinctorius* or other mycorrhizal fungi that produce sporocarps were green and robust, while trees with no association with sporocarps were chlorotic and had dieback symptoms. Soil pH was lower and sulfate concentrations were higher in the rhizosphere of infected loblolly pine than in noninfected loblolly pine. Apparently *Pisolithus tinctorius* does not inhibit the growth and activity of *Thiobacillus* species.

476. Hennessy, G. G. In-Greenhouse Response of Four-wing Saltbush (*Atriplex canescens*) to Different Types of Mine Spoils Materials. Reclam. & Reveg. Res., v. 4, No. 1, 1985, pp. 117-127.

A greenhouse study was conducted to determine the growth responses of four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) to four types of New Mexico strip mine spoils material. Four-wing saltbush was seeded in root observation boxes (46 cm wide by 64 cm high by 10 cm deep) and soil columns (47.5 cm sections of 18-cm-diameter PVC pipe). Four treatments were used in both the soil boxes and columns. Treatments in the soil boxes were (1) 60 cm of shale spoil, (2) 20 cm of spoil plus 20 cm of spoil incorporated with topsoil plus 20 cm of topsoil, (3) 30 cm of topsoil over 30 cm of spoil, and (4) 60 cm of topsoil. Treatments in the soil columns were (1) 46 cm of spoil, (2) 15 cm of topsoil over 15 cm of topsoil and shale incorporate over 15 cm of topsoil, (3) 23 cm of topsoil over 23 cm of spoil, and (4) 46 cm of topsoil. In both experiments, topsoiled treatments showed significantly greater plant height than spoil treatments. Based on top growth and root growth, topsoiled treatments provided a better growth medium than did spoil for four-wing saltbush.

477. Henning, S. J., and T. S. Colvin. Management of Reclaimed Surface-Mined Lands for Row Crop Production. Paper in Fifth Symposium on Surface Mining and Reclamation (NCA/BCR Coal Conf. and Expo IV, Louisville, KY, Oct. 18-20, 1977). Natl. Coal Assoc. and Bitum. Coal Res., 1977, pp. 298-305.

The authors discuss the criteria used to develop a restoration plan suitable for row-crop farming as a part of the Iowa Coal Project Demonstration Mine situated approximately 9 miles south and west of Oskaloosa, IA. Results are presented for the first-year studies, in which corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) were grown on a restored portion of the demonstration

mine. It was concluded that row crops can be grown with moderate success the first year after restoration. To accomplish this, good seedbed preparation is needed that may require heavier than normal farm tillage implements and seed planters. Minimum-tillage or zero-tillage row-cropping machinery may be suitable. An agricultural subsoiler proved to be superior to a bulldozer ripper because the latter increased the difficulty of preparing a good seedbed. The authors feel that the difficulty will eventually diminish, but the need for deep tillage will continue until large, well-developed root systems are obtained consistently.

478. Henry, D. S., W. F. Kuenstler, and S. A Sanders. Establishment of Forage Species on Surface Mined Land in Kentucky. J. Soil and Water Conserv., v. 36, No. 2, 1981, pp. 111-113.

Eight forage species were seeded on the surface mine spoil of two eastern and western Kentucky minesites. Tall fescue (*Festuca arundinacea* Schreb.), caucasian bluestem (*Andropogon caucasicus* Trin.), big bluestem (*Andropogon gerardi* Vitman), Indiangrass (*Sorghastrum nutans* (L.) Nash), switchgrass (*Panicum virgatum* L.), crownvetch (*Coronilla varia* L.), and two different lespedezas (*Lespedeza* spp.) were seeded by various methods. After 3 years there was no difference in plant response due to establishment method at either site. The most consistent stands at both sites resulted from caucasian bluestem seeded alone. In western Kentucky switchgrass performed as well as the caucasian bluestem, and all warm-season grasses outperformed their counterparts in eastern Kentucky. Legume response was better at the eastern site than at the western site. Rainfall and soil pH were primarily responsible for the regional differences.

479. Hensley, D. L., and P. L. Carpenter. Effect of Lime Additions to Acid Strip-Mine Spoil on Survival, Growth, and Nitrogen Fixation (Acetylene Reduction) of Several Woody Legume and Actinomycete-Nodulated Species. Plant and Soil, v. 79, No. 3, 1984, pp. 353-367.

An acid surface coal mine in southwest Indiana was amended with lime and planted with autumn olive (*Elaeagnus umbellata* Thunb.), European black alder (*Alnus glutinosa* (L.) Gaertn.), black locust (*Robinia pseudoacacia* L.), bristly locust (*Robinia fertilis* Ashe), northern bayberry (*Myrica pensylvanica* Lois.), Siberian pea shrub (*Caragana arborescens* Lam.), and silver buffaloberry (*Shepherdia argentea* (Pursh.) Nutt.). Lime was applied at rates of 0, 12.5, 25, and 39 Mg ha^{-1} $CaC0_3$. Survival and soil pH data were collected periodically over a 15-month period and nodulated top dry weights were determined after 15 months. Acetylene reduction assays for nitrogenase activity were performed on the nodules.

Lime additions resulted in a significant increase in spoil pH; 39 Mg ha^{-1} of lime was required to maintain a pH of 5.75, 15 months after application. The 25- and 12.5-Mg-ha^{-1} treatments resulted in an increase in pH to 6.1 and 5.0 initially, but those values declined to 4.8 and 3.5 after 15 months. Without lime the pH remained at 2.9. Species survival was greatest at the highest rate of lime addition, although individual species' response varied. Autumn olive, black locust, bristly locust, and black alder were more tolerant of lower spoil pH values. The combined dry weight of aboveground tissues of all species was greatest at the 25.0- and 39.0-Mg-ha^{-1} lime treatments. The least accumulation of dry weight occurred on unamended plots. Nodulation increased with increasing amounts of limestone applied. The correlation coefficient between lime rates and subsequent mean nodule dry weights from all species was r = 0.94. The specific nodule dry weight response to pH or lime application varied with species. Mean acetylene reduction rates by all species showed a 99.3-pct linear correlation with increasing lime application rates. Liming was the minimum site modification necessary for plant growth.

480. Hensley, D. L., and P. L. Carpenter. Survival and Coverage of Several N_2-Fixing Trees and Shrubs on Lime-Amended Acid Mine Spoil. Tree Plant. Notes, v. 37, No. 3, 1986, pp. 27-31.

An acid surface coal mine in southwest Indiana was amended with agricultural-grade limestone ($CaCO_3$) at rates of 0, 12.5, 25, and 39 Mg ha^{-1} and planted with European black alder (*Alnus glutinosa* (L.) Gaertn.), Siberian pea shrub (*Caragana arborescens* Lam.), autumn olive (*Elaeagnus umbellata* Thunb.), northern bayberry (*Myrica pensylvanica* Lois.), bristly locust (*Robinia fertilis* Ashe), black locust (*Robinia pseudoacacia* L.), and silver buffaloberry (*Shepherdia argentea* (Pursh.) Nutt.). Lime requirements were determined using the SMP buffer pH method. The initial pH was 2.85.

The addition of lime raised the pH within 30 days of application. To achieve a pH of 6.8 and maintain a pH of 5.75 for 15 months, 39 Mg ha^{-1} lime was required. Initially the 25- and 12.5-Mg-ha^{-1} lime treatments increased pH to 6.1 and 5.0, respectively, but these values declined to 4.8 and 3.5, respectively, after 15 months. Tree and shrub survival was greatest at the highest lime treatment; however, some species were more tolerant of acid conditions. Bristly locust and black locust were the only species to survive without lime additions, but the highest lime application rate resulted in the highest survival rates for all species except northern bayberry. Projected biomass, an index of growth and ground cover associated with species and treatment, was calculated. This study demonstrates that liming is the minimum site modification treatment necessary for plant growth and survival.

481. Hensley, D. L., H. Sparks, and G. R. Brown. Survival of Blackberries on Mined Land. Reclam. & Reveg. Res., v. 2, No. 3, 1983, pp. 237-240.

This study evaluated the survival and growth of commercial blackberry (*Rubus* spp.) cultivars planted as root sections on mined land in eastern Kentucky. The blackberries were planted during 1979 and 1980, and the following cultivars were used: Comanche, Cheyenne, Cherokee, and Darrow thorny blackberries. For the 1979 planting no statistically significant differences in survival or cane growth were found. In the 1980 plantings, however, the survival of the Comanche cultivar was significantly greater than that of either the Darrow or Cherokee cultivars. No statistically significant differences were found in cultivar cane growth for the 1980 plantings. For the two plantings, cane growth was generally good regardless of cultivar. Growth generally improved with increased management.

482. Herbel, C. H. Seeding Shrubs in the Field. Reclam. & Reveg. Res., v. 5, No. 1-3, 1986, pp. 377-385.

Principles and practices of direct seeding degraded rangelands are summarized. Prior to seeding, the necessity and desirability of seeding must be established. The plant species selected for seeding must be compatible with management objectives and seeded at the right times. Whenever possible, seed mixtures should be utilized. In harsh environments, mulches should be used to aid vegetation establishment by increasing infiltration and retention of soil moisture, delaying surface crusting, and reducing soil temperatures. Equipment and practices used for range seeding are presented.

483. Hern, J. L., H. A. Menser, R. C. Sidle, and T. E. Staley. Effects of Surface-Applied Lime and EDTA on Subsoil Acidity and Aluminum. Soil Sci., v. 145, No. 1, 1988, pp. 52-57.

A possible mechanism for chelation and removal of exchangeable aluminum from acid subsoil was tested. Soil columns were treated with ethylenediamine tetraacetic acid (EDTA) and lime, singly and continuously, and the effluent from weekly irrigation was monitored for changes in pH, aluminum, calcium, iron, magnesium, and manganese. One week after the final irrigation, the soil in each column was partitioned into six 10-cm-deep sections and analyzed for exchangeable calcium and aluminum and soil pH.

Effluent analyses showed that columns treated with a combination of EDTA and lime had significant amounts of aluminum removed. Columns treated with lime only exhibited no significant change in subsoil aluminum concentration compared with controls. Postirrigation analyses of soil cations showed significant decreases in aluminum concentrations at the lower depth sections when treated with EDTA. The movement of calcium and magnesium was also increased in columns that received EDTA. The authors speculate that EDTA, a chelating agent, is responsible for the chelation reactions occurring within the subsoil ion-exchange system, with aluminum being removed from the soil exchange sites and replaced by calcium. Aluminum is removed by either direct complexation with EDTA or by ionic mass action. This paper contains useful information on the successful treatment of acid subsoils under a controlled laboratory situation. Further research is necessary to examine EDTA and lime treatments on test plots in the field.

484. Herricks, E. E., A. J. Krzysik, R. E. Szatoni, and D. J. Tazik. Best Current Practices for Fish and Wildlife and Surface Mined Lands in the Eastern Interior Coal Region (U.S. Fish and Wildl. Serv. contract 14-16-0009-79, Dep. Civil Eng., Univ. IL). U.S. Fish and Wildl. Serv., FWS/OBS-80/68, May 1982, 212 pp.

This document identifies and reviews some best current practices (BCP's) that are available for the reclamation of fish and wildlife resources on lands mined for coal in the Eastern Interior Coal Region (EICR). A BCP is defined as a technique or method that reflects the best technology or state of the art currently available for surface mine reclamation for the fish and wildlife component. Two general types of BCP's are identified. The first includes reclamation procedures based on ecological principles of fish and wildlife management practices. The second type includes reclamation practices regularly used by mine operators in the EICR developed through operational experience and demonstration. This review of BCP's includes sections on site preparation activities and methods for fish and wildlife restoration, maintenance, or enhancement. Information on surface preparation includes sections dealing with topographic development, preparation of the land surface for vegetation development, and protection of the surface from erosion. Procedures that affect water chemistry and physical configuration (including stream channel characteristics) have received particular attention owing to their role in development and maintenance of water quality.

This document was developed to help surface coal mine operators identify and implement the BCP's for protecting and improving fish and wildlife resources on their minesites during both the active coal extraction and postmining phases of their operations. It will also be useful to fish and wildlife management agencies, technical assistance agencies, and land owners. BCP information is presented in a form that will facilitate direct incorporation of the procedures into mining and reclamation activities. This

document is designed to be a user-oriented handbook. Consequently, much of the theory supporting BCP's has been omitted, and the report concentrates instead on providing information on applying the BCP's to particular situations. Technical references are listed at the end of each practice, which provide background and theoretical bases for the development of the techniques.

485. Hersman, L. E., and D. A. Klein. Retorted Oil Shale Effects on Soil Microbiological Characteristics. J. Environ. Qual., v. 8, No. 4, 1979, pp. 520-524.

This laboratory study was conducted to investigate the effects of retorted oil shale additions on the microbiological characteristics of surface soils. Paraho retorted oil shale from Rifle, CO, was mixed with native northwestern Colorado soils. Five soil-shale treatments were used: (1) 100 pct soil (control), (2) 95 pct soil-5 pct shale, (3) 90 pct soil-10 pct shale, (4) 75 pct soil-25 pct shale, and (5) 100 pct shale (control). The microbiological parameters of interest were nitrogen fixation, dehydrogenase activity, oxygen utilization rates, glucose mineralization, ATP concentrations, and microbial counts for the bacteria, actinomycetes, and fungi present. Of the microbial parameters tested, nitrogen fixation was most affected by the retorted oil shale. This suggests that nonsymbiotic nitrogen fixation in surface soils may be sensitive to the presence of oil shale. Dehydrogenase activity, ATP concentrations, C-glucose mineralization activity, oxygen utilization, and fungal populations were also significantly decreased by retorted oil shale. Bacterial and actinomycete populations were not significantly affected by the presence of up to 25 pct by weight of retorted oil shale. The authors concluded that it would be necessary to ensure that sufficient surface soil is used to cover retorted oil shales for development and functioning of a diverse vegetative microbiological community.

486. Hersman, L. E., and K. L. Temple. Comparison of ATP, Phosphatase, Pectinolyase, and Respiration as Indicators of Microbial Activity in Reclaimed Coal Strip Mine Spoil. Soil Sci., v. 127, No. 2, 1979, pp. 70-73.

The authors collected soil samples from reclaimed coal strip mine spoils in Montana in 1975 and 1977 and analyzed them for adenosine triphosphate (ATP), respiration, phosphatase, and pectinolyase. Although soil microbial activity correlated to some extent with each parameter measured, ATP was the most satisfactory measurement. ATP is more expensive to measure owing to reagent cost, but the authors recommend this method over the others because it correlates better and is a faster procedure, not requiring long incubation periods.

487. Hickman, T. J., S. M. Jenkusky, and S. Massie. The Illinois Abandoned Mined Lands Reclamation Program: A Progress Report. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 41-47.

A review of the progress made by the Illinois Abandoned Mined Lands (AML) Reclamation Council in dealing with Illinois abandoned mine problems is presented. Problems associated with abandoned mines in Illinois include open mine shafts, subsidence, gas leaks, mine refuse fires, unstable tipple structures, acid-producing coal refuse, dangerous highwalls, eroding spoil banks, and polluted water impoundments. A history of the Illinois program is presented. Reclamation of these lands generally follows standard reclamation techniques. Unique reclamation practices of Illinois AML sites, along with success factors, are presented.

488. Hill, R. D., and W. E. Grube, Jr. Surface Mine Reclamation at the Elkins Mine Drainage Demonstration Project After 17 Years. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 55-60.

This article presents the results of an evaluation of the reclamation and revegetation success of a coal-mined area 17 years after treatment. The evaluation indicated the importance of covering toxic spoil, grading, and seeding with herbaceous species after lime and fertilizer amendments. This provided the most expedient and long-term reclamation of the 640-acre site.

489. Hill, R. D., K. R. Hinkle, and M. C. Apel. Reclamation of Pyritic Waste. U.S. EPA, Munic. Environ. Res. Lab., EPA-600/D-82-340, 1982, 22 pp.

Laboratory and greenhouse studies and a full-scale demonstration project were conducted to examine the reclamation of land used for the disposal of pyritic waste with sewage sludge. Some of the mining waste had a pH as low as 1.8 and copper and zinc contents as high as 10 mg g^{-1} and 2 mg g^{-1}, respectively. Good grass growth was supported, and the quality of the leachate generated improved when mine waste was treated with sewage sludge, agricultural limestone, and fertilizer in column studies. In 1976, reclamation was initiated on 8 ha of disturbed mine land. By 1982, fair to good vegetative cover had been established on over 90 pct of the area. Yearly maintenance has been required on the more toxic areas to assure success of the vegetation. Maintenance includes

addition of fertilizer and limestone, and in the worst area, irrigation during drought periods. Weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees) and Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) have been the most successful vegetation. The field studies reported were conducted at the Sulphur and Boyd Smith deep-shaft pyrite mines along Contrary Creek in Louisa County, VA.

490. Hillel, D., and R. S. Baker. A Descriptive Theory of Fingering During Infiltration Into Layered Soils. Soil Sci., v. 146, No. 1, 1988, pp. 51-56.

A hypothesis is presented to explain the occurrence of fingering during infiltration and redistribution. The hypothesis is that a spatially distributed flow field, such as a planar wetting front, tends to constrict where flow accelerates. If the flow field is wide, the constriction may cause the flow field to separate into discrete, concentrated (partial volume) currents. Initially parallel streamlines tend to converge and form spatially separated streams when velocity increases along the direction of flow. Fingering can occur during infiltration at the transition layer between a less permeable top layer and a more permeable sublayer. The conductivity of the sublayer at the suction of water entry must exceed the flux of water through the top layer.

491. Hiller, R. M., and D. H. Graves. Relative Effectiveness of Some Coal Mine Refuse Revegetation Techniques: Leachate Quality. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 337-383.

This paper evaluates direct liming and seeding of herbaceous species as an alternative for reclaiming coarse refuse areas in central Illinois. The effectiveness of these methods is based on comparisons between direct-limed and seeded areas, soil-covered and seeded areas, and untreated areas. Tension lysimeters were installed, and the leachate samples were analyzed for the presence of plant nutrients, phytotoxic elements, conductivity, and pH. It is recommended that direct liming and seeding not be used as a sole treatment on unweathered refuse, owing to oxidation and acid production. Direct liming and seeding would best be used on prelaw refuse areas that have undergone seasonal cycles of weathering, oxidation, acidification, and leaching. This environment can maintain an effective equilibrium between limestone neutralization and acid production.

492. Hinckle, C. R., R. E. Ambrose, and C. R. Wenzel. A Handbook for Meeting Fish and Wildlife Information Needs To Surface Mine Coal—OSM Region I (U.S. Fish and Wildl. Serv. contract 14-15-0009-79-092, Sci. Appl., Inc.). U.S. Fish and Wildl. Serv., FWS/OBS-79/48.3.1, Feb. 1981, 381 pp.

This handbook is one volume in a five-volume set. Each provides information pertaining to consideration of fish and wildlife resources in the premining, mining, reclamation, and compliance phases of surface mining. Methods and sources for obtaining the information necessary to satisfy State and Federal regulations are suggested. Specifically, this handbook contains suggestions for locating sources of fish and wildlife information, describing fish and wildlife on minesite and permit areas, analyzing mining impacts on fish and wildlife, establishing postmining land uses and reclamation objectives, mitigating negative impacts on fish and wildlife, identifying ways to enhance fish and wildlife on the permit area, and monitoring and complying to obtain bond release. Emphasis is placed on providing assistance to operators in enhancing fish and wildlife resources during the postmining use of the land. Suggestions concerning selected species and habitat management are given, with fish and wildlife as either the primary or the secondary land use. Several appendixes are included to provide information on agency contacts, technical references, and sources of plant materials for revegetation specific for this region.

This document provides an excellent framework for developing reclamation plans. It was designed to provide assistance to coal mine operators, landowner, and other parties involved in planning for the protection and/or enhancement of fish and wildlife resources during the surface mining process. This report has been rated excellent or good for numerous keywords used in the evaluation process. The information provided is largely specific to OSM Region I, which correlates to the northern portions of the Eastern Coal Mining Region.

493. Hinckle, C. R., R. E. Ambrose, and C. R. Wenzel. A Handbook for Meeting Fish and Wildlife Information Needs To Surface Mine Coal—OSM Region II (U.S. Fish and Wildl. Serv. contract 14-16-0009-79-092, Sci. Appl., Inc.). U.S. Fish and Wildl. Serv., FWS/OBS-79/48.3.2, Feb. 1981, 368 pp.

The comments and evaluation contained in the annotation for a similar handbook in this series (item 492) also apply here. The information provided, however, is largely specific for OSM Region II, which correlates to the southern portions of the Eastern, the extreme southwestern portion of the Interior, and the eastern portion of the Gulf Coast Coal Mining Regions.

494. Hinckle, C. R., R. E. Ambrose, and C. R. Wenzel. A Handbook for Meeting Fish and Wildlife Information

Needs To Surface Mine Coal—OSM Region III (U.S. Fish and Wildl. Serv. contract 14-16-0009-79-092, Sci. Appl., Inc.). U.S. Fish and Wildl. Serv., FWS/OBS-79/48.3.3, Feb. 1981, 367 pp.

The comments and evaluation contained in the annotation for a similar handbook in this series (item 492) also apply here. The information provided, however, is largely specific for OSM Region III, which correlates to the central portion of the Interior Coal Mining Region.

495. Hinckle, C. R., R. E. Ambrose, and C. R. Wenzel. A Handbook for Meeting Fish and Wildlife Information Needs To Surface Mine Coal—OSM Region IV (U.S. Fish and Wildl. Serv. contract 14-16-0009-79-092, Sci. Appl., Inc.). U.S. Fish and Wildl. Serv., FWS/OBS-79/48.3.4, Feb. 1981, 363 pp.

The comments and evaluation contained in the annotation for a similar handbook in this series (item 492) also apply here. The information provided, however, is largely specific for OSM Region IV, which correlates to the western portions of the Interior and Gulf Coast Coal Mining Regions.

496. Hinckle, C. R., R. E. Ambrose, and C. R. Wenzel. A Handbook for Meeting Fish and Wildlife Information Needs To Surface Mine Coal—OSM Region V (U.S. Fish and Wildl. Serv. contract 14-16-0009-79-092, Sci. Appl., Inc.). U.S. Fish and Wildl. Serv., FWS/OBS-79/48.3.5, Feb. 1981, 405 pp.

The comments and evaluation contained in the annotation for a similar handbook in this series (item 492) also apply here. The information provided, however, is largely specific for OSM Region V, which correlates to the Northern Great Plains, Rocky Mountain, Southwest, Pacific, and Alaska Coal Mining Regions.

497. Hinedi, Z. R., and A. C. Chang. Phosphorus Solubility in Sludges and Sludge Amended Soils. Am. Soc. Agron., Agron. Abstr., 1985, p. 25.

Abstract of a paper presented at the 1985 Annual Meeting of ASA, CSSA, and SSSA. The availability of phosphorus in sludge and sludge-amended soils was determined. Availability depends on the identity of the solid phase controlling the solubility of phosphorus in the soils studied. The data suggest that the solubility of phosphorus is determined by the density of the sludge used rather than that of the soils.

498. Hinesly, T. D., K. E. Redborg, R. I. Pietz, and E. L. Ziegler. Cadmium and Zinc Uptake by Corn (*Zea mays* L.) With Repeated Applications of Sewage Sludge. J. Agric. and Food Chem., v. 32, 1984, pp. 155-163.

Annual applications of anaerobically digested sewage sludge were made on an acid silt loam soil and a calcareous strip mine spoil for 12 and 7 years, respectively, to determine the effects of annual applications on cadmium and zinc concentration in the leaves and grain of corn (*Zea mays* L.). Sludge was applied annually by furrow irrigation of corn growing on lister ridges. Liquid applications of 0, 6.4, 12.7, and 25.4 mm were made when plots reached a height of 15 cm, and applications were continued until 3 weeks before harvest. For the acid soil, leaves and grain had cadmium and zinc contents proportional to the amounts of sludge-borne cadmium and zinc applied during the previous growing season by irrigation. Repeated sludge application on acid soil in successive years did not cause the concentration of cadmium in leaves and grain of corn to increase. Zinc concentrations increased only in plants growing on soil repeatedly irrigated at the two lower rates of sewage sludge. Repeated applications of sludge on strip mine spoil resulted in additive increases in both cadmium and zinc in corn leaves and grain. Sludge-borne organic matter and phosphorus applications may have caused the uptake of cadmium and zinc by corn in response to repeated sludge applications on the strip mine spoil.

499. Ho, I. Interaction Between VA-Mycorrhizal Fungus and Azotobacter and Their Combined Effects on Growth of Tall Fescue. Plant and Soil, v. 105, No. 2, 1988, pp. 291-293.

The interactions of inoculation with *Azotobacter chroococcum*, *Glomus mosseae* (a VA-mycorrhizal fungus), and molybdenum addition on the growth and yield of tall fescue (*Festuca arundinacea* Schreb.) were investigated in this greenhouse experiment. The treatments were *G. mosseae* alone, *G. mosseae* plus *A. chroococcum*, *G. mosseae* plus *A. chroococcum* plus molybdenum (50 $\mu g\ g^{-1}$), *A. chroococcum*, *A. chroococcum* plus molybdenum (50 $\mu g\ g^{-1}$), and a control. Leaf, culm, and root dry weights of tall fescue were significantly higher when *G. mosseae* and *A. chroococcum* were inoculated together than with *A. chroococcum* alone. There was no significant difference in dry weights when *G. mosseae* was used alone. When molybdenum was added with *A. chroococcum*, which requires molybdenum, no significant increase in dry weight was found compared with *A. chroococcum* alone. When molybdenum was added to *G. mosseae* plus *A. chroococcum*, however, the dry weight of tall fescue was significantly higher than in all other treatments. At the end of the study, spores of *G. mosseae* were coated with *A. chroococcum*, suggesting a synergism between species.

The author suggests that *G. mosseae* may supply *A. chroococcum* with phosphate in exchange for nitrogen, which may contribute to increased growth and yield for the host plant. This paper was included in the review process because tall fescue is frequently used in establishing vegetative cover on surface-mined land. The increased yield of tall fescue with the inoculation of both *G. mosseae* and *A. chroococcum* should be considered when tall fescue is seeded on mined lands. Field trials are necessary to determine if the results would be applicable on mined lands.

500. Hodder, D. T., and R. C. Jewell (eds.). Reclaimability Analysis of the Emery Coal Field, Emery County, Utah. EMRIA Rep. No. 16 (U.S. Bur. Land Manage. contract YA-512-CT9-32, Geoscientific Systems and Consulting). U.S. Bur. Land Manage., Final Rep. BLM/YA/EM-77/16, Aug. 1979, 413 pp.

This report examines the reclaimability of coal strip-mined land in the Emery, UT, coalfield. Data collected in the study area covered the geology, overburden, hydrology, climate, and vegetation of the area. Site-specific problems relevant to revegetation that were identified included a lack of available topsoil, a potential excess of boron, and a general nutrient deficiency in the overburden. The use of fly ash and/or bottom ash from local powerplants was recommended as both a geochemical soil supplement and a mulch.

501. Hofmann, L., R. E. Ries, and R. J. Loren. Livestock and Vegetative Performance on Reclaimed and Nonmined Rangeland in North Dakota. J. Soil and Water Conserv., v. 36, No. 1, 1981, pp. 41-44.

This study compared the effects of heavy, moderate, and light grazing intensity on vegetation and steer performance on a revegetated area and an adjacent nonmined area (reference area). The study site was located near Center, ND. The criteria used to make the comparison were animal performance, vegetative production, vegetative composition and diversity, and plant and canopy cover. The comparisons between the reclaimed and unmined sites showed that the productivity of the reclaimed site was comparable to that of unmined land, indicating a successful reclamation program.

502. Holechek, J. L. Initial Establishment of Four Species on a Mine Spoils. J. Range Manage., v. 34, No. 1, Jan. 1981, pp. 76-77.

Greenhouse and field studies are reported. The objective of these studies was to evaluate initial establishment of Fairway crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.), Critana thickspike wheatgrass (*Agropyron dasystachyum* (Hook) Scribn.), Ranger alfalfa (*Medicago sativa* L.), and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.). All four species exhibited good initial establishment in both studies. Postemergence fertilization with nitrogen and phosphorus had no effect on the survival of any of the species tested.

503. Holechek, J. L. Root Biomass on Native Range and Mine Spoils in Southeastern Montana. J. Range Manage., v. 35, No. 2, Mar. 1982, pp. 185-187.

An examination of root biomass was conducted at five locations in the vicinity of Colstrip, MT. Study sites included native range in excellent, good, and poor condition; a naturally revegetated 40-year-old leveled, ungrazed strip mine spoil; a 5-year-old leveled, ungrazed strip mine spoil; and a 5-year-old seeded and fertilized mine spoil. The 5-year-old seeded and fertilized mine spoil exhibited the highest total root biomass. Native range in good condition had higher root biomass than either the excellent- or poor-condition native range. The root biomass of the 40-year-old mine spoil and the native range in excellent condition were not significantly different. Root biomass distribution did not differ among the sites, with over 55 pct of the biomass in the upper 15 cm of the soil profile.

504. Holechek, J. L., E. J. DePuit, J. G. Coenenberg, and R. Valdez. Legume Establishment on Strip Mined Lands in Southeastern Montana. J. Range Manage., v. 35, No. 3, May 1982, pp. 298-300.

This article reports the results of a 6-year study conducted on strip-mined land at Colstrip, MT, in which the germination, survival, productivity, and cover characteristics of five species and/or varieties of legumes were evaluated. These included Eski sainfoin (*Onobrychis viciaefolia* Scop.), Lutana cicer milkvetch (*Astragalus cicer* L.), birdsfoot trefoil (*Lotus corniculatus* L.), and Ranger and Spreader alfalfa (*Medicago sativa* L.). Low rates of nitrogen and phosphorus fertilizer were applied during the first year of the study. Lutana cicer milkvetch and both varieties of alfalfa exhibited good characteristics for the parameters evaluated. Spreader alfalfa was superior to the Ranger variety. Based on the observed site stabilization, persistence, palatability, nitrogen fixation, and productivity characteristics, the authors felt that Lutana cicer milkvetch has high potential for use in revegetating surface-mined land throughout portions of the Northern Great Plains Coal Mining Region.

505. Holechek, J. L., E. J. DePuit, J. G. Coenenberg, and R. Valdez. Long-Term Plant Establishment on Mined Lands in Southeastern Montana. J. Range Manage., v. 35, No. 4, July 1982, pp. 522-525.

This article reports the results of a 6-year study conducted on strip-mined land at Colstrip, MT in which the germination, survival, and cover characteristics of Fairway crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.), Critana thickspike wheatgrass (*Agropyron dasystachyum* (Hook) Scribn.), Ranger alfalfa (*Medicago sativa* L.), and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) were evaluated. Good initial establishment and long-term survival and growth were exhibited by all species. Initial and long-term survival was unaffected by postemergence fertilization with nitrogen and phosphorus. These fertilizer applications did account for increases in plant canopy and litter cover of the grass and legume species. Invasion by native species into the study area was insignificant. Critana thickspike wheatgrass appears to be well suited for inclusion in seeding mixtures in this area. Fairway crested wheatgrass was too aggressive to be recommended for inclusion in seeding mixtures where the revegetation goal is to achieve species diversity for native species.

506. Holland, L. J., and L. B. Phelps. Topsoil Compaction During Reclamation Field Studies. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 55-62.

Reclamation is complete when revegetation standards are met. Revegetation can be impeded by soil compaction caused by machinery used to replace and respread soil. This study was designed to determine the differences in soil compaction caused by dozers and scrapers at three sites in Pennsylvania. Soil samples were collected at each site and analyzed for field moisture content and bulk density. Results show that soil under scraper tires had density values higher than those for soil compacted by dozers, while values for soil between scraper tires were much lower. This is important because scraper tires occupy one-third of the total swath. The density values of soils between the tires were similar to those of undisturbed sites. The compaction created by scrapers is greater than the compaction expected from agricultural machines and would limit plant growth. Dozers caused densities similar to those expected from agricultural equipment; these densities would not limit plant growth. Recommendation for proper soil handling includes (1) minimize the amount of traffic on the soil, (2) minimize stockpile compaction by making the pile with the maximum possible lift thickness, (3) redirect traffic over the width of the pile, decreasing the number of passes seen in any part of the pile, (4) seed and mulch the stockpile to prevent erosion and nutrient loss, (5) minimize the time the soil is stockpiled, (6) when soil is respread, minimize the traffic on newly respread soil, and (7) use dozers rather than scrapers; if scrapers are used, till the soil prior to planting.

507. Hollis, J. F., R. Keren, and M. Gal. Boron Release and Sorption by Fly Ash as Affected by pH and Particle Size. J. Environ. Qual., v. 17, No. 2, 1988, pp. 181-184.

Fly ash, a major solid residue produced from the combustion of coal, has been demonstrated to be a beneficial soil amendment under the appropriate soil conditions. Additions of fly ash tend to increase soil boron levels, soil pH values, and soil salinity, depending on the coal source and powerplant design. The effect of fly ash particle size and pH on boron dissolution in aqueous media and the effect of pH and calcium on boron adsorption by boron-free fly ash particles were determined in this study.

Dissolution was found to be pH dependent; as the pH decreased from 12.5 to 7.0, the concentration of boron increased 100 times. The solubility of boron at pH 12 was extremely low; boron was found to concentrate in the smaller size fractions of the fly ash. The adsorption of boron by boron-free fly ash is also pH dependent. When NaCl plus NaOH solutions are used with boron-free fly ash, the amount of boron sorbed increases with pH values to 12. In the presence of $CaCl_2$ plus $Ca(OH)_2$, however, boron adsorption increases with increases in pH. In the presence of calcium, boron is thought to be resorbed by fly ash by two mechanisms: ligand exchange with hydroxyl groups or coprecipitation with $CaCO_3$. The first mechanism, ligand exchange, is thought to participate at pH values of 7.0, since at that pH no calcium precipitation occurred and small amounts of boron were adsorbed by fly ash. As the pH increased boron sorption increased, owing to coprecipitation with $CaCO_3$. There is strong competition of hydroxyl ions for adsorption sites. Boron is toxic to many plant species when present in the soil solution in concentrations slightly above the optimal concentrations required for plant nutrition. Fly ash as a soil amendment can be of benefit to plants only if the concentration of boron in the fly ash is below toxic levels. This paper is a good reference on the effects of fly ash, pH, and particle size on the release and sorption of boron by fly ash.

508. Holm, J. D. Ecological, Design, and Regulatory Considerations for Wetlands Treatment of Mine Drainage From the Pennsylvania Mine. Paper in Proceedings of the Eighth Annual National Abandoned Mine Lands Conference (Billings, MT, Aug. 10-15, 1986). MT Dep. State Lands, Helena, MT, 1986, pp. 81-86.

This article discusses the design and construction of a passive mine drainage treatment system (wetland) to treat acid mine drainage from the abandoned Pennsylvania

Mine (silver) in Colorado. Technical and policy issues are discussed.

509. Holm, J. D., and S. Jones. Passive Mine Drainage Treatment: An Effective Low-Cost Alternative. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 115-120.

Passive mine drainage treatment systems were implemented at two Colorado coal mines in order to neutralize acidity and remove metals from mine waters. Each system consisted of constructed peat bogs to remove metals, crushed limestone-filled channels to neutralize acidity, and drop structures and waterfalls to provide aeration. Cost data for design and construction of the two systems are presented.

510. Holmberg, G. V., and S. J. Henning. Reclamation. Ch. in Surface Mining Environmental Monitoring and Reclamation Handbook. Elsevier, 1983, pp. 279-369.

This chapter consists of two sections, one by Holmberg and one by Henning. The section by Holmberg, entitled "Land Use, Soils, and Revegetation," provides an excellent treatment of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) and the procedures for adherence to and monitoring under the law. The subjects discussed include the legal requirements for land use, premining land use planning, postmining land use monitoring, the legal requirements for soil (other than prime farmland), steps in monitoring topsoil, mine-soil interpretation, mine-soil evaluation, monitoring and inventory of baseline data for the mining plan, mine-soil management, topsoil storage, topsoil redistribution, monitoring the handling of soils and overburden, mine-soil analysis after reconstruction, postmining mine-soil development, site conditions and animal habitat, factors involved in overcompetition and measurement of compaction, the legal requirements for revegetation, plant species selection, use of introduced species, timing the revegetation process, soil stabilization, livestock grazing on revegetated mined lands, assessment of revegetation success, and soil erosion.

As the title of the book implies, its purpose is to act as a handbook for environmental monitoring and reclamation. The chapter reviewed here follows this format. It includes literature reviews for the topics discussed and provides an excellent source for planning, monitoring activities, and establishing criteria for assessing proposed reclamation plans. This reference has been rated good for numerous keywords used and is designed specifically for broad national application. It suggests approaches to answering questions about some of these subjects; however, it stops short of providing clear-cut solutions. It does provide potential sources of pertinent information that could aid in treating specific problems.

The section by Henning, entitled "Prime Farmland" more specifically discusses prime farmland and factors that must be considered in returning surface-mined areas to crop production. It outlines methods for assessing crop production. A method using available soil survey information of soils present before mining to determine the success of production is presented. Since this section is designed for broad national application, its treatment of most key subject areas is general in nature. It does provide, however, potential sources of pertinent information that could aid in treating specific problems. The two sections making up the chapter provide an excellent source of background information for individuals concerned with compliance with State and Federal regulations controlling reclamation of surface-mined lands.

511. Holmgren, G. G. S. The Point Representation of Soil. Soil Sci. Soc. Am. J., v. 52, No. 3, 1988, pp. 712-716.

This article presents an alternative definition of a pedon. Individual observations are related spatially and temporally to a common point of geographic reference. Soil features can be systematically assigned to these point locations. The author proposed this definition of a pedon because of the ambiguities of the current pedon definition. This article was included in the review process since a pedon and polypedon are the units of sampling and classification in soils, respectively.

512. Hons, F. M., P. E. Askenasy, L. R. Hossner, and E. L. Whiteley. Physical and Chemical Properties of Lignite Spoil Material as It Influences Successful Revegetation. Paper in Proceedings Gulf Coast Lignite Conference: Geology, Utilization, and Environmental Aspects (Austin, TX, June 2-4, 1976). Bur. Econ. Geol., Univ. TX, Austin, TX, 1978, pp. 209-217.

This research was done to determine the feasibility of producing agricultural crops on lignite spoil in Freestone County, TX. Of particular interest were the spoil physical and chemical properties that affect revegetation. The spoil material was found to contain adequate amounts of calcium, magnesium, and potassium for sustained plant growth (6,000, 500, and 300 kg ha^{-1}, respectively). Nitrogen and phosphorus, however, must be added to achieve revegetation. The biological oxidation of ammonium to nitrate by nitrification is restricted in these mine soils. This indicates that the use and efficiency of added forms of ammonium fertilizers are restricted. Up to 50 pct of applied nitrogen is unavailable to plants because of low

use efficiency. Of the forage grasses and legumes tested, coastal bermudagrass (*Cynodon dactylon* (L.) Pers.), bahiagrass (*Paspalum notatum* Flugge), kleingrass (*Panicum coloratum* L.), a nonrhizomatous variety of bermudagrass, Yuchi arrowleaf clover (*Trifolium vesiculosum* Savi.), crimson clover (*Trifolium incarnatum* L.), and alfalfa (*Medicago sativa* L.) were established successfully in fertility trials. Corn (*Zea mays* L.), grain sorghum (*Sorghum bicolor* (L.) Moench.), and soybeans (*Glycine max* (L.) Merr.) were also established, with grain sorghum being the most promising of the row crops from an economic viewpoint. With proper fertilization and management, the yield potential of forage grasses, legumes, and grain sorghum on mine soil appears to be excellent.

513. Hons, F. M., and L. R. Hossner. Soil Nitrogen Relationships in Spoil Material Generated by the Surface Mining of Lignite Coal. Soil Sci., v. 129, No. 4, 1980, pp. 222-228.

This study was done to quantify the nitrogen relationships of surface-mined soil near Fairfield, TX. Soil samples were taken from spoil materials to a depth of 15 cm from four sites: an area mined in 1972, one mined in 1973, one mined in 1975, and an adjacent unmined site. Soils were evaluated for nitrification potentials and retention of nonexchangeable ammonium nitrogen. Of the 100 ppm NH_4 nitrogen applied, the mine soils nitrified only 7 pct, while the unmined site nitrified 93 pct. The low nitrification potentials of the mined sites were attributed to the lack of soil micro-organisms and an acidic pH. Mine soils exhibited a large nonexchangeable NH_4-nitrogen retention capacity, ranging from 1.4 to 7.8 meq NH_4-nitrogen per 100 g soil. Based on this nonexchangeable retention capacity of the soils, the 1972, 1973, and 1975 spoils have a theoretical capacity to convert 2,340, 1,282, and 1,326 kg of NH_4-nitrogen, respectively, into a nonexchangeable form. The authors concluded that the conversion of applied NH_4-nitrogen to nonexchangeable forms in mine soils, along with their low nitrification potentials, may result in an inefficient use of applied NH_4-nitrogen fertilizers and a decreased reclamation potential of planted crop species.

514. Hons, F. M., L. R. Hossner, and E. L. Whiteley. Reclamation and Yield Potential of Various Forages on Surface Mined Soil. Ch. in Reclamation of Surface-Mined Lignite Spoil in Texas. TX Agric. Exp. Stn. College Station, TX, Rep. RM-10, 1980, pp. 36-47.

A 3-year study was conducted in Freestone County, TX, to determine the yield potential and fertilizer requirements of grass and legume forages planted on surface coal mine spoils. Grass species included bermudagrass (*Cynodon dactylon* (L.) Pers.), bahiagrass (*Paspalum notatum* Flugge), kleingrass (*Panicum coloratum* L.); legumes included Yuchi arrowleaf clover (*Trifolium vesiculosum* Savi.), crimson clover (*Trifolium incarnatum* L.), and alfalfa (*Medicago sativa* L.). Generally, the soil required only nitrogen and phosphorus fertilization to provide proper nutrients for all test species. Besides moisture, which was found to be a major yield-determining factor, nitrogen fertilizer had the greatest effect on grass production and phosphorus fertilizer affected the legume production more than the nitrogen treatment did. Kleingrass and bermudagrass were the highest yielding grasses, and Yuchi arrowleaf clover was the most productive legume in the study. The NO_3 form of nitrogen fertilizer was more effective with grasses than the NH_4 form because of higher NO_3 mobility. It was also more effective in dry years.

515. Hooks, C. L., and I. J. Jansen. Recording Cone Penetrometer Developed in Reclamation Research. Soil Sci. Soc. Am. J., v. 50, No. 1, 1986, pp. 10-12.

A method to effectively measure physical differences among constructed soils that affect root system development is needed. Soil strength, by penetrometer measurements, is a parameter used to evaluate newly constructed soils, which vary because of reclamation method. This paper describes a power-operated, constant-velocity cone penetrometer that was developed to compare the effects of reclamation method on soil strength. Tests at minesites have shown that compaction zones can be located without excavation. Results were repeatable and confirmed by excavation and core sampling.

516. Hooks, C. L., I. J. Jansen, and R. W. Holloway. Deep Tillage Effects on Mine Soils and Row Crop Yields. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 179-182.

The effects of deep tillage using a Kaeble-Gmeinder TLG-12 were assessed in southwestern Illinois. Deep tillage, to 30 cm, was implemented on mine soil consisting of 100 cm of scraper-placed rooting medium and 20 cm of scraper-placed topsoil. Corn (*Zea mays* L.), soybean (*Glycine max* (L.) Merr.), and grain sorghum (*Sorghum bicolor* (L.) Moench.) yields were compared between scraper-replaced deep-tilled mine soil, scraper-replaced mine soil, and undisturbed soil. Penetrometer readings were also taken to evaluate soil strength of deep-tilled and non-deep-tilled mine soils. Deep tillage resulted in a significant reduction in soil strength compared with areas where deep tillage was not used. Crop yields showed a positive response to deep tillage treatments. The scraper-replaced deep-tilled treatment yields were equal to or

greater than the yields from undisturbed soil for all test crops. A management plan for deep-tilled soils is presented along with a discussion of the beneficial aspects of deep tillage on mine-soil physical characteristics.

517. Hopkins, D. W., A. G. O'Donnell, and R. S. Shiel. The Effect of Fertilization on Soil Nitrifier Activity in Experimental Grassland Plots. Biol. and Fertil. Soils, v. 5, 1988, pp. 344-349.

Relationships between soil nitrifier activity, soil pH, and fertilizer additions were studied in an 89-year-old grassland. Fertilizer additions consisted of ammonium sulfate and farm manure. In soils with pH values below 5.2, nitrifer activity was insignificant. The effect of ammonium sulfate additions on nitrifer activity could not be assessed because of the acidification of the soil when applied; pH values were less than 4.8. The frequency and quantity of manure applications were an important determining factor in nitrification rates. Nitrate losses increased with frequent additions of manure and application of manure in excess of plant nitrogen demands. This paper is a good reference on the effects of manure additions on soil nitrification.

518. Hoving, S. J., and W. C. Hood. The Effects of Different Thicknesses of Limestone and Soil Over Pyrite Material on Leachate Quality. Paper in Proceedings 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 2-7, 1984). Univ. KY, Lexington, KY, 1984, pp. 251-257.

A column leaching study was conducted to determine if 4 ft of cover soil is needed over an acid-producing material to retard or stop the oxidative weathering process. Leaching columns were constructed of 3-in PVC pipe ranging in height from 4 to 6 ft. The columns were open at the top and capped on the bottom. Each column was assembled with an 18-in layer of reactive pyritic material on the bottom covered by various thicknesses of limestone (0, 3, or 6 in). Soil was the uppermost layer, with thicknesses of 0, 6, 12, or 24 in. Each possible consideration was duplicated so that a total of 24 leaching columns were constructed. Each leaching cycle was 1 week in length. One liter of deionized water was poured into the open end of each column and allowed to percolate through the layers of material. The columns were allowed to drain for 7 days. At the end of the cycle, the leachates in the collection bottles were analyzed for pH, total dissolved solids (TDS), electrical conductivity (EC), acidity, sulfur, calcium, iron, magnesium, and manganese. A total of 12 leaching cycles were conducted in this manner. Results indicate that the soil had more effect on leachate quality than did the limestone. Twelve inches of soil decreased the amount of oxygen reaching the pyritic material, reducing the oxidation of the pyritic material.

519. Howard, G. S., G. E. Schuman, and F. Rauzi. Growth of Selected Plants on Wyoming Surface-Mined Soils and Flyash. J. Range Manage., v. 30, No. 4, July 1977, pp. 306-310.

This greenhouse study was initiated to determine potential plant growth on three surface-mined soils and their overburden materials, and on fly ash, under controlled soil moisture and temperature conditions. Topsoil and overburden were collected at three minesites near Gillete, Hanna, and Shirley Basin, WY, and the fly ash was collected from the Dave Johnson power-generating plant at Glenrock, WY. Various combinations of topsoil, overburden, fertilizer, sludge, manure, and fly ash were used. Neither the topsoil nor the overburden materials had detrimental effects on plant growth under nonlimiting conditions. Forage plants and range shrubs benefited from the addition of 67 kg ha^{-1} nitrogen and/or phosphorus. Additions of sewage sludge or manure also increased the growth of the plant species. This study also indicated that certain mixtures of fly ash in soil and sludge can be successfully revegetated.

520. Howard, P. J. A., and D. M. Howard. Numerical Characterization of Forest Soils Using Biological and Biochemical Properties. Biol. and Fertil. Soils, v. 5, 1987, pp. 61-67.

The variations in biological and biochemical properties of forest soils in relation to pH and moisture were examined to find if these properties define groups of soil. The 0- to 5-cm depth was sampled in 48 woods and measured for pH, loss-on-ignition/moisture content, oxygen uptake, cellulase activity, and phosphatase activity. The variation between plots (within sampling) and between sampling (within plots) was examined using principal component analysis. Analysis of variance was conducted to test significance of between-plot and within-plot differences. None of the principal component analyses showed any evidence of distinct clusters of plots. Analysis of variance did show that there were significant differences between plots for all properties examined. The authors conclude that no individual physiological property can be used as a measure of soil bioactivity. Since the plots studied showed no tendency to form clusters, a priori groupings were examined based on pH. Three groupings were developed: (1) pH <3.8, (2) pH 3.8-5.0, and (3) pH >5.0. On a loss-on-ignition basis, no significant difference between groups was found with respect to moisture content. Oxygen uptake was significantly lower in group 1 than 2, cellulase activity was significantly greater in group 3 than in 1 and 2,

phosphatase activity was significantly lower in group 1 than in 2 and peaked in the pH range of 3.8 to 5.0. These results demonstrate that the idea of using a single measurement to represent the diversity of soil biochemical processes is unrealistic.

521. Hue, N. V., J. A. Silva, and R. Arifin. Sewage Sludge—Soil Interactions as Measured by Plant and Soil Chemical Composition. J. Environ. Qual., v. 17, No. 3, 1988, pp 384-390.

The interactions between municipal sewage sludge and soils through plant and soil chemical composition were quantified in this plant and soil greenhouse pot experiment using lettuce (*Lactuca sativa* L.) as the test crop. The lettuce seedlings were transplanted into three mineralogically different soils: a lime, volcanic ash-derived Andept; an alkaline Vertisol; and a limed, manganiferous Oxisol. Each soil was amended with four rates of municipal sewage sludge (0, 45, 90, and 180 Mg ha^{-1}) and an N-P-K fertilizer treatment that served as a control.

Plant concentrations of copper and iron were not significantly affected by sludge or fertilizer application rates. Plant nickel concentration remained constant in two of the soils, but increased as sludge rates increased in the manganiferous Oxisol. The highest plant nickel concentration, however, was lower than what is considered to be phytotoxic. Plant zinc and cadmium increased consistently with sludge rate in all three soils, but concentrations were below levels considered to be phytotoxic. Manganese in the soil solution, however, increased drastically with increased sludge rates and became phytotoxic in Oxisol with increasing rates and at the 180-Mg-ha^{-1} treatment in the Vertisol. The Andept, which had a high absorption capacity, retained most of the heavy metals added by sludge application. Phosphate was also retained so strongly by the Andept that phosphorus was the growth-limiting factor in all treatments as indicated by low lettuce dry-matter yields, low plant phosphorus, and low soil-solution phosphorus concentration. The results show that Andept, with its high adsorption capacity, can tolerate high sludge heavy-metal loading rates, while the Oxisol tolerates the lowest rates.

522. Hughes, T. H., E. A. Cross, F. C. Gabrielson, and D. K. Bradshaw. Some Effects of Spoil Composition and Mulch Types on Erosion in Walker County, AL. Abstr. of paper pres. at Meet. Am. Counc. Reclam. Res. (Univ. AL, Sept. 19-20, 1979). Reclam. Rev., v. 3, No. 1, 1980, pp. 61.

The authors developed this experiment to test the Universal Soil Loss Equation (USLE) on coal strip mine soil. The USLE was developed for common agricultural conditions and was found to greatly underestimate erosion on topsoil and topsoil-shale mixes, but it did predict erosion on shale plots. Mulch treatments (followed by revegetation) included wood fiber, paper-slag, hardwood bark, pine bark, organic compost, and no treatment. The barks provided the best erosion control, but the other mulches provided the best plant growth.

523. Humphries, H. B., and D. O. Meeker. Alternative Systems for Determining Post-Mining Land Use. Paper in Symposium on Western Coal Mining Regulatory Issues: Land Use, Revegetation, & Management (West. Reclam. Group, Denver, CO, Apr. 1982). Range Sci. Dep., CO State Univ., Fort Collins, CO, Sci. Ser. 35, Aug. 1983, pp. 6-13.

The problem of determining postmine land use is addressed, and some general recommendations on land use and classification are provided. The authors present an analysis of various land classification systems and discuss the relationship of land classification to land use capabilities and the concepts of land use and potential land use. These discussions are presented within the framework of present Federal and State regulations. This paper provides a good reference on land classification and land use that is pertinent to mine-land reclamation not only in the Northern Great Plains and Rocky Mountain Coal Mining Regions, but nationwide as well.

524. Hung, L. L. L., and R. Molina. Temperature and Time in Storage Influence the Efficacy of Selected Isolates of Fungi in Commercially Produced Ectomycorrhizal Inoculum. For. Sci., v. 32, No. 2, 1986, pp. 534-545.

This study determined how long commercially produced inoculum could be stored and still remain effective in relation to different inoculation rates, storage temperatures, fungal species, and isolates within species. Eight inoculation rates (0, 1:4, 1:8, 1:16, 1:32, 1:64, 1:128, 1:25, volume-to-volume basis, ratio of inoculum to potting substrate), two storage temperatures (2° and 21° C), and eight storage periods (1, 2, 3, 4, 5, 6, 9, and 12 months) were used as experimental variances in a functional design. Seedlings of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) inoculated with fresh inoculum had significantly more overall mycorrhizal than those inoculated with stored inoculum. Mycorrhizal-forming effectiveness of inoculum stored for 4 months or more at the cold temperature was greater than that of inoculum stored at room temperature for the same time period. Different fungi responded to storage and temperature differently. Inoculum effectiveness after storage followed a general trend: fresh inoculum was most effective, with its effectiveness remaining high through 1 month; there was then a rapid decline for

a short period, followed by a slow decline to a point where there was no mycorrhizal formation.

525. Hunt, C. S., J. W. Hendrix, and D. M. Maronek. The Relationship Between Acid Production by *Thiobacillus* spp., Fertilizer and the Mycorrhizal Fungus *Pisolithus tinctorius* in Strip-Mine Spoil. Reclam. & Reveg. Res., v. 4, No. 3, 1986, pp. 293-306.

The hypothesis that *Pisolithus tinctorius* inhibits *Thiobacillus thiooxid* and *Thiobacillus ferrooxidans* and the associated acid production in the root zones of its pine symbionts was tested in a greenhouse study. Spoil from an acid, abandoned minesite was collected, and 20 nonmycorrhizal and 20 mycorrhizal pitch pine (*Pinus rigida* Miller) seedlings were transplanted into the spoil material. Fertilizer-enhanced acid production was also studied using the same spoil material. Leachates from spoils containing seedlings infected with *Pisolithus tinctorius* did not differ from leachates of spoils containing nonmycorrhizal seedlings. Populations of bacteria in fertilizer-amended spoil were higher than in mine spoils that were not amended. The rhizosphere pH of mycorrhizal seedlings was higher than that of nonmycorrhizal seedlings, but when fertilizer amendments were used, the effect of mycorrhizae on rhizosphere pH was negated. The bulk soil pH was not affected by mycorrhizal infection. Fertilization with N-P-K fertilizer stimulated the activity of *Thiobacillus* species in mine spoils more than when they were amended with sulfur. The authors recommend that the fertilization of pyritic mine spoils be reevaluated for its effect on acid generation by *Thiobacillus* species.

526. Huntsman, B. E., R. L. P. Kleinmann, and T. O. Tiernan. Hydrologic and Geochemical Considerations in Maintaining Man-Made Wetlands Constructed for Acid Mine Drainage Abatement. Paper in Wetlands and Water Management on Mine Lands, ed. by R. P. Brooks, D. E. Samuel, and J. B. Hill (Proc. Conf. PA State Univ., State College, PA, Oct. 23-24, 1985). PA State Univ., State College, PA, 1985, p. 375.

Important operational parameters for treatment of acid mine drainage by constructed wetlands include maintaining a proper hydrologic balance (retention time in the biologically active zones for maximum contaminant reduction) and influent water quality. Fluctuations in the influent water quality can control the growth and diversity of aquatic plants used to attenuate acid mine drainage.

527. Hussain, S. K., L. N. Mielke, and J. Skopp. Detachment of Soil as Affected by Fertility Management and Crop Rotations. Soil Sci. Soc. Am. J., v. 52, No. 5, 1988, pp. 1463-1468.

Soil erosion involves two factors, detachment of soil particles by raindrops and transport of soil by water or wind. In this study the effects of soil fertility management and crop rotation on soil detachment due to splash were compared. Treatments compared various crop rotations versus a continuous corn monoculture and the use of manure versus herbicide plus inorganic fertilizers. Crop rotations compared were soybean (*Glycine max* (L.) Merr.) after corn (*Zea mays* L.), corn after soybean, and oat plus red clover and yellow sweetclover (*Avena sativa* L. plus *Trifolium pratense* L. and *Melilotus officinalis* Lam.) after corn. Each rotation was treated with both fertility management options. The continuous corn monoculture was treated with a herbicide, fertilizer, insecticide management plan. Surface soil samples (25 mm) from each treatment were subjected to simulated rainfall intensities of low (35 mm h^{-1}) medium (62 mm h^{-1}), and high (120 mm h^{-1}). Soil detachment due to splash (simulated rain-fall) was determined by dividing the mass of soil detached (milligrams) by the product of intensity in millimeters per hour and number of hours of simulated rainfall.

Soil detachment between fertility treatments (manure versus inorganic fertilizer) was not significant ($p < 0.05$) at any rainfall intensity. Differences in soil detachment between continuous corn and crop rotations were not significant at low and medium rainfall intensity; however, at high intensity continuous corn had greater detachment than any of the crop rotations. Rate (milligrams per cubic centimeter) of soil detachment was greater for continuous corn than for any of the crop rotations. Rates of detachment were 48, 40, 39, and 31 mg cm^{-3} for continuous corn, corn after soybean, soybean after corn, and oat plus red and yellow sweetclover, respectively. As rainfall intensity increased, there was a significant linear increase in soil detachment. Aggregate size distribution in the splash revealed that soil treated with manure generally had more detached aggregates of 1,000- to 2,000-μm diameter and greater than 2,000-μm-diameter size than did soils treated with inorganic fertilizer and herbicide. Continuous corn had fewer detached aggregates greater than 2,000-μm diameter than did the corn-after-soybean treatment for low and medium rainfall intensities; however, continuous corn had a larger percentage of small aggregates than did soils from the crop rotation treatments. The aggregates in manured soils were less dense, requiring less energy to detach. This explains the higher percentage of larger aggregates in splash from this fertility treatment. Although manured soils may detach more easily, they are not as easily dispersed by simulated rainfall. The authors conclude that soils continuously cropped to corn have a higher potential to be eroded by water than do soils under crop rotation.

528. Hutchinson, T. C., and A. Kuja. The Use of Acid Tolerant Native Grasses for Reclamation of Mine

Tailings. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 1012-1016.

This article describes a greenhouse study to select plant species naturally occurring on extremely acid areas and test their survivability on tailings from mines in the Yukon and in Sudbury, ON. The plants tested were collected from the Smoking Hill area on Cape Bathurst in the Canadian western arctic. These species included tufted hairgrass (*Deschampsia cespitosa* (L.) Beauv.), alpine sweetgrass (*Hierochloe aplina* (Sw.) R. & S.), polargrass (*Arctagrostis latifolia* (R. Br.) Griseb.), Bigelow's carex (*Carex bigelowii* Torr.), and Aleutian mugwort (*Artemisia tilesii* Ledeb.). Tailings material had pH values ranging from 1.4 to 9.1. The species were tested for their ability to grow without amendment. Since this is an interim report, no firm conclusions are offered. The results reported indicate that, even on the most unfavorable tailings sites having both high acidity and metal toxicity problems, native species, if carefully selected and tested, could probably be used for revegetation. The species discussed and the results obtained may be specific for Canada and Alaska; however, the approach would appear valid for application to revegetating problem areas regardless of their location.

529. Hutnik, R. J. Hardwood Regeneration on Disturbed Sites. Paper in 1983 Penn State Forestry Issues Conference Proceedings on Regenerating Hardwood Stands (State College, PA, Mar. 15-16, 1983). PA State Univ., State College, PA, 1983, pp. 182-189.

This article summarizes recent data on hardwood tree species establishment on strip-mined land in Pennsylvania. The article is divided into three sections and contains information on the invasion of mined land by hardwood species, plantings made on orphan spoil banks, and current reclamation practices in Pennsylvania that utilize hardwood species. The author emphasizes the important role that hardwoods play in revegetating disturbed land in Pennsylvania.

530. Ibeabuchi, I. O., and R. W. Taylor. Growth Response and Heavy Metal Uptake by Selected Legumes in Acid Mine Spoils. Am. Soc. Agron., Agron. Abstr., 1986, p. 31.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. This greenhouse study was conducted to identify cover crop legumes capable of growing on and removing large quantities of toxic metals from acid spoil. Cowpea (*Vigna sinensis* L.) grew best on all spoils, with soybean (*Glycine max* (L.) Merr.) > crimson clover (*Trifolium incarnatum* L.) > hairy vetch (*Vicia villosa* Roth.). The species that grew the best accumulated the least aluminum. Additionally, cowpea accumulated the largest quantity of manganese, zinc, lead, and nickel when compared with other test species. Cowpea appears to be a good cover crop for growth on and removal of toxic metals from Alabama acid mine spoils.

531. Indorante, S. J., and I. J. Jansen. Perceiving and Defining Soils on Disturbed Land. Soil Sci. Soc. Am. J., v. 48, No. 6, 1984, pp. 1334-1337.

A procedure for mapping and classifying soils on surface-mined land is outlined. Soils are mapped by defining soil units (grouping soils that are alike and separating soils that are different) and then delineating the corresponding soils as they exist on the landscape. Soil units on surface-mined land were defined by gathering information on the premine and postmine overburden and soil characteristics, mining method, and reclamation or soil construction method. Once the soil units were defined, the soil mapping units were designed and the corresponding soil bodies were delineated on aerial photographs. Four soil series were mapped on surface-mined land in southern Illinois: the Morristown, Lenzburg, Schuline, and Swanwick series. The identified soil series were Typic Udorthents. Particle size class, including rock fragments, and the reaction class of the control section were the main morphological differences among the series.

532. Indorante, S. J., and I. J. Jansen. Soil Variability on Surface Mined and Undisturbed Land in Southern Illinois. Soil Sci. Soc. Am. J., v. 45, No. 3, 1981, pp. 564-568.

Five different reclaimed surface-mined soil units were defined to determine if such lands could be subdivided into relatively homogeneous segments of soil to allow more effective management. These units were compared with three undisturbed soil units. Analysis of variance of selected properties showed more significant differences among the five disturbed sites than among the three undisturbed sites. Variability within the disturbed sites was similar to that within the undisturbed sites. The authors examine the spatial variability of selected mine-soil characteristics as applicable to soil mapping. The techniques used and the results discussed would be applicable to similar studies and in planning reclamation procedures.

533. Institute of Land Rehabilitation. Utah State University. Rehabilitation of Western Wildlife Habitat: A Review (U.S. Fish and Wildl. Serv. contract 14-16-0008-2110). U.S. Fish and Wildl. Serv., FWS/OBS-78/86, Dec. 1978, 252 pp.

This publication provides a review of information available from previous research on habitat requirements of key wildlife species and on major, successful land rehabilitation techniques. An attempt has been made to bring this information together in a single source. Synecological and autoecological information about plant species important to the rehabilitation of wildlife habitat is presented in a systems planning format to encourage the incorporation of wildlife habitat and values into the total rehabilitation planning process. This rehabilitation planning process includes predisturbance inventory, identifying goals or objectives, preparing the plan, implementing the plan, postrehabilitation management, and followup assessment. The geographical area considered in this review includes portions of North Dakota, South Dakota, Montana, Idaho, Wyoming, Colorado, Utah, Nevada, Arizona, and New Mexico.

534. Iverson, L. R. The Role of Pioneering Species on the Reclamation of North Dakota Surface Mined Lands. Ph.D. Thesis, Univ. ND, Grand Forks, ND, 1981, 202 pp.

This study analyzes the initial vegetative succussion and associated changes in mine soils on reclaimed strip-mined sites in western North Dakota. Four reclaimed areas, ranging in age from 1 to 4 years since mining, were studied to quantify the early successional changes in vegetative composition, soil chemistry, and plant chemical composition. The sites all had been contoured, topsoiled, fertilized, and seeded after mining. The sites were compared with a native, mixed-grass prairie site in the immediate area. Of the 95 species encountered, summer-cypress (*Kochia scoparia* (L.) Roth.) was the most dominant in the first 2 years after mining. During the third and fourth years, the density of *Kochia* declined, while planted grass densities increased. Field studies showed that *Kochia* acted as a nurse crop, while field and growth chamber studies showed that autotoxicity in *Kochia* appeared to be the main reason for its decline. A bioassay experiment showed that allelochemics were also important in other colonizing species. Experiments with mowing and burning had both beneficial and detrimental effects, depending on when the site was mowed or burned. Analyses of seeds present in topsoil on a grazed site, an ungrazed site, and two stockpiled topsoils showed that most colonizers were not present in the topsoil, but came from nearby areas. Seed densities in stockpiled topsoil were very low. This study presents an excellent analysis of what happens to vegetative communities and mine soils during the first 4 years after seeding in western North Dakota.

535. Iverson, L. R., D. Szafoni, and C. Grunnwald. Factors Affecting Revegetation of Northern Illinois Gob Piles: A Case Study at Standard, Illinois. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 255-264.

The authors describe two research studies conducted on barren gob piles near Standard, IL. These studies were conducted to better understand the conditions to which plants must accommodate for establishment and survival. A field study was conducted to inventory the plant species present, and to determine gob temperature, moisture characteristics, and chemical characteristics. A greenhouse study was also conducted to characterize and identify plant-soil relations. The germination and growth of little bluestem (*Schizachyrium scoparium* (Michx.) Nash), side-oats grama (*Bouteloua curtipendula* (Michx.) Torr.), Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), crownvetch (*Coronilla varia* L.), and black locust (*Robinia pseudoacacia* L.), treated in six different ways, were evaluated. The treatments used were (1) gob alone, (2) gob and sand at a 1:1 ratio by volume, (3) gob and sewage sludge at a 1:1 ratio by volume, (4) gob and lime at a lime rate of 1 g per 100 g of gob, (5) gob and fertilizer (Miracle-Grow), and (6) gob, fertilizer, and lime.

Most of the species present on the gob represent early successional species. Measurements of water potential and temperature of the gob revealed excessively harsh conditions, especially on southern slopes. The chemical analysis of the gob revealed nitrogen, phosphorus, and potassium deficiencies, along with possible iron and aluminum toxicities. With proper liming and fertilizer treatments, however, these conditions could be corrected for the species tested in the greenhouse experiment. Black locust responded best to fertilization; for the other species, sewage sludge application resulted in the greatest production of biomass. The response of the plant species to treatment can be ranked as follows, from greatest biomass response to least: sewage sludge, fertilizer, lime and fertilizer, lime, and sand.

536. Jackson, C. L. An Update of URAD Mine Reclamation. Paper in Proceedings: High-Altitude Revegetation Workshop No. 5 (CO State Univ., Fort Collins, CO, Mar. 8-9, 1982). CO Water Resour. Res. Inst., CO State Univ., Fort Collins, CO, Inf. Ser. 48, Dec. 1982, pp. 79-104.

The author provides an excellent description of the reclamation practices used by AMAX, Inc., at the URAD Mine in the Woods Creek Valley, approximately 50 miles west of Denver, CO. The sequence of revegetating the tailing areas was (1) cover with development rock to the tailing material as a growth medium, (2) landscape with rock to break the uniform flat contour, (3) spread inorganic phosphate fertilizer and wood chips, (4) rip the

wood chips and phosphate fertilizer on the surface, (5) spread municipal sewage sludge to act as a source of nitrogen and organic matter, (6) seed with grass, (7) scatter dead timber onto the reclaimed surface, (8) irrigate during the first growing season, (9) plant transplants and seedlings of trees and shrubs during the second season following the establishment of grass, and (10) periodically apply maintenance inorganic fertilizers. Each of these steps is discussed in some detail. Supportive revegetation research is summarized, and heavy-metal and toxic chemical uptake by vegetation is discussed. Although the reclamation procedures described were specifically developed for the unique prob-lems present at this mine, some of the procedures could find application in other areas of the country in surface coal mine reclamation, particularly where toxic material presents a particular problem.

537. Jackson, D. Western Coal Is the Big Challenge to Reclamation Experts Today. Coal Age, v. 82, No. 7, 1977, pp. 90-108.

This article discusses reclamation efforts in the Northern Great Plains, Rocky Mountain, and Gulf Coast Coal Regions. For each region, the climate, native soil, native vegetation, reclamation methods, and reclamation costs are given. Also included are specific examples of land reclamation programs within each region. These examples contain information on site preparation techniques and the equipment used to prepare a site, the plant species and seeding techniques used, and the soil amendments applied to the spoil. The estimated reclamation cost per acre for a particular example is also given. The article provides a good characterization of what is involved in reclamation in the Western United States and the conditions under which reclamation is accomplished.

538. Jacobs, L. W., A. E. Erickson, P. E. Sierzega, and B. A. MacKellar. Improving Crop Yield Potentials of Coarse Textured Soils With Coal Fly Ash Amendments. Am. Soc. Agron., Agron. Abstr., 1987, pp. 27-28.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. High rates of fly ash amendments to coarse-textured agricultural soils were evaluated in terms of increasing soil water-holding capacity and potential crop yields. Fly ash was applied at rates of 200 to 600 tons per acre. Corn (*Zea mays* L.) yields and soil moisture content were significantly increased because of fly ash amendments.

539. Jacobs, M. J., B. R. Funke, and S. D. Merrill. Enumeration and Characterization of Nitrogen-Fixing Bacteria in a Stripmine Site. Plant and Soil, v. 84, No. 1, 1985, pp. 3-10.

Nitrogen-fixing heterotrophic bacteria in the rhizosphere of grasses growing in mine spoil plots, with or without topsoil, during the active growing and dormant seasons, were enumerated and identified from a western North Dakota strip mine site. Soil cores were taken from two sites: (1) highly sodic mine spoil with no topsoil and (2) topsoil spread to a depth of 30 cm. A stand of crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.) had been established 9 years prior to sampling. Plate counts using the most-probable-number technique showed that the total number of bacteria adhering to the roots in nontopsoil sites was higher than in topsoiled sites, but 1 bacterium in 5,000 in topsoiled sites was capable of fixing nitrogen, while only 1 in 500,000 was found in nontopsoiled sites. The identification of nitrogen-fixing bacteria showed that of 232 isolates, 164 were *Bacillus* spp., 38 were *Enterobacter* spp., and 21 were *Clostridium* spp.

540. Jansen, I. J. The Physical Condition Factor in Soil Construction. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South IL Univ., Carbondale, IL, 1985, pp. 1-7.

This article discusses the need to design and construct soil after reclamation for suitable row-crop production. Poor soil physical conditions were found to be the major problem limiting row-crop productivity after mining in Illinois. A favorable texture for each soil horizon can be achieved and chemical problems avoided with selective soil placement. Reducing soil strength either during soil construction or by subsequent treatment should be the major goal. The results of two experiments conducted in southern Illinois show the significance of the soil physical condition for row-crop production.

541. Jansen, I. J. Reconstructing Soils After Surface Mining of Prime Agricultural Land. Min. Eng. (N.Y.), v. 33, No. 3, 1981, pp. 312-314.

The author discusses the concept of "prime farmland" referred to in the Surface Mining Control and Reclamation Act (Public Law 95-87). Principal site and soil parameters and material-handling techniques are reviewed in the context of reconstructing postmine soils that will be acceptable under the "equivalent or higher levels of yield" provision of Public Law 95-87.

542. Jansen, I. J., R. E. Dunker, C. W. Boast, and C. L. Hooks. Rowcrop Yield Response to Soil Horizon Replacement. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 411-430.

This study evaluated corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) yield responses to topsoil replacement at two Illinois coal surface mine sites. The two sites were selected to include a range of soil quality. The natural soils of the western Illinois site are Mollisols, and the topsoils and subsoils are ideal for row-crop production, while the natural soils of the southern Illinois site are Alfisols, which are less desirable for prime farmland. At the western Illinois site, a wedge of topsoil was constructed over graded wheel spoil so that yields could be related to thickness of replaced topsoil. The wedge ranged in thickness from 0 to 60 cm. At the southern Illinois site, a wedge of subsoil material (B horizon) was placed by strips over rocky shovel spoil. The wedge ranged in thickness from 0 to 120 cm. Topsoil was replaced to a depth of 22 cm on half of the experimental area so that yields could be related to the thickness of replaced subsoil material both with and without replaced topsoil. At the western Illinois site, yields of corn and soybean increased with increasing thickness of replaced topsoil; however, when yield response was averaged over years only corn had a significant response. At the southern Illinois site, both corn and soybeans responded positively to topsoil replacement during the first year, but yields decreased in subsequent years. Corn and soybean yields increased with the thickness of the subsoil material, with maximum yields obtained at subsoil thicknesses of 60 to 80 cm.

543. Janzen, H. H., and C. Chang. Cation Nutrition of Barley as Influenced by Soil Solution Composition in a Saline Soil. Can. J. Soil Sci., v. 67, No. 3, 1987, pp. 619-629.

This pot study was conducted to determine the effect of cationic concentration and composition of the soil solution on the yield and cation uptake of barley (*Hordeum vulgare* L.) under saline conditions. Soil was artificially salinized using five salt types containing various ratios of Na:Mg:Ca. Each salt type was applied at five levels (24, 48, 72, 96, and 120 mmol cation per kilogram). A control treatment was included in the analyses. Barley was grown for 75 days in a greenhouse and harvested for dry matter yield and tissue cation concentration analysis.

The various salt types used in the salinized soil treatments did not differentially affect the growth of barley. Sodium and magnesium concentrations in barley tissues increased proportionally to salinity stress; however, the accumulation of sodium and magnesium did not restrict barley yield since no significant relationship was observed between dry matter yield and sodium-magnesium concentration in the plant tissue. Potassium concentrations were severely suppressed by soil salinity. The authors speculate that the suppressed potassium uptake with increasing salinity is a result of a physiological antagonism between sodium and potassium uptake. Calcium uptake was suppressed even more than potassium uptake by increasing salinity. Barley yield was strongly related to calcium concentration in plant tissues; yield was significantly reduced when the calcium concentration fell below 85 mmol cation per kilogram. This relationship was not affected by the type of salt used to salinize the soil. The reduced availability of calcium was attributed to the formation of precipitates or ion pairs with sulfate and other anions.

544. Jastrow, J. D., A. J. Dvorak, M. J. Knight, and B. K. Mueller. Revegetation of Acid Coal Refuse: Effects of Soil Cover Material Depth and Limiting Rate on Initial Establishment (U.S. Dep. Energy contract W-31-109-Eng 38; Abandoned Mined Land Reclam. Counc., State of IL, Capital Dev. Board Proj. 555-090-004; IL Inst. Nat. Resour., Proj. 80.043). Argonne Natl. Lab., ANL/LRP-17, Sept. 1981, pp. 79.

This article reports the first-year results of a study conducted on a recontoured coal refuse disposal site near the town of Staunton in southwestern Illinois. The study was part of a larger project that is demonstrating and evaluating new, cost-effective methods for reclaiming abandoned coal refuse sites. Comparisons were made of the effects of four soil cover material depths and two limestone application rates on vegetation establishment and growth. Plant survival and growth on plots without soil cover material were very poor. Excellent plant cover developed over the first growing season on all plots with soil cover material. Plant cover and production were dominated during the initial growing season by invading annuals characteristic of old field succession. Plant density data indicated that the perennials planted were becoming established in relatively large numbers on the plots with soil cover material, although they were not yet contributing to plant cover or production. The article provides extensive soil characterization data as well as plant cover, productivity, and density data. These data could be applicable to planning reclamation efforts in similar spoil material in this geographic area, as well as assessing the results of reclamation at this stage. An extensive appendix includes associated laboratory pot-culture experiments that were conducted prior to the field-plot study reported in the main body of the paper. These experiments indicated that placement of soil cover over unamended spoil material would allow plant establishment. These studies were also used to establish seeding and liming rates to be used in the field study.

545. Jastrow, J. D., and R. M. Miller. Effects of Topsoil Replacement Method on Revegetation of Mined Land in the Red Desert of Wyoming. Am. Soc. Agron., Agron. Abstr., 1985, p. 27.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. This study evaluated the effects of topsoil replacement methods on the rate of plot community reestablishment at an active coal mine in Wyoming. Treatments consisted of (1) topsoil that was stored in a stockpile 2 years and then placed over graded overburden, (2) unstored topsoil that was excavated and applied directly to graded overburden, and (3) a nearby undisturbed area that was used as a control. Vegetation establishment was initially characterized by the invasion of introduced annuals. After 7 years, native species cover on the directly applied topsoil was not significantly different from that of the undisturbed control. Native species cover on the stored topsoil was significantly less. Species diversity on both replaced topsoils was similar; the diversity on both treatments was significantly less than that of the undisturbed control.

546. Jastrow, J. D., R. M. Miller, S. C. Rabatin, and R. R. Hinchman. Revegetation of Disturbed Land in Arid Ecosystems. Ch. in Ecological Studies of Disturbed Landscapes: A Compendium of the Results of Five Years of Research Aimed at the Restoration of Disturbed Ecosystems, ed. by A. J. Dvorak. U. S. Dep. Energy, Off. Sci. Tech. Inf., DOE/NBM-5009372, 1984, pp. 2-1—2-37.

The effect of topsoil replacement method on the rate of plant community reestablishment was determined at the Jim Bridger Mine in Wyoming. The topsoil replacement methods studied were application of stored or stockpiled topsoil versus unstored or directly applied topsoil, along with an undisturbed control. A line-intercept method was used to estimate plant cover. Species frequency and diversity were also calculated. Initial vegetation establishment on the topsoil-replaced treatments was characterized by the invasion and dominance by annual species. Seedling establishment by planted species was poor. After the initial establishment year, native perennials contributed more cover on all treated plots than did the annual species, which declined. Cover of native species differed among the treatments, with the control > directly applied topsoil > stored topsoil. The cover of native species increased significantly for both topsoil treatments, but the rate of increase was greater on directly applied topsoil than on stored topsoil. Comparisons were made between soil properties of the topsoil-replaced and the undisturbed control treatments. The major difference in chemical properties between the undisturbed control soils and topsoil replacement soils was carbon and mineral nutrient content. Soil-vegetation associations were used to evaluate the potential reclaimability of the study areas. The overall conclusion was that the rate of native plant community reestablishment is improved by eliminating topsoil storage. The potential for native plant revegetation by seed and propagule reserves in the soils was also evaluated.

547. Jastrow, J. D., J. P. Schubert, W. S. Vinikour, A. A. Sobek, P. J. Sullivan, W. A. Master, E. D. Pentecost, and S. D. Zellmer. Amelioration of Acidic Waste Materials Resulting From Energy Mineral Extraction. Ch. in Ecological Studies of Disturbed Landscapes: A Compendium of the Results of Five Years of Research Aimed at the Restoration of Disturbed Ecosystems, ed. by A. J. Dvorak. U.S. Dep. Energy, Off. Sci. Tech. Inf., DOE/NBM-5009372, 1984, pp. 4-1—4-67.

Methods were evaluated for establishing and maintaining vegetation on an abandoned acidic coal refuse disposal site in Illinois. The entire refuse disposal site was reclaimed, and the success of the reclamation effort was quantitatively evaluated. This article contains excellent information on the use, rates, and short- and long-term effects of various soil amendments on the revegetation of acidic abandoned sites, along with the species that should be used to revegetate such sites. The major factors affecting plant community establishment and the success of specific plants on the coal refuse studied were the limited rooting depths, the high potential acidity, and extremely low pH.

548. Jastrow, J. D., C. A. Zimmerman, A. J. Dvorak, and R. R. Hinchman. Plant Growth and Trace-Element Uptake on Acidic Coal Refuse Amended With Lime or Fly Ash. J. Environ. Qual., v. 10, No. 2, 1981, pp. 154-160.

This study was conducted to compare fly ash and lime as amendments for acidic gob typical of abandoned minesites of southern Illinois. Using statistically designed growth-chamber pot studies, the authors evaluated growth response of Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) and 'Lincoln' smooth brome (*Bromus inermis* Leyss.) on gob amended with either lime or fly ash. Most of the article is an excellent discussion on trace element uptake of the plants as amended and grown on typical topsoil. Lime-amended gob produced more vigorous plant growth than did the fly ash treatment; in most cases trace element uptake was greater on the amended gob substrate, with the fly ash treatment producing the greatest uptake. This article is an excellent reference when trace element uptake is a major concern.

549. Jing, J. J., and T. J. Logan. Estimation of Cadmium Activities in Sewage Sludge of Variable Composition. Am. Soc. Agron., Agron. Abstr., 1988, p. 39.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The hypothesis that cadmium bioavailability is proportional to cadmium content was tested using 17 anaerobically digested sewage sludges that gave a range of iron, aluminum, and cadmium contents. The cadmium content ranged from 14

to 285 mg kg^{-1}, iron from 1.4 to 6.7 pct, and aluminum from 1.5 to 7.1 pct. All sludges were equilibrated, and Cd^{2+} activities were calculated using the computer program GEOCHEM. Analysis showed that Cd^{2+} activities were most correlated with total cadmium content of the sludge, however, iron, aluminum, and phosphorus content and organic carbon were also related to cadmium activity.

550. Johnson, D. W., and D. E. Todd. Nitrogen Fertilization of Young Yellow Poplar and Loblolly Pine Plantations at Differing Frequencies. Soil Sci. Soc. Am. J., v. 52, No. 5, 1988, pp. 1468-1477.

Experimental yellow poplar (*Liriodendron tulipifera* L.) and loblolly pine (*Pinus taeda* L.) plantations were established and fertilized with 300 kg ha^{-1} of urea-N over a 3-year period at two different frequencies: (1) 100 kg ha^{-1} yr^{-1} of urea-N applied in a single application in the spring and (2) 100 kg ha^{-1} yr^{-1} of urea-N applied quarterly (spring, summer, fall, and winter) at 25-kg-ha^{-1} doses. Additionally, mycorrhizal and nonmycorrhizal seedlings, inoculated prior to planting, were used. The treatments consisted of the two tree species; mycorrhizal or nonmycorrhizal seedlings; and control (nonfertilized), quarterly fertilized, or annually fertilized plots.

Results show that for loblolly pine, quarterly fertilization did not increase growth over that of the control, while annually fertilized plots exhibited growth increases. Growth responses in yellow poplar were not significant. There were no fertilizer effects. Quarterly fertilization did increase nitrification rates and nitrate leaching in each plot fertilized in this manner. Neither quarterly nor annual fertilization caused or prolonged enhancement of soil available nitrogen. There were no significant differences in nitrogen mineralization rates among the fertilizer treatments, indicating that prolonged tree growth responses were due not to a long-term increase in soil labile nitrogen, but to nonmineral nitrogen. Tree growth responses, particularly the response of loblolly pine, to fertilization resulted in advanced stand development and nitrogen conservation within trees. Annually fertilized trees contained approximately 50 pct more biomass and 50 to 100 pct more nitrogen than did unfertilized trees. Results suggest that quarterly fertilization is of greater benefit to nitrifying bacteria than to trees; however, the optimum fertilizer strategy for biomass production may involve fertilization more often than quarterly.

551. Johnson, K. Use of Geochemical Modeling in the Interpretation of Water Quality and Overburden Chemical Analysis. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 494-412.

This paper describes how data from monitoring wells, column leach tests, bulk analysis, and soil extracts can be used to evaluate the geochemical reactions of the mineral-water system and predict the effects on water quality. The chemical reactions (precipitation and dissolution) between the minerals and water are described by thermodynamic models. The behavior of trace metals is a function of the aqueous species and the substrate available for sorption.

552. Jones, J. H., and F. J. Olsen. Productivity of Parent Materials on Mined Prime Farmlands Using Alternative Sources of Organic Materials Compared to Topsoil Replacement (BuMines grant G1115174). IL Min. and Miner. Resour. Res. Inst., South. IL Univ., Carbondale, IL, 1985, 20 pp.

Parent materials of loess, glacial till, a mixture of B horizon soil material, and a mixture of the B material with the underlying C_1 loess and C_2 glacial till horizons were compared as rooting media for prime farmland reclamation. Organic amendments were incorporated into the surface of each rooting medium to compare organic additions with topsoil replacement. Amendments used were animal manure, green manure, and a forage-grass-legume crop. Each parent material rooting medium was characterized chemically and physically. Yields of corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) were determined for each treatment. Soil chemical and physical properties are presented for each parent material. In general, bulk density of each parent material decreased with increased rates of animal manure application. At the highest rate of animal manure application, organic matter levels approached those of the replaced topsoil treatment. Organically amended spoil had higher crop yields than did the replaced topsoil treatment on unmined soil. It is not the level of organic matter that is important, but the additions of fresh organic matter annually for optimum crop yields. This study indicated that amending spoil with organic amendments is a viable alternative to topsoil replacement for soils developed under forest vegetation, such as those found in southern Illinois, southern Indiana, and western Kentucky.

553. Jones, J. H., F. J. Olsen, B. Davies, D. M. Curnock, and R. J. Christ. Characterization of Organically Amended Parent Materials on Reconstructed Strip-mined Prime Farmland for Corn Production. Am. Soc. Agron., Agron. Abstr., 1984, p. 28.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. The chemical and physical properties of four different southern Illinois parent materials amended with animal manure were evaluated and compared with the soil characteristics of

replaced topsoil. The rates of manure application were 0, 50, 100, and 200 mt ha^{-1}. The parent materials studied were B horizon, Roxanna loess, glacial till, and a mixture of the three materials. The amended parent materials and topsoil replacement treatments compared favorably in terms of chemical and physical properties and corn (*Zea mays* L.) yields obtained.

554. Jones, J. H., F. J. Olsen, and R. E. Joost. Grass Establishment on Coal Refuse Amended With Sewage Sludge and/or Limestone. Paper in Annual Progress Report: July 1, 1980-June 30, 1981, Volume II, Research Development Summaries, Final Draft. Coal Extr. and Util. Res. Cent., South. IL Univ., Carbondale, IL, Mar. 1982, pp. 86-93.

This report summarizes the results of investigations conducted at Peabody Coal Co.'s Will Scarlet Mine in Williamson County, IL. The study examined the effects of varying rates of sewage sludge and/or limestone application on grass establishment. Eleven treatments were tested. Each amendment treatment was seeded to tall fescue (*Festuca arundinacea* Schreb.), redtop (*Agrostis alba* L.), and reed canarygrass (*Phalaris arundinacea* L.). Stand counts, dry matter production, and plant cover measurements were used for comparison. Best yields for all three grasses were obtained on the sewage-sludge-amended treatments. Redtop and tall fescue had the highest yields. Plant toxic levels of heavy metals were present in the soils, but did not accumulate in plant tissues to levels potentially toxic to livestock. The highest rates of either sewage sludge or limestone increased the pH of the coal refuse material from 2.4 to 4.8.

555. Jones, M. D., and T. C. Hutchinson. The Effects of Nickel and Copper on the Axenic Growth of Ectomycorrhizal Fungi. Can. J. Bot., v. 66, No. 1, 1988, pp. 119-124.

Ectomycorrhizal fungi infection has been shown to increase the ability of plants to grow in the presence of heavy metals. This paper describes two experiments that were conducted to study the effects of copper and nickel on the axenic (free from symbiosis) growth of ectomycorrhizal fungi. Axenic growth is used to test mycorrhizal fungi that may show tolerance to a certain heavy metal. The first study compared ectomycorrhizal isolates from a metal-contaminated site with isolates from an uncontaminated site to test which isolates grew better on a metal-amended medium. Concentrations used were 25 or 100 mg L^{-1} Ni and 20 or 100 mg L^{-1} Cu. The effects of copper and nickel on fungal growth were measured three ways: lag time prior to the beginning of growth, maximum linear increase in diameter, and final dry weight.

Results show that for all 10 fungi studied, the growth parameters of the isolates from the metal-contaminated site did not outperform those of the isolates from the noncontaminated site. No clear relationship existed between the site of isolate origin and its copper or nickel tolerance. In the second study, four ectomycorrhizal fungi, which have previously been found to vary in their effect on the metal tolerance of paper birch (*Betula papyrifera* Marsh.), were grown in a liquid medium containing 2 or 5 mg L^{-1} Ni or 4 mg L^{-1} Cu to determine if the axenic growth of these fungi was predictive of their ability to increase the metal tolerance of their host. In general, no relationship was found between the tolerance of the fungi to metals and their ability to increase the metal tolerance of paper birch, particularly for nickel. The fungi that were least tolerant to copper in liquid culture, however, were the same species that were present when birch had the greatest growth reduction in the presence of copper. The most copper-tolerant fungi tended to produce the most tolerant trees.

The authors state that axenic screening will not always predict which fungi will increase host tolerance to metals, particularly nickel. For copper, however, some types of axenic screening may be useful. Further studies are necessary to clarify the relationship between the tolerance of axenically grown fungi and their effect on host tolerance for heavy metals. This paper contains useful information on the methods that may be used to choose the appropriate mycorrhizal inoculant for amending surface-mined soils that contain heavy metals.

556. Joost, R. E., J. H. Jones, and F. J. Olsen. Physical and Chemical Properties of Coal Refuse as Affected by Deep Incorporation of Sewage Sludge and/or Limestone. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1982, pp. 307-312.

The purpose of the study was to determine the effect of sewage sludge and limestone incorporation on the chemical and physical properties of coarse coal refuse material and on vegetation establishment. Sewage sludge incorporation increased the organic matter and pH of refuse material and reduced the bulk density. The use of limestone also increased the pH of the material. There appear to be no adverse affects on vegetation establishment using either treatment.

557. Joost, R. E., F. J. Olsen, and J. H. Jones. Revegetation and Minesoil Development of Coal Refuse Amended With Sewage Sludge and Limestone. Am. Soc. Agron., Agron. Abstr., 1985, p. 27.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. The effects of incorporating dried sewage sludge and limestone (at depths of 30 and 60 cm) on the physical and chemical properties of gob and the survival of three forage grasses were evaluated. Mine-soil pH increased from 2.7 in unamended gob to 5.0 in all treatments. All treatments maintained good stands of vegetation over 4 years, with one exception, 225 Mg ha^{-1} sludge plus 45 Mg ha^{-1} lime-stone at 60 cm. Plant tissue accumulation of heavy metals was not a problem.

558. Joost, R. E., F. J. Olsen, and J. H. Jones. Revegetation and Minesoil Development of Coal Refuse Amended With Sewage Sludge and Limestone. J. Environ. Qual., v. 16, No. 1, 1987, pp. 65-68.

Factors that restrict vegetation on coal waste piles include low pH, poor water-holding capacity, low nitrogen availability, and high surface temperatures. This study evaluated the deep incorporation of sewage sludge and limestone on acid coal refuse in southern Illinois. Dried sewage sludge and limestone amendments were applied at 10 different experimental rates and incorporated into the coal refuse at either 30 or 60 cm using a modified cable trencher. Reed canarygrass (*Phalaris arundinacea* L.), tall fescue (*Festuca arundinacea* Schreb.), and redtop (*Agrostis alba* L.) were established on the treated coal refuse. Changes in vegetation development and persistence, minesoil chemical and physical properties, and heavy-metal and NO_3 accumulations were monitored over a 4-year period following amendment applications.

All amendments were effective in reducing bulk density and increasing soil pH compared with unamended refuse. Sewage sludge treatments were effective in increasing the proportion of sand-size, water-stable aggregates. Most treatments were effective in maintaining a vegetative cover of greater than 80 pct over 4 years. Reed canarygrass was the most persistent grass and main invader of adjacent test plots. The only treatment not effective in maintaining a good vegetative cover was the 225-Mg-ha^{-1} sewage sludge plus 45-Mg-ha^{-1} limestone mixture incorporated to 60 cm, the lowest application rate of either amendment. Mean herbage yield on all treatments was 4.0 Mg ha^{-1}. Although cadmium, chromium, lead, and nickel were present at levels considered toxic to plants, tissue accumulation of heavy metals was within the range considered safe for animal consumption. Nitrate concentrations were at levels considered to be in excess of safe consumption by animals; however, nitrate levels in the forage did decrease over time and were within safe levels by the fourth year. This study shows that it is possible to establish and maintain vegetative cover on coal refuse without topsoil replacement for a 4-year period.

559. Jordan, J. E., and S. W. Dewar. Vegetation Characterization of a Taconite Tailing Basin in Minnesota. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 249-254.

Changes in vegetation over time were followed on a typical revegetated tailing basin in northern Minnesota to determine if indigenous species were invading the basin and whether the established plant communities were self-maintaining. The basin studied was revegetated using grass and legume seed mixtures, and trees were planted as windbreaks. In the basin cell, pumping resulted in segregation of tailings sizes, with coarse tailings (coarse- soil- to fine-gravel-sized particles) nearest the outlet and, as the slurry flowed, finer tailings (fine-sand- to clay-sized particles) settling later. The raw tailings were chemically characterized as alkaline and low in organic matter, CEC, soluble salts, NO_3-nitrogen, phosphorus, and zinc. Concentrations of copper, manganese, iron, SO_4, and potassium were high. Percent cover, visually, and biomass were determined over a 3-year period, and dominant plant species were determined. Sixty-four species representing nineteen families were identified over the 3-year period, two-thirds of which were volunteers.

Species seeded by the mining company dominated the majority of the sites. Most dry matter was produced on the youngest sites, followed by a decline in dry matter yield the second year. This is explained by the colonizing of the site by kochia (*Kochia scoparia* (L.) Roth.), which contributed 61 pct of the dry matter yield. In the second season, this yield decreased by 95 pct. The primary reason is the autotoxicity created by decaying first-year kochia leaves and roots. The older sites consistently had greater than 90 pct cover, indicating a more stable community. Tree stocking increased during the sampling period, partly because of planting by the mining company, but the greatest proportion of the increase is due to colonization by native tree species. The authors conclude that the basin cell is still in the early stages of succession.

560. Jorgensen, D. W., and T. W. Gardner. An Analysis of Soil and Surface Properties Which Affect Infiltration and Runoff on Mined Lands, Centre County, Pennsylvania. Paper in Wetlands and Water Management on Mined Lands, ed. by R. P. Brooks, D. E. Samuel, and J. B. Hill (Proc. Conf. PA State Univ., State College, PA, Oct. 23-24, 1985). PA State Univ., State College, PA, 1985, pp. 83-105.

The magnitude of infiltration under a variety of post-mining conditions was determined on five surface coal mines in northwestern Centre County, PA. The soil and

surface properties that regulate infiltration capacity with age were documented. Mine soil ranged in age from 1 to 4 years. A dripping rainfall simulator was used to measure infiltration rates. Runoff was collected at the downslope end of each plot. Cumulative runoff was recorded and used to calculate the infiltration rate by subtracting observed runoff from applied rainfall. The combination of minesite and surface age produced a wide range of infiltration curves. In general, newly reclaimed, low-gradient, and poorly vegetated surfaces tended to have sharply dropping curves and low steady-state rates. As age increases, infiltration curves approach rates observed in undisturbed forest sites of the region. Runoff was observed 2 to 3 min after the start of the test, but for well-vegetated or absorptive sites, runoff took as long as 8 to 10 min. Sediment losses and drop splash heights were greater for bare soils than for vegetated soils. Shallow wetting fronts were common on poorly vegetated areas, while deep wetting fronts were associated with well-vegetated, coarse-textured soils. Differences in vegetative cover, bulk density, and soil texture, factors that regulate the magnitude of infiltration, increase with age.

561. Josiah, S. J. and G. R. Philo. Minesoil Construction and Ripping Affects Long Term Black Walnut Growth. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 209-226.

The growth and survival of black walnut (*Juglans nigra* L.) after four growing seasons are compared on four different mine soils and an unmined area in southern Illinois. The sites studied were (1) an unmined site consisting of a poorly drained silt loam soil, (2) an ungraded cast overburden minesite, (3) a graded cast overburden minesite, (4) a ripped (to 85 cm) graded cast overburden minesite, and (5) a topsoiled (minimum of 20 cm) minesite with replaced topsoil over graded spoil. Four-year measurements included soil density, top growth, root growth, and survival.

Statistically significant differences existed among treatments for mean soil bulk density. Bulk density was low on both the unmined site (1.36 g cm^{-3}) and ungraded spoil (1.27 g cm^{-3}). Bulk density was consistently higher at all depths on graded spoil. After four growing seasons, statistically significant differences existed for tree height and diameter among the various treatments. The ripped graded minesite had the best growth, while topsoiled, graded, and unmined sites had stunted trees. Survival was poorest on the topsoiled plots, followed by the unmined site. On both sites, tree survival was less than 50 pct after 1 year and less than 25 pct after two growing seasons. Survival was over 50 pct after four growing seasons on ungraded plots and 76 pct on the ripped graded plots. Root growth was dependent on mine-soil placement and grading. Root growth was profuse and extensive on sites with lower bulk densities, while on sites with high densities root growth and form were more limited and distorted. General root growth characteristics are given for each site.

The authors state that walnut survival and growth were highly dependent on the mine-soil construction technique used. Mine-soil compaction was a major factor reducing the survival, growth, and vigor of black walnut in this study. Ripping compacted graded spoil created soil conditions favorable for root growth. The highest tree survival, height, and diameter growth were found on ripped plots.

562. Julian, E. L. Big Sky Coal—A Mine-Site Study of Benefits and Costs of Reclaiming Surface-Mined Land in the West, Part III (U.S. Natl. Sci. Found. contract APR 76 18486). Coll. Earth and Miner. Sci., Dep. Miner. Econ., PA State Univ., State College, PA, NSF/RA-790385, 1979, 202 pp.

This report presents several analyses of benefits and costs of reclamation using a case study of the Big Sky Mine in southeast Montana. Discussions of the environment at the minesite, the Federal and State laws and regulations affecting the mine, and the procedures and costs of reclamation are included and used as a basis for the economic analyses. Methods of assigning values to outdoor recreation and recreational benefits are examined, and values are estimated. Benefits and costs are compared with respect to both priority and social benefits. Based on the results of this study, the author concluded that with the "best" estimates of hydrological, agricultural, and recreational benefits, with and without overvalued aesthetic benefits, and with the "best" estimate of cost, these costs exceed benefits by large margins. This article presents one of the few benefit-cost analyses for reclamation of surface coal mine land in the Western United States. Additionally, the approach and methods used may be applicable to other areas of the Nation.

563. Jurinak, J. J. Overview of Soils Considerations in High Altitude Revegetation. Paper in Proceedings: High-Altitude Revegetation Workshop No. 5 (CO State Univ., Fort Collins, CO, Mar. 8-9, 1982). CO Water Resour. Res. Inst., CO State Univ., Fort Collins, CO, Inf. Ser. 48, Dec. 1982, pp. 128-135.

This article provides an excellent review of some of the fundamental concepts of soil, clay mineralogy, soil chemistry, and soil fertility as they apply to mine-land reclamation.

564. Jurinak, J. J., C. Amrheim, and R. J. Wagenet. Effect of Salinity and SAR on the Sodic Hazard of

Overburden Materials. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1982, pp. 31-38.

Using the sodium adsorption ratio (SAR), the sodic hazard of overburden materials can be diagnosed by the equation ESR = Kg SAR, where ESR = exchangeable sodium ratio, and Kg = modified Gapon's selectivity coefficient. Two bulk overburden samples were obtained from two locations in Montana, and a Yolo loam soil was obtained from California. To study the effects of salinity and SAR on the ESR of Kg, the soils were equilibrated with known concentrations of electrolyte solutions. The results show that the overburden material and the Yolo loam soil had a linear relationship between the ESR and SAR over the electrolyte and SAR ranges studied.

565. Jurinak, J. J., J. Bowden, F. Samson, and T. Portol. Electrical Conductivity. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytical Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 27-34.

In the reclamation of disturbed western land, a salinity hazard exists if there is a sufficient soluble salt concentration in a soil or overburden to interfere with the growth of the reestablished vegetation. This chapter discusses a well-established and simple method for measuring salinity or the salt concentration, electrical conductivity. As the ionic concentration increases so does the electrical conductivity. The reduced availability of soil water to plants is the main adverse effect of soil salinity on plant reestablishment. The response of soils to saline conditions and the mitigation of salinity problems are discussed. Mitigation treatments include fertilization, mulching, use of organic amendments, and the proper choice of species to plant under saline conditions.

566. Keefer, R. F., D. K. Bhumbla, and R. N. Singh. Phosphorus Retention by Fly Ashes Alone and Those Treated With Acid Mine Drainage. Am. Soc. Agron., Agron. Abstr., 1988, p. 40.

Abstract of paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Phosphorus retention of 12 fly ashes was determined in laboratory equilibration experiments using fly ashes that were unweathered, weathered by leaching to remove soluble salts, neutralized with sulfuric acid, and neutralized with acid mine drainage. Phosphorus retention was greatest in fly ashes treated with acid mine drainage and least in fly ashes neutralized by sulfuric acid. Phosphorus was retained in unweathered alkaline fly ashes through precipitation reactions, while adsorption was the mechanism responsible for phosphorus retention in fly ashes treated with acid mine drainage. The chemical composition of the fly ashes was not responsible for the phosphorus retention capacity of the fly ashes.

567. Keefer, R. F., S. M. Mushiri, and R. N. Singh. Metal Complexation of Soil Organic Pyrophosphate Fractions From Sludge-Amended Soils. Am. Soc. Agron., Agron. Abstr., 1987, p. 28.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Nine northeastern U.S. soils were incubated with three sewage sludges, and pyrophosphate extracts were fractionated on resin columns into hydrophilic and hydrophobic acids, neutrals, and bases and examined for the presence of heavy metals. Porphyrins and complex amines (hydrophobic bases) were associated with copper, nickel, and zinc, while amino acids (hydrophilic bases) were strongly associated with lead and zinc. Carbohydrates (hydrophilic neutrals) complexed nickel, lead, and zinc, while uronic acids (hydrophilic acids) complexed chromium, nickel, and zinc. Both the hydrophobic acids (phenols) and neutrals (hydrocarbons) were unimportant in complexing heavy metals. Cadmium was present only in negligible amounts. These results indicate a need for a sewage sludge classification system.

568. Keefer, R. F., R. N. Singh, O. L. Bennett, and D. J. Horvath. Chemical Composition of Plants and Soils From Revegetated Mine Soils. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 155-161.

This study was conducted to determine how mine soils and plants growing in the soil are affected by the application of sewage sludge, fly ash, and chicken manure. The effects were measured by yield and chemical analyses for nutrients and heavy metals. Three abandoned minesites located in Preston and Monongalia Counties, WV, were used for this study. Each site was treated as follows: (1) 0, 22.4, or 44.8 Mg ha^{-1} chicken manure, (2) 0, 13.4, or 27 Mg ha^{-1} fly ash, and (3) 0, 45, or 90 Mg ha^{-1} sewage sludge. Following the application of these amendments, alfalfa (*Medicago sativa* L.) and sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don) were seeded onto the sites. Sewage sludge and chicken manure applications did not affect plant growth. Sludge applications increased the phosphorus, calcium, zinc, copper, chromium, nickel, lead, and cadmium concentrations in the mine soils. In general, soil phosphorus and exchangeable calcium concentrations were increased by applying any of the three byproducts onto the mine soil used in this study. Legume phosphorus and potassium concentrations were increased by chicken

manure applications. The differences that were found in legume growth among the three sites were related to the properties of the mine soils. The authors conclude that plant growth is limited whenever soils contain high total sulfur (>0.3 pct), exchangeable aluminum (>2 meq per 100 g), and extractable manganese (>30 ppm) along with low pH (<4.0).

569. Keefer, R. F., R. N. Singh, W. Chobthum, D. K. Bhumbla, and J. D. Burnell. Comparison of Fly Ashes as Topsoil Substitute for Revegetating Mine Spoils. Am. Soc. Agron., Agron. Abstr., 1988, p. 40.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Three fly ashes were compared as topsoil substitutes for reclaiming a highly acidic mine spoil that had been mined for coal and had no topsoil available for cover. Fly ash from three sources was applied at two rates: 600 and 1,200 Mg ha^{-1}. Control plots were treated with ground agricultural limestone at 4.8 Mg ha^{-1}. Changes in the physical and chemical properties of the mine spoil were monitored. Seeded vegetation grew well on one fly-ash-amended spoil, pH 8.0, while vegetation grew poorly on the other two fly ash treatments, pH 10.

570. Keefer, R. F., R. N. Singh, and D. J. Horvath. Chemical Composition of Vegetables Grown on an Agricultural Soil Amended With Sewage Sludges. J. Environ. Qual., v. 15, No. 2, 1986, pp. 146-152.

Vegetable crops were grown on a sandy loam soil amended with four different sewage sludges to compare the absorption of heavy metals by the various vegetables grown. The sludges studied were one aerobically digested, two anaerobically digested, and one composted sludge. All sludges were applied at 0, 90, and 180 Mg ha^{-1}. Two sets of control plots were established: one fertilized according to soil test recommendations and the other not fertilized. All plots received 56 kg ha^{-1} N as ammonium nitrate in addition to any other treatment. Heavy metals were analyzed in the edible and nonconsumable parts of radish (*Raphanus sativus* L.), carrots (*Daucus carota* L.), green beans (*Phaseolus vulgaris* L.), cabbage (*Brassica oleracea* L. var. *capitata*), sweet corn (*Zea mays* L. var. *rugosa*), and tomatoes (*Lycopersicum esculentum* Mill.). Concentrations of copper, zinc, cadmium, chromium, nickel, and lead in each vegetable grown on sludge-amended soil are presented. Edible portions of vegetables grown on the sludge-amended soils showed no appreciable accumulation of heavy metals. It may be necessary, however, to widen the zinc-cadmium ratios to >200 for tomato fruits (100) and radish roots (50 to 100), since there is a chance of toxicity if the ratio is below 200. The chemical analysis of the sewage sludges used was not related to metal absorption by the vegetables grown on the sludge-amended soils.

571. Keener, M. E., and J. M. Farmer. Revegetation of Copper Mine Tailings. II. Field Plot Results. Am. Soc. Agron., Agron. Abstr., 1988, p. 40.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The revegetation of two copper mine tailings ponds, located in Utah and Nevada, was evaluated on a relative scale.

572. Keeney, T. A., and D. Coyer. Valuation of Surface Mining Design To Improve Post-Mining Land Resources. Paper in Conference on the Economics of Mined-Land Reclamation (cosponsored by Land Reclam. Prog., Argonne Natl. Lab., and U.S. Dep. Energy; Chicago, IL, Sept. 1-2, 1981). Argonne Natl. Lab., ANL/LRP-TM-20, Sept. 1981, pp. 123-146.

This paper presents an economic analysis of mountaintop removal mining. The authors incorporate the concept of selective placement of spoil material to improve the agricultural potential of the site. They stress that the implementation of these reclamation techniques could result in land more adaptable to a use with higher economic returns, thus enhancing the postmining land value and increasing total returns. Since this report deals with a computer model and not an actual field study, the ratings for the keywords used in the evaluation process represent the apparent treatment of these subject areas in the analysis.

573. Keeney, T. A., and R. M. Smith. Modern Mining and Reclamation Procedures for Reduced Costs and Improved Land Resources. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 188-211.

Site factors that influence mine design, soil and overburden characterization, engineering criteria and design, and factors affecting improved short-term and long-term economics were discussed for a steeply sloping West Virginia surface mine. Site conditions that influence mine design include the topography and geology of the minesite, in combination with the physical and chemical characteristics of the coals to be mined at the maximum economical stripping ratio. Soil overburden characterization was a means of establishing procedures to assure quality drainage and successful revegetation for an agricultural postmining land use. These data indicate which interval of overburden is superior to native soil for use as the plant growth medium. Earthmoving costs are reduced by

eliminating storage, rehandling, and distribution of the native soil. The engineering criteria for design of the surface mine operation were based on the controlled placement of overburden materials and effective sediment control measures. Construction of improved landscape and soil features should result in increased land value and higher anticipated returns from the postmining agricultural land use.

574. Kelley, K. R., and F. J. Stevenson. Effects of Carbon Source on Immobilization and Chemical Distribution of Fertilizer Nitrogen in Soil. Soil Sci. Soc. Am. J., v. 51, No. 4, 1987, pp. 946-951.

Three carbon sources (glucose, a phenolic glycoside, and catechol) and nitrogen-15 (^{15}N) labeled ammonium sulfate ($(NH_4)_2SO_4$) were added to an Illinois silt loam soil and allowed to incubate for periods up to 120 days. The availability, extractability, and chemical composition of immobilized ^{15}N were compared to study the effects of aliphatic and phenolic substrates on the transformations of fertilizer nitrogen. The rapid microbial utilization of the added carbon substrates resulted in a rapid net immobilization of fertilizer nitrogen. Maximum immobilization of soil nitrogen and ^{15}N occurred at 6, 10, and 20 days for glucose-, phenolic-glycoside-, and catechol-amended soil, respectively. A portion of the added ^{15}N was accounted for as nonexchangeable (clay-fixed) NH_4 for all substrates. This fixation was rapid and varied with the carbon substrate added. A sharp reduction in clay-fixed nonlabeled NH_4 was observed with the first 10 days of incubation for all substrates, indicating that fixed NH_4 was released and immobilized by the heterotrophic micro-organisms during the utilization of available carbon. The availability of immobilized ^{15}N decreased with time of incubation. At the point of maximum incorporation into microbial biomass, nonexchangeable $^{15}NH_4$ was 3.5 to 8.0 times more susceptible to mineralization than native soil nitrogen. Microbial transformations were more important than the type of added substrate in determining the distribution of immobilized ^{15}N after 120 days.

575. Kelley, N. E. Vegetational Stabilization of Uranium Spoil Areas, Grants, New Mexico. Ph.D. Thesis, Univ. NM, Albuquerque, NM, 1978, 89 pp.

This study examined physical and chemical factors of uranium mine and mill tailings affecting vegetative stabilization. Analyses were done for selected trace elements in mill tailing material and associated vegetation from waste piles in New Mexico, Colorado, and Utah. Uptake and concentration of toxic elements by plants growing on specific spoil materials were reported. Specific geologic material was identified for segregation and placement on the surface of dumps to reduce problems of revegetation. This was verified by a pilot revegetation project examining reestablishment of native vegetation on mine waste material. This study specifically deals with revegetation of uranium spoils; however, much of the information is applicable to surface coal mine reclamation activities.

576. Kelly, W. Evaluation of the Environmental Effects of Western Surface Coal Mining. Volume II: Mine Inventory. U.S. EPA, Rep. EPA-600/7-79-034, Feb. 1979, 197 pp.

This report contains a general summary of information for 37 surface coal mines that were active during 1975 in the Western United States, and for 7 additional mines that were under development. For each of the mines the following information is given: (1) general production information, mine life, employment, and disturbed acreage, (2) coal seam characteristics, average thickness, heating value, sulfur content, and ash content, (3) reclamation practices, (4) types of mining and reclamation research studies in progress, (5) overburden characteristics, pit geometry, and mining methods, and (6) equipment types and capacities for major stripping equipment only.

577. Kepler, D. A. Manganese Removal From Mine Drainage by Artificial Wetland Construction. Paper in Proceedings of the Eighth Annual National Abandoned Mine Lands Conference (Billings, MT, Aug. 10-15, 1986). MT Dep. State Lands, Helena, MT, 1986, pp. 74-80.

This research was conducted to study the treatment of manganese in acid mine drainage (AMD) by constructed wetlands. Volunteer wetlands were studied, and reduction in iron, sulfate (SO_4), and acidity, with concurrent increases in pH, was common. In wetlands where significant amounts of manganese were removed from AMD, the field horsetail (*Equisetum arvense* L.) was consistently present, while in volunteer wetlands where manganese was not effectively removed, horsetail was absent. A wetland system was designed and constructed utilizing both cattail (*Typha* spp.) and field horsetail to treat AMD. Field horsetail was planted down-gradient of the main wetland to allow the system to remove most of the iron from AMD before the flow reached the horsetail plantings. There was a definite improvement in water quality from AMD source to wetland outflow. Total iron and acidity values were reduced, and manganese values were reduced during the first year. Several probable courses as to why pH and manganese values did not continue to show improvement the second year are given. This study shows that wetland design and vegetation selection are critical in determining the effectiveness of wetland manganese removal.

578. Kepler, D. A., and P. J. Lusardi. Abatement of Mine Drainage by Wetland Treatment Systems on Abandoned Mine Land Sites in Pennsylvania. Paper in Tenth Annual Coal Conference (Wilkes-Barre/Poconos, PA, Oct. 10-14, 1988). Assoc. Abandoned Mine Land Prog., 1988, pp. 1-4.

Article discusses the use of constructed wetlands in treating acid mine drainage in Pennsylvania. Two examples are given of constructed wetlands, and preliminary results are presented. In general, effluent pH values increased, alkalinity exceeded acidity, iron and aluminum concentrations decreased consistently, and sulfate and manganese concentrates decreased slightly.

579. Kerr, S. N., and W. E. Sopper. Gaining Public Support for Spreading Sludge (Proceedings: 1979 Conference on Composting and Waste Recycling—Part II). Compost Sci./Land Util., v. 20, No. 5, Sept.-Oct. 1979, pp. 14-16.

The authors discuss the problems of public opinion in utilizing sludge as a mine-soil amendment and how, after one proposed project failed in Pennsylvania because of local opposition, several projects were successful both in gaining public approval and in reclaiming the mine spoils. The successful projects in Venango and Lackawanna Counties incorporated both liquid and dewatered sludge into prepared bituminous and anthracite spoils and seeded a mixture of Kentucky-31 tall fescue, (*Festuca arundinacea* Schreb.), Pennlate orchardgrass (*Dactylis glomerata* L.), Penngift crownvetch (*Coronilla varia* L.), and Empire birdsfoot trefoil (*Lotus corniculatus* L.). In all cases, the revegetation was successful through three growing seasons and no indication of decreasing productivity was observed, reportedly because of the slow nutrient release of the sludge.

580. Kerr, S. N., and W. E. Sopper. Utilization of Municipal Sludge for Woody Biomass Production on Mined Land. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 313-317.

Field demonstration plots were established on anthracite refuse and bituminous spoil in Pennsylvania to study the feasibility of using treated municipal sludge for the reclamation and reforestation of mined land. The studies indicate that the use of municipal sludge to help correct adverse site conditions increases the survival of hybrid poplar (*Populus* spp.) cuttings and the biomass of woody species.

581. Keys, R. N., F. C. Cech, and W. H. Davidson. Nutrient Content and Growth of an Austrian Pine (Pinus Nigra Arnold), Seed Source Study on Surface Mine Spoils. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 267-274.

Austrian pine (*Pinus nigra* Arnold) was planted on six sites in Pennsylvania and West Virginia in a seed source study. This paper reports on the height, diameter, survival, and nutrient content of Austrian pine for each site after 8 years. Eight seed sources were used at each site. Soil analyses of three sites are reported. Differences among sites were significant for height, diameter, survival, and several plant elemental levels. Height and diameter were significantly correlated with soil NO_3-N, phosphorus, and organic matter content, and there was a significant positive correlation between survival and organic matter. The lack of organic matter is one of the major limiting factors for pine growth on most acidic surface mine spoils. These results suggest that the addition of N-P-K fertilizer would further improve the growth of Austrian pine on the sites studied. Differences among sources for height and diameter were significant, but there was no effect of source on survival. Cluster analysis showed that there was a relationship between the seed sources' soil of origin and their ability to absorb minerals from the soil and their height growth.

582. Keys, R. N, F. C. Cech, and W. H. Davidson. The Performance of Austrian Pine Seed Sources on Various Sites in West Virginia and Pennsylvania. Paper in Proceedings of the 27th Northeastern Forest Tree Improvement Conference (Burlington, VT, July 29-31, 1980). Sch. Nat. Resour., Univ. VT, 1981, pp. 103-114.

This article reports the results of a study testing 12 sources of Austrian pine (*Pinus nigra* Arnold) on six sites. These sites included five mine spoil sites where the growth media were acid to extremely acid and an agricultural site where the soil had a pH of 6.1. Pines from a Yugoslavian source and an Austrian source are recommended for planting in Pennsylvania and West Virginia. Best survival of Austrian pine in West Virginia was found at elevations of about 2,500 ft above sea level. Lime and fly ash were found to improve survival of plantings on extremely acid sites. The information presented will be helpful for choosing species and planting stock sources for use in revegetating acid mine spoils in the Eastern Coal Mining Region.

583. Kiemnec, G. L., T. L. Jackson, D. D. Hemphill, Jr., and V. V. Volk. Relative Effectiveness of Sewage

Sludge as a Nitrogen Fertilizer for Tall Fescue. J. Environ. Qual., v. 16, No. 4, 1987, pp. 353-356.

A 3-year field study was conducted to determine the sewage sludge application necessary to give comparable yields of tall fescue (*Festuca arundinacea* Schreb.) as when inorganic nitrogen fertilizer was applied. Additionally, the cumulative effect of sewage sludge application on the heavy-metal concentration of tall fescue was determined. Sewage sludge applications consisted of 110, 220, 440, and 880 kg ha^{-1} yr^{-1} total nitrogen, while ammonium nitrate (NH_4NO_3) fertilizer treatments consisted of 0 (control), 110, 220, and 440 kg ha^{-1} yr^{-1} N. Four equal applications of sewage sludge and fertilizer occurred throughout the year to achieve the yearly total nitrogen application rate. Dry matter yield response was significantly greater for NH_4NO_3-amended soils for the 3-year study period. Sewage sludge was 27, 41, and 44 pct as effective as NH_4NO_3 fertilizer as a source of available nitrogen during the 3-year study period. The mean nitrogen recovery over the 3-year study period for all sludge rates was 27 pct and for all NH_4NO_3 rates, 74 pct. Plant tissue concentrations of zinc, cadmium, and copper were higher and concentrations of manganese lower in sludge-amended soil than in NH_4NO_3-amended soil. Plant tissue concentrations did not reach toxic levels at any time during this study.

584. Kiger, J. A., W. A. Berg, J. T. Herron, C. M. Phillips, and R. G. Atkinson. Shrub Reestablishment in the Mountain Shrub Zone. Paper in Fourth Biennial Symposium on Surface Mining and Reclamation on the Great Plains and Fourth Annual Meeting of the American Society for Surface Mining and Reclamation (Billings, MT, Mar. 17-19, 1987). Reclam. Res. Unit, MT State Univ., Bozeman, MT, Rep. 8704, 1987, pp. L-3-1—L-3-6.

The major reclamation objective on surface-mined land in the mountain shrub zone of northwestern Colorado is the reestablishment of shrubs for wildlife habitat. This paper presents research findings on shrub reestablishment after 9 to 11 growing seasons and outlines current reclamation practices to reestablish shrub densities to meet State criteria for bond release. The direct-seeding studies indicate that stands of serviceberry (*Amelanchier* spp.) and snowberry (*Symphoricarpos* spp.) can be established if grass competition during the first growing season is moderate. Current reclamation practices eliminate grass seedings in areas where shrubs are established.

585. Kilkelly, M. K., H. P. Harbert III, and W. A. Berg. Field Studies on Paraho Retorted Oil Shale Lysimeters: Leachate, Vegetation, Moisture, Salinity, and Runoff, 1977-1980. U.S. EPA, Rep. EPA-600/7-81-131, Aug. 1981, 98 pp.

This report gives the results of a study that analyzed leachate, runoff, moisture, and salt movement from vegetated and unvegetated retorted oil shale. Compacted, retorted oil shale was placed in lysimeter sets, facing north on a 2-pct slope. Six replicated treatments, four with varying depths of topsoil, the other two a retorted shale control and a soil control, were seeded with a mixture of grasses, shrubs, and forbs. The lysimeters were monitored over three growing seasons. Data on percent cover are reported. Recommendations for establishing vegetation on retorted oil shale are made.

586. Kilkelly, M. K., H. P. Harbert III, and W. A. Berg. Revegetation Studies on TOSCO II and USBM Retorted Oil Shales. Paper in Fourteenth Oil Shale Symposium Proceedings (Golden, CO, Apr. 22-24, 1981). CO Sch. Mines, Golden, CO, 1981, pp. 410-421.

This study was done to evaluate a variety of intensive management techniques and practices used to reclaim processed oil shales in northwestern Colorado. Two locations were chosen to simulate disposal sites: a low-elevation and a high-elevation site. The objectives were to investigate surface stabilization through the establishment of vegetation and to monitor moisture and soluble salts in treatment profiles. Each site contained a set of several treatments using various leaching and soil coverings on two types of processed shales (TOSCO II and U.S. Bureau of Mines). After plot construction, all plots were fertilized with nitrogen and phosphorus; seeded with a mixture of native grasses, forbs, and shrubs; mulched with a grass hay; and irrigated until vegetation was established. After seven growing seasons all plots maintained a good vegetative cover. There were no significant differences in cover among plots except for the TOSCO retorted shale, which supported less perennial vegetation. During the experiment the most notable change was that in species composition, from a population dominated by perennial grasses to one dominated by shrubs. With the development of a satisfactory cover, surface runoff and sediment yield remained low. After an initial accumulation on the plots, surface salts were leached downward by seasonal precipitation and did not cause a serious problem.

587. Kim, S. K., A. C. Chang, A. L. Page, and J. E. Warneke. Extractable Cd and Zn Contents of Sludge-Treated Soils and Their Relationship With Cd and Zn Concentration in Plants. Am. Soc. Agron., Agron. Abstr., 1988, p. 40.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. A plant's ability to absorb potentially toxic metals from sludge-treated soils was predicted using a linear model ($Y = A + BX$), an

exponential model ($Y = A \times 10^{BX}$), or a power function model ($Y = AX^B$), where Y is the metal concentration of plant tissue, X is the extractable metal content of soil, and A and B are constants. A greenhouse pot experiment was conducted to evaluate each of the models; five different soil extractants were used to predict plant availability of cadmium and zinc in soils. None of the chemical extractants tested adequately assessed plant available cadmium and zinc in soils of the models tested. The exponential model described the data better than did the other proposed models.

588. Klein, D. A., D. L. Sorenson, and W. C. Metzger. Soil Microorganisms and Management of Retorted Shale Reclamation. Ch. in Revegetation Studies on Oil Shale Related Disturbances in Colorado (U.S. Dep. Energy contract DE-AS02-76EV04018, Range Sci. Dep., CO State Univ.). U.S. Dep. Energy, DOE/EV/04018-6, June 1982, pp. 27-44.

This study is part of a larger project evaluating the impact and potential for reclamation following oil shale mining and retorting processes. This paper reports the sixth-year results. The objectives of this study were to (1) evaluate microbial responses during reestablishment of plant communities on disturbed sites, (2) examine the effect of soil storage and disturbance on microbiological populations and on micro-organism-related nutrient cycling processes, and (3) determine the effects of retorted shale on the microbiological characteristics and activities in surface soils placed over the retorted matter as they relate to revegetation potential. A single fertilizer treatment at the beginning of reclamation on a disturbed site appeared to have a long-lasting effect. Monitoring of nitrification and ammonia volatilization suggested that only a minor part of the added nitrogen would be lost because of volatilization. A major shift in biogeochemical cycling with nitrogen and phosphorus entering less available pools seemed to occur as reestablished plant communities matured. This paper is an excellent reference for planning revegetation activities and for understanding the microbial ecology of revegetated areas.

589. Klein, D. A., D. L. Sorensen, and E. F. Redente. Soil Enzymes: A Predictor of Reclamation Potential and Progress. Ch. in Soil Reclamation Processes: Microbiological Analyses and Applications, ed. by R. L. Tate III and D. A. Klein. Marcel Dekker, 1985, pp. 141-171.

This chapter discusses the use of soil enzymatic methods to evaluate factors influencing the reclamation of retorted oil shales. Enzymatic approaches should be able to provide information for reclamation management in terms of (1) estimates of the relative fertility status of soil and spoil materials, (2) potential effects of energy wastes on soil enzymatic processes, and (3) information on plant community development with and without effects of an underlying or codisposed waste material. Experiences using soil enzymatic monitoring with retorted oil shale are presented.

590. Klein, D. A., and R. L. Tate III. General Interactions of Microbes in Reclamation Processes: Ch. in Soil Reclamation Processes Microbiological Analyses and Applications, ed. by R. L. Tate III and D. A. Klein. Marcel Dekker, 1985, pp. 333-338.

This chapter provides an overview of the role of microbiology in the reclamation process and evaluates current and future needs for reclamation research. The contributions of microbiologists to the evaluation of reclamation procedures are listed and discussed. Microbial community management primarily involves adjustment of the physical and chemical conditions to the range favorable to the desired microbial processes.

591. Kleinman, L. H. and D. E. Layton. Reclamation Techniques and Vegetation Response at Decker Coal. Paper in Surface Coal Mining and Reclamation Symposium, Coal Conference and Expo V (sponsored by Coal Age, Louisville, KY, Oct. 23-25, 1979). McGraw-Hill, 1979, pp. 255-259.

This paper describes the revegetation program at Decker Coal Co.'s mine near Decker, MT. After briefly reviewing the method of site preparation, seeding, and fertilizing a reclaimed area, the authors detail the results of the program. Data are given for vegetative canopy cover and annual herbage production for shrubs, perennial grass, annual grass, forbs, and total vegetation.

592. Kleinmann, R. L. P. Treatment of Acid Mine Water by Wetlands. Paper in Control of Acid Mine Drainage. BuMines IC 9027, 1985, pp. 48-52.

A pilot-scale field test was conducted to determine if a constructed bog system could treat acid mine water. The design of the pilot scale system is presented. It is a portable bog system that allows water to flow through divided chambers sequentially. The first five sections were packed with *Sphagnum* moss, and the final section was packed with coarsely crushed limestone. The acid water source was a badly contaminated stream. The moss was effective in removing iron from the acid water; however, sulfate concentration and acidity were not affected by flow through the *Sphagnum*. Dissolved oxygen concentrations indicated that conditions were not anaerobic. The limestone was effective in increasing water pH; as the acid

mine water flowed through the limestone bed, pH increased an average of 1.4 units and as much as 2.5 units. A field evaluation of the wetland approach is described. The author concludes that wetlands can be constructed in acid mine site discharges to improve drainage quality.

593. Kleinmann, R. L. P., and P. M. Erickson. Field Evaluation of Bactericidal Treatment To Control Acid Drainage. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 325-329.

Inhibition of *Thiobacillus ferrooxidans*, an iron-oxidizing bacterium, has been shown to slow the rate of pyrite oxidation on surface-mined land. This inhibition has been accomplished by using sodium lauryl sulfate (SLS), an anionic surfactant, from rubber pellets. Field tests were conducted at inactive, acid-producing surface mines and coal refuse piles at sites in Ohio, Pennsylvania, and West Virginia. The effectiveness of this technique requires good infiltration of rainfall. On highly compacted sites, the overburden may be too impermeable for the surfactant to infiltrate the pyritic material. On more permeable sites, 50- to 95-pct reductions in acidity have been observed. The controlled release of anionic surfactants should be useful in augmenting revegetation and in reducing or suppressing acid drainage from refuse piles and surface-mined land.

594. Kleinmann, R. L. P., and M. A. Girts. Constructed Wetlands for Treatment of Mine Water—Successes and Failures. Paper in Proceedings of the Eighth Annual National Abandoned Mine Lands Conference (Billings, MT, Aug. 10-15, 1986). MT Dep. State Lands, Helena, MT, 1986, pp. 67-73.

Constructed experimental wetlands are an alternative to conventional acid mine water treatment facilities in the Eastern United States. Metal ions are removed from mine water by the vegetation and indigenous bacteria present in the wetlands through adsorption, surface oxidation, ion exchange, bacterial oxidation, filtration, and reduction. Wetlands dominated by *Typha* or *Equisetum* are more efficient in removing metal ions (particularly iron and manganese) than are wetlands dominated by *Sphagnum*. There is a need to evaluate the long-term effectiveness of constructed wetlands in treating mine drainage.

595. Klemp, M. T., and J. A. Burger. Changes in Site Factors During Pine Plantation Establishment on Surface-Mined Lands. Am. Soc. Agron., Agron. Abstr., 1987, p. 28.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Relationships among loblolly (*Pinus taeda* L.), Virginia (*Pinus virginiana* Mill.), and eastern white (*Pinus strobus* L.) pines were evaluated based on performance, weed control, fertilization responses, and soils and foliar nutrient levels after one, two, and five growing seasons on two surface-mined sites in southwestern Virginia. Loblolly and Virginia pines performed significantly better than white pine throughout the 5-year period. Volume index on both sites was significantly improved with herbicide treatment after the third and fifth years. Fertilization did not have any significant effect on pine performance or response. Foliar nitrogen and phosphorus levels were significantly different after 5 years, with lower foliar nitrogen levels attributed to the reduction of nitrogen-fixing herbaceous species. The sand fraction and soluble-salt levels of both mine soils significantly increased over time because of weathering.

596. Klemp, M. T., J. L. Torbert, J. A. Burger, and S. H. Schoenholtz. The Effect of Fertilization and Chemical Weed Control on the Growth of Three Pine Species on an Abandoned Bench and Return-to-Contour Site in Southwestern Virginia. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 77-81.

The effects of slow-release fertilizer pellets and chemical weed control on loblolly pine (*Pinus taeda* L.), Virginia pine (*Pinus virginiana* Mill.), and white pine (*Pinus strobus* L.) after 5 years were determined. The two sites studied were a flat bench site (pre-SMCRA) and a return-to-contour site (post-SMCRA). At each site, the three species and two fertilizer treatments were factorially arranged and all plots were split for a herbicide treatment. Seedlings treated with fertilizer at the time of planting were planted with an Agriform 21-g slow-release pellet (20-15-15) placed 10 cm deep and within 10 to 15 cm of the seedling. Prior to the fourth growing season, 56 kg ha^{-1} N (NH_4NO_3) was broadcast to these plots. In the herbaceous vegetation control plots, glyphosate was applied prior to planting. After the fifth growing season, tree survival, height, root collar diameter, and volume index (diameter squared times height) were used as measures of tree growth.

After five growing seasons, growth of loblolly and Virginia pines was significantly greater than growth of white pine. Both loblolly and Virginia pines had survival rates of 80 pct, while white pine had a survival rate of 64 pct. Loblolly and Virginia pines had 32 and 23 times the volume of white pine, respectively. Loblolly pine height was significantly greater than that of the other two species.

Fertilization at the time of planting and the broadcast application significantly improved tree survival and height. Overall mean survival was increased from 69 to 82 pct, and tree volume was increased by 150 pct. Herbicide treatment also had a significant effect on survival and volume on both study sites.

597. Klock, G. O. Soil Productivity—What Is It? Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 25-28.

Forest soil productivity is defined as the ability of a site's soil to support and produce biomass, where the maximum potential production is a function of both extrinsic and intrinsic site factors. Extrinsic factors, factors that the ecosystem has no influence over, include soil parent material, topography, and regional climate. Intrinsic factors, factors influenced by the presence of the ecosystem and processes occurring within it, include a range of soil-form processes such as water, nutrient, and carbon cycling. Forest land managers are most often concerned with intrinsic soil factors and the modification of them. Maintaining long-term productivity requires an understanding of the role and response of intrinsic site factors to forest management and an understanding of a soil's resilience to management activities.

598. Knight, M. J., J. D. Jastrow, and L. A. Shannon. Plant Growth on Soils Amended With Spray-Drying Flue Gas Desulfurization Waste. Am. Soc. Agron., Agron. Abstr., 1985, p. 27.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. The potential of spray-drying flue gas desulfurization waste as a soil amendment was investigated. The waste was added to three different soils at 0, 1, 2, and 4 pct by weight. Unamended and lime-amended soil served as controls. Corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) were grown on each treatment in the greenhouse for 42 days. After the crops were harvested, all treated pots were weathered out-of-doors for 5 months and cropped with the same species for 35 days. Prior to weathering, leaf number and biomass were significantly reduced for both species on amended soils. Following weathering, growth on amended soils and control soils was equivalent. Boron toxicity may have caused the reduction in plant growth, and weathering reduced the symptoms of boron toxicity.

599. Knuteson, J. A. Summary of Land Application of Municipal Sewage Research in Minnesota. Am. Soc. Agron., Agron. Abstr., 1987, p. 29.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. A summary is presented of the results of a 14-year study of municipal sewage sludge application to agricultural land. Management guidelines for land disposal of sewage sludge were developed, and long-term environmental effects were evaluated. Heavy metals applied in sludge versus those removed by crops over time were contrasted, along with changes in water quality.

600. Knuth, W. M., and E. L. Fritz. Utilization of Color and Color Infrared Aerial Photography in the Surface Coal Mining Process. Paper in Fifth Symposium on Surface Mining and Reclamation (NCA/BCR Coal Conf. and Expo IV, Louisville, KY, Oct. 18-20, 1977). Natl. Coal Assoc. and Bitum. Coal Res., 1977, pp. 4-7.

The authors provide a general discussion of the potential for applying aerial photography interpretation techniques to surface coal mine planning and reclamation. No data or examples are provided. However, the article would be very good for individuals working in reclamation who have little or no background in aerial photo interpretation. The information relayed is applicable nationwide.

601. Knuth, W. M., E. L. Fritz, J. A. Schad, and W. F. Nagle. Development of New Bond Release Criteria for Surface Coal Mines in the Eastern and Interior Coal Provinces of the United States (contract J0177024, Energy and Natural Resources Dep., HRB-Singer). BuMines OFR 35-79, 1978, 225 pp., NTIS PB 294 708.

The bonding and bond release practices in the States of the Eastern and Interior (midwestern) Coal Provinces are reviewed. Bonding and release procedures that are related to achieving successful reclamation were documented by collecting data from regulatory authorities and site visits. The regulations related to Public Law 95-87 are reviewed. The analysis that is included suggests new bond release criteria and modifications to existing criteria, reviews the applicable inspection techniques for bond release, and provides a conceptual graduated bonding system and incentive procedures for reclamation of surface mine sites to alternative or higher land uses. Numerous conclusions and recommendations for further research are included, as well as a detailed bibliography and glossary. This report provides an excellent reference for planning reclamation activities and monitoring revegetation for bond release.

602. Kolar, C. A., and W. C. Ashby. Successful Forestation as a Guide for Future Reclamation. Paper in Proceedings of the Fourth Annual Better Reclamation With Trees Conference (Owensboro, KY, June 7-8, 1984).

Madisonville Community Coll., Madisonville, KY, 1984, pp. 117-133.

Many tree plantings 30 years of age or older exist in the Eastern and Interior Coal Provinces. The existence of these plantings provides a valuable reference that can be used for developing mining and reclamation techniques for reforestation or afforestation of coal surface mine land. This paper reviews recent and older surveys of forest plantings and relates their success or failure to geographic location and to variables in mining, reclamation, and planting practices.

603. Kollman, A. L. Field Evaluation of Some Amendments in Terms of Soil Properties and Plant Productivity. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 934-950.

This paper reports the results of a study designed to evaluate the effects of some amendments on the physical and chemical characteristics of the spoils and the growth of plants at field test sites in Mercer and Oliver Counties in western North Dakota. This study was part of a 5-year project entitled "A Systems Approach to the Reclamation of Strip-Mined Areas in North Dakota," funded by the U.S. Bureau of Mines. It was found that fertilizers were required at most sites. The addition of leonardite, a naturally oxidized lignite material, reduced grass growth but increased legume production. The leonardite decreased the upward movement of salts from sodic spoils to topsoils. Plant establishment and productivity were also improved by the addition of as little as 1 ft of topsoil. This article provides a good reference for reclamation planning.

604. Koon, D. L., and D. H. Graves. Five-Year Vegetative Responses of Grasses and Legumes Planted Under Differing Rates of Soil Amending Mulches on Eastern Kentucky Surface Mines. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 509-513.

This study was conducted to determine the long-term effects of various soil-amending mulches on the establishment, growth, and composition of a pastureland species seed mixture on Falcon Coal Co. land in eastern Kentucky. The species in the seeding mixture included Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), tetraploidal ryegrass (*Lolium* spp.), yellow sweetclover (*Melilotus officinalis* (L.) Lam.), and birdsfoot trefoil (*Lotus corniculatus* L.). The mulching materials used were (1) hardwood bark applied at rates of 35 and 70 yd^3 $acre^{-1}$, (2) wood fiber mulch applied at rates of 250, 500, 750, and 1,500 lb $acre^{-1}$, (3) composted municipal waste at 10 and 20 tons per acre, (4) bark at 35 and 70 yd^3 $acre^{-1}$ plus chicken manure (2.5 and 5.0 tons per acre), and (5) 72 yd^3 composted municipal waste and bark mixture in equal volumes. Plots treated with organic mulches produced higher percentages of vegetative cover than plots treated with wood fiber mulch alone. The results of this study indicate that the use of organic mulches can enhance the reclamation and stabilization of drastically disturbed sites through rapid establishment and long-term maintenance of grasses and legumes.

605. Kormanik, P. P., and R. C. Schultz. Significance of Sewage Sludge Amendments to Borrow Pit Reclamation With Sweetgum and Fescue. U. S. For. Serv., Res. Note SE-329, 1985, p. 7.

The long-term effects of subsoiling and sewage sludge application on the establishment and growth of Kentucky-31 fescue (*Festuca arundinacea* Schreb.) and sweetgum (*Liquidambar styraciflua* L.) planted on borrow pits in South Carolina are described. The site was subsoiled by ripping furrows 0.9 m deep, and an aerobically digested sewage sludge was broadcast at rates of 0, 17, 34, and 68 Mg ha^{-1}. Prior to sludge amendments, the soils were characterized. The entire borrow pit area was seeded with Kentucky-31 fescue in the fall, and the following spring, vesicular-arbuscular mycorrhizal-infected (75 pct of feeder roots colonized) sweetgum seedlings were outplanted. Initial root-collar diameter and height were measured prior to bud break. Height growth, root-collar diameter, and survival were measured annually for 5 years, while mycorrhizal development was assessed the first 3 years. After the first three growing seasons, grass biomass was determined. Foliar nutrient concentrations in sweetgum seedlings were determined in midsummer of the second growing season. Results show that the current rate of sweetgum growth after sludge and subsoiling is comparable to that of sweetgum established in plantations on routine reforestation sites. At the end of the second growing season, tree heights were significantly greater on amended plots than on nonamended plots. Root-collar-diameter growth followed the same trend as height growth. Tree survival for nonamended plots and for the 17-, 34-, and 68-Mg-ha^{-1} sludge treatments were 76, 54, 52, and 42 pct, respectively. Lower survival on sludge plots is attributed to the heavier grass biomass.

606. Kost, D. A. Leaf Conductance, Transpiration Rates, and Leaf Abscission of Water-Stressed Northern Red Oak Seedlings Inoculated With Various Ectomycorrhizal Fungi. Paper in Proceedings of the Fifth Better

Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 31-40.

Greenhouse experiments were conducted to examine the effects of specific ectomycorrhizal fungi on the water relations of northern red oak (*Quercus rubra* L.). The fungal species used in this experiments were *Thelephora terrestris* Ehrh. ex Fr., *Cenococcum geophilum* Fr., and *Pisolithus tinctorius* (Pers.) Coker & Couch. Topsoil from a southern Illinois surface mine stockpile was collected, and the soil was inoculated. Northern red oak seed was grown in the inoculated soil in pots. Seedlings were allowed to grow for 2 or 3 weeks before they were subjected to water stress (four drying periods). Leaf conductance, water vapor diffusion, transpiration, and leaf abscission were the variables considered. There were no statistically significant differences in leaf conductance among treatments on any measurement dates. Only one significant difference occurred in the rate of transpiration among treatments—the last drying period. In general, the transpiration rates for ectomycorrhizal treatments were usually less than or equal to that of nonmycorrhizal controls. The occurrence and extent of leaf abscission were inversely related to ectomycorrhizal development; 43 pct of all nonmycorrhizal seedlings abscised leaves, while only 19 pct of all ectomycorrhizal seedlings abscised. Conclusive proof that the water relations of northern red oak seedlings are improved by ectomycorrhizal colonization was not obtained in this study.

607. Kroehler, C. J., R. K. Antibus, and A. E. Linkins. The Effects of Organic and Inorganic Phosphorus Concentrations on the Acid Phosphatase Activity of Ectomycorrhizal Fungi. Can. J. Bot., v. 66, No. 4, 1988, pp. 750-756.

This study investigated the regulation and production of surface and extracellular soluble acid phosphatase by isolates of *Cenococcum geophilum* and *Entoloma sericeum* grown in axenic (free of symbiosis) cultures at two concentration of orphosphate (KH_2PO_4) or sodium inositol hexaphosphate (phytic acid, 2 or 50 μM). Isolates of the ectomycorrhizal fungi were taken from phosphorus-poor arctic and temperate environments. Changes in the concentration of either form of phosphorus, organic or inorganic, were hypothesized to affect mycelial growth and the kinetic constants (K_m and V_{max}) of surface and extracellular soluble acid phosphomonoesterase.

When assayed at 12-day intervals, the surface phosphatase V_{max} estimates for the isolates responded similarly to both inorganic and organic phosphorus. However, the V_{max} estimates were significantly higher for fungi grown in 2 μM than 50 μM phosphorus. Extracellular soluble phosphatase activity generally decreased with time. Activity was greater in the 2-μM supplied cultures than in the 50-μM cultures. Media prepared with organic phosphorus had no measurable inorganic phosphorus at the beginning of the incubation period; however, inorganic phosphorus concentration increased with the initial growth phase of the isolate, and soluble phosphates activity increased. This suggests that substrate hydrolysis is taking place in excess of phosphate uptake. No consistent relationship was found between apparent K_m estimates and phosphorus treatments. An inverse relationship exists between phosphorus concentration in the growth medium and phosphatase activity. The changes in the activity and V_{max} values of surface and extracellular phosphatase in response to phosphorus concentration at the micromolar level supports the hypothesis that available soil phosphorus has a role in the regulation of ectomycorrhizal phosphatase activity. This article was included in the review process because of the importance of mycorrhizae in the phosphorus nutrition of higher plants.

608. Kuhlmeier, P. D. Reclamation of Sodic Mine Spoils. Paper in Proceedings 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 2-7, 1984). Univ. KY, Lexington, KY, 1984, pp. 485-492.

Field and greenhouse pot experiments were conducted to evaluate three sodic soil amendments on plant biomass production on coal mine spoil and bentonite mine spoil in the Northern Great Plains. Sodic mine spoils affect plant growth characteristics through the toxic effects of soluble salts, adverse nutritional conditions associated with sodic soils, or the low availability of water due to osmotic potential limitations on infiltration restrictions. The three sodic soil amendments studied were sand, peat, and hydrochloric acid (HCl). The spoil materials tested were chemically and physically characterized. Peat was added to increase available plant nutrients, sand was used to improve soil texture, and HCl was added to induce cation exchange between sodic salts and the acid, with H^+ replacing Na^+ (resulting in increased nutrient availability). All amendments were used alone and in all possible combinations, along with a control. Plant aboveground and belowground biomass was monitored, as well as the height of plants.

In the greenhouse study, the biomass of crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.) ranged from a low of 1.48 g m^{-2} in pots containing peat to 60.32 g m^{-2} in pots with no amendment. Perennial ryegrass (*Lolium perenne* L.) production ranged from 3.85 g m^{-2} in pots containing peat to 70.31 g m^{-2} in pots containing sand. Field results paralleled the greenhouse pot studies, with biomass ranging from a low of 2.6 g m^{-2} on peat-amended plots to

88.5 g m^{-2} on plots amended with HCl and sand. Grass stalk development was best using the HCl treatment in both the field and greenhouse experiments. Peat moss was the most ineffective of the amendments used. Sand amendments increased water infiltration of the bentonite clay from 9.5 to 80 cm d^{-1}. Available water is the most important factor controlling the growth of the species tested on these mine spoils regardless of the soil amendment used.

609. Kuhlmeier, P. D. Redevelopment of Groundwater Table in Reclaimed Land. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 383-388.

Ground water profile development following mining is dependent on the physical and chemical properties of the new soil matrix. The potential for reforming a ground water profile within spoil banks was determined in an effort to predict any excess seepage problems that might occur from stockpile drainage. Three separate stockpiles at a northeast Texas lignite mine were evaluated in several stages. Based on infiltration tests and physical and chemical analyses, projected development of a new water table was estimated.

610. Kumar, P., and K. Sharma. Coal Mining and Reclamation in the Alberta Foothills. Coal Miner, v. 2, No. 2, 1977, pp. 20-24.

This article provides a general review of the present status of coal mining and reclamation in the foothill physiographic province of Alberta, Canada. The Alberta government's overall policy for coal mining is discussed. Short descriptions are given of the ecological components of the Alberta foothills region, including climate, topography, geology, soils, and vegetation. Current revegetation research for this region is surveyed with reference to properties of the growth media, soil improvements, seeds, and seedlings. Special reference is made to introduced species and exotic species recommended for this area. The article provides an adequate survey of the topics covered and is a good introduction for individuals interested in Canadian reclamation research.

611. Ladwig, K. J., P. M. Erickson, and R. L. P. Kleinmann. Alkaline Injection: An Overview of Recent Work. Paper in Control of Acid Mine Drainage. BuMines IC 9027, 1985, pp. 35-40.

A brief overview of the current status of alkaline injection into surface mine spoil to control acid mine drainage is presented. The premise of the exchange is in-place neutralization of acid water stored in the spoil. Materials used for injection are sodium hydroxide, hydrated lime, and sodium carbonate. Potential advantages of injection over conventional water treatment are given. Two injection programs in Pennsylvania are described. Central to the success of an alkaline injection program is a good mixing of the alkaline fluid and contaminated spoil water. This requires a thorough understanding of site hydrology and acid-producing characteristics. Ways in which to improve alkaline injection are hypothesized.

612. LaGory, K. E., E. D. Pentecost, and W. S. Vinikour. Reclamation Success at an Abandoned Deep Coal Mine Site Near Staunton, Illinois. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 221-227.

This article evaluates the success of reclamation activities at an abandoned deep mine 10 years after the initial reclamation efforts were initiated. At the site, general reclamation procedures included grading and recontouring the coal refuse pile and slurry areas, covering the exposed refuse material with soil, liming the soil, fertilizing the soil, and seeding with selected species. Reclamation was evaluated by experimentally manipulating the depth of soil replacement (30 and 60 cm) and liming rates (112 and 224 mt ha^{-1} $CaCO_3$ equivalent).

Results are presented on the vegetative cover that has become established on the area. In the experimental plots, vegetative cover varied among the treatments used. Soil depth had the greatest effect on vegetative cover. Plots with 60 cm of soil cover had the highest percentage of cover; liming rate did not affect cover in these plots. Where 30 cm of soil was used, plots amended with 224 mt ha^{-1} lime had greater plant cover than plots amended with 112 mt ha^{-1} lime. Increased soil depth apparently increased the distance between the acidic coal refuse and plant roots. Additionally, increased soil depth increased plant available water. With less soil material over the refuse, lime is needed to neutralize the acidic refuse material. The authors recommend that a fine-textured neutralizing material be used on coarse coal refuse. Information is presented on the number of birds and mammals observed 10 years after the initiation of reclamation. The more diverse the habitat, the greater the number of wildlife sightings.

613. Lamb, B., G. Loomis, A. Gold, and C. McKiel. Nitrogen Removal From On-Site Sewage Disposal Systems: A Field Evaluation of Alternative and Conventional Designs. Am. Soc. Agron., Agron. Abstr., 1988, p. 41.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Three nitrogen removal systems for on-site sewage disposal were evaluated

to identify the most practical system. The systems evaluated were a recirculating sand filter (RSF) system, a RUCK system, and a conventional system. Nitrogen outputs were monitored for 2 years. The RSF system showed average nitrogen removals of 60 to 90 pct, the RUCK system 20 to 80 pct, and the conventional system 1 to 9 pct.

614. Larson, J. E. Revegetation Equipment Catalog. U.S. For. Serv., Equip. Dev. Cent., Missoula, MT, Rep. 8042 2501, Feb. 1980, 198 pp.

This publication is an excellent compendium of available revegetation equipment. Helpful comments on equipment function, capabilities, and limitations are provided. Also included are comparative specifications for rubber-tired tractors and crawler tractors, as well as a list of forage plants commonly seeded on range and other perennial pastures. The geographical focus of the document is the Western United States. However, some of the equipment discussions are relevant to other regions as well. This is an excellent reference that could aid in planning revegetation activities.

615. Larson, M. M. Invasion of Volunteer Tree Species on Stripmine Plantations in East-Central Ohio. Agric. Res. and Dev. Cent., OH State Univ., Columbus, OH, Res. Bull. 1158, 1984, 10 pp.

Three 30-year-old strip mine plantations located in eastern Ohio were investigated to determine the number and basal area of volunteer trees by species. Subplots within each plantation were established, with each subplot originally planted to a single species 30 years earlier. Only subplots containing white pine (*Pinus strobus* L.), yellow-poplar (*Liriodendron tulipifera* L.), and white ash (*Fraxinus americana* L.), or black locust (*Robinia pseudoacacia* L.) as plantings were selected, and each subplot contained 160 or more surviving trees per acre. Each plantation had a different soil type. The number of volunteer trees per acre varied with plantation location and spoil type. Near-neutral spoils derived from glacial till and sandstone had 929 volunteer trees per acre, while acid shale spoil had 698 trees per acre, and calcareous limestone and clay spoil had 516 volunteer trees per acre. Black cherry (*Prunus serotina* Ehrh.) was the most abundant volunteer on neutral and acid spoil, while black locust and white ash predominated on calcareous clay spoil. Volunteer trees outnumbered planted trees on each plantation, with an overall mean for the plantations of 714 volunteer trees to 401 planted trees per acre. On the near-neutral and acid spoils, mean number of volunteer trees was higher in the black locust plantings than in the white pine stands, while on the calcareous spoil white pine stands had the highest mean number of volunteers. The potential for tree species to volunteer on a particular site is determined by the presence of a nearby seed source, soil type, and the amount and kind of vegetation established on the area.

616. Larson, M. M., and J. P. Vimmerstedt. Evaluation of 30-Year-Old Plantations on Stripmined Land in East Central Ohio. Agric. Res. and Dev. Cent., OH State Univ., Columbus, OH, Res. Bull. 1149, 1983, 20 pp.

This study remeasured 13 experimental plantations that had been established in 1946-47 by the U.S. Forest Service in eastern and southeastern Ohio. All of the surviving trees on each area were counted, and mean diameter and height of each species were estimated. The survival of all planted trees averaged 36.6 pct on calcareous spoil and 23.3 pct on noncalcareous spoil after 30 years. Of the tree species planted, white ash (*Fraxinus americana* L.) and green ash (*Fraxinus pennsylvanica* Marsh.) had the highest survival rates, averaging 65 pct on calcareous spoil and 34 pct on noncalcareous spoil. White pine (*Pinus strobus* L.) had the greatest diameter growth of all species planted. Of the tree species direct-seeded on the spoil banks, bur oak (*Quercus macrocarpa* Michx.) had the best survival after 30 years, 37.2 pct survival of all seed spots, especially when seeded on the south slopes of spoil banks. After 30 years, the study initiated by the U.S. Forest Service has demonstrated the potential of forest plantings as productive, permanent, and protective cover on coal spoils.

617. Larson, M. M., and J. P. Vimmerstedt. The Volunteer Component in Reforestation of Mined Lands. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 104-110.

Three 30-year-old plantations planted with four different tree species were examined and volunteer tree species inventoried. Each of the plantations was located on a different mine-soil type in east-central Ohio. Plantation 1 was a calcareous mine soil with a pH of 7.0, derived from coarse limestone and clay; plantation 2 was a near-neutral mine soil with a pH between 6.5 to 7.8, derived from glacial till and sandstone; and plantation 3 was an acid mine soil with pH values between 3.8 to 5.5, derived from shale. Near-neutral mine soils had the greatest number of volunteer trees at 929 trees per acre, followed by 698 trees per acre on the acidic mine soil, and 516 trees per acre on the calcareous mine soil. Volunteer trees outnumbered planted trees on all tree plantations, a mean value of 714 volunteer trees per acre to 401 planted trees per acre. The planted trees, however, had a greater mean basal area per acre, 55.7 ft^2, than did the volunteer species, 21.8 ft^2. A total of 20 volunteer species were found in the combined census of the plantations. The acidic mine soil had

the greatest number of species, 15, followed by 13 species on the near-neutral mine soil, and 7 on the calcareous mine soil. Both mine-soil type and tree species planted influenced the number and kind of tree that invaded a plantation. The occurrence of a potential invading tree species on a particular site is largely dependent upon mine-soil type, climate, topography, seed source, established vegetation, damaging agents, and time since mining. This paper was included in the review process because it establishes the importance of mine-soil type (characterization) in determining the volunteer vegetative component of mined lands.

618. Laue, S. K., R. I. Barnhisel, and J. L. Powell. Yield, Forage Quality of Grass Species and Varieties Established on Topsoiled Mine Spoils in Western Kentucky. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 535-540.

This study was conducted to compare yield and productivity of 16 cool-season, perennial grass species and varieties growing on topsoiled mine spoils in Muhlenberg County, KY. The effects of harvesting grasses on ground cover were evaluated for grasses harvested in May and November. In addition, nutrient levels, neutral detergent fiber (NDF), and acid detergent fiber (ADF) were analyzed in the harvested grasses. Tall fescue (*Festuca arundinacea* Schreb.) had the highest production for both harvests, good nutrient content, and low fiber. Reed canarygrass (*Phalaris arundinacea* L.), Kentucky bluegrass (*Poa pratensis* L.), creeping red fescue (*Festuca rubra* L.), and perennial ryegrass (*Lolium perenne* L.) also had low fiber and high fall yields, but had moderate nutrient content and low spring yields. Orchardgrass (*Dactylis glomerata* L.) and redtop (*Agrostis alba* L.) had intermediate nutrient content and production, but high fiber. Pubescent wheatgrass (*Agropyron trichophorum* (Link.) Richt.), intermediate wheatgrass (*Agropyron intermedium* (Host.) Beauv.), crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.), and timothy (*Phleum pratense* L.) had a high spring yield, but low fall yields, low nutrient content, and high fiber. Grasses in the vegetative stage had lower fiber than grasses in the seed stage. By cutting the grasses in the early spring, at the boot or early seed heading stage, it may be possible to increase the digestibility and lower the fiber content of many species. Of the varieties tested, Manhattan perennial ryegrass and Kenhy tall fescue outproduced Omega and Kentucky-31 varieties in yield, protein, nutrient, and fiber content, and ground cover for at least one harvest. The results presented in this paper are the first in a 5-year study.

619. Lauren, J. G., R. J. Wagenet, J. Bouma, and J. H. M. Wosten. Variability of Saturated Hydraulic Conductivity in a Glossaquic Hapludalf With Macropores. Soil Sci., v. 145, No. 1, 1988, pp. 20-28.

This paper was reviewed because of the importance of saturated hydraulic conductivity (K_{sat}) in determining the maximum capacity of a soil to conduct water. This study defines the best field method to measure K_{sat} in a clayey soil with macropores, the optimal sample volume for measurement of K_{sat} in soil as a function of soil structure, the number of measurements and measurement location as a function of spatial patterns, and procedures by which K_{sat} can be predicted by using physical characteristics such as soil texture and structure. A 370-m transect was established, with 37 sampling sites along the transect at 10-m intervals. Saturated hydraulic conductivity was measured in situ using columns. Four different sampling sizes were used to determine the effects of sample size on the spatial variability of measured K_{sat}. Columns at each sample site were constructed within the limits of the previous (larger) column. Volumes used in the in situ columns were 2.4×10^5, 1.2×10^5, 0.5×10^5, 6.28×10^3, and 884 cm^3.

In situ K_{sat} measurements varied along the transect, with the value of K_{sat} and its spatial variability influenced by the size of the soil column. The optimum sample size for measuring K_{sat} in the field was 0.5×10^5 cm^3, which was larger than the estimated representative elementary volume (REV) for this soil. Samples larger than this were acceptable for measuring K_{sat}, but considerations such as time and cost may preclude their use. Smaller samples produced biased results and were unrepresentative of the actual hydraulic regimes. Saturated hydraulic conductivity values measured in detached cylinders in the laboratory were unreliable and not comparable to values obtained for in situ cylinders. Saturated hydraulic conductivity values measurements of detached columns were at least two orders of magnitude greater than those of attached columns. These values of detached columns are a reflection of waterflow through pores that are continuous over the length of a column. Results of a spatial correlation suggest that macrovoid area or the percentages of silt or clay may be used to predict the spatial distribution of K_{sat} in the field.

620. Lautenbach, W. E. The Greening of Sudbury. J. Soil and Water Conserv., v. 42, No. 4, 1987, pp. 228-231.

This article discusses the land reclamation program and projects conducted on barren areas near Sudbury, ON, Canada. The results of this program have been the restoration of 6,425 acres of barren landscape, with improvement in another 2,420 acres.

621. Laycock, W. A., and W. J. McGinnies. Reclamation of Grazing Management on a Surface Coal Mine in Northwestern Colorado. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 73-76.

The authors discuss how surface-mined areas, which were of poor or fair range condition prior to disturbance, can be reclaimed to valuable improved rangeland in northwestern Colorado. The reclamation program involves careful topsoil handling, proper seedbed preparation, and selection of adapted species. An example of how reclaimed mined land in northwestern Colorado can be managed for high forage and livestock production is presented. The preliminary results indicate that when a reclaimed site is seeded with alfalfa (*Medicago sativa* L.) and grasses, daily gains of yearling cattle can double, and the gain in total red meat production per acre can be seven to eight times greater than gains obtained from native ranges.

622. Leauge, L. Turning Mined Land Back Into Farmland. Am. Min. Congr. J., v. 69, No. 16, 1983, pp. 8-9.

This is a general article that describes R & F Coal's techniques to reclaim farmland in southeastern Ohio. Very little technical information is presented other than the amount of straw mulch used in the reclamation process.

623. Lee. C. R., J. G. Skogerboe, D. L. Brandon, J. W. Linkinhoker, and S. P. Faulkner. Vegetative Restoration of Pyritic Soils. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ KY, Lexington, KY, 1983, pp. 271-274.

Results are presented on a vegetative restoration project of pyritic soil created at a U.S. Army Corp of Engineers construction site in northeastern Mississippi. The area is characterized as being extremely acid (pH 2.9), droughty, and severely compacted. To ameliorate these conditions, four soil amendments were used: (1) lime, 100 mt ha^{-1} fine agricultural limestone and 100 mt ha^{-1} coarse limestone, (2) lime plus 79.6 mt ha^{-1} chicken manure, (3) lime plus 6.5 mt ha^{-1} rock phosphate, and (4) lime plus manure plus phosphate. The amendments were incorporated to a depth of either 15 or 45 cm, with and without subsoiling. All plots were seeded to weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees), Pensacola bahiagrass (*Paspalum notatum* Flugge), and sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don). Soil samples were collected and analyzed before and after the soil amendments were incorporated.

Lime amendments allowed vegetation establishment on all plots. However, the largest biomass production was found on plots receiving the chicken manure amendment. Weeping lovegrass was the only species that responded to the 45-cm incorporation depth. After 1 year of growth, 10 woody species were planted in each plot to evaluate long-term restoration, erosion control, and wildlife habitat. After one growing season, autumn olive (*Elaeagnus umbellata* Thunb.), white ash (*Fraxinus americana* L.), bristly locust (*Robinia fertilis* Ashe), and indigobush (*Amorpha fruticosa* L.) had the best survival. No significant differences in woody species survival were found during the first year between plots with amendments incorporated to depths of either 15 or 45 cm. With continued monitoring, deep incorporation of soil amendments to a depth of 45 cm should show a pronounced effect on plant growth and survival.

624. Lee, D., R. R. Mileur, F. J. Olsen, and J. H. Jones. The Effects of Herbage Removal on the Soil Restoration Process in the Reclamation of Surface Mined Spoil. Trans. IL Acad. Sci., v. 80, Nos. 3 - 4, 1987, pp. 161-168.

The effects of grazing, hay removal, and no hay removal of alfalfa (*Medicago sativa* L.) on the soil restoration processes were determined on a reclaimed surface mine in southern Illinois. The experimental site was reconstructed using bucket-wheel excavations. Soil was a mixture of the B horizon and underlying loess and glacial till; no topsoil was replaced. Additionally, the performance of beef cattle grazing the alfalfa and hay yields were assessed. Bulk densities and organic matter contents of soils in each treatment were determined to characterize their effects on soil restoration with time. Bulk density changes among the treatments were not significantly different. Organic matter content did increase for all treatments over a 2-year period, from a mean value of 0.48 pct to 0.85 pct. Increased organic matter content for all treatments indicated that hay removal or grazing would be viable alternatives, compared with no hay removal, for strip mine soil restoration. The economic returns from grazing or hay removal also justify their use in mine-soil restoration.

625. Lehrsch, G. A., F. D. Whisler, and M. J. M. Romkens. Spatial Variation of Parameters Describing Soil Surface Roughness. Soil Sci. Soc. Am. J., v. 52, No. 2, 1988, pp. 311-319.

Soil surface roughness is the configuration or microrelief of the soil surface, which affects infiltration, soil surface depression storage of water, runoff velocities, and plant establishment and growth. There exists a need for the development of a quantitative description of soil surface roughness that can be used in models to aid in the

selection of tillage practices. Possible indices of soil roughness were identified: maximum peak height, maximum depression depth, peak frequency, the ratio of peak frequency to peak height, microrelief index, ratio of microrelief index to peak height, ratio of microrelief index to peak frequency, and the product of microrelief index and peak frequency. This study determined the spatial variability of these roughness indices using semivariogram analysis. Analysis showed that in over two-thirds of the cases, no evidence of spatial dependence was found. When a roughness parameter was spatially dependent, its semivariogram was either spherical or linear with a nugget constant, or exhibited a hole effect. In plots on which soil surface roughness parameters were spatially dependent, zones of influence averaged 15 to 20 cm. Suggestions for further research on these roughness parameters are given.

626. Lekhakul, S. The Effect of Lime on Chemical Composition of Surface-Mined Coal Spoils, the Growth of Plants on Spoils, and the Leachate From Spoils. Ph.D. Thesis, Univ. KY, Lexington, KY, 1981, pp. 154.

This thesis reports the results of a greenhouse study designed to examine the effects of three liming rates and two leaching rates on the chemical composition of spoil, spoil leachate, and the response of grain sorghum (*Sorghum bicolor* (L.) Moench). Freshly exposed spoil material collected from the western Kentucky coal district was used. Crop yields were low for all treatments. Tissue analysis indicated nitrogen and phosphorus deficiencies. The results indicated that liming plus heavy leaching can reduce the potentially toxic iron, manganese, and aluminum in spoils.

627. Lewis, B. G. Extractable Trace Elements and Sodium in Illinois Coal-Cleaning Wastes: Correlation With Concentrations in Tall Fescue. Reclam. & Reveg. Res., v. 2, No. 2, 1983, pp. 55-68.

The purpose of this greenhouse study was to correlate the uptake of trace elements by tall fescue (*Festuca arundinacea* Schreb.) with the extractable element concentrations of five different southern Illinois coal-cleaning wastes (gob and slurry). Trace elements were extracted with one or more of the following: (1) dilute acid (0.05*M* HCl and 0.0125*M* H_2SO_4) at pH 1.6, (2) DTPA (diethylenetriamine pentaacetic acid) at pH 6.4, (3) DTPA at pH 8.4, and (4) hot water (for boron only). The results indicate that there was little or no correlation between shoot concentrations of iron and the iron extracted from the wastes by dilute acid (r = 0.60), DTPA at pH 6.4 (r + 0.47) or DTPA at pH 8.4 (r = -0.17). Much better r values were obtained for manganese (0.94, 0.97, and 0.96), for zinc (0.96, 0.96, and 0.88), and for copper (0.67, 0.90, and 0.88), respectively. Shoot boron correlated well with hot-water-soluble boron (r = 0.96) and acid-soluble boron (r = 0.91). Shoot sodium also correlated well with water-soluble sodium and acid-soluble sodium (r = 0.96 for both). The concentrations of aluminum, arsenic, cadmium, lead, nickel, and selenium in the shoots were below reported upper critical levels and were similar to concentrations found in tall fescue grown on a silt loam under the same greenhouse conditions.

628. Lewis, B. G. Macronutrient and Boron Ratios in Tall Fescue: Relationship to Yields on Pyritic Coal Wastes. J. Environ. Qual., v. 13, No. 2, 1984, pp. 313-316.

A greenhouse study was conducted to determine if the yields and nutrient concentrations of tall fescue (*Festuca arundinacea* Schreb.) were significantly different when grown on bulk coal wastes (gob and slurry) or an agricultural soil. All materials were treated with limestone and fertilizer. After 8 weeks of growth, yields of tall fescue grown on the wastes were significantly lower than yields on the soil when the calcium-boron ratio was outside a range of 1.7 to 2.8. Within this ranges, yields were not significantly different among the materials despite lower concentrations of phosphorus and potassium in the shoots of waste-grown plants.

629. Lewis, L. R., A. O. Perry, and J. R. LaFevers. A Case Study of Surface Mining and Reclamation Planning: South Boulder Creek Park Project, Sand and Gravel Operations, Boulder, Colorado. Integrated Mined-Area Reclamation and Land Use Planning, v. 3A. Argonne Natl. Lab., ANL/EMR-1, Feb. 1977, 95 pp.

This report is one of a 10-volume series prepared by the Energy and Environmental Systems Division of Argonne National Laboratory and the Resource and Land Investigations (RALI) Program of the U.S. Department of the Interior under the sponsorship of the U.S. Geological Survey. The reclamation practices of Flatiron Companies on their South Boulder Creek Project in Boulder, CO, are examined in this case study. The purpose of this case study is to allow the planner to gain insight into the procedures, possibilities, and constraints involved in premining planning in a cooperative situation. The site of this study contains a deposit of high-quality sand and gravel in a highly visible area, adjacent to a residential portion of the city. To maximize use of premining planning for resolution of conflicts over the company's proposed operation, an extensive cooperative effort was initiated. The article discusses salient points of cooperative and contractual agreements that were worked out. This document specifically addresses an aggregate mining operation and subsequent reclamation. Some of the

information and discussions may be applicable to coal mine land reclamation.

630. Leydon, J. J. Coal Mine Reclamation in Cape Breton. Paper in Reclamation: A Multifaceted Activity (Proc. 7th Annu. Meet., Sydney, NS, Canada, Aug. 29-Sept. 1, 1982). Can. Land Reclam. Assoc., Guelph, ON, Canada, 1982, pp. 223-239.

This paper presents the methods and materials used in reclaiming three minesites in the New Waterford area of Nova Scotia. Complete seeding, moisture, fertilizer, and lime application information is related.

631. Li, R. S., W. L. Daniels, and J. C. Bell. Nitrogen Accumulation in Southwest Virginia Mine Soils. Am. Soc. Agron., Agron. Abstr., 1988, p. 41.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Nitrogen accumulation was studied at 37 mine soils ranging in age from 0 to 30 years in southwest Virginia. Each soil was divided into the following depth sections: 0 to 5, 5 to 10, 10 to 20, and 20 to 30 cm. Nitrogen accumulation was due to symbiotic fixation and was correlated with organic matter accumulation. The rates of nitrogen accumulation were 60 kg ha^{-1} yr^{-1} at the 0- to 5-cm depth, 16 kg ha^{-1} yr^{-1} at the 5- to 10-cm depth, and very little at depths below 10 cm. The interrelationship between nitrogen level and site age was significant.

632. Liberta, A. E. Effects of Topsoil-Storage Duration on Inoculum Potential of Vesicular-Arbuscular Mycorrhizae. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 45-48.

The objective of the study was to assess the effect of topsoil storage durations of 1, 2, and 3 years and undisturbed topsoil on the mycorrhizal inoculum potential of the soil. The results indicate that as storage time increases, mycorrhizal inoculum potential decreases.

633. Lilly, C. K., S. J. Tajchman, P. S. Frank, Jr., and D. A. Eckhardt. On the Microclimates of Light and Dark Strip Mine Surfaces. Coll. Agric. and For., Div. For., WV Univ., WV For. Notes, No. 8, 1980, pp. 13-16.

Surface temperatures exceeded air temperatures on dark spoils (coal covered) by a maximum of 34.4° C. On light-colored spoils (sandstone and weathered sandstone materials), surface temperatures exceeded air temperatures by a maximum of 12.2° C. Surface temperatures on both spoils reached magnitudes reported in the literature as sufficient to restrict plant growth. The magnitudes of these temperatures appeared to be related to all-wave net radiation and net shortwave radiation. The authors note that subsurface conditions may also significantly affect surface temperatures. This research note discusses an often overlooked, yet very important, consideration for the revegetation of surface-mined lands. The study reported was conducted near Morgantown, WV; however, the methods used are applicable to all geographical regions.

634. Lin, C. and C. Chen. Kinetic Approach for Estimating Application Rates of Heavy Metal Sludges to Soils. Am. Soc. Agron., Agron. Abstr. 1986, p. 33.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. A kinetic reaction model was proposed as a method for estimating the application rates of sludges to soils. This method was based on the assumptions that heavy metals released from sludges would simultaneously react with soil and that the concentration of heavy metals remaining in the soil solution should not be greater than the level suitable for plant growth. This method was shown to have potential for estimating application rates.

635. Lindemann, W. C., G. A. Connell, and N. S. Urquhart. Previous Sludge Addition Effects on Nitrogen Mineralization in Freshly Amended Soil. Soil Sci. Soc. Am. J., v. 52, No. 1, 1988, pp. 109-112.

Soils with and without a history of sludge amendments were amended with additional applications of anaerobically digested sludge to determine the effect of previous sludge additions on nitrogen mineralization in freshly amended soil. Soils with no previous sludge amendment or with sludge applied at a rate of 67.3 Mg ha^{-1} over a 2-year period were collected and amended with 30 g kg^{-1} of gamma-irradiated, dried, anaerobically digested sewage sludge. Each soil (unamended, amended year 1, and amended year 2) with each sludge treatment (no sludge and freshly amended) was incubated aerobically for 16 weeks at 0.01 MPa water potential and 35° C. Mineralized nitrogen and organic nitrogen were determined following 1, 2, 4, 8, 10, 12, 14, and 16 weeks of incubating by leaching the soil with 0.01*M* $CaCl_2$.

Leachate data and organic nitrogen data show that previously sludge-amended soils were similar in the amount of nitrogen leached and levels of organic nitrogen loss regardless of whether fresh sludge was applied or not. Soils previously amended leached 56 to 60 mg kg^{-1} more nitrate or nitrite than unamended or freshly amended soils never previously amended with sludge. The authors state that if previous sludge amendments had an effect on the

mineralization of fresh sludge, enhanced nitrogen loss in the fresh sludge amendment treatment would have been higher than in the unamended treatments. The interaction term between soil previously amended and the fresh sludge amendment was not significantly different; previous amendments with sludge had no effect on nitrogen mineralization in soils freshly amended with sludge. Total organic nitrogen mineralization was similar regardless of sludge amendment history or treatment.

A second objective of this study was to delineate statistical models for determining N_0 (nitrogen mineralization potential) and the mineralization rate constants, K and h. The model that fits all data sets modeled nitrogen mineralization as the sum of an exponential equation of the rapidly decaying organic nitrogen fraction and the rate constant h so that the slowly decaying component was constant with time. This article was included in the review process since the rate or type of an organic amendment used is one factor that influences nitrogen mineralization.

636. Lindemann, W. C., D. L. Lindsey, and P. R. Fresquez. Amendment of Mine Spoil to Increase the Number and Activity of Microorganisms. Soil Sci. Soc. Am. J., v. 48, No. 3, 1984, pp. 574-578.

This study was conducted to determine the effects of various amendments on numbers of micro-organisms, dehydrogenase enzyme activity, fungal genera formation, and mycorrhizae formation on mine spoil located near Farmington, NM. Amendments used in this study included hay (2.2 Mg ha^{-1}), gamma-irradiated sewage sludge (11.2 Mg ha^{-1}), various soil and root inocula, and topsoil applied to a depth of 30 cm. Results indicate that the addition of sludge, hay, or topsoil increased the number of micro-organisms, enzyme activity, and fungal genera distribution in nonrhizosphere spoil. Topsoil added as an inoculum had little or no effect on these biological parameters. Inocula sources and amendments had little effect on the level of mycorrhizal infection or on the percentage of mycorrhizal roots. The greatest amount of mycorrhizal infection was found on plots covered with 30 cm of topsoil. The authors conclude that organic amendments are more critical in the stimulation of spoil microflora than is the addition of topsoil inoculum.

637. Lindsay, R. E. Evaluation of Natural Revegetation of Problem Spoilbanks. Paper in Annual Progress Report: July 1, 1980-June 30, 1981, Volume II, Research Development Summaries, Final Draft. Coal Extr. and Util. Res. Cent., South. IL Univ., Carbondale, IL, Mar. 1982, pp. 81-85.

This report summarizes an investigation that determined the effects that natural weathering processes and time had on phytotoxin levels in surface mine spoil banks and the consequent influence on natural revegetation. Sites in Jackson, Perry, Saline, and Williamson Counties in Illinois were used in the study. Selected physical and chemical spoil parameters were compared with measures of vegetation quantity and quality to identify factors influencing natural revegetation. Significant regional differences were found in overburden and revegetation characteristics. These differences are primarily due to the greater concentration of pyritic materials in the overburden in Saline and Williamson Counties, resulting in substantially higher acidity and lower macronutrient levels. The author reports that a classification system was developed for spoil banks occurring in Illinois based on successional stage, inhibiting factors precluding vegetation establishment, time needed for natural recovery, and reclamation needs. Few hard data are presented in this research summary. This classification is not described in detail; however, it is a source of potentially useful information for revegetation planning.

638. LoBuglio, K. F., and H. E. Wilcox. Growth and Survival of Ectomycorrhizal and Ectendomycorrhizal Seedlings of *Pinus resinosa* on Iron Tailings. Can. J. Bot., v. 66, No. 1, 1988, pp. 55-60.

The effects of two ectomycorrhizal and two ectendomycorrhizal fungi on the survival and growth of red pine (*Pinus resinosa* Ait.) seedlings outplanted from a nursery onto iron tailings were compared. Soil was inoculated with two ectendomycorrhizal fungi (BDG-58 (*Complexipes* sp. Walker emend. Yang & Korf) and *Phialophora finlandia* Wang & Wilcox) or with two ectomycorrhizal fungi (*Pisolithus tinctorius* (Pers.) Coker & Couch and *Suillus subluteus* (Peck) Snell ex Slipp & Snell) and sown with sterile seed of red pine. Seedlings were grown in the nursery for 3 years prior to planting on iron tailings. Chemical properties of the iron tailings did not vary significantly among the various planting sites. No significant differences were evident in seedling height or mean shoot dry weight among the treatments. However, seedlings infected with BDG-58 had the largest root-collar diameters. All mycorrhizal-infected seedlings had higher survival rates than the controls, with seedlings inoculated with BDG-58 and *P. finlandia* having the greatest survival percentages. After two growing seasons on iron tailings, the original mycorrhizal inoculum still existed on the planted seedlings. Control seedlings had the weakest infection. The results of this study show the positive effects that mycorrhizal infection has on the growth and survival of pine species in the reforestation of disturbed lands.

639. Loebel, K. J., E. G. Beauchamp, and S. Lowe. Soil Modification and Plant Growth on a Calcareous

Subsoil Material Treated With a Partially Composted "Sludge-Leaf" Mixture. Reclam. & Reveg. Res., v. 1, No. 3, 1982, pp. 283-293.

This study assessed the ameliorative effects of a mixture of sewage sludge and leaves on a road construction waste subsoil pile and the establishment of woody and herbaceous species at a site located in Guelph, ON, Canada. Three partially composted sewage sludge-leaf mixture treatments were applied to the waste area and incorporated. The treatments used were (1) none, a control, (2) 125 mt ha^{-1}, and (3) 250 mt ha^{-1}. Root cuttings of 1-1 Carolina poplar (*Populus canadensis eugenei* (Schelle) Rehd.) and seedlings of 2-2 eastern white cedar (*Thuja occidentalis* L.) and 2-0 autumn olive (*Elaeagnus umbellata* Thunb.) were planted in the experimental area. The entire area was broadcast seeded with 30 kg ha^{-1} creeping red fescue (*Festuca rubra* L.) and 20 kg ha^{-1} birdsfoot trefoil (*Lotus corniculatus* L.). Selected soil and foliar analyses were done, along with measurements of plant growth characteristics.

Addition of the composted sludge-leaf mixture significantly increased the organic matter content of the soil. The 125- and 250-mt-ha^{-1} treatments increased the organic matter content from 0.8 pct to 2.3 and 5 pct, respectively. With addition of the sludge-leaf mixture, the cation-exchange capacity (CEC) of the 125-mt-ha^{-1} treatment was double that of control plots, and the 250-mt-ha^{-1} treatment resulted in a fourfold increase in the CEC of the soil. The composted mixture also increased the concentrations of ammonium, nitrate, phosphorus, and potassium, compared with control plots. Treatment with the mixture resulted in a decrease in bulk density and an increase in available water capacity. Dry matter production of the herbaceous species increased five to eight times. Plant cover increased 65 to 100 pct on plots treated with the composted sludge-leaf mixture. Only Carolina poplar showed significant improvement in growth due to treatment; shoot growth was increased, as was leaf size. Autumn olive growth was not improved by treatment, and eastern white cedar tended to have increased plant mortality (survival decreased by 30 pct) when plots were amended with the sludge-leaf mixture. Nitrogen and phosphorus concentrations in trefoil shoots and poplar leaves increased with increasing sludge-leaf mixture application rates. The effects of sludge-leaf treatments were inconsistent with respect to the concentrations of other elements.

640. Logan, T. J., A. C. Chang, A. L. Page, and T. J. Ganje. Accumulation of Selenium in Crops Grown on Sludge-treated Soil. J. Environ. Qual., v. 16, No. 4, 1987, pp. 349-352.

Selenium uptake by barley (*Hordeum vulgare* L.), Swiss chard (*Beta vulgaris* L.), and radish (*Raphanus sativas*) from high rates of sewage sludge applied to soil over a 10-year period was examined. Sludge was applied at rates of 0, 22.5, 45, 90, and 180 Mg ha^{-1} yr^{-1}. Surface (0 to 15 cm) soil selenium increased with rate of sludge addition from less than 0.1 Mg kg^{-1} in the 0-Mg-ha^{-1}-yr^{-1} treatment to 1.2 Mg kg^{-1} in the highest sludge treatment. Of the selenium added to the soil by sludge amendments, only 13 to 25 pct could be accounted for in the 0- to 15-cm depth, and measurable concentrations in all test crops were at or below detection limits in all amended soils.

641. Loggy, W. D. Morphology and Classification of Selected Southeast Alaska Forested Soils. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 55-56.

Characteristics of six typical forest soil series of southeastern Alaska are presented. Information on soil morphological, physical, and chemical properties, and soil spatial distribution is needed in order to determine soil suitabilities for forest planning, management, project planning and initiating, and monitoring.

642. Lohse, J. S., P. M. Giordano, M. C. Williams, and F. A. Vogel. Illinois Agricultural Land Productivity Formula. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 24-39.

The purpose of the agricultural land productivity formula is to provide a calculated standard yield to be used as a comparison to determine if productivity has been restored to mined land. The formula has several advantages over reference areas as a method for determining a yield standard: (1) it is less expensive than managing a research plot on undisturbed soil, (2) it provides seasonal adjustments in yield standards based on the USDA Crop Reporting Service, and (3) it computes estimated soil productivity at high and average levels of management of crops reflected by the county yield. This formula is not site specific. Field evaluations were performed over a 5-year period, and these evaluations established a close correlation between formula target yields and yields on prime soil types.

643. Loree, M. A. J., and S. E. Williams. Colonization of Western Wheatgrass (*Agropyron smithii* Rydb.) by Vesicular-Arbuscular Mycorrhizal Fungi During the Revegetation of a Surface Mine. New Phytol., v. 106, No. 4, 1987, pp. 735-744.

The colonization dynamics of vesicular-arbuscular (VA) mycorrhizal fungi during the recovery of revegetated sites at a Wyoming open-pit uranium mine were investigated. Mycorrhizal status and spore frequency associated with western wheatgrass (*Agropyron smithii* Rydb.) were determined for sites of various ages. The effects of the concentration of extractable soil phosphorus and soil organic matter content on the occurrence of infection were studied. Topsoil that had been salvaged and stockpiled for periods of 3 years or more was the primary source of mycorrhizal inoculum. Site age since reclamation ranged from 1 month to 7 years. Wheatgrass seedlings from all sites were mycorrhizal. The degree of infection was lowest in seedlings from the younger sites. No significant relationships were found between soil organic matter content and total rooting density or mycorrhizal rooting density. Extractable phosphorus content was positively (weakly) correlated to rooting density and mycorrhizal rooting density. Total rooting density, infected rooting density, and percent infection all increased as a function of site age. Spores were present in samples from disturbed sites of all ages; however, spore frequency was positively correlated with site age. Spore frequency in older sites was comparable to that of adjacent and disturbed areas. Topsoil salvage and replacement does not guarantee mycorrhizal development; however, development of VA mycorrhizal can be enhanced by topsoil replacement. This study shows that the reestablishment of symbiotic communities following disturbance is time dependent.

644. Louderbough, E. T., and L. D. Potter. Mancos Shale: Physical and Chemical Properties Which Affect Vegetative Communities on Shale Outcrops. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 547-550.

The purpose of this research was to describe the chemical and physical properties of Mancos shale that inhibit the establishment of vegetation on natural outcrops in the Four Corners area. Bedrock samples were collected from 78 Mancos outcrops in New Mexico, Arizona, Colorado, and Utah and analyzed for clay mineral composition, organic carbon, pH, electrical conductivity, texture, sodium, sulfate, and gypsum saturation index. A hydroponic growth experiment was also conducted to observe the effect of chemical parameters on the growth of western wheatgrass (*Agropyron smithii* Rydb.) and alkali sacaton (*Sporobolus airoides* (Torr.) Torr.). The results indicate that ion concentration alone does not explain why Mancos outcrops remain barren or sparsely vegetated. Other factors such as soil texture, water penetration, and aeration may provide insight into the complex interactions of the chemical and physical environment of Mancos shale.

645. Lowe, L. E. , A. M. Sagel, and K. Klinka. Chemical Properties and Classification of Organic Horizons From Selected Soils in British Columbia. Can. J. Soil Sci., v. 67, No. 2, 1987, pp. 383-394.

The extent to which organic and inorganic chemical properties of organic horizons support their differentiation on the basis of morphological characteristics, as used by the Canadian System of Soil Classification, was assessed. Upland and wetland organic horizons were analyzed for 26 chemical properties. The results of canonical variate analysis support the 6 organic horizon types (3 upland and 3 wetland types) based on 10 selected chemical properties. Soil moisture regimes had a greater overall effect on the horizon properties studied than did the degree of decomposition.

646. Luken, J. O. Potential Patch Dynamics on a Roadside Embankment: Interactions Between Crownvetch and Kentucky-31 Tall Fescue. Reclam. & Reveg. Res., v. 6, No. 3, 1987, pp. 177-186.

Contiguous patches of vegetation, either crownvetch (*Coronilla varia* L.) or Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), were studied on a revegetated roadside embankment in northern Kentucky. Field and greenhouse studies were conducted to predict future changes in patch dynamics. Each vegetation type was fertilized with nitrogen alone (25 g m^{-2}), or phosphorus alone (25 g m^{-2}), or left unfertilized. Both fescue and crownvetch were grown in soils dominated by the other species (alien soils—greenhouse experiment, or alien patches—field experiment). Aboveground standing crop was greater in crownvetch patches than in fescue patches. The aboveground biomass of tall fescue was increased threefold with nitrogen fertilization. Root biomass was not affected by nitrogen fertilization. Tall fescue did not respond to phosphorus fertilization. Crownvetch aboveground and belowground biomass was significantly increased by phosphorus fertilization, but it did not respond to nitrogen fertilization. Tall fescue biomass was enhanced (in alien soils) or unaffected (in alien patches) compared with its growth in home soils or home patches. Crownvetch biomass was reduced when grown in alien soils or alien patches. Greenhouse experiments using mixed and monocultures showed that tall fescue was the superior competitor at a 1:1 density relationship. The author speculates that tall fescue will invade and possibly dominate crownvetch patches.

647. Lyle, E. S., Jr. Coal Surface Mine Revegetation in the Eastern U.S. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, p. 39.

The natural revegetation on five spent oil shale development sites in northwestern Colorado, abandoned 50 to 60 years, was evaluated. At each site, data were collected on vegetation and soils in three stratified zones: (1) immediate area of deposited spent shale, (2) adjacent areas of drastic surface disturbance (secondary disturbance) associated with shale retort, and (3) surrounding areas that were undisturbed. Measurements included canopy cover, diversity, similarity indices, species composition differences among zones, and differences in soil chemical and physical properties among zones. The secondary disturbed zones were similar to undisturbed zones in terms of plot cover and diversity but not in species composition. Spent shale zones had significantly lower overall cover and a different species composition than did the undisturbed zones. Spent shale areas remained in an early stage of succession; 50 to 60 years was not enough time for natural succession to produce plant communities on shale sites similar to those on undisturbed sites. It may be necessary to apply soil cover or amendments to attain predisturbance vegetation composition.

656. Macyk, T. M. Reclamation Research in the Foothills/Mountains Regions of Alberta: A Case Study. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 13-17.

A summary of the reclamation technique used by the Alberta Research Council at a coal mining operation in the Rocky Mountain Foothills is presented. Objectives included: (1) characterization of unmined and reconstructed soils, (2) determining the suitability of grasses and legumes for erosion control, (3) determining nutrient requirements for maintaining vegetative cover, and (4) developing methods of establishing long-term cover that is in harmony with adjacent, undisturbed areas. Undisturbed soils were slightly and medium textured, and had low levels of available plant nutrients, while reconstructed soils were coarse textured, higher in pH, and lower in available nutrients than unmined soils. Native and agronomic grass and legume species were compared for use in revegetation. Most agronomic species that were planted survived and developed good stands of vegetation. Fertilization trials indicated that annual fertilization is not necessary to maintain vegetative cover. Recommendations as to timing of applications are given. Native species generally had lower germination and took longer to establish than did the agronomic species; however, with time they will invade the site on their own. Tree and shrub establishment trials indicated that the growth rate for trees on reclaimed areas was comparable to or greater than those of trees growing in undisturbed, natural forests.

657. Maddox, J. B., J. E. Brown, and G. N. Bartley, Jr. The Effects of Fertilizer and Acid Strip Mine Spoil on Germination of Grass Seeds. Paper in Fifth Symposium on Surface Mining and Reclamation (NCA/BCR Coal Conf. and Expo IV, Louisville, KY, Oct. 18-20, 1977). Natl. Coal Assoc. and Bitum. Coal Res., 1977, pp. 245-254.

The purpose of this study was to examine the effects of ammonium nitrate (AN) and triple superphosphate (TSP) fertilizer slurries and acid spoil on grass seed germination. The study was designed to simulate hydraulic seeding conditions and was conducted in a greenhouse. Six grass species were included in the study: annual ryegrass (*Lolium multiflorum* Lam.), Kentucky-31 fescue (*Festuca arundinacea* Schreb.), orchardgrass (*Dactylis glomerata* L.), perennial ryegrass (*Lolium perenne* L.), redtop (*Agrostis alba* L.), and weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees). Spoil from a Campbell County, TN, coal strip mine was used as the germination medium for the fertilizer treatments. Soil from an area along the Clinch River near Norris, TN, was used as a control.

Germination percentage for all species tested was highest with the river bottom soil. Germination of orchardgrass and redtop was significantly increased by TSP. AN suppressed germination of all species except redtop. Germination percentages of TSP-treated seeds were significantly higher than those for AN-treated seeds. Seeds treated with TSP alone and sown on the mine spoil resulted in healthier looking seedlings than did seeds with any other fertilizer treatment used in this study. The authors suggest that when hydraulically seeding grasses on acid spoil, AN at the rate of 112 kg ha^{-1} or greater should be applied with some other fertilizer amendment such as TSP. TSP can be used alone at rates up to at least 336 kg ha^{-1} with no detrimental effects. In some cases TSP appeared to enhance germination. The authors suggest that TSP or some other phosphate carrier should always be used when hydraulically seeding grasses on acid strip mine spoil. The results of this study would be most applicable to the Interior and Eastern Coal Mining Regions.

658. Madison, F. W., and K. McSweeney. Reclamation and Vegetation of Sulfidic Mine Waste. Am. Soc. Agron., Agron. Abstr., 1986, p. 34.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. The chemical and physical characteristics of an abandoned sulfidic mine waste are described. Reclamation strategies have focused on stabilizing the surface with vegetation and minimizing surface and ground water concentration.

659. Majerus, M. E., J. G. Scheetz, and L. K. Holzworth. Selection Plants for Mine Reclamation in

Western Wyoming. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 139-143.

A plant material project is described that was conducted to identify additional species that have potential for reclaiming arid rangelands. Establishment techniques were also evaluated. The objective was to increase the diversity of species available for revegetation of arid range and mine sites in Montana and Wyoming. The timing and amount of spring moisture were the most important factors affecting germination and establishment. All plantings were evaluated using a relative rating. The species and cultivars with the best overall performance are presented.

660. Manula, C. B., F. A. Camilli, and J. Kiusalaas. Site Selection and Financial Analysis of Deep Surface Mining of Anthracite Coal, Volume II, Wabash Valley Site (U.S. Dep. Energy contract ET-76-G-01-9006, Dep. Miner. Eng., PA State Univ.). U.S. Dep. Energy, FE-9006-TI, v. 2, Sept. 1979, 351 pp.

The economic feasibility of developing a large-scale deep open-pit mine in the Wabash Valley west of Tamaqua, PA, in the Southern Anthracite Field is evaluated. The assumed production is 3 million tons of clean coal per year for a 40-year life. Based on data provided by the U.S. Geological Survey, average mining locations, strip ratios, and reserves were estimated using a computer model. This information was combined with equipment performance characteristics in a computer simulation model to determine sizes for truck fleets, shovels, and front-end loaders. A discounted-cash-flow model was applied using calculated capital investment and costs to obtain a selling price. Problems of drainage, pit slope stability, overburden characteristics, and revegetation are addressed, as are details of the social and economic background of the area and local land use regulations. The aim of the study was to design an operation that would achieve maximum anthracite recovery and provide permanent reclamation. A conventional shovel-truck system was used. No serious attempt was made to minimize costs; the purpose was rather to determine the cost of a feasible mine system that would fulfill basic objectives. This report provides an excellent sample of an analysis of this type and would be pertinent not only to activities in this specific area but also to planning in other areas.

661. Marchesini, A., L. Allievi, E. Comotti, and A. Farrari. Long-Term Effects of Quality-Compost Treatment on Soil. Plant and Soil, v. 106, No. 2, 1988, pp. 253-261.

This greenhouse experiment studied the effects of compost addition on the yield of sunflower (*Helianthus annuus* L.) grown in pots containing sandy soil. The treatments used were (1) compost mixed with 5 pct of soil, (2-5) 0, 10,000, 20,000, and 30,000 kg ha^{-1} compost added to an N-P-K mineral fertilizer consisting of 190 kg ha^{-1} N $(NH_4)_2SO_4$, 160 kg ha^{-1} P (perphosphate), and 180 kg ha^{-1} K (KSO_4), and (6) no fertilizer or compost treatment (control). Sunflower yields were determined 3, 4, and 5 years after treatment. Additionally, soils were analyzed for chemical properties and number and kind of microorganisms 5 years after treatment.

Although sunflower yield decreased progressively, the 95-pct compost treatment resulted in yields that were double those of all compost-fertilizer treatments. The compost-fertilizer treatments also produced significant yield increases over the control. In soils that received the compost-fertilizer addition there was a progressive increase in yield with increasing amounts of compost. There was no significant difference in yield between the mineral fertilizer alone and mineral fertilizer and compost at the lowest test addition. The progressive decrease in sunflower yield in each treatment is attributed to a reduction in nutrient reserves. After 5 years, organic matter, organic carbon, total nitrogen, assimilable phosphorus, assimilable potassium, and the carbon-nitrogen ratio were all higher in the maximum compost treatment. No significant differences were found in soil nutrient status between the compost-fertilizer treatments and the control. The maximum compost treatment contained the highest number of heterotrophic micro-organisms for seven of the nine groups identified. The smallest number of autotrophic nitrifying bacteria was found in the maximum compost treatment. In the other two groups of heterotrophic micro-organisms, no relationship between treatment and number could be identified. Although the 95-pct compost treatment is not practical or possible in terms of actual application, it does show the positive effects of compost addition on soil chemical and microbiological features and crop yield. The usefulness of compost is not related to its supply of readily available nutrients, but to its maintaining long-term natural fertility through the biochemical cycling of nutrients.

662. Mardon, D. N., and F. M. Rothwell. An Azospirillum lipoferum Isolate With High Nitrogen-Fixing Capabilities From a Coal Surface-Mined Site. KY Acad. Sci. Trans., v. 46, No. 1-2, 1985, pp. 33-35.

Azospirillum lipoferum, an asymbiotic nitrogen-fixing bacterium found in association with herbaceous species, was isolated from the rhizosphere of tall fescue (*Festuca arundinacea* Schreb.) growing on an eastern Kentucky coal

surface-mined site. Acetylene reduction was used to compare the nitrogen-fixation capacity of this species with that of other *Azospirillum* cultures. The nitrogen-fixing capacity of *Azospirillum lipoferum* was significantly higher than that of the other *Azospirillum* species tested. This nitrogen-fixing species may play a significant role in establishing and maintaining vegetative growth on mine soils when nitrogen is a limiting factor.

663. Marshall, I. B. Post-Production Stage—Land Reclamation. Sec. from Ch. 2 in Mining, Land Use and the Environment, I. A Canadian Overview. Land Use in Canada Series, No. 22. Land Dir. Environ. Can., Ottawa, ON, Canada, 1982, pp. 60-68.

A general overview of postmining reclamation efforts in Canada is provided as a section of a chapter discussing the nature of mining both metallic and nonmetallic minerals. Technical descriptions of reclamation procedures or data are not provided. The purpose of this section is to provide the reader with a relatively brief orientation statement for factors considered and affecting reclamation efforts in Canada.

664. Martindale, M. T., C. E. Clapp, J. A. E. Molina, N. A. Schumacher, and W. E. Larson. Nitrogen Mineralization of Municipal Solid Waste Composts. Am. Soc. Agron., Agron. Abstr., 1987, p. 30.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. The nitrogen dynamics of several municipal solid waste composts and cocomposts were determined over a 140-day incubation period. Four types of net nitrogen mineralization release patterns were exhibited: Type I, a long phase of net nitrogen mineralization; Type II, a short period of nitrogen immobilization followed by a long period of mineralization; Type III, a short period of nitrogen mineralization, followed by immobilization, followed by a final period of mineralization; and Type IV, net nitrogen mineralization near zero for several weeks, followed by a slow increase in mineralization. Immobilization and mineralization phases were the results of high amounts of available carbon (uncomposted material) and low amounts of available carbon (stable materials), respectively.

665. Marx, D. H. Manipulation of Selected Mycorrhizal Fungi to Increase Forest Biomass. Paper in 1977 TAPPI Forest Biology Wood Chemistry Conference (Madison, WI, June 20-22, 1977). Tech. Assoc. Pulp and Paper Ind., Atlanta, GA, 1977, pp. 139-149.

The article outlines the use and benefit of both ectomycorrhizal and endomycorrhizal fungi for reclamation and reforestation purposes. Results are given of studies on coal mine soils in Kentucky and Virginia, clay spoils in Georgia, and undisturbed sites in North Carolina and Florida. The studies show how certain species of mycorrhizal fungi can greatly increase tree seedling survival, height, stem diameter, and volume when the trees are inoculated prior to outplanting. When the article was written, one fungus, *Pisolithus tinctorius*, was nearly at a point where it was to be commercially produced. The studies on coal mine spoils used *Pisolithus tinctorius* to form mycorrhizae with Virginia (*Pinus virginiana* Mill.), loblolly (*Pinus taeda* L.), and shortleaf (*Pinus echinata* Mill.) pine, with very good success.

666. Marx, D. H. Role of Mycorrhizae in Forestation of Surface Mines. Paper in Trees for Reclamation (Lexington, KY, Oct. 27-29, 1980). U.S. For. Serv., Gen. Tech. Rep. NE-61, 1980, pp. 109-116.

The author reviews the role of mycorrhizae in the forestation of surface-mined lands. A brief introduction is given on ectomycorrhizae and endomycorrhizae, their association with plant species, and the importance of these fungi to plant growth. The studies presented illustrate the importance of ectomycorrhizae, particularly those formed by *Pisolithus tinctorius*, to the survival and growth of *Pinus* spp. seedlings on surface-mined lands. Endomycorrhizal fungi have been shown to affect the growth of grass species and certain hardwood species on surface-mined land. The author states that there is a need to develop a commercial inoculation of *Pisolithus tinctorius* for seedling tailoring in the nursery prior to outplanting. Several of the studies presented by Marx are contained in this bibliographic listing.

667. Marx, D. H., and J. D. Artman. *Pisolithus tinctorius* Ectomycorrhizae Improve Survival and Growth of Pine Seedlings on Acid Coal Spoils in Kentucky and Virginia. Reclam. Rev., v. 2, No. 1, 1979, pp. 23-31.

The results of a study comparing the growth and survival of nursery-grown loblolly (*Pinus taeda* L.) and shortleaf (*Pinus echinata* Mill.) pine seedlings infected with *Pisolithus tinctorius* and *Thelephora terrestris* ectomycorrhizae on coal spoil are given in this article. Following fumigation of nursery soils, seedlings often become ectomycorrhizal with *Thelephora*, a fungus that is well adapted to greenhouse conditions but that does not survive well when seedlings are outplanted onto coal mine spoils. *Pisolithus*, on the other hand, is frequently found on coal mine spoils. Plots were established and monitored for 3 years on an acid coal spoil in Kentucky, and for 4 years on an acid spoil in Virginia. Treatments at the Kentucky site were loblolly and shortleaf pine seedlings with either

Pisolithus or *Thelephora*, with or without a fertilizer tablet. At the Virginia site, loblolly pine seedlings with *Pisolithus* or *Thelephora* were planted. Survival and growth were taken after each growing season. The ability of *Pisolithus* to persist and spread to new roots stimulated seedling growth on these acid spoils, while *Thelephora*-inoculated seedlings showed poor survival and growth.

668. Mascagni, H. J., Jr., and F. R. Cox. Residual Effect of Manganese Fertilization. Soil Sci. Soc. Am. J., v. 52, No. 2, 1988, pp. 434-438.

This study evaluated the change in extracted manganese following a single application of manganese fertilizer over an 8-year period in order to determine if there is a carry-over effect of manganese fertilization and if the residual effect is related to other soil properties. Soils that were low in native manganese levels were chosen for study. Manganese was broadcast at 0, 30, and 90 kg ha^{-1} and incorporated into the soil. Extractable manganese was determined using the Mehlich 1 (M1) and Mehlich 3 (M3) extractants. An empirical model was developed to evaluate the effects of fertilization and time. The model predicted that 43 and 52 pct of the manganese applied was extractable immediately after application with M1 and M3, respectively. Extractable manganese then decreased exponentially with time. No apparent relationship existed between the manganese fertilizer residual effect and soil organic matter and cation-exchange capacity. The authors state that knowledge of a residual effect of manganese fertilization is helpful in interpreting soil test results and in making fertility recommendations based on the test results. Recommendations for manganese fertilization may be based on the second crop rather than the first.

669. Massie, S., and K. Shamhart. The Buffalo Rock Reclamation Project. Paper in Proceedings of the Eighth Annual National Abandoned Mine Lands Conference (Billings, MT, Aug. 10-15, 1986). MT Dep. State Lands, Helena, MT, 1986, pp. 161-164.

A unique approach to the reclamation of an abandoned mine-land site for public recreational use in Illinois is presented. Land sculpting was done at the site to create five representations of native Illinois fauna. Following the construction of the earthen sculptures, traditional reclamation techniques (limestone incorporation, mulching, etc.) were used. Cost of this project was less per acre than the cost of traditional surface mine reclamation in Illinois.

670. Master, W. A., and J. D. Taylor. Grundy County Reclamation Demonstration Project. Phase II, Progress Report for 1977-1978. Argonne Natl. Lab., ANL/LRP-TM-16, Sept. 1979, 46 pp.

Forty research plots were established at an abandoned strip coal mine in Illinois. The plots were treated with topsoil, digested sewage sludge, chemical stabilizer, scrubber slag, straw mulch, or lime. The plots were evaluated for vegetative cover after the 1976 and 1977 growing seasons. Plots treated with straw mulch, topsoil, and scrubber slag, as well as the control plots, were monitored for temperature in 1978. The data from these studies are given. Additionally, seven native Illinois prairies species were grown in the greenhouse on spoil with pH ranging from 3.2 to 5.2. Eight native prairie species were planted on a spoil plot at the strip mine site. The only plant species showing significant productivity in either of these studies was switchgrass (*Panicum virgatum* L.), which dominated the field test plot 12 weeks after seeding.

671. Mays, D. A., and G. W. Bengtson. 'Interstate' Sericea Lespedeza: A Long-Term Nitrogen Source for Loblolly Pine Growing on Coal Mine Spoil. Tree Plant. Notes, v. 36, No. 3, 1985, pp. 9-12.

The 9-year results of a study conducted to evaluate the effects of combinations of fertilizer treatments and cover crop on the growth of loblolly pine (*Pinus taeda* L.) are reported. Nitrogen and phosphorus fertilizers were applied in several combinations during the first few years of the study, and tall fescue (*Festuca arundinacea* Schreb.), bermudagrass (*Cynodon dactylon* (L.) Pers.), and sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don var. Interstate) were seeded. Tree height and diameter at breast height were measured. For the first 5 years, sericea lespedeza supplied little or no nitrogen for loblolly pine growth; nitrogen fertilization applied for 3 consecutive years resulted in greater loblolly pine height growth. During the fifth and sixth years, nitrogen from the lespedeza resulted in slightly more growth than did the multiple fertilizer treatments, and during the seventh through ninth years, trees growing with lespedeza grew more than trees that received fertilizer treatments. After 9 years, nitrogen supplied by sericea lespedeza resulted in significantly better tree growth than that which occurred on plots receiving multiple fertilizer applications. Plant and soil nitrogen analyses indicated that sericea was at least as effective in supplying nitrogen to loblolly pine as were the other fertilizer and cover crop combinations.

672. Mays, D. A., and P. M. Giordano. Stack Gas Desulfurization Waste Effects on Long-Term Alfalfa Yields and Soil Chemical Characteristics. Paper in Proceedings: Eighth International Ash Utilization Symposium, Volume 1 (Washington, DC, Oct. 28-31, 1987). Electr. Power Res. Inst., Palo Alto, CA, 1987, pp. 30-1—30-8.

Limestone scrubber sludge (LSS) and fluidized-bed combustion waste (FBCW), waste products from the process of reducing sulfur dioxide emissions, were evaluated as potential soil liming material. LSS is composed of gypsum, calcium sulfite, unreacted calcium carbonate, and fly ash. Only unreacted calcium carbonate affects soil pH, while gypsum and calcium sulfite are sources of calcium and sulfur. FBCW contains gypsum, calcium oxide, unreacted calcium carbonate, magnesium oxides, and magnesium carbonate. The calcium and magnesium oxides and carbonates of FBCW affect soil pH. Alfalfa (*Medicago sativa* L.), which requires a soil pH of 6.5 to 7.0 for growth, was selected as the test crop to evaluate LSS and FBCW as soil liming agents. LSS was applied at rates equivalent to 4.5, 9, 18, 72, and 144 mt $acre^{-1}$, and FBCW was applied at rates of 4.5, 9, and 18 mt $acre^{-1}$. These materials were compared with finely ground dolomitic limestone applied at 2.2, 4.5, and 9 mt $acre^{-1}$. No control treatment was used because the pH of unamended soil was too low for alfalfa growth.

None of the soil amendments resulted in adverse soil conditions, nor did they affect alfalfa establishment and survival. The greatest alfalfa yield was produced on plots receiving the highest rates of LSS; however, these rates of application are not economically feasible for the small yield increase obtained. The lowest rate of LSS resulted in the least alfalfa growth because it caused the least change in soil pH. The FBCW also was a satisfactory lime source for alfalfa at the rates applied. The greatest change in soil pH occurred in the upper 6 in of soil; however, the highest application rates of LSS and FBCW caused significant changes in the 6- to 12-in soil depth section. Changes in alfalfa tissue nutrient concentrations were small.

673. McCarthy, M. M. Alternation of Microbial Populations in Surface Mine Revegetation and Their Effects on Nitrogen Cycling. Ph.D. Thesis, UT State Univ., Logan, UT, 1980, 149 pp.

This thesis details the results of a study on microbial activity and soil chemistry of revegetated and undisturbed sites at the Decker Mine in southeastern Montana. The research was divided into two phases. Phase 1 was a field study looking at the effects of revegetation on soil chemistry and microbial activity. Soil samples from an undisturbed site and three revegetated sites of differing ages were used. Phase 2 was a laboratory study to analyze those variables found during the field study to have the most influence on the microbial community. The effects of microbial activity on the availability of nitrogen and other nutrients is evaluated, and changes in the nitrogen cycle on disturbed sites versus undisturbed sites are delineated.

674. McClenahen, J. R., and R. J. Hutnik. Effects of Cutting Intensity, Deer Browsing, and Liming on Allegheny Hardwood Tree Regeneration. Can. J. For. Res., v. 9, 1979, pp. 362-368.

A study was conducted in Elk County, PA, to determine the influence of liming, cutting intensity, and deer browsing on survival and growth of tree seedlings and on development of understory vegetation. The study site was occupied by a 70-year-old second-growth hardwood stand. Percentages of total basal area for the major overstory species were 34 pct black cherry (*Prunus serotina* Ehrh.), 28 pct sugar maple (*Acer saccharum* Marsh.), 24 pct red maple (*Acer rubrum* L.), 6 pct beech (*Fagus grandifolia* Ehrh.), and 4 pct eastern hemlock (*Tsuga canadensis* (L.) Carr.). Treatments consisted of two levels of dolomitic limestone (0 and 0.91 mt ha^{-1}), two deer-browsing intensities (browsed and nonbrowsed), and cutting to residual basal areas of 0, 16, and 28 m^2 ha^{-1} (clearcut, partial cut, and no cutting, respectively). Mortality rates and seedling height data for each treatment are detailed. Results showed that deer browsing did not statistically impact height after 6 years, liming was not effective, and partial cutting was superior to clearcutting and no cutting as a means of increasing the abundance of desirable tree species, especially black cherry.

675. McComb, W. C., S. B. Carpenter, and R. S. Caldwell. Direct Seeding of Sawtooth Oak on Surface Mine Spoil. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 497-500.

This article discusses the potential use of direct-seeded sawtooth oak (*Quercus acutissima* Carruth.) for wildlife plantings on surface-mined lands in southeastern Kentucky. Sawtooth oak acorns were direct seeded in the field and laboratory. The laboratory situation was used to determine seed germination without environmental stress. The field study was conducted to determine the effects of fertilization, mulching, and competing vegetation on the stocking, survival, and height growth of direct-seeded sawtooth oak. The results indicate that direct seeding of sawtooth oak on mine spoil is a feasible alternative. However, a mulch or mulch fertilizer treatment increased the germination and survival of sawtooth oak.

676. McCormack, D. E. Legislating Soil Reconstruction on Surface-Mined Land in the United States. Miner. and Environ., v. 6, No. 4, 1984, pp. 154-156.

This article discusses the criteria for judging the effectiveness of restoring soil productivity on coal

surface-mined land, with emphasis on the restoration of prime farmland. The Surface Mining Control and Reclamation Act implies that if soil is properly handled, the productivity after mining will be as good as, if not better than, it was before.

677. McCoy, J. L., L. J. Sikora, and R. R. Weil. Plant Availability of Phosphorus in Sewage Sludge Compost. J. Environ. Qual. v. 15, No. 4, 1986, pp. 403-409.

Field and greenhouse studies were conducted to compare the effectiveness of two sewage sludge composts and triple superphosphate as sources of phosphorus for corn (*Zea mays* L.). Phosphorus application rates were 0, 15, 30, 50, 100, 500, 1,000, and 1,500 kg ha^{-1} P as triple superphosphate and 15, 30, 100, 500, 1,000, and 1,500 kg ha^{-1} total P from the compost. In the second year of this study, plots were split, with one-half receiving no additional phosphorus and one-half receiving phosphorus equal to first-year rates. Nitrogen (NH_4NO_3) was applied to all treatments at rates equivalent to 100 and 219 kg ha^{-1} available N for the first and second year, respectively. Dry matter yield and phosphorus uptake were measured at the eight-leaf stage and at maturity. There were no significant differences in phosphorus uptake or yield among the sources of phosphorus applied at rates below 100 kg ha^{-1} P. Above 100-kg-ha^{-1} rate, triple superphosphate resulted in significant increases in growth and phosphorus uptake by corn in both experiments. The application of triple superphosphate stimulated corn growth four to seven times more than applications of composts containing equivalent amounts of total phosphorus. Information is also given on the effect of compost application on soil test indices of phosphorus availability, the forms of phosphorus availability, and the forms of phosphorus in the composts and compost-amended soils. Phosphorus fractionation of the compost indicated that most of the phosphorus was associated with iron and aluminum, and only 2 to 5 pct was in organic forms.

678. McDonald, J. D., and J. C. Errington. Reclamation of Lands Disturbed by Coal Mining in British Columbia. Paper in Stability in Coal Mining (Proc. 1st Int. Symp. on Stability in Coal Mining, Vancouver, BC, 1978). Miller Freeman Publ., San Francisco, CA, 1979, pp. 481-490.

This paper presents a concise overview of reclamation on lands disturbed by coal mining and coal exploration in British Columbia. Legislation regulating coal mine reclamation in British Columbia is reviewed. Revegetation problems and procedures for two of the major coalfields in British Columbia, the Crownest Coalfield and the Pease River Coalfield, are discussed. These discussions contain limited, but good general information concerning the revegetation techniques employed. Some of the areas considered are in alpine environments, and the information may be of use in limited, but specific areas of the Rocky Mountains and Alaska.

679. McFee, W. W., W. R. Byrnes, and J. G. Stockton. Characteristics of Coal Mine Overburden Important to Plant Growth. J. Environ. Qual., v. 10, No. 3, 1981, pp. 300-308.

This article reports the results of a study conducted in the Illinois Coal Basin of southwestern Indiana and designed to evaluate the physical and chemical properties of mine-land overburden, to evaluate plant growth in these materials, and to determine if any properties of the overburden materials might serve as predictors of potential plant growth. No chemical or physical properties examined during the study could be consistently used in a formula for predicting potential plant growth. Selected soil amendments were tested. Sewage sludge was more effective than N-P-K fertilization in improving growth of wheat (*Triticum aestivum* L.) and alfalfa (*Medicago sativa* L.). This article provides excellent tables of data that could be applied in comparisons to other studies or in planning reclamation work on the materials treated in the study.

680. McGinnies, W. J. Effects of Hay and Straw Mulches on the Establishment of Seeded Grasses and Legumes on Rangeland and a Coal Strip Mine. J. Range Manage., v. 40, No. 2, 1987, pp. 119-121.

The effectiveness of mulches for establishing seeded stands on disturbed rangelands and on surface-mined lands was evaluated. Wheat straw and grass hay mulches were applied at rates of 1,120 and 3,360 kg ha^{-1} to the surface after seeding or were incorporated into the soil before seeding for 3 consecutive years at an abandoned farm site (rangeland) and at an active surface mine site in Colorado. At the rangeland site, stand ratings (percentage of seeded row fully occupied with seeded species) of Russian wild rye (*Psathyrostachys juncea* (Fisch.) Nevski) were significantly higher for the control (no mulch) treatment than for the mulch treatments. Surface mulches at this site did increase the average soil moisture content and moderated soil temperature, but not significantly. At the surface mine site, stand ratings were significantly improved when 1,120 kg ha^{-1} of straw mulch was surface applied following seeding. At this site the species that consistently had the best stand ratings were cicer milkvetch (*Astragalus cicer* L.), meadow brome (*Bromus biebersteinii* Roem & Shult.), smooth brome (*Bromus inermis* Leyss.), mountain brome (*Bromus marginatus* Nees), intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), pubescent wheatgrass

(*Agropyron trichophorum* (Link.) Richt.), sickle alfalfa (*Medicago falcata* L.), alfalfa (*Medicago sativa* L.), and timothy (*Phleum pratense* L.). Regardless of whether sites were mulched or not, no wind or water erosion was observed. If mulches are to be used, mulch materials should be free of seeds of unwanted species.

681. McGinnies, W. J., and K. A. Crofts. Effects of N and P Fertilizer Placement on Establishment of Seeded Species on Redistributed Mine Topsoil. J. Range Manage., v. 39, No. 2, 1986, pp. 118-121.

Field and greenhouse studies were conducted to determine the effects of fertilizer on the establishment of seeded stands on surface coal mines in northwest Colorado and to determine if fertilizer is necessary for successful establishment. In both studies, nitrogen (0, 28, 56, and 112 kg ha^{-1}) and phosphorus (0 and 56 kg ha^{-1}) were applied alone or in combination to spoils before topsoiling or to the surface after topsoiling and seeding. Physical and chemical analyses of the topsoil and spoil showed nothing that would restrict germination or growth of seeded species. In the greenhouse experiment, there were no obvious differences in the number of seedlings emerged that could be related to fertilizer levels. Neither phosphorus application nor fertilizer placement treatments caused significant differences in herbage yield or root production. Herbage yield and root production did, however, tend to increase as the rate of nitrogen application increased. In the field study, there were no significant overall effects of nitrogen or phosphorus on stand establishment ratings. Only during the third year were herbage yields affected significantly by the level of nitrogen and placement of nitrogen. Fertilizer placement on spoil prior to topsoiling resulted in a 15-pct decrease in yields compared with fertilizer placement on the surface.

682. McGinnies, W. J., and W. G. Hassell. Establishment of Native and Introduced Range Plants in the Central Great Plains. Paper in Impacts of the Conservation Reserve Program in the Great Plains, ed. by J. E. Mitchell (Symp. Proc., Denver, CO, Sept. 16-18, 1987). U.S. For. Serv., Gen. Tech. Rep. RM-158, 1988, pp. 35-41.

General principle, seeding methods, and procedures used to establish native and introduced grass species in the Central Great Plains are presented. Information is given on the planning process involved in establishment of seedbed preparation (including mulching), seeding techniques (fertilizer use is not recommended), effects of temperature and precipitation on seeding establishment, and the standards and specifications of seeding. A brief summary of common grass varieties recommended for use in the Central Great Plains is presented.

683. McGinnies, W. J., and P. J. Nicholas. Effects of Topsoil Thickness and Nitrogen Fertilizer on the Revegetation of Coal Mine Spoil. J. Environ. Qual., v. 9, No. 4, 1980, pp. 681-685.

Two studies were conducted to evaluate the benefits of topsoil on reshaped mine spoils in northwestern Colorado. A greenhouse study was utilized to (1) determine the effects of topsoil thickness on the herbage and root growth of winter wheat (*Triticum aestivum* L.) and intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), (2) evaluate the effects of mixing equal parts of topsoil and spoil on the growth of both species, and (3) evaluate the effects of nitrogen fertilization (112 kg ha^{-1} nitrogen fertilizer applied in the form of ammonium nitrate) on the aboveground and root growth of intermediate wheatgrass. A field study was used to determine the effect of topsoil thickness on the establishment and growth of a mixture of grass, forb, and shrub species. The topsoil thickness treatments were 0, 10, 20, 30, and 46 cm of topsoil placed over spoil in both the greenhouse and field studies.

The thickness of the topsoil placed over the mine spoil directly influenced plant growth and production in both studies. As the depth of topsoil increased, there was a linear increase in the growth, productivity, and coverage of the plants used. The greenhouse study indicated that there was no apparent advantage to mixing topsoil and subsoil. The herbage and root production of intermediate wheatgrass was the same as when it was grown in 15 cm of topsoil alone. (The mixture was a combination of 15 cm of topsoil with 15 cm of spoil.) The nitrogen fertilization study showed increased aboveground and belowground growth of intermediate wheatgrass. This enhanced growth caused by nitrogen fertilization could be an additional aid in soil development and stabilization on reclaimed minesites, particularly on slopes where topsoil is shallow.

684. McGuire, P. E., M. R. Spivey, and R. H. Mason. The Palzo Project Water Quality Trends Within a Sludge-Amended Strip Mine Site. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 57-66.

This study was conducted to determine the effects of a large-scale sludge application and reclamation project on the ground and surface water quality of the Palzo tract in Williamson County, IL. Sludge application had a positive effect on the ground water quality by decreasing the spoil surface temperature, decreasing oxygen availability, minimizing exposure of reactive spoil material through erosion control, and decreasing infiltration of leachate because of water loss from evapotranspiration. Even though there

has been a favorable change in the Palzo water quality, the ground and surface water discharge remains poor. This condition can be attributed to the untreated portions of the tract. The authors conclude that one of the primary factors contributing to the improved water quality of the Palzo tract is that sludge treatment and establishment of a vegetative cover have reduced the potential for the production of acid mine drainage.

685. McHerron, L. E. The Seasonal Effectiveness of a *Sphagnum* Wetland in Removing Iron and Manganese From Mine Drainage. Paper in Wetlands and Water Management on Mined Lands, ed. by R. P. Brooks, D. E. Samuel, and J. B. Hill, (Proc. Conf., PA State Univ., State College, PA, Oct. 23-24, 1985). PA State Univ., State College, PA, 1985, p. 385.

The seasonal efficiency of a *Sphagnum* wetland in removing iron and manganese from mine drainage was evaluated. Data on metal cation concentrations, pH, temperature, waterflow, and precipitation were collected. Results show that cations are removed during the winter at rates comparable to those during summer conditions.

686. McIntosh, T. H., A. E. Peterson, N. J. Sell, and C. W. Severance. Amending Soil With Bottom Ash From Coal Fired Boilers. Am. Soc. Agron., Agron. Abstr., 1987, p. 30.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Coal bottom ash was incorporated into the surface layer (0 to 15 cm) of a clay loam soil at rates equal to 6, 12, 15, and 35 pct by weight. Ash additions reduced penetration resistance and soil bulk density values. A greenhouse experiment, in which corn (*Zea mays* L.) was grown in soil-sand-ash mixtures ranging from 0 to 100 pct, indicated that ash was a favorable medium for plant growth, although boron content increased with increasing ash concentrations. In a field study, there were positive correlations between increased ash and potassium and boron in corn leaf tissue and a negative correlation with aluminum.

687. McKee, W. H., Jr., and G. E. Hatchell. Pine Growth Improvement on Logging Sites With Site Preparation and Fertilization. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 411-416.

The growth of planted loblolly pine (*Pinus taeda* L.) was observed for 12 years on an area that had been clearcut. Prior to planting, skid trails and a log deck were treated with three site preparation techniques and three fertility amendments to determine if cultural treatments could alleviate adverse effects of logging. The three site preparation treatments were (1) herbicide with no mechanical site preparation, (2) shearing, root raking, disking, and (3) shearing, root raking, bedding. Fertility treatments included (1) unfertilized, (2) medium level of fertilizer (N-P-K) plus 3/4-in depth of sawdust. Height and DBH were measured at the end of the 12th growing season.

Survival of planted loblolly pine seedlings was affected by site preparation and fertilization during the first through the fourth growing seasons; soil compaction had no effect. Mechanical site preparation increased pine survival by reducing competition during establishment, but fertilization at planting reduced survival because of increased competition grasses and herbs. At 12 years, survival by site-preparation treatment was 75 pct for bedding, 64 pct for disking, and 53 pct for herbicide, while with zero fertilizer, survival was 77 pct, which was significantly higher than survival with medium (60 pct) or high (55 pct) fertilizer amendments. Bedding significantly improved tree height of planted loblolly pine, while medium fertilization increased height growth, DBH, and total volume of trees grown on compacted soil, but not on areas that were not disturbed by logging. Bedding or the application of a moderated level of fertilizer will effectively restore tree growth on areas disturbed by logging.

688. McKee, W. H., Jr., and L. P. Wilhite. Response of Newly Planted Loblolly Pines to Herbicide and Nitrogen. South. J. Appl. For., v. 12, No. 1, 1988, pp. 33-36.

The results of three studies in which nitrogen fertilizer and herbicide were applied to newly established loblolly pine (*Pinus taeda* L.) plantations on the lower Atlantic Coastal Plain are reported. The studies measured the effects of site drainage, time of application, and the amount of nitrogen applied on the effectiveness of herbicide-nitrogen treatment combinations. The growth response of seedlings to nitrogen addition was significant in only one of the three studies, while herbicide treatments resulted in positive responses in height, diameter, and aboveground biomass in all three studies when herbicide was applied the spring following planting. In the study in which nitrogen application resulted in a positive response, the interaction between nitrogen and herbicide applications resulted in significant increases in seedling dry weight and diameter over the response for fertilizer nitrogen alone. The authors attribute the lack of response to fertilizer nitrogen at the two sites to the lack of moisture in the form of rainfall at one study site and to nitrogen being mineralized from organic matter at the other site. The authors conclude that nitrogen applied in conjunction with herbicide holds promise in the management of loblolly pine plantations. This paper was included in the review process because it contains information on the use of

fertilizer as an amendment to aid in the establishment of trees on cleared sites.

689. McKell, C. M. New Developments in Soil Amendments—A Biologist's Point of View. Paper in Proceedings: High-Altitude Revegetation Workshop No. 5 (CO State Univ., Fort Collins, CO, Mar. 8-9, 1982). CO Water Resour. Res. Inst., CO State Univ., Fort Collins, CO, Inf. Ser. 48, Dec. 1982, pp. 151-163.

This paper contains a general discussion of several different types of soil amendments available for ameliorating unfavorable soil characteristics. A brief review of pertinent literature is offered for each type of soil problem discussed, together with potential methods of mitigating the problem. This article presents an excellent overview of information that could be helpful to individuals planning reclamation activities, who have little experience or knowledge of soil amendments.

690. McKell, C. M., J. Fuhrinman, G. F. Gifford, S. G. Richardson, A. G. Southard, G. A. Van Epps, J. S. Williams, and G. Workman. Energy Mineral Rehabilitation Inventory and Analysis. Henry Mountain Coal Field. EMRIA Report 15 (U.S. Bur. Land Manage. contract YA-512-CT6-258, UT State Univ.). U.S. Bur. Land Manage., Rep. BLM/YA/TR-78/15, May 1978, 289 pp.

This publication summarizes baseline data specific to the area of coal deposits in the Henry Mountains Resource Area in south-central Utah. Chemical and biological analyses of eight geologic cores obtained from the overburden were correlated with field plantings on geologic outcrops and representative soils identified by a Soil Conservation Service soil survey. An excellent review and discussion of the reclamation potential of the area and recommendations for reclamation are provided.

691. McKell, C. M., and G. A. Van Epps. Comparative Results of Shrub Establishment in Arid Sites. Paper in Shrub Establishment on Disturbed Arid and Semi-Arid Land (Proc. Symp., Laramie, WY, Dec. 2-3, 1980). WY Game and Fish Dep., 1981, pp. 138-154.

The authors review various aspects of reestablishing shrub species on disturbed land in arid environments. Their studies on the control of weedy plant competition in the oil shale region of northeastern Utah are used as a basis for the discussion. Control of weedy plant competition from Russian-thistle (*Salsola kali* L. var. *tenuifolia* Tausch) and downy cheese (*Bromus tectorum* L.) for 2 years allowed survival of 88 and 71 pct of transplanted shrub species in two separate studies. In the latter study, natural conditions resulted in a 41-pct shrub survival. Native shrub species exhibiting the best establishment and survival included four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.), big sagebrush (*Artemisia tridentata* Nutt.), rubber rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Britt.), black sagebrush (*Artemisia arbuscula* var. nova (A. Nels.) Cronq.), and black greasewood (*Sarcobactus vermiculatus* (Hook.) Torr.). The best adapted species for revegetation of very harsh sites include mat saltbush (*Atriplex corrugata* Wats.), shadscale (*Atriplex confertifolia* (Torr. & Frem.) S. Wats), and prostate summer-cypress (*Kochia prostrata* (L.) Schrad.). The proper handling of transplant material and optimum planting conditions are discussed. The information contained in this article is applicable to revegetation of surface coal mines in major portions of the Rocky Mountain and Northern Great Plains Coal Mining Regions.

692. McKell, C. M., and G. A. Van Epps. Vegetative Rehabilitation of Arid Land Disturbed in the Development of Oil Shale and Coal. U.S. EPA, Rep. EPA-600/7-80-071, Apr. 1980, 38 pp.

Two representative arid locations in Utah were utilized to study new approaches that could be used to rehabilitate disturbed arid lands. Field experiments were established in northeastern Utah on a site disturbed by exploratory drilling for oil shale and on disturbed sites on a potential coal mine in south-central Utah. The specific objectives of this study were to (1) develop propagation and transplanting techniques for selected native species in harsh sites with varying soil properties, (2) determine the suitability of a number of materials for soil surface stability that would also promote water harvesting, (3) study the ecology of selected native species in relation to germination, seedling vigor, and field survival, and (4) study soil moisture patterns in relation to plant survival. Greenhouse studies were used to gain a better understanding of the biology of selected native plants.

The results of field experiments indicated that the establishment of containerized transplants was more successful that were plantings than utilized bare-root stock or were direct seeded. Planting the native species in the spring gave better results than planting in the fall. Using plant species that were tolerant of the adverse soil conditions gave higher survival percentages than using other native species that were not tolerant of harsh soil conditions. Shaping the soil surface to collect water increased plant survival. Water harvesting could be improved by applying a soil surface stabilization material. Recommendations given are applicable to the oil shale regions of Utah, Wyoming, and Colorado or the Four Corners of Utah, Arizona, New Mexico, and Colorado.

693. McKell, C. M., G. A. Van Epps, and S. G. Richardson. Plant Establishment Research on Disturbed

Arid Sites in the West. Paper in Surface Coal Mining and Reclamation Symposium, Coal Conference and Expo V (sponsored by Coal Age, Louisville, KY, Oct. 23-25, 1979). McGraw-Hill, 1979, pp. 260-277.

This article discusses a revegetation study in the arid Henry Mountains Coalfield of south-central Utah. The climate, soils, and vegetation of the study area are briefly described. Geologic cores and soil samples were taken, and their chemical and physical characteristics were measured. Six field test plots were set up on representative soils and outcrop materials. After the plots were ripped, scraped, and dozed, five different species were planted. The sites were monitored over 2 years. Results of the chemical analyses of the soils and geologic materials are given, as well as percent survival and yields of the five species planted. The correlations between shoot biomass and pH, salinity, and boron concentration were calculated. Finally, the difficulty of and recommendations for revegetating disturbed sites in the Henry Mountains Coalfield are discussed.

694. McMinn, J. W., R. R. Roth, C. R. Berry, and W. H. McNab. Comparison of Five Woody Species for Reclamation of an Upper Coastal Plain Spoil Bank. U.S. For. Serv., Southeast. For. Exp. Stn., Asheville, NC, Res. Note SE-300, Sept. 1980, 2 pp.

The results of a 3-year revegetation study are reported. European black alder (*Alnus glutinosa* (L.) Gaertn.), autumn olive (*Elaeagnus umbellata* Thunb.), flowering crabapple (*Malus floribunda* Neubert), sawtooth oak (*Quercus acutissima* Carruth.), and Virginia pine (*Pinus virginiana* Mill.) were compared for their potential use in revegetating a spoil bank formed during the excavation of a large water-retention basin in Barnwell County, SC. The best height growth was exhibited by autumn olive and European black alder. Flowering crabapple and sawtooth oak exhibited the best survival. European black alder did not become adequately established during the study. The most successful species used in the study were autumn olive and sawtooth oak. The results of this study may be applicable to revegetation of surface coal mine land in the Eastern Coal Mining Region under similar climatic, site, and soil conditions.

695. McMullen, M. P., and R. W. Stack. The Effects of Surface Mining and Reclamation on Fusarium Populations of Grassland Soils. Reclam. & Reveg. Res., v. 2, No. 3, 1983/1984, pp. 253-266.

The effects of surface mining and reclamation efforts on the population of the fungus *Fusarium* were determined by studying the occurrence, prevalence, and diversity of *Fusarium* associated with different-aged reclaimed mine spoils and undisturbed and cultivated grassland sites in North Dakota. Seventeen species and two varieties of *Fusarium* were identified, with the most abundant species being *Fusarium oxysporium*. Surface mining results in increased densities and diversity indices of *Fusarium* compared with undisturbed grassland soils. *Fusarium* species were not distributed independently over sites; there was an interaction between individual species and sample site. *Fusarium* species may have a direct interaction with the plant species chosen for revegetation, and with time *Fusarium* community composition and levels return to those found in undisturbed soils.

696. McSweeney, K., and I. J. Jansen. Soil Structure and Associated Rooting Behavior in Minesoils. Soil Sci. Soc. Am. J., v. 48, No. 3, 1984, pp. 607-612.

The study was conducted to identify and describe soil structural patterns and associated rooting behavior in reclaimed mine soils located at the Captain Mine, Perry County, IL. The soil used in this study consisted of 0.4 m of topsoil (A horizon) placed on 1.5 m of B-horizon materials. Corn (*Zea mays* L.) was used as the test crop, and four soil pits were excavated in order to expose the root systems. At each pit detailed soil and root pattern descriptions were made. A pictorial relationship between soil structure and rooting behavior was developed by superimposing an outline of soil structure over the root pattern. Results indicated that plant rooting was more profuse where fritted structure (rounded aggregates loosely compressed together) was present than where the soil was massive and compact. The authors conclude that construction operations need to be carefully evaluated to determine their influence on the physical condition of the resultant mine soils.

697. McSweeney, K., I. J. Jansen, and W. S. Dancer. Subsurface Horizon Blending: An Alternative Strategy to B Horizon Replacement for the Construction of Post-Mine Soils. Soil Sci. Soc. Am. J., v. 45, No. 3, 1981, pp. 794-799.

The study reported was designed to evaluate combinations of substratum and B-horizon material. The study was conducted in a greenhouse using materials collected from solum and substratum horizons to depths of about 6 m at two surface mine sites in southern and west-central Illinois. A-horizon material or a blend containing A-horizon material was placed over the various combinations of surface rooting media to simulate field conditions where seeds germinate in topsoil and root in the underlying material. The test crop was soybeans (*Glycine max* (L.) Merr.). In tests with the Darmstadt soil series (Albic

Natraqualf) from southern Illinois, the best performance of the test crop was found on segregated A-horizon material replaced over a blend of the next 3 m of B-horizon and substratum material. Performance was poorest where A-horizon material was replaced directly over the B_2-horizon material (natric horizon) of the Darmstadt. Similar results were obtained for tests with the Sable soil series (Typic Haplaquoll) from west-central Illinois. However, the difference in performance between the best and poorest treatment was not as marked. The information presented in this article is particularly relevant to topsoil and rooting medium handling and placement for reclamation of agricultural land in the Interior Coal Mining Region.

698. McSweeney, K., and F. W. Madison. Formation of a Cemented Subsurface Horizon in Sulfidic Minewaste. J. Environ. Qual., v. 17, No. 2, 1988, pp. 256-262.

A pedological approach was used to characterize and explain the formation of a cemented horizon in sulfidic mine waste created from the processing of lead and zinc ores during the late 1800's and early 1900's in southwestern Wisconsin. Two soil profile pits were excavated in the tailings pile, and three samples from each horizon were taken. The pore space relationship of the unconsolidated material and the elemental and mineral distribution of each horizon were determined using micromorphological techniques.

The results show that since their deposition, the mineralogy of the mine wastes has sustained substantial physical and chemical changes, resulting in the formation of distinct horizons even though the site is unvegetated. Three chemical-physical environmental zones were delineated: an oxidation zone extending to a depth of 53 cm consisting of the E1 (0 to 6 cm), E2 (6 to 16 cm), and BE (16 to 53 cm) soil horizons; a cemented horizon, Bm, beneath the oxidation zone, which was greater than 0.75 m thick; and a reduction zone, which was not excavated. The hydrology, porosity, and redox chemistry of the mine waste result in several mineralogical transformations. The dense cemented horizon is a result of these transformations. Particularly, the precipitation of gypsum and iron oxides and hydroxides in the interaggregate pores and hydrated iron sulfates within intra-aggregate pores is responsible for the formation of the Bm horizon. An excellent paper on the pedology and mineralogy of mine waste.

699. Medina, O. A., D. M. Sylvia, and A. E. Kretschmer, Jr. Response of Siratro to Vesicular-Arbuscular Mycorrhizal Fungi: I. Selection of Effective Vesicular-Arbuscular Fungi in Amended Soil. Soil Sci. Soc. Am. J., v. 52, No. 2, 1988, pp. 416-419.

This greenhouse study determined the relative ability of five vesicular-arbuscular (VA) mycorrhizal fungi to stimulate the growth of *Macroptilium atropurpureum* Urb. cv. Siratro in limed, nonpasteurized soil inherently low in phosphorus. Lime was applied at an equivalent rate of 1,500 mg kg^{-1}. The mycorrhizal fungi inoculated were *Glomus etunicatum* Becker & Gerdemann, *Glomus deserticola* Trappe, Bloss & Menge, *Glomus versiforme* Berch & Fortin, *Glomus intraradices* Schenck & Smith, and *Gigaspora margarita* Becker & Hall.

At 40 and 70 days after planting, siratro inoculated with *G. etunicatum* and *G. intraradices* had significantly higher shoot dry weights and root fresh weights than plants inoculated with the other three VA mycorrhizal fungi or the control. Plants inoculated with *G. versiforme*, *G. margarita*, and *G. deserticola* had shoot dry weights and root fresh weights that were not significantly different from those of the control. The percentage and total root length of siratro colonized by VA mycorrhizae increased with time. *G. etunicatum* and *G. intraradices* had the highest colonization at both 40 and 70 days. Root colonization among *G. versiforme*, *G. margarita*, and the control was not significantly different. Significant correlations were found between the shoot dry weight of siratro with total root length (r^2 = 0.95) and the percentage of root length colonized by VA mycorrhizal fungi (r^2 = 0.83). Even though the indigenous population of VA mycorrhizal fungi in the soil studies was high (two propagules per gram soil), the native population was ineffective in stimulating the growth of siratro in lime-amended soil. This study demonstrated that with careful selection of VA mycorrhizal fungi, the growth of siratro can be significantly increased in a lime-amended soil that contains ineffective populations of indigenous VA mycorrhizal fungi.

700. Medina, O. A., D. M. Sylvia, and A. E. Kretschmer, Jr. Response of Siratro to Vesicular-Arbuscular Mycorrhizal Fungi: II. Efficacy of Selected Vesicular-Arbuscular Fungi at Different Phosphorus Levels. Soil Sci. Soc. Am. J., v. 52, No. 2, 1988, pp. 420-423.

Based on a previous study, the authors evaluated the effects of *Glomus etunicatum* Becker & Gerdemann and *Glomus intraradices* Schenck & Smith, vesicular-arbuscular (VA) mycorrhizal fungi, on the growth and root infection of *Macroptilium atropurpureum* Urb. cv. Siratro in a greenhouse study using nonsterlized soil at various levels of phosphorus fertilization. Three inoculation treatments were used (*G. etunicatum*, *G. intraradices*, and a control) and four phosphorus treatments (2, 5, 10, 20, and 40 mg kg^{-1} P as $Ca(H_2PO_4)_2$) in a 3 × 4 factorial experimental design. In a second greenhouse study, the effects

of inoculation with *G. etunicatum* on the uptake of phosphorus and nitrogen by siratro grown in sterilized soil were evaluated. In this study three levels of phosphorus were used: 12.5, 25, and 50 mg kg^{-1}.

At the lowest level of phosphorus addition there were no significant differences in the shoot dry weight and root fresh weight between inoculated and control plants. At higher levels of phosphorus, fertilized inoculated plants had higher shoot dry weights and root fresh weights than did the control plants. Inoculation with *G. etunicatum* resulted in the significantly higher shoot dry weights at the higher phosphorus levels; however, there were no significant differences in siratro root fresh weights between treatments using *G. etunicatum* and *G. intraradices* at the higher phosphorus levels. Maximum yield of inoculated plants was achieved at the 20- to 40-mg kg^{-1} P application rate. When the plants were inoculated, the percentage and total root length colonized by VA mycorrhizal fungi increased with phosphorus addition, with this effect being greater for plants inoculated with *G. etunicatum*. Phosphorus addition did not alter the percentage of total root length colonized in control plants grown in nonsterilized soil. Siratro shoot dry weight was highly correlated with the percentage and total root length colonized by VA mycorrhizal fungi over the range of phosphorus applied. In the second study, only the highest level of applied phosphorus did not significantly increase the uptake and concentration of phosphorus and nitrogen in siratro compared with the control treatment. The authors conclude that inoculation with effective VA mycorrhizal fungi can significantly increase the growth of siratro in soils where phosphorus has been applied and that have an ineffective native population of VA mycorrhizal fungi under the fertilizer treatment imposed. Although this study is not related to soil amendment use on coal surface-mined lands, it contains useful reference material on the positive effects of mycorrhizal inoculation and phosphorus fertilization on plant growth.

701. Melanson, M. A., and S. M. Carter. Rehabilitation of Disturbed Arid Lands: Long Range Planning and the Role of Mycorrhizae in Rehabilitation. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 79-87.

This article discusses the need to consider practical solutions to rehabilitation problems early in the project development to ensure proper rehabilitation after the project is completed. An example of original research is presented. A study was conducted on a disturbed site (a power transmission line corridor) and an undisturbed site in the northern Mojave Desert to determine whether mycorrhizal fungi aid in plant growth and development. Two desert species, bursage (*Ambrosia dumosa* (Gray) Payne.) and creosote bush (*Larrea tridentata* (DC) Cov.) were found to have greater growth rates, shoot dry weights, survival rates, and plant vigor when mycorrhizal inoculum was added to the soil.

702. Melichar, M. W., H. E. Garrett, and G. S. Cox. Mycorrhizal Benefit Growth and Development of Eastern Black Walnut Seedlings. North. J. Appl. For., v. 3, 1986, pp. 151-153.

Species of mycorrhizal fungi most suited for inoculation of black walnut (*Juglans nigra* L.) have not been identified. This greenhouse study evaluated the effects of four vesicular-arbuscular (VA) endomycorrhizal fungi on the growth and development of black walnut seedlings. Seedlings were inoculated with spores of *Glomus caledonium*, *G. mosseae*, *G. microcarpum*, and *G. microcarpum* (60 pct) plus *G. fasciculatum* (40 pct); a noninoculated control was also included. After 198 days, roots were sampled for percent infection and root lengths, and leaf surface areas were also measured. Inoculated container-grown seedlings successfully produced viable VA endomycorrhizal associations. *G. microcarpum* plus *G. fasciculatum*, *G. microcarpum*, and *G. caledonium* significantly increased mycorrhizal colonization. Root growth was increased when seedlings were inoculated with *G. microcarpum* or *G. microcarpum* plus *G. fasciculatum*; dry root weights increased 83 and 113 pct, respectively, over the control treatment. Black walnut top growth was also stimulated by mycorrhizal colonization. Seedlings colonized by mycorrhizal fungi had larger diameters than noninoculated control seedlings. The total dry weight (root plus shoot plus leaves) of *G. microcarpum* and *G. microcarpum* plus *G. fasciculatum* seedlings was twice that of control seedlings.

703. Merino, J. M., and R. B. Crookston. Reclamation of Spent Oil Shale. Min. Congr. J., v. 63, No. 10, 1977, pp. 31-36.

This article discusses the techniques and practices used by Tosco Corp. in the reclamation of spent oil shale. A good portion of the article is devoted to the physical and chemical characteristics of the processed shale. These properties affect the revegetation of an area. The major problems that have been encountered when establishing vegetation on processed shale are low fertility, poor infiltration rates, and high soluble-salt content. Fertilization and mulching are amendments that may help to ameliorate these problems. The article also contains a general reclamation plan for TOSCO II processed shale.

704. Merrill, S. D., J. R. Deutsch, and M. W. Pole. Saturation Percentage. Ch. in Reclaiming Mine Soils and

Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 35-58.

Saturation percentage is defined as the amount of water by weight necessary to form a minimally flowable mud from dry soil. This amount is typically greater than that held by in situ soil materials and should be distinguished from the various measures of water saturation of in situ soil. Saturation percentage is used as an indication of soil water-holding properties. Current standard methods of saturation percentage determination (saturated paste), procedural effects, and the correlation between saturation percentage and other soil properties are presented. Saturation percentage has been used to evaluate overburden materials as soil substitutes in the Western United States.

705. Merrill, S. D., E. J. Doering, and J. F. Power. Changes of Sodicity and Salinity in Soils Reconstructed on Strip-Mined Land. ND Farm Res., v. 37, No. 6, May 1980, pp. 13-16.

This article reports the results of a project involving both laboratory and field studies designed to examine upward salt migration in reconstructed soil profiles on reclaimed mine land. The four field sites used in the study were located in Oliver and Mercer Counties, ND. A mathematical model considering waterflow, salt flow by convection (salt carried by water), salt flow by diffusion (movement of each kind of salt in proportion to differences in concentration), and cation exchange was applied to laboratory column experiments. Calculations using this model indicated that chemical diffusion accounted for most of the upward movement of sodium in the columns. The calculated diffusion accounted for about 50 pct of the upward migration of sodium observed at two of the field sites. The authors feel that clay mineralogy is an important factor affecting hydraulic conductivity at a given sodium adsorption ratio.

706. Metzger, W. C., D. A. Klein, and E. F. Redente. Physiological Diversity of Rangeland Soil Microbial Communities as Affected by Retorted Oil Shale. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 332-339.

A greenhouse pot experiment was conducted to evaluate the effects of retorted shale on the development of rhizosphere, rhizoplane, and nonrhizosphere microorganisms. Western wheatgrass (*Agropyron smithii* Rydb.) and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) were grown on the following plant growth mediums: (1) soil control, (2) retorted oil shale, and (3) 8.5 cm soil over 8.5 cm of retorted oil shale. All treatments were fertilized and pots were maintained near field capacity. Microbial analyses included viable enumeration of the rhizosphere, rhizoplane, and nonrhizosphere population in each growth medium, and characterization of bacterial isolates by physiology and nutritional tests, bacterial diversity (rare-fraction method), and community similarity. Chemical characteristics of the soil and shale are presented. The soil was nonsaline and nonsodic with a near-neutral pH. The predominant cations were calcium and magnesium. The shale was highly alkaline and sodic, which was reflected by the sodium and potassium concentrations.

Rhizosphere and rhizoplane viable bacteria were significantly higher when retorted shale was present in the growth medium, while nonrhizosphere bacteria were not affected by growth medium. Bacterial diversity increased with the presence of spent shale in the growth medium. The total number of physiological groups of bacteria were not affected by growth medium treatment; however, cluster profiles showed distinct differences in the bacterial groups that made up the clusters. The tolerance to salinity and alkalinity was affected by the type of growth medium, with bacteria from the retorted shale growth medium being more tolerant than bacteria from the soil control. Bacterial clusters from the retorted shale and the soil control were the most dissimilar regardless of population source. Responses to processed shale were dependent on the bacterial population source. Rhizosphere and rhizoplane populations of soil-over-shale and soil-only treatments had the highest level of similarity. In the nonrhizosphere comparisons, populations in the soil-over- shale treatment were more similar to those from spent shale, suggesting that nonrhizosphere populations may be more sensitive to retorted oil shale than root-associated populations.

707. Meurisse, R. T. Soil Productivity Protection and Improvement: Objectives, Policy, and Standards in the Pacific Northwest Region of the Forest Service. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 63-68.

A policy developed by the Pacific Northwest Region of the USDA Forest Service on soil productivity protection and improvement is presented. This policy is based on completed research concerned with the management practices affecting potential productivity. Three principal objectives have been established for managing land under principles of multiple use and sustained yield without permanent impairment of productivity and, where appropriate, improving productivity. There are three main

features of the policy: (1) analysis of potential of soil for damage, (2) appropriate mitigating or rehabilitation measures, and (3) monitoring using established standard objectives. Specified standards are presented for detrimental compaction, puddling displacement, erosion, and severely burned soils. The author states that this policy has been effective in reducing soil damage by compaction, displacement, puddling, and severe burns.

708. Mexal, J. G., and J. T. Fisher. Organic Matter: Short-Term Benefits and Long-Term Opportunities. Paper in Meeting the Challenges of the Nineties: Proceedings, Intermountain Forest Nursery Association (Oklahoma City, OK, Aug. 10-14, 1987). U.S. For. Serv., Gen. Tech. Rep. RM-151, 1987, pp. 18-23.

The benefits derived from organic amendments are discussed. A case study is presented that examines the actual and potential benefits of organic amendments as determined by the kinds, amounts, and frequencies of application. The short-term response of nursery soils to sewage sludge, pine bark, pine sawdust, and peat moss are discussed. All organic amendments were applied at a rate of 67 mt ha^{-1}, except sawdust at 43 mt ha^{-1}. Organic matter addition caused immediate, but short-term changes in soil organic matter and nutrient availability. Sawdust affected soil organic matter the most, increasing it to 4 pct 2 months after application. Amendments larger than 2 mm did not affect soil microbial activity or influence seedling nutrients. Sewage sludge was the only amendment that increased soil nitrate-nitrogen (NO_3-N) concentrations. Bark and peat moss had no effect on soil NO_3-N; sawdust amendments resulted in the immobilization of NO_3-N. Organic amendments had no effect on seedling yield, height, caliper diameter, or fresh weight. Bark, sewage sludge, and peat moss amendments did, however, significantly reduce the root-shoot ratios of seedlings. Organic matter amendments did alter seedling morphological development. In order to cause a net increase in the stable organic matter content, amendments would have to be applied more frequently over a 3- to 4- year period.

709. Meyer, S. L. F., and M. C. Heath. A Comparison of the Death Induced by Fungal Invasion or Toxic Chemicals in Cowpea Epidermal Cells. I. Cell Death Induced by Heavy Metal Salts. Can. J. Bot., v. 66, No. 4, 1988, pp. 613-623.

Although this study does not contain any information on the characterization of coal surface-mined soils, the use of soil amendments on surface-mined soil, or regulatory policy, it was included in the review process because it is an excellent reference on the effects of heavy metals in inducing plant epidermal cell death. Cowpea (*Vigna sinensis* (L.) Engl.) leaf epidermal cells were treated with $CuCl_2$, $CuSO_4$, and HgCl to determine if there were identifiable and repeatable stages during cell death. Cells were observed using light and electron microscopy after metal treatment. Cell degeneration and death followed a series of stages: (1) slowing and stopping of cytoplasmic streaming, (2) changes in the cytoplasm morphology, such as the development of large vesiclelike structures in the cytoplasm, and (3) the collapse of the protoplast away from the cell wall. Timing of these stages varied with the heavy metal applied and its concentration.

In general, time spans shortened as the heavy-metal concentration increased. Electron microscopy was used to study ultrastructural changes in cells. The ultrastructure of untreated tissues was compared with that of $CuCl_2$-treated tissue when cells still exhibited cytoplasmic streaming, immediately after streaming stopped, after structural changes were observed, and after the protoplast had collapsed. The ultrastructural observations showed that cell degeneration occurred with the application of $CuCl_2$. Changes included disruption of coiled polyribosomes and endoplasmic reticulum, the loss of Golgi bodies and microtubules, and dilation of the cristae of the mitochondria. This study suggests that morphological changes in the cytoplasm of dying cells are reflected in ultrastructural changes that occur.

710. Miller, E. W. Environmental Legislation and the Coal Mining Industry. Ch. in Environmental Consequences of Energy Production: Problems and Prospects, ed. by S. K. Majumdar, F. J. Brenner, and E. W. Miller. PA Acad. Sci., 1987, pp. 501-522.

This chapter reviews State (Pennsylvania) and Federal laws passed to improve the quality of land, water, and air, particularly as each law pertains to the coal mining industry. Federal legislation discussed includes the Surface Mining Control and Reclamation Act (SMCRA), the Clean Air Act, and the Federal Water Pollution Control Act. Pennsylvania legislation discussed includes a history of surface mining legislation in the State, Pennsylvania's State program to secure primary jurisdiction to enforce the Federal SMCRA, Pennsylvania's Clean Stream Law, the Coal Refuse Disposal Act, and the Mine Subsidence and Land Conservation Act.

711. Miller, F. T., and R. L. Guthrie. Classification and Distribution of Soils Containing Rock Fragments in the United States. Ch. in Erosion and Productivity of Soils Containing Rock Fragments, ed. by J. D. Nichols, P. L. Brown, and W. J. Grant (Proc. Symp., Anaheim, CA, Nov. 28-Dec. 3, 1982). Soil Sci. Soc. Am., Madison, WI, SSSA Spec. Publ. 13, 1984, pp. 1-6.

Statistics on the amounts and kinds of rock fragments in soils and some effects of rock fragments on soil behavior are presented. Rock fragments are particles 2 mm or larger in diameter; they include all sizes that have horizontal dimensions less than the size of a pedon and are unattached pieces of rock that do not break down when shaken in a weak solution of sodium hexametaphosphate. Rock fragments are classified by size and shape. Coarse fragments are rock fragments larger than 2 mm and smaller than 25 cm. Information on rock fragments and soil classification, the determination of the distribution of rock fragments in soil and on the surface, and the distribution of soil containing rock fragments in the United States is presented. Nationally, it is conservatively estimated that 15.6 pct of the hectarage identified as soil map units are soils with rock fragments. The authors state that knowing the distribution and kinds of soils containing rock fragments is important in assessing the suitability of soils for use in cultivation and for predicting soil loss. This article was included in the review process because of the influence of rock fragments on infiltration, runoff, moisture storage, and land use.

712. Miller, J. P., Jr. Environmental Impact of Fly Ash Disposal. Ch. in Environmental Consequences of Energy Production: Problems and Prospects, ed. by S. K. Majumdar, F. J. Brenner, and E. W. Miller. PA Acad. Sci., 1987, pp. 223-231.

The nature of the ash produced is determined by the configuration of the coal furnace used for power generation. Of the total ash produced, 71 pct is fly ash, 21.5 pct is bottom ash, and 7.5 pct is boiler slag. Utilizing this waste can reduce its environmental impact. The physical properties and chemical composition of ash are discussed.

713. Miller, M. Sludge Compost Recycling: The Philadelphia Story. J. Soil and Water Conserv., v. 41, No. 5, 1986, pp. 292-296.

This article describes the land-based sludge utilization of the Philadelphia Water Department's sludge compost processing and recycling program. The composting process involves five steps: (1) mechanical dewatering, (2) blending with wood chips, (3) aerobic digestion (composting), (4) curing, and (5) screening. Compost utilization programs are described, including strip mine applications.

714. Miller, M. H., W. A. Mitchell, M. Stypa, and D. A. Berry. Effects of Nutrient Availability and Subsoil Bulk Density on Corn Yield and Nutrient Absorption. Can. J. Soil Sci., v. 67, No. 2, 1987, pp. 281-292.

The extent to which nutrient availability and subsoil bulk density limit corn (*Zea mays* L.) yield was studied over a 4-year period. The soil used was a silt loam with a well-structured, but compact loam Bm horizon and a very compact loam glacial-till Ck horizon. Three soil treatments were used: (1) soil was replaced to a depth of 1 m with a highly fertilized soil-peat-perlite (3:1:1 by volume mixture) artificial medium (AM), (2) the natural soil was fertilized at the recommended rates (RF), and (3) the natural soil was fertilized at very high rates (VHF). Corn yields on the AM and VHF treatments were not significantly different over all 4 years of the study. Grain yields on the VHF treatments (7.8 mt ha^{-1}) were significantly higher than those on the RF treatment (5.3 mt ha^{-1}). The response appears to be due to nitrogen, phosphorus, and potassium fertility rather than bulk density, particularly phosphorus fertility. Subsoil bulk density will not limit corn grain yields on the soil when adequate water and nutrients are provided. The yield response to phosphorus applications above the recommended rates indicates that the fertility requirements of high-yielding corn hybrids need to be reevaluated.

715. Miller, R. E., and J. W. Hazard. Strategy and Tactic for Monitoring Long-Term Site Productivity. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 57-62.

Types of monitoring and measuring forest management outputs and effects that are currently being considered by the USDA Forest Service are discussed. Three types of monitoring are identified: implementation, effectiveness, and validation monitoring. The authors present items necessary in the design of a cost-effective monitoring plan that will provide reliable, quantitative data.

716. Miller, R. M. Microbial Ecology and Nutrient Cycling in Disturbed Arid Ecosystems. Ch. in Ecological Studies of Disturbed Landscapes: A Compendium of the Results of Five Years of Research Aimed at the Restoration of Disturbed Ecosystems, ed. A. J. Dvorak. Off. Sci. Tech. Info., U.S. Dep. Energy, DOE/NBM-5009372, 1984, pp. 3-1—3-29.

This study investigated different methods of topsoil handling and the associated microbiology implications of each method relative to the reestablishment of the belowground ecosystem at an active Wyoming coal surface mine. The fate and role of vesicular-arbuscular mycorrhizal fungi in vegetation establishment and succession on reclaimed areas, along with the effect of soil disturbance on soil carbon and nitrogen cycling in newly formed soil ecosystems,

were studied. There was a strong correlation between myotrophy and plant community diversity. The infection potential of both stored topsoil and direct-applied topsoil decreased with time. Data suggest that the survival of vesicular-arbuscular mycorrhizal propagules in stockpiled topsoil is related to the soil water potential at which the soils are stored. Stockpiling should be limited to times when soil water potentials are less than -2 MPa to ensure propagule survival. Edaphic factors associated with high infection potential are soil and plant moisture availability and soil aeration. The effects of disturbance on the soil microflora community structure are discussed. There were no significant differences between topsoil storage treatments and in the ability of saprophytic communities within each treatment to decompose plant litter or cellulose. The way in which topsoil is handled does influence the composition of soil carbon and nitrogen resource pools. The levels of organic carbon and total nitrogen are higher in the topsoil treatments than in the undisturbed controls, but these pools appeared to be decreasing with time.

717. Miller, R. M., B. A. Carnes, and T. B. Moorman. Factors Influencing Survival of Vesicular-Arbuscular Mycorrhizae Propagules During Topsoil Storage. J. Appl. Ecol., v. 22, No. 1, 1985, pp. 259-266.

A vesicular-arbuscular (VA) mycorrhizal bioassay procedure was used to obtain a relative measure of propagules in soils that had been stockpiled over various time periods. This study examined the effects of soil storage on the survival of propagules of VA mycorrhizae fungi and identified factors that influence propagule survival. Soil samples were collected from eight topsoil stockpiles from an active Wyoming mining operation, which ranged in duration of storage from 0.5 to 6.0 years. Soil cores to 2.0 m were taken from each stockpile and divided into 0.5-m increments. A portion of each sample was used for soil chemical and physical analyses, while the rest was used for VA mycorrhizal bioassay.

The endophyte species found in the stockpiles was *Glomus fasciculatum* (Thax. ex Gerd.) Gerd. & Trappe. The bioassay indicated no decrease in VA mycorrhizae propagule numbers during the first 2 years of topsoil storage. After 2 years of soil storage, however, a decrease in the population of VA mycorrhizae propagules was found. The soil characteristics significantly correlated to propagule levels were those associated with soil moisture. Chemical factors were not correlated to propagule level. Two distinct trends in the relationship between infection levels of mycorrhizae fungi and soil water potential were suggested. A piecewise linear regression was used to describe bioassay infection as affected differentially by water potential regime (less than -2 MPa and greater than -2 MPa). When water potential was less than -2 MPa, it was an important predictor of inoculum, while length of storage had little predictive capability. When soil water potential was greater than -2 MPa, however, the predictive importance of soil moisture and length of storage was reversed. The data indicate that if soils are to be stored, stockpiling should be limited to time when soil water potentials are below -2 MPa to ensure adequate propagule survival.

718. Miller, R. M., and S. W. May. Staunton 1 Reclamation Demonstration Project, Soil Microbial Structure and Function: Final Report. Argonne Natl. Lab., ANL/LRP-11, Feb. 1981, 32 pp.

This publication reports the results of a study conducted at the Staunton 1 reclamation demonstration project near Staunton in southwestern Illinois. Microbial decomposition rates, respiration, and microbial numbers were compared for several coal refuse reclamation treatments. After 1.5 years, decomposition rates, microbial species diversity, and microbial respiration remained lower than that found on the old-field control plot. Microbial numbers in the reclamation plots approached those of the old-field plot. The information contained in this article is pertinent to similar studies conducted throughout the Interior Coal Mining Region.

719. Miller, W. P., and J. Scifres. Effect of Sodium Nitrate and Gypsum on Infiltration and Erosion of a Highly Weathered Soil. Soil Sci., v. 145, No. 4, 1988, pp. 304-309.

A clayey Coastal Plain soil was assessed to determine the effects of added sodium, in the form of $NaNO_3$ fertilizer, on sodium-induced dispersion. Dispersion usually results in soil crusting, lowered infiltration rates, and accelerated soil erosion. Gypsum ($CaSO_4$) was added as an amendment in order to study its effects on infiltration and soil loss in both the presence and absence of sodium. Gypsum has been shown to displace sodium held on soil colloids and increase the ionic strength of the soil solution, resulting in flocculation of clays and improved structure, porosity, and water infiltration of a clay soil. A rainfall simulator was used to measure infiltration and erosion on an untreated control and soil treated as follows: (1) 5 mg ha^{-1} gypsum, (2) 0.6 mg ha^{-1} $NaNO_3$, (3) gypsum and $NaNO_3$ (same rates), and (4) 5 mg ha^{-1} gypsum on a soil that had been previously treated with $NaNO_3$.

Treatment with $NaNO_3$ resulted in immediate surface sealing, as shown by a rapid decline in infiltration. Simulated rainfall on soils treated with $NaNO_3$ resulted in slaked and puddled soils. Application of gypsum alone and in combination with $NaNO_3$ had the opposite effect on infiltration: infiltration rates increased. Gypsum applied

to soils previously treated with $NaNO_3$ resulted in infiltration rates lower than those in gypsum-only treatments, but higher than those in treatments with $NaNO_3$ alone. Differences in soil loss among treatments followed the same trends as the infiltration data, $NaNO_3$- treated soil having the greatest soil loss, followed by the gypsum-after-$NaNO_3$ treatment, the untreated control, and the gypsum-only treatment. These results suggest that dispersion at the soil surface is affected by applied treatments. The authors suggest that on highly weathered clayey soils sodium-containing fertilizers should be used with caution; if sodium applications are made, simultaneous use of gypsum should be considered.

720. Million, J. B., R. X. Gonzalez, W. D. Carrier, III, and J. B. Sartain. Production of Vegetables on Mixtures of Sand Tailings and Waste Phosphatic Clay. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation, (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 355-362.

Byproducts of the phosphate mining industry in central Florida include quartz sand tailings and waste phosphatic clays. The phosphatic-clay water slurries, which have low dewatering rates, require years of self-weight consolidation in aboveground settling ponds before load-bearing surfaces are achieved. Sand-clay mix technology has been developed to speed up the reclamation of disposal areas. Prethickened clays (15 to 18 pct solids) are mixed with dewatered sand tailings at selected sand-clay ratios before being deposited into settling ponds. These artificially created soils are a compromise between fertile but extremely plastic and poorly drained clays and infertile but well-drained sands, for agricultural production. The vegetable production potential of sand-clay mixes was assessed, along with an evaluation of the effects of sand-clay ratio (SCR), plastic mulch, peat amendments, and phosphogypsum amendments on the yield and composition of vegetable crops. Clay slime and sand tailings were used to formulate SCR's of 2, 4, 6, and 8 (dry weight basis). After 1 year of drying, two seasons of vegetable production (spring and fall) were compared.

Three bed preparation treatments were evaluated for each SCR mix in the spring production season: (1) unamended and without plastic mulch, (2) unamended and with plastic mulch, and (3) 45 tons per acre of peat without plastic mulch. The fall production season treatments consisted of two phosphogypsum rates (0 and 10 tons per acre) with three peat mulch methods: (1) unamended and without plastic mulch, (2) residual peat from the previous season and without mulch, and (3) new peat application (45 tons per acre) and with plastic mulch. The addition of two and four parts of sand to the clay changed the textural class from a clay to a sandy clay loam and sandy loam, respectively. The cation-exchange capacity and water-holding capacity were reduced with increasing sand content, but they still compared favorably with those of undisturbed sandy soils of the area. The vegetable production potential of sand-clay mixes using a two-cropping season is good. Although there were variable yield results with the different SCR's used, the major concerns of SCR's were tillage and water management. There were significantly greater problems with tillage and water control in the 2:1 SCR mix than in to the 4:1 and higher SCR mixes. The use of plastic mulch decreased fertilizer loss and increased yields in the fall season when weed control was important. Phosphogypsum addition had no effect on yield or elemental composition of the vegetables. Except for a boron deficiency in some vegetables, nutrient tissue levels were within a normal range and not affected by SCR or the other treatments.

721. Million, J. B., R. X. Gonzalez, J. B. Sartain, and W. D. Carrier, III. Vegetable Nutrition as Affected by Various Mixtures of Waste Phosphatic Clay and Sand Tailings for Reclamation. Am. Soc. Agron., Agron. Abstr., 1987, p. 30.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Mixtures of montmorillonitic waste phosphatic clay and sand tailings were evaluated for their potential as an agricultural soil medium. Sand-clay ratios (SCR's) of 2, 4, 6, and 8 were evaluated over two cropping seasons. Treatments evaluated included vegetable type, peat (0 and 45 tons per acre) and phosphogypsum (0 and 10 tons per acre) amendments, and black plastic mulch. The cation-exchange capacity was 109, 43, 21, and 1 cmol cation per kilogram, and the water-holding capacity (0.033 MPa) was 68, 23, 10, and 0.4 pct for the clay, SCR of 2, SCR of 6, and sand, respectively. Mixture pH values and calcium concentration varied little with SCR; however, with the addition of peat or phosphogypsum, the pH was reduced by 0.5. Sand-clay ratios and treatments had little effect on soil and plant nutrition, but micronutrient availability must be monitored since availability is marginal.

722. Mills, A. L. Acid Mine Waste Drainage: Microbial Impact on the Recovery of Soil and Water Ecosystems. Ch. in Soil Reclamation Processes: Microbiological Analyses and Application, ed. by R. L. Tate, III and D. A. Klein. Marcel Dekker, 1985, pp. 35-81.

This chapter examines acidic mining waste generation, its effect on the microbiology of aquatic and terrestrial ecosystems, and the homeostatic recovery of microbial communities in contaminated areas. The review focuses

on the types of naturally occurring processes that allow the communities to recover and how these processes might be included in reclamation schemes for contaminated environments. Two distinct types of solid mine wastes are identified, tailings and overburden. The most effective means of reducing the impact of acid mine drainage problems is through rapid revegetation. The main environmental factors inhibiting plant growth in waste material from mineral extraction activities are listed. The key factor in the reclamation of mine spoils is the accumulation of organic matter through soil amendments. The most successful methods of acid mine drainage treatment are those that effectively prevent effluent formation. The reclamation of mine waste is associated with the recovery of a stable microbial community resembling that of a normal soil.

723. Mislevy, P., and W. G. Blue. Reclamation of Clay Tailings Following Phosphate Mining: I. Biomass Crops. Am. Soc. Agron., Agron. Abstr., 1987, pp. 30-31.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Quartz sand (50 mm) and a control treatment (no quartz sand) were placed on a dry phosphatic clay pond and seeded with several different species. Dry matter yields were determined one to three times annually over a 2- to 5-year period. The seeded perennials consistently produced the highest dry matter yields compared with the seeded annual crops.

724. Mislevy, P., W. G. Blue, and C. E. Roessler. Reclamation of Clay Tailings Following Phosphate Mining: II. Forage Crops. Am. Soc. Agron., Agron. Abstr., 1988, p. 43.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. A dry phosphatic clay pond was amended with either a surface layer of quartz sand (50 mm) or phosphatic clay without sand; both treatments received nitrogen either as nitrogen fertilizer or through leguminous species. Subtropical grasses were established, and the dry matter yield and forage quality of the grasses were compared. Results show that a 50-mm sand layer on phosphatic clay had little effect on yield or forage quality. Crude protein analysis and IVDMD show that grass grown in combination with white clover (*Trifolium repens* L.) had higher values (20.4 and 70.0 pct) than grass grown with nitrogen fertilizer treatment (11.5 and 62.2 pct).

725. Mitchell, W. W., A. Mitchell, and J. D. McKendrick. Revegetation of Alaskan Coal Mine Spoils, Progress Report for Research (U.S. Dep. Energy contract AMO6-76RLO2229). AK Agric. Exp. Stn., Univ. AK, Palmer, AK, DOE/EV/10256-2, Oct. 1981, 60 pp.

This document contains interim results of a research project being conducted at three locations in Alaska, designed to establish options for surface coal mine reclamation and revegetation in this area. The report contains soil characterization data, soil fertility trial data, irrigation and mulching trial data, water quality data, plant nutrient uptake data, and the results of vegetation planting trials. The preliminary results of a plant colonization and faunal habitat study are also included. Analysis of reclamation plantings conducted over a 9-year period at the Usibelli Mine indicate a significant decline in productivity without continued soil amendments. No definitive conclusions are offered; however, the interim results and the discussions will be useful to individuals planning surface mine reclamation activities or research in this region.

726. Mitoff, S. D., and B. G. Lewis. Phosphate Fertilization of Pyritic Waste: Foliar Versus Ground Application to Soya Bean Plants. Reclam. & Reveg. Res., v. 6, No. 2, pp. 95-108.

This pot experiment was conducted to compare the effect of foliar applications and ground application of phosphorus to coal-cleaning slurry waste and a nonmined surface soil (silt loam) on tissue phosphorus concentration, root nodulation, and growth of soy beans (*Glycine max* (L.) Merr.). The soil and coal waste were limed and fertilized with nitrogen and potassium, and enough orthophosphate to make 20 ppm total extractable phosphorus. Three fertilizer treatments were imposed on both growth mediums: (1) 0.4-pct-P foliar sprays as ammonium pyrophosphate, (2) 0.2-pct-P foliar sprays as ammonium pyrophosphate, and (3) 80 ppm P surface-applied as orthophosphate. Soya bean plants were sampled 24, 55, and 90 days after planting for dry weight and nutrient content determination.

For the first 55 days of growth, foliar applications of phosphorus (0.2 pct) significantly increased yields of leaves, stems, pods, and total tops of plants grown on coal waste compared with soya beans receiving all phosphorus through ground application. The 0.4-pct foliar treatment also increased yields on coal waste compared with ground applications, but these increases were not significant. At the end of the growing season there were no significant differences in yield among phosphorus fertilizer treatments of plants grown on coal waste. During each sampling period, yields on coal waste were significantly lower than yields on soil. Nodulation was greater on coal-waste-grown plants receiving foliar sprays than on plants receiving surface-applied phosphorus; nodulation was slightly better on plants receiving the 0.2-pct-P foliar application.

Foliar fertilization of soya beans, whether grown in soil or coal waste, resulted in lower phosphorus and nitrogen concentrations at pod fill (55 DAP) than when fertilizer was surface applied. Potassium deficiency and boron toxicity may have played a role in reducing yields of soya beans grown on coal waste compared with plants grown on soil. Foliar applications of phosphorus could improve yields of soya beans grown on coal waste by eliminating phosphorus fixation, which is common in coal waste when fertilizer is surface applied. Spraying phosphorus foliar fertilizer (0.4 pct) four times led to higher yields of soya bean than eight 0.2-pct-P applications, thus reducing the cost of foliar applications by reducing the number of times foliar fertilizers were applied.

727. Mitsch, W. J., M. A. Cardamone, J. R. Taylor, and P. L. Hill, Jr. Wetlands and Water Quality Management in the Eastern Interior Coal Basin. Paper in Wetlands and Water Management on Mined Lands, ed. by R. P. Brooks, D. E. Samuel, and J. B. Hill (Proc. Conf. PA State Univ., State College, PA, Oct. 23-24, 1985). PA State Univ., State College, PA, 1985, pp. 121-137.

Research on the usefulness of wetlands in treating acid mine drainage in the Eastern and Interior Coal Mining Regions is presented. Examples of water quality data from wetlands in western Kentucky and southwestern Indiana are given. Data show that streams passing through wetlands have a greater capacity for reducing suspended and dissolved substances than do nonwetlands streams. Wetlands play a role in maintaining water quality by acting as an interface system to reduce the impact of sediments and acid mine drainage from active and abandoned mines, and they can be used to aid the reclamation of abandoned mine lands.

728. Miyamoto, S. Effects of Wetting Agents on Water Infiltration Into Water Repellent Coal Mine Spoils. Soil Sci., v. 125, No. 3, 1978, pp. 184-187.

Commercially available wetting agents were studied under greenhouse conditions for their effects on increasing infiltration. These included linear sulfonate (anionic), alkyl polyethylene glycol ether (nonionic), and ethoxolated alcohol (nonionic) compounds. Soil and water application methods were used. Coal mine spoils from the Fruitland Formation on the Navajo Indian Reservation in New Mexico were used in the tests. The results of this study as reported are specific for the material used.

729. Moditz, P., and E. R. Buckner. Container-Grown Pine Seedlings Enable Extended Planting Season on Surface Mines in East Tennessee. Paper in Proceedings of the Second Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-5, 1982). U.S. For. Serv., Gen. Tech. Rep. SE-24, 1983, pp. 141-143.

This study evaluated the use of containerized loblolly pine (*Pinus taeda* L.) and Virginia pine (*Pinus virginiana* Mill.) to extend the planting season and improve tree survival over that achieved with bare-root seedlings planted on surface-mined land in Morgan County, TN. Seedlings were grown in the greenhouse for outplanting at 3- to 4-week intervals. Treatments used to test for improved survival and growth were (1) control planting, (2) inoculation of container rotting medium with spores and mycelia of *Pisolithus tinctorius*, and (3) disking to reduce herbaceous competition. Seedling survival rates for all planting dates and treatment combinations were found to be over 90 pct. Neither disking nor mycorrhizal inoculation affected the survival of planted trees over control treatments. The results of this study indicate that containerized pine seedlings can be successfully planted throughout the growing season on surface-mined land in east Tennessee.

730. Monsen, S. B., and A. P. Plummer. Plants and Treatment for Revegetation of Disturbed Sites in the Intermountain Area. Ch. in Reclamation of Disturbed Arid Lands. Univ. NM Press, 1978, pp. 155-173.

The authors provide an excellent discussion of the major factors that must be considered in revegetating disturbed arid lands. The authors focus on plant selection and establishment techniques. A list of grass and herbaceous species, together with their areas of adaption, is included. Numerous shrub and tree species are also listed, together with ratings for establishment by seed, seedling growth rate, competitive ability, and seedling drought tolerance.

731. Montoya, D. R., and K. W. Brown. Erodibility of Strip-Mine Spoils. Soil Sci., v. 138, No. 5, 1984, pp. 365-373.

The erodibility of lignite strip mine spoils from the Gulf Coast Coal Mining Region was evaluated using a rainfall simulator and physical and chemical data using equators developed for agricultural soils. The chemical and physical characteristics of the samples studied varied widely. The soil erodibility factor (K) was determined, and values were compared with the values calculated from the physical and chemical properties. Erodibility can be estimated from the physical and chemical properties by calculating the erodibility factor, modifying the calculated value, and using the modified erodibility factor in the Universal Soil Loss Equation.

732. Moore, J. A. Response of Douglas-Fir, Grand Fir, and Western White Pine to Forest Fertilization. Paper in Future Forests of the Mountain West: A Stand Culture Symposium (Missoula, MT, Sept. 29-Oct. 3, 1986). U.S. For. Serv., Gen. Tech. Rep. INT-243, 1988, pp. 226-230.

The author reviews what is known about nitrogen fertilization in the intermountain region of the Northwest. Unfertilized foliar nitrogen concentration of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) distributed in six regions was found to average 1.12 pct. More than 90 pct of the stands were below the inadequate level of 1.40 pct. This indicates that nitrogen is deficient throughout the region. When 200 lb $acre^{-1}$ N was applied, the average foliar nitrogen concentration increased to 1.37 pct, however, over 50 pct of the stands remained below 1.40 pct. Stands treated with 400 lb $acre^{-1}$ N had average foliar nitrogen concentrations of 1.75 pct, with 20 pct of the stands being below the critical level of 1.40 pct. Significant growth responses are expected with nitrogen fertilization. Variation in stand response to nitrogen fertilization was explained by differences in stand density, soil parent material, and prefertilization mineralizable nitrogen rates. As stand density at the time of fertilization increased, the predicted fertilizer treatment response decreased, and stands with low levels of pretreatment mineralizable nitrogen had significantly higher fertilizer responses than those with high mineralizable nitrogen rates. Examples are presented on the duration of the growth response to nitrogen fertilization for grand fir (*Abies grandis* (Dougl.) Lindl.) and western white pine (*Pinus monticola* Dougl.). Growth responses to fertilization peaked at 4 years after treatment; however, fertilizer treatment responses were still significant 6 to 8 years after treatment. This is a good reference for growth responses to fertilization and the factors influencing the responses.

733. Moore, R., and T. Mills. An Environmental Guide to Western Surface Mining. Part Two: Impacts, Mitigation, and Monitoring (Coal Proj., U.S. Fish and Wildl. Serv. contract 14-16-0009-77-008). U.S. Fish and Wildl. Serv. FWS/OBS-78-04, Dec. 1977, 345 pp.

The impacts of surface mining for coal, copper, bentonite, oil shale, phosphate, gypsum, and uranium are addressed by this manual for the Northern Great Plains and Rocky Mountain Coal Mining Regions. The purpose of this manual is to assist U.S. Federal regulatory agency biologists and others in making decisions when drafting lease and permit stipulations for surface mine development projects. The manual is designed primarily for use by biologists; however, it includes introductory information on regional ecology, minerals, and mining methods, making it useful to managers, industry planners, and other decision makers of diverse backgrounds. The manual is organized in four substantive sections: "Regional Ecology and Mining Descriptions," "Effects of Surface Mining," "Recommendations for Mitigation and Enhancement," and "Recommendations for Monitoring." It is assumed that users of this manual will have fairly specific information about the type of surface mining operation planned for a given site and more site-specific ecological information available to them than is contained in this document. As a consequence, the manual provides a starting point for determining the impacts and their effects, and for developing mitigation and monitoring recommendations for a mine in a particular area. It identifies the types of information a biologist should have when evaluating surface mining impacts. In addition, it provides criteria for evaluating mitigation and monitoring procedures. Chapter 4, "Recommendations for Mitigation and Enhancement," and chapter 5, "Recommendations for Monitoring," will be of particular interest to those dealing directly with rehabilitation of minesites and associated monitoring.

In chapter 4, recommendations concerning site-specific mitigation and associated stipulations are considered in relation to three possible levels of mitigatory action (high, medium, and low). These levels are separated based on (1) the degree to which the adverse impact would be eliminated or minimized, (2) the availability and practicability of the technology, (3) the relative cost of achieving each level of protection, and (4) the demonstrated or anticipated success of each procedure in protecting, reclaiming, rehabilitating, or enhancing the wildlife resources. The high level of mitigation implies application of "best available technologies" with respect to a given activity.

Chapter 5 is divided into several sections. The first section outlines a conceptual approach to designing a monitoring program. The sections that follow utilize information presented in the first section to evaluate existing monitoring stipulations and provide guidelines for site-specific monitoring. Ratings for keywords used in the evaluation process have been applied somewhat differently for assessing this manual, since it primarily presents guidelines for land management decision making rather than reporting an actual field study. Consequently, the ratings represent the treatment of these subject areas in the guidelines presented and the conceptual basis for these guidelines.

734. Morin, M. D. Heavy Metal Concentrations in Sludge-Amended Acid Spoil Medium Three Years After Application. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 705-713.

Anaerobically digested sewage sludge was applied to an abandoned surface-mined area in southeast Williamson County, IL (Palzo tract). Three years after application, pH conditions were adjusted in order to simulate the average pH of the Palzo soils. When the 0.1*N* HCl extraction technique was used, higher levels of metals were extracted. The higher concentrations may be due to the low pH's of the Palzo tract and the acidic nature of the extraction method. This method also extracts total amounts of the metals present rather than available amounts. Using the DTPA chelate method resulted in lower extractable amounts, which indicates the soluble chelated forms available for plant uptake. The extractions were a function of the metals encountered.

735. Morin, M. D. Heavy Metal Concentrations in Three-Year-Old Trees Grown on Sewage-Amended Surface Mine Spoil. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 297-306.

This article discusses the concentration of cadmium, copper, iron, manganese, nickel, and zinc in 3-year-old leaf, stem, and root tissue of silver maple (*Acer saccharinum* L.), green ash (*Fraxinus pennsylvanica* Marsh.), Virginia pine (*Pinus virginiana* Mill.), river birch (*Betula nigra* L.), and eastern cottonwood (*Populus deltoides* Bartr. var. *deltoides*). Comparisons were made among trees that had survived for 3 years on abandoned surface-mined land treated with varying amounts of sewage sludge and nursery grown stock. All trees had been planted as seedlings 3 years prior to sampling except for eastern cottonwood, which had invaded the area as a volunteer species. Roots and foliage of 3-year-old trees were found to have higher heavy-metal contents than stems. However, the heavy-metal concentrations in tissues were lower than those found in first-year tissues. This work was conducted on the Palzo tract in southern Illinois.

736. Morse, R. D. Increasing Vegetable Productivity of Strip Mine Spoil Through the Use of Organic Soil Amendments. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 926-933.

Selected vegetable crops were grown on reclaimed strip-mined land in Wise and Buchanan Counties in southwest Virginia. They were evaluated for their ability to adapt and produce under different soil amendment regimes. The vegetables used in the study included JetStar and Redpak tomato (*Lycopersicum esculentum* Mill.), Calwonder and Banana pepper (*Capsicum annuum* L.), Market Prize and Defender cabbage (*Brassica oleracea* L. var. *capitata*), Green Duke broccoli (*Brassica oleracea* L. var. *italica*), Bush Lake 274 green bean, Cherokee Wax wax bean and French Horticultural shell bean (*Phaseolus vulgaris* L.), Bridgeton lima bean (*Phaseolus coccincus* L.) Poinsett cucumber (*Cucumis sativus* L.), Seneca Prolific and Zucchini Elite summer squash (*Cucurbita pepo* L.), and Waltham Butternut winter squash (*Curcubita moshata* Duch. ex Poir.). Sawdust added as a surface mulch or incorporated enhanced the yield of all vegetables. Yields were further increased when black plastic was used as a surface mulch on warm-season vegetables. Yields of snap beans and summer squash, grown after 1 year's cover of yellow sweetclover and fescue sod, were more than double those of the controls. The results are primarily applicable to reclamation planning in the Eastern Coal Mining Region.

737. Morse, R. D., and C. O'Dell. Utilization of Minesoils for Production of Vegetable Crops. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 163-168.

This study assessed the effects of incorporating green-manure crops on soil properties and yield of snap bean (*Phaseolus vulgaris* L.) and yellow summer squash (*Cucurbita pepo* L.) in mountaintop-removal mine soils of Appalachia. The green-manure regimes used were (1) control, (2) sod of yellow sweetclover (*Melilotus officinalis* Lam.) and Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), (3) sod of sericea lespedeza (*Lespedeza cuneata* (Dum.-Cours.) G. Don) and Kentucky-31 tall fescue, and (4) a rotation of sorghum sudangrass (*Sorghum sudanense* (Piper) Stapf.), followed by Abruzzi cereal rye (*Secale cereale* L.) and crimson clover (*Trifolium incarnatum* L.), followed by York soybeans (*Glycine max* (L.) Merr.), followed by Abruzzi cereal rye. One or two years (two years being better) growth of green-manure crops resulted in the improvement of soil bulk density, aggregate stability, moisture content, and the subsequent yield of snap bean and squash compared with unamended control plots. The yields obtained in the green-manure plots were equal to or greater than national and State averages. In general, nutrient concentrations in the vegetable crops fell within the normal ranges found for the same crops in agricultural soils. However, boron and calcium leaf concentrations were below normal, while magnesium, iron, and aluminum levels were above normal. Even under these conditions, no deficiency or toxicity symptoms occurred. The results of this study show that properly reclaimed and amended mine soils can produce commercial yields of horticultural crops. The production of these crops offers a viable alternative for use of selected mine soils.

738. Morton, J. B., and C. Walker. Glomus Diaphanum: A New Species in the Endogonaceae Common in West Virginia. Mycotaxon, v. 21, 1984, pp. 431-440.

Glomus diaphanum, a new species of vesicular-arbuscular mycorrhiza, is described. This species forms abundant soilborne as well as intraradical hyaline spores characterized by a laminated outer wall and a membranous inner wall. The species has been found most commonly in abandoned or partially reclaimed surface coal mine soils that are acidic and have high aluminum concentrations.

739. Moss, R. G. Abandoned Mined Land Reclamation on the Wayne National Forest—An Interdisciplinary Approach. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 181-185.

A case study is presented for which a systematic and interdisciplinary approach to planning and implementing abandoned mined land reclamation was utilized. The abandoned mined land was within the Wayne National Forest in southeastern Ohio. Before the project was designed, an environmental assessment report was prepared that provided the information needed to select reclamation alternatives. The author presents the reclamation design concept used in the Yost II Abandoned Mine Land Reclamation Project case study. The techniques used include burial of toxic spoil, pond underdrain, topsoiling, liming, and rapid reestablishment of herbaceous cover for erosion control and wildlife enhancement.

740. Moss, S. A, J. A. Burger, and W. L. Daniels. The Effects of Organic Amendments on Nitrogen Availability. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 94-103.

The nitrogen components in mine soils amended with various organic amendments, as well as mine spoils alone, were determined in order to study the effects that these amendments have on the availability of nitrogen over a 3-year period. Overburden (a 2:1 mixture of sandstone-siltstone) was amended with (1) local topsoil (mixed A, B, C, and CR horizon material) to a depth of 30 cm, (2) sawdust at a rate of 56 Mg ha^{-1}, and (3) municipal sewage sludge at rates of 22, 56, 112, and 224 Mg ha^{-1}, and (4) was used alone as a control. The overburden alone, topsoil plots, and sawdust plots received 1,120 kg ha^{-1} 15-15-15 fertilizer; topsoil plots received 7.8 Mg ha^{-1} lime; sawdust plots received an additional 336 kg ha^{-1} slow-release nitrogen. All plots were mulched with 90 Mg ha^{-1} and hydroseeded with a slurry containing 170 kg ha^{-1} Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) and 840 kg ha^{-1} wood fiber mulch. The following spring, one-half of each plot was treated with herbicide and planted with 4 loblolly pine (*Pinus taeda* L.) and 12 pitch-loblolly pine (*Pinus rigida* × *taeda*) seedlings. Soil nitrogen components (organic matter, total nitrogen, nitrate nitrogen, and ammonium nitrogen) were determined at the end of each growing season for 3 years at the 0- to 5-cm and 25- to 30-cm depths. Tree seedling growth and survival were also monitored.

The organic amendments increased the organic matter and total nitrogen content of the mine spoils throughout the 3-year study period. Organic matter was increased the most with the sawdust amendment, while the highest sludge rates increased total nitrogen the most. The total nitrogen level at the control and topsoil plots increased significantly from the first to the third year because of uptake of nitrogen by the plants and deposition on the spoil surface as organic nitrogen in the plant residue. The addition of organic amendments increased the rates of nitrogen mineralization and nitrification over the control and topsoil levels. Pine seedling growth was significantly increased on the sawdust at 22- and 56-mg-ha^{-1} sludge treatments over that on the control on topsoil; the sawdust amendment resulted in the best overall growth of the pine seedlings.

741. Mott, J. B., and D. A. Zuberer. Occurrence of Vesicular-Arbuscular Mycorrhizae in Mixed Overburden Mine Spoils in Texas. Reclam. & Reveg. Res., v. 6, No. 2, 1987, pp. 145-156.

The occurrence of endomycorrhizal infection of coastal bermudagrass (*Cynodon dactylon* (L.) Pers.) and the abundance of endomycorrhizal fungal spores in mixed overburden mine spoils of various ages were investigated on mined sites in Texas. Revegetated sites ranging in postmining age from 1 to 10 years were compared with an unmined soil field succession and site on a sandy loam soil. Endomycorrhizal infection (percentage of root length infected or percentage of root segments exhibiting infection) returned to premining levels 3 to 7 years after disturbance. The intensity of infection was not affected by disturbance, site age, or time of sampling. Spore numbers were significantly greater in unmined soil than in mined soils; no significant differences were found for numbers of spores in variously aged mine spoils.

742. Mueller, B. K., and P. A. Vance. Soil Moisture Retention Curves for Evaluating Plant Moisture Availability of Cover Materials and Coal Refuse From the Staunton 1 Reclamation Demonstration Project. Argonne Natl. Lab., ANL/LRP-TM-21, Sept. 1981, 26 pp.

The publication reports the results of a study conducted near Staunton, IL. Moisture retention curves were characterized for the three soil materials present at the site and used in this reclamation. Based on these curves, gravimetric moisture contents of field soil samples were converted to tension values and used as indications of the importance of type and depth of soil cover material in situations where soil moisture is a growth-limiting parameter.

743. Mullins, G. L., and L. E. Sommers. Characterization of Cadmium and Zinc in Four Soils Treated With Sewage Sludge. J. Environ. Qual., v. 15, No. 4, 1986, pp. 382-387.

The changes in soil solution cadmium and zinc, liable soil cadmium and zinc, and cadmium and zinc diffusion coefficients as a result of a 100-Mg-ha^{-1} sludge application were determined for four different soils. The sludge application resulted in 19 kg ha^{-1} Cd and 340 kg ha^{-1} Zn. Concentrations of calcium, cadmium, magnesium, manganese, PO_4-P, SO_4-S, and zinc generally increased with the sewage sludge application. Sludge addition increased the amount of liable soil cadmium and zinc, as determined by DTPA extractions and isotopically. The effective diffusion coefficients for cadmium and zinc were dependent on soil type.

744. Mullins, G. L., L. E. Sommers, and S. A. Barber. Modeling the Plant Uptake of Cd and Zn From Soils Treated With Sewage Sludge. Am. Soc. Agron., Agron. Abstr., 1985, pp. 28-29.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. Sensitivity analyses of a nutrient uptake model were conducted to determine how soil and plant factors affect predicted metal uptake. Plant factors having the greatest effect on cadmium and zinc uptake were root growth constants, average root radius, and water influx rate. Concentrations of cadmium and zinc in the soil solution had the greatest effect on predicted uptake. Management practices that promote decreased cadmium and zinc solubility will depress metal uptake by crops.

745. Muncy, J. A. Aerial Treatment Activities for Revegetating Disturbed Lands. Paper in Proceedings of the Eighth Annual National Abandoned Mine Lands Conference (Billings, MT, Aug. 10-15, 1986). MT Dep. State Lands, Helena, MT, 1986, pp. 165-175.

Experiences in aerial seeding and fertilization of disturbed lands are reported. Ground-support needs, loading techniques, application methodology, and costs are discussed. Aerial broadcast seeding and fertilization offers a practical and cost-effective method for revegetating disturbed lands. Advantages of aerial broadcasting are given.

746. Muncy, J. A. Practical Revegetation Techniques for Tennessee's Copper Basin Lands. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 1-9.

The long-term offsite environmental problems associated with unvegetated lands, recent revegetation experiences, the remining problem areas, the proposed treatments, and their associated cost are reported for the Copper Basin located in Tennessee, Georgia, and North Carolina.

747. Muncy, J. A. Reclamation of Abandoned Mica, Feldspar, and Kaolin Surface Mines and Associated Tailings Disposal Sites in Western North Carolina. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 153-157.

This paper reports on the cooperative efforts of the Tennessee Valley Authority (TVA), local, State, and Federal agencies, mining industry, and land owners to reclaim abandoned mica, feldspar, and kaolin surface mines in western North Carolina. General information is given on the characteristics of the mine spoils and tailings and on the reclamation approaches and techniques used.

748. Muncy, J. A., and E. R. Buckner. Reclamation of Abandoned Coal Refuse Piles and Underground Adit Entries in the Big South Fork National River and Recreation Area. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 49-54.

A review of the approaches used in reclaiming both coal refuse piles and underground adit entries in the Big South Fork National River and Recreation Area, in Kentucky and Tennessee, is presented. Chemical and physical characteristics of the refuse are presented, along with the reclamation scheme utilized. The closure of mine openings involved four basic techniques: (1) backfilling, (2) sealing, (3) blasting, and (4) barriers. The project demonstrated cost-effective techniques for use in reclaiming highly acidic abandoned coal refuse piles and closure of abandoned underground coal mine adits. The minimum disturbance reclamation approach was used on the refuse piles.

749. Munn, L., N. Harrington, and D. R. McGirr. Rock Fragments. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 259-282.

The success of reclamation efforts is affected by the quantity, size, lithology, and distribution of rock fragments. Rock fragments reflect both the initial rock fragment content of the parent material and the weathering redistribution that has occurred over time within the soil. Many soil physical and chemical properties are affected by rock fragment content. Definitions and descriptions of rock fragments are given. Rock fragment contents of soils are usually reported as volume percentages or percent surface coverage. The effects of rock fragments on soil properties, productivity, and plant distribution are reviewed. Rock fragment guidelines that have been recommended or proposed for mine soils by various State and Federal agencies and researchers for western mined lands are presented. The effects of rock fragment content on the vegetative productivity and performance in surface mine soils are reviewed.

750. Munshower, F. F., and D. R. Neuman. Elemental Concentrations in Native Plant Species Growing on Minesoils and Native Range. Reclam. Rev., v. 3, No. 1, 1980, pp. 41-46.

This study was done to determine if there were changes in elemental concentrations of indigenous range plants grown on mine soils in southeastern Montana as the result of disruption of the native soils by mining. If changes were found, a second objective was to determine if the changes could be mitigated with time and/or spoil treatment during the initial reclamation process. Four different sites were chosen for this study: (1) an unmined grassland reference area, (2) a 2-year-old nontopsoiled mine soil, (3) a 6-year-old poorly topsoiled mine soil, and (4) a 50-year-old nontopsoiled area. Sites 2 and 3 were seeded to native plants, while site 4 was revegetated by natural seed dispersal. Macronutrient levels (nitrogen, phosphorus, potassium, magnesium, and calcium) were found to be reduced in plants grown on the nontopsoiled areas, while plants grown on topsoiled sites had elemental concentrations similar to those grown on native unmined soil. Micronutrient levels (zinc, copper, manganese, iron, and molybdenum) were higher in plants grown on the topsoiled sites, while vegetation on the nontopsoiled sites had concentrations similar to those found for the unmined site. The authors conclude that the higher micronutrient levels found in vegetation growing on the recently revegetated sites may be beneficial for meeting the nutritional need of cattle.

751. Munshower, F. F., D. R. Neuman, and S. E. Fisher, Jr. Variation in Physical Properties of Overburden Produced by Preparation of the Materials. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 279-282.

This study was conducted to evaluate the performance of two types of overburden preparation equipment (grinders) and two overburden particle size fractions on the soil chemical and physical properties of three different overburden samples collected from southeastern Montana. The two grinders used were a flailer and a plate grinder, while the two particle size fractions analyzed were 2 and 0.25 mm. No significant differences were found in the chemical analyses of soils processed by the flailer and the grinder. The 2- or 0.25-mm size fractions, whether prepared by the flailer or grinder, were not significantly different. Analyses of the two size fractions resulted in only two parameters with significant differences. The DTPA extraction of both copper and zinc yielded significantly greater quantities of these elements from the smaller particle size. When particle size distributions were compared (2 mm versus 0.25 mm), little difference was found between the two treatments. The authors recommend that regulatory agencies should clarify soil and overburden handling techniques and analytical procedures to ensure uniformity and consistency of reported analyses.

752. Murray, D. R. Influence of Uranium Mill Tailings on Tree Growth at Elliot Lake. CIM Bull., v. 71, No. 800, 1978, pp. 79-81.

This article reports the results of a 4-year study to determine the ability of conifers to aid in reclamation of uranium tailings at Elliot Lake, ON, Canada. Two-year-old, bare-root seedlings of white cedar (*Thuja occidentalis* L.), white spruce (*Picea glauca* (Moench) Voss), jack pine (*Pinus banksiana* Lamb.), scotch pine (*Pinus sylvestris* L.), and red pine (*Pinus resinosa* Ait.) were planted in areas of established grasses and on bare tailings. The tailings were categorized as "coarse" or "fine." The survival and growth of these conifers were related to species, environmental conditions, and tailings properties. Percent survival and annual growth, measured as plant height, were used as criteria for assessment. Overall survival and growth were below those anticipated. The best survival rates were exhibited by the pine species, with 68 pct when planted in bare coarse tailings, 45 pct in revegetated coarse tailings, and 34 pct in vegetated fine tailings. The worst survival rates were exhibited by white cedar with 49, 14, and 7 pct in the same materials, respectively. The results reported specifically refer to revegetation of uranium mill tailings; however, they may also be applicable to surface coal mine reclamation where similar materials and/or climate are involved.

753. Murray, D. R. Mine Waste Description and Case Histories. Suppl. 10-1 of Pit Scope Manual. Can. Cent. Miner. and Energy Technol., Ottawa, ON, CANMET Rep. 77-31, Dec. 1977, 120 pp.

This document supplements chapter 10, "Environmental Planning," in a multichapter manual. Each chapter, as well as the supplements to these chapters, has been published separately. The purpose of this supplement is to outline the general principles of reclamation by vegetation. It summarizes and reviews numerous case histories in Canada. Type of mine wastes, their characteristics, and problems commonly encountered in attempting revegetation are discussed. This document offers a good reference for planning reclamation activities. It was written specifically for application in Canada; however, much of the material presented is pertinent to reclamation activities in the northern portions of the United States as well.

754. Murray, D. R., and D. Okuhara. Effect of Surface Treatment of Tailings on Effluent Quality. Reclam. Rev., v. 3, No. 3, 1980, pp. 167-177.

This paper describes the quality and quantity of effluent generated from uranium tailings containing sulfide at Elliot Lake, ON, Canada, on which various surface treatments have been used. Four lysimeter pits were constructed, each 9 m square by 1.5 m deep. Approximately 125 mt of uranium tailings was added to each pit. The surface treatments used are as follows: pit 1, covered with 15 cm of gravel; pit 2, covered with 15 cm of sawdust; pit 3, no treatment; and pit 4, treated with limestone and fertilizer and seeded to redtop (*Agrostis alba* L.) and creeping red fescue (*Festuca rubra* L.). Pit 4 received monthly fertilization during the first growing season and the 4 subsequent years of this study. Chemical analyses were done on the tailings (five samples per pit) and the effluent (every 2 weeks from the first spring flow until flow stopped the following fall or winter). During the 5-year period of this study, the surface treatments were compared with bare tailings where no surface additions were made.

The results indicate that the surface treatments did not alter the effluent quality to an acceptable level. The surface treatments did not affect the leaching of radium-226, ammonium, or nitrate. The acidity of the tailings also changed over the course of the study, from an initial pH of 9.5 to a pH of 2 to 3. As the acidity rose, the concentration of iron, sulfate, copper, lead, and aluminum in the effluent increased. The rate and extent of these chemical changes varied with surface treatment. The authors conclude that the surface treatments used in this study did not prevent the deterioration of effluent water passing through nonsaturated portions of uranium mill tailings.

755. Myers, J. A., E. O. McLean, and J. M. Bigham. Reductions in Exchangeable Magnesium With Liming of Acid Ohio Soils. Soil Sci. Soc. Am. J., v. 52, No. 1, 1988, pp. 131-136.

It has been reported in the literature that in acid soils there are substantial reductions in exchangeable magnesium with liming, sometimes referred to as "magnesium fixation." This reduction may be due to interaction between exchangeable magnesium and the exchangeable aluminum content of acid soils. Using a series of acid Ohio soils, the authors conducted a study in which the aluminum present was fractionated using a variety of extractants. This information was used to determine if consistent relationships between the various forms of extractable aluminum and exchangeable Mg could be interpreted in order to predict when reductions in exchangeable magnesium with liming may result in plant nutritional problems.

Seven soils were selected for study based on their texture, clay mineralogy, and aluminum content. Each soil was characterized chemically, physically, and mineralogically. A laboratory experiment was conducted using four lime rates (none and additions of CaO to raise soil pH to 5, 6, and 7) and two magnesium rates (added as $MgSO_4$ to equal 0 and 25 pct of the cation-exchange capacity) on each of the seven soils. Exchangeable magnesium losses were regressed against aluminum solubilized in each soil by six extracts commonly used in aluminum fractionation. The extracts used included 1*M* KCl, 1*M* NH_4OAc, 0.5*M* $CuCl_2$, 0.1*M* Na-pyrophosphate, 0.2*M* NH_4-oxalate, and sodium-citrate-dithionite.

The results show that there were significant reductions in exchangeable magnesium in response to liming in all seven acid soils. Reductions in exchangeable magnesium increased as the pH approached neutrality. The addition of magnesium to the soil increased the absolute amount of exchangeable magnesium lost, but had little effect on the nature of the decline. In soils limed to near neutrality, the decrease in exchangeable magnesium ranged from 17 to 34 pct. The largest quantities of aluminum were solubilized by Na-citrate-dithionite, NH_4-oxalate, and Na-pyrophosphate. All extractants, except sodium-citrate-dithionite, removed aluminum species that could be related to the observed reductions in exchangeable magnesium. The best correlation was obtained by the KCl-Al fraction. All whole-soil extractable aluminum data provided the best correlations with magnesium fixation. The strong correlation obtained between KCl-Al and the degree of magnesium fixations suggests to the authors that the exchangeable aluminum is important in the magnesium-fixation process.

The results of this study support the hypothesis that magnesium fixation is due to the formation of amorphous

aluminum polymers when exchangeable aluminum is precipitated when acids soils are limed. Magnesium is thought to be occluded in these aluminum polymers or coprecipitated with aluminum to form a hydrotalcite-like mineral. Soils with high levels of exchangeable aluminum should result in the most fixation of magnesium with liming, and this may be especially critical for plant nutrition in highly acid soils with low natural exchangeable magnesium levels. This paper is an excellent reference on the effects of liming acid soils on magnesium availability.

756. Naeth, M. A., W. B. McGill, and A. W. Bailey. Persistence of Changes in Selected Soil Chemical and Physical Properties After Pipeline Installation in Solonetzic Native Rangeland. Can. J. Soil Sci., v. 67, No. 4, 1987, pp. 747-763.

The effects of natural gas pipeline installation on soil-plant-water relations of solonetzic native rangeland near Princess, AB, Canada, are reported. Soil physical and chemical properties, at selected soil depths, are reported for installed pipelines of various ages in order to examine changes in soil characteristics over time (a chronosequence). Pipeline construction tended to improve the surface chemical and physical properties of soils compared with eroded pits, but reduced soil quality compared with undisturbed soil. Pipeline construction resulted in increased bulk density, reduced organic matter, and increased concentrations of soluble salts on the soil surface compared with undisturbed soil. Evidence suggests that there was greater amelioration of soil chemical properties than soil physical properties of disturbed areas over time.

757. National Academy of Sciences—National Research Council. Disposal of Excess Spoil From Coal Mining and the Surface Mining Control and Reclamation Act of 1977: A Study of Regulatory Requirements, Engineering Practices, and Environmental Protection Objections. Natl. Acad. Press, Washington, DC, 1981, 207 pp.

Although the report deals extensively with the disposal of excess spoil to control erosion and the regulatory impacts, Section 8.4, "Revegetation of Excess Spoil," is a general discussion of the planning and potential impacts of revegetation of coal spoils. Other sections mention revegetation as appropriate, but Section 8.3 discusses the benefits, practices, and criteria for successful revegetation for industry as a whole.

758. National Academy of Sciences—National Research Council. Surface Coal Mining in Alaska: An Investigation of the Surface Mining Control and Reclamation Act of 1977 in Relation to Alaskan Conditions. Natl. Acad. Press, Washington, DC, 1980, 379 pp.

This is an extremely comprehensive publication on coal mining in Alaska as related to Public Law 95-87. Although general in their treatment of any particular subject, the committees responsible for this report cover every aspect of coal mining from concerns over permafrost and earthquakes, which are not covered in Public Law 95-87, to social impacts of industrial development. Although the report does not deal in detail with coal mine land revegetation, it was included in this bibliography because of the vast amount of information pertaining to all areas of concern for mining development in Alaska.

759. National Academy of Sciences—National Research Council. Surface Mining: Soil, Coal, and Society. Natl. Acad. Press, Washington, DC, 1981, 246 pp.

This report was prepared by the Committee on Soil as a Resource in Relation to Surface Mining for Coal, under the National Research Council. It describes major aspects of the impact of mining on soils and depicts soil as a mineral resource. The study was multidisciplinary in nature, drawing upon expertise in the fields of mining, soils, civil engineering, geology, and resource management. A methodology was developed to evaluate soil and land as an economic and environmental resource. As stated, an appropriate goal for reclamation is to ensure that society does not lose important land use opportunities that were available before soil disturbance, or that could be generated in the reclamation process. The development of productive capacity in soils is governed by climate, parent material, topography, and biota. These factors produce important variations among major coal-producing regions and local variations within each region. Thus, reclamation goals and techniques must be adapted to these variations and public and private concerns. Additionally, scientific and technical information must be considered when determining the most appropriate reclamation practice for a given site. Although the report generalizes a great deal, it provides guidance and direction for meeting the challenges of effective reclamation and includes an excellent bibliography of related literature.

760. Naughton, G. G. Spoil Bank Energy Forest Systems. Final Report to the Ozarks Regional Commission. KS Energy Off., Topeka, KS, and Dep. For., KS State Univ., Manhattan, KS, Apr. 1981, 66 pp.

This publication reports the results of a study conducted on lands in Crawford and Cherokee Counties, KS, that had been strip mined for bituminous coal between 1877 and 1969. A classification system was designed and applied to categorize current land use and vegetation types in the area. The areas were analyzed for their potential fuel wood and sawtimber production. The author concluded

that the total costs of reclamation of these lands can never be recovered solely on the basis of their subsequent economic production and must, therefore, depend in part on the amenity values associated with reclamation. This publication is an excellent reference for determining reclamation options on these types of lands in the Interior Coal Mining Region.

761. Nawrot, J. R. Wetland Development on Coal Mine Slurry Impoundments: Principles, Planning, and Practices. Paper in Wetlands and Water Management on Mined Lands, ed. by R. P. Brooks, D. E. Samuel, and J. B. Hill (Proc. Conf. PA State Univ., State College, PA, Oct. 23-24, 1985). PA State Univ., State College, PA, 1985, pp. 161-172.

An overview of the hydrogeochemical principles and planning involved in the establishment of wetlands on coal mine slurry impoundments is presented. There is a horizontal zonation of physiochemical factors between the elevated discharge and low-lying decantant zone because of the separation and distribution of slurry constituents. An understanding of slurry pond characteristics is needed to successfully implement reclamation alternatives. In wetland development it is important to recognize site-specific uniqueness and the variability that exists within each impoundment. In the development of diverse wetland habitats it is necessary to characterize the site physically, chemically, and hydrologically prior to reclamation and to control the water level, acid-base balance, and nutrients within each designated management zone. Reclamation considerations for each management zone are presented.

762. Nawrot, J. R., M. L. Fuson, and D. M. Downing. Reedgrass and Slurry Pond Reclamation. Min. Cong. J., v. 67, No. 9, 1981, pp. 23-28.

This study was conducted at the Monterery Coal Co. No. 1 Mine in Macoupin County, IL, to determine if reedgrass (*Phragmites australis* Trin.) could grow directly on slurry refuse and prevent embankment erosion. The objectives of the study were to (1) demonstrate the practicality of revegetating refuse and slurry areas without the use of topsoil, (2) provide protection for slurry dikes against wave erosion, and (3) enhance the wildlife habitat potential of the slurry pond. Reedgrass not only stabilized the coal slurry area without topsoil replacement, but also provided erosion control and wildlife enhancement. Reedgrass has the potential of stabilizing and covering both inactive and abandoned coal slurry areas.

763. Nawrot, J. R., and W. D. Klimstra. Mine Waste or Mine Soils, Time Does Make a Difference. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 172-183.

The reclamation of an acid coarse-refuse pile in southern Illinois that had been a source of acid runoff for more then 15 years was discussed. The principles of refuse aging and weathering played an important role in the reclamation of the refuse pile studied. With surface weathering, direct vegetation establishment is feasible without the need for soil cover. Reduction in the acid-producing potential through weathering represents a significant contribution to the chemical stability of the refuse pile. Amending weathered refuse with lime will provide a suitable substrate for the establishment of vegetative cover.

764. Nawrot, J. R., and C. A. Kolar. Problem Spoilbanks: Enhancing Succession Through Reforestation. Paper in 1982 Seminar on Post-Mining Productivity With Trees (Carbondale, IL, Mar. 31-Apr. 2, 1982). South. IL Univ., Carbondale, IL, 1982, pp. 151-156.

This article discusses natural revegetation and changes in mine-soil properties on Illinois coal spoil banks. In the late 1960's and early 1970's the Cooperative Wildlife Research Laboratory at Southern Illinois University evaluated over 11,000 acres of spoil banks with acid conditions (pH <5) and/or a vegetative cover less than 25 pct. Many of these areas were also evaluated approximately 10 years later. While the rate of natural succession varied widely, some areas had increased plant cover from less than 25 pct to greater than 75 pct. Using the latest data, a spoil bank classification system was developed based on the current successional rate and trend, primary inhibiting factors (such as pH), speculated time required for natural recovery, and the level of reclamation effort for enhancement of current successional trends. The use of tree plantings to enhance reclamation is discussed in the context of the study findings.

765. Nawrot, J. R., J. Sandusky, and W. D. Klimstra. Acid Soils Reclamation: Applying the Principles. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 93-103.

This article reviews abandoned mine-land reclamation practices used at a 2,400-acre Illinois prelaw site. Emphasis is placed on improving and building soil through chemical and biological reclamation practices, such as lime and organic matter amendments, rather than the more common grading of abandoned mine lands and covering with fill from borrow areas. Natural soil processes such as

aging, weathering, and leaching, and plant succession, along with selective grading, minimal grading, neutralization amendments, and vegetation enhancement and preservation, have been used to reclaim acid spoils. The authors state that working with nature to improve and build existing soils, enhancing succession, and treating the cause rather than the symptom are all basic principles in cost-effective prelaw reclamation. This type of reclamation has been successful on the abandoned acid spoils at the site studied. Other cost-effective reclamation practices that suggest soil aging and weathering and soil neutralization and organic additions, rather than grading and covering, are described for refuse reclamation. Direct revegetation, alkaline capping, flooding, and organic matter enhancement of inactive slurry areas for wetland development and acid mine drainage treatment are employed. This article presents cost-effective alternatives for the reclamation of abandoned mine lands.

766. Nawrot, J. R., and D. B. Warburton. Guidelines for Slurry Reclamation Alternatives. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 277-283.

This paper summarizes and outlines the basic approach used in acquiring meaningful prereclamation site characterization data of slurry ponds. Uniform data gathering and presentation of significant trends are emphasized. A thorough site characterization is needed to implement alternative techniques. A management zone approach is recommended in slurry reclamation to ensure that appropriate reclamation techniques are implemented for unique physical, chemical, and hydrologic conditions within zones. Success of this approach depends on the understanding of several key principles of slurry reclamation: (1) aging and weathering, (2) neutralization amendments, (3) organic matter enhancement, and (4) water-level management. It is necessary to address the limiting factors affecting successful vegetation establishment or acid generation abatement.

767. Nawrot, J. R., D. B. Warburton, and V. P. Wiram. Wetland Reclamation of the AMAX Ayrshire Slurry Impoundment. Coal Min., v. 24, No. 5, 1987, pp. 44-47.

This article reviews an ongoing slurry reclamation project at AMAX's Ayrshire Mine in southern Indiana. The approach used in reclaiming the slurry impoundment is the Management Zone strategy. At this site, five Management Zones were identified based on prereclamation site characterization. A general discussion of the reclamation procedures used in each zone is presented. The authors state that this reclamation method is cost effective and environmentally sound, providing mining companies an opportunity to increase wetland habitats.

768. Nawrot, J. R., and S. C. Yaich. Slurry Pond Forestation: Potential and Problems. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 180-194.

The potential for habitat development and diversification on slurry impoundments through forestation is discussed. A study was conducted examining tree growth on a number of inactive slurry impoundments in Illinois and Indiana. This investigation revealed that plantings during 1965-75 were most successful in moist soil zones near impoundment decantant areas. In these areas, survival was greatest for hydrophytic species such as baldcypress (*Taxodium distichum* (L.) Rich.) and river birch (*Betula nigra* L.). Growth rates for these species in these areas were comparable to those of individuals growing in natural soil. More limited and localized success was obtained with plantings of red (*Pinus resinosa* Ait.) and Virginia pine (*Pinus virginiana* Mill.) in the discharge areas. Horizontal and vertical zonations of hydrogeochemical slurry characteristics relating to the separation and distribution of slurry constituents were identified. Coarse-textured pyritic materials are deposited near the discharge point, while fine silt and clay materials migrate farther toward the decantant portion of the pond. Material characteristics pertinent to forestation efforts are discussed in conjunction with techniques for ameliorating problems related to acid-base balance and surface stability, and taking advantage of slurry zones that have inherently favorable physiochemical qualities for tree growth.

769. Neal, R. H., and G. Sposito. Effects of Soluble Organic Matter and Sewage Sludge Amendments on Cadmium Sorption by Soils at Low Cadmium Concentrations. Soil Sci., v. 142, No. 3, 1986, pp. 164-172.

This study investigated the adsorption of cadmium as influenced by sewage sludge amendments in six soils that varied chemically and in mineralogical composition. The loss of cadmium from the aqueous solution to the solid phase is described as sorption. The results show that the amount of cadmium sorption decreases with the application of sewage sludge. This suggests the formation of nonsorbing cadmium complexes in the soil solution at very low concentrations of cadmium. Removal of soluble organic material by washing resulted in cadmium sorption, indicating that cadmium in soils is complexed by aqueous organic ligands.

770. Nelson, J. L., and D. J. Mersky. Improving or Creating New Land Use Possibilities With Abandoned Mined Lands Reclamation. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 299-300.

Several examples of abandoned mined-land use applications are presented. Factors for abandoned mine-land sites suitable for land use consideration are given. Land use possibilities include pasture-agricultural use, wildlife habitat improvement, recreation, and housing, commercial, and industrial development.

771. Nelson, R. W., J. F. Orsborn, and W. J. Logan. Planning and Management of Mine-Cut Lakes at Surface Coal Mines. U.S. Off. Surf. Min., OSM/TR-82/1, May 1982, 248 pp.

This manual was designed as a guide for the coal industry and regulatory agencies in the planning, design, and management of surface coal mine lakes created by mining cuts when left as permanent impoundments. The guidelines presented in the manual are not legally binding. They are meant to be used by land reclamation planners and managers to help determine the feasibility and utility of planned new lakes. Two sections of the document deal with revegetation. For the most part this information is fairly general. The manual does, however, point out several important considerations for reclamation planning. A good review of some of the herbaceous and woody species that have been used in surface mine reclamation is provided. Special techniques for establishing aquatic and shoreline plant species are discussed.

772. Neuman, D. R., J. L. Schrack, and L. P. Gough. Copper and Molybdenum. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 215-232.

Copper and molybdenum are discussed in terms of their metabolic role, determination of concentration, occurrence (native and mine soils, availability, tissue concentrations, and relations between soils and plants), and toxicity. Several recommendations are given concerning copper and molybdenum that are applicable to western mined land reclamation.

773. Nguyen, P. V., D. G. Brockway, and J. B. Hart. Forest Land Application of Municipal Sludge in Northern Michigan: Forest Floor, Soil and Vegetation Responses. Am. Soc. Agron., Agron. Abstr., 1987, p. 31.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Four forest types were used to assess waste water sludge application technology and its effects on vegetation, forest floor, soil, ground water quality, wildlife populations, and food chains, and resulting public opinion. Forest types used were aspen (*Populus* spp.), oak (*Quercus* spp.), pine (*Pinus* spp.), and mixed hardwoods. Sludge was applied at rates ranging from 8 to 10 Mg ha^{-1}. Four years of sludge treatment increased tree diameter growth by 23, 78, 23, and 48 pct for aspen, oak, pine, and hardwood forest types, respectively, and total basal area growth was increased by 48, 56, 36, and 56 pct, respectively. At each site, sludge applications significantly increased the concentrations of most nutrients in the O1 and O2 horizons of the forest floor. Few changes in nutrient or metal concentrations occurred in the mineral soil.

774. Nicholas, P. J., and W. J. McGinnies. An Evaluation of 17 Grasses and 2 Legumes for Revegetation of Soil and Spoil on a Coal Strip Mine. J. Range Manage., v. 35, No. 3, May 1982, pp. 288-293.

This paper reports the results of a greenhouse study that evaluated the potential of 17 grass species and 2 legume species for revegetation of surface coal mined areas. Growth medium treatments included 53 cm of spoil material without topsoil and 25 cm of topsoil placed over 28 cm of mine spoil. Grasses grown in topsoil exhibited herbage yields seven times greater and root yields six times greater than grasses grown in spoil without topsoil. Native and introduced grass species exhibited similar average herbage yields. Introduced species averaged greater root production, particularly in spoil material. Two legumes, alfalfa (*Medicago sativa* L.) and cicer milkvetch (*Astragalus cicer* L.), produced much higher yields and higher crude protein than any of the grasses studied, regardless of the growth medium treatment. The study was conducted using spoil and soil material collected from a minesite near Steamboat Springs, CO. The results of this study are primarily relevant to that specific area. With careful consideration they might be applied to species selection for revegetation efforts over a slightly broader geographical area.

775. Nielsen, G. A., and E. V. Miller. Crop Yields on Native Soils and Strip Mine Soils: A Comparison. J. Soil and Water Conserv., v. 35, No. 1, 1980, pp. 44-46.

This article summarizes parts of a national survey on mine-land productivity, which sought comparisons of crop yields before and after mining operations. The objectives of the survey were to (1) identify the major sources of information about mined-land productivity in the United

States, (2) find comparable yield figures for corn (*Zea mays* L.) production on native soils (reference area) and strip mine soils, and (3) suggest a means of obtaining soil performance data for crop production. The survey was sent to an organization that actively investigated strip mine spoil reclamation in order to obtain information on yields and associated yield parameters (i.e., fertilization, weed control, crop varieties used, soil conditions, and climate). The survey indicated that corn yields on mine soils were 4 to 90 pct less than on adjacent native soils. This reduction in yield was dependent upon topsoil application, age, and the special treatments used. The authors concluded that yield reductions from strip mining can be large or small depending upon the reclamation procedures and spoil qualities. The data illustrated the importance of soil replacement, supplemental additions of lime and manure, and the initial planting of legume and grass forage species.

776. Nieves, L. A., and M. H. Marti. Economic Feasibility Analysis of Water-Harvesting Techniques for Mined-Land Reclamation (U.S. Dep. Energy contract DE-AC06-76RLO-1830). Battelle Pac. Northwest Lab., Richland, WA, PNL-3737, July 1981, 47 pp.

This publication provides a preliminary economic feasibility study evaluating the net private benefits of water-harvesting reclamation techniques compared with conventional reclamation systems. Peabody Coal Co.'s Kayenta Mine on the Black Mesa in Arizona was used in the case analysis. The present value of direct net benefits (income minus production and reclamation costs) is calculated for grazing (representing conventional reclamation) and for cropping (representing water-harvesting techniques). Three of the slope treatments tested in the water-harvesting study were found to have lower estimated total costs than conventional reclamation. The water-harvesting method also has advantages based on the higher estimated value of agricultural production capacity. The water-harvesting system appears to be potentially viable on sites receiving only 25 to 30 pct of the precipitation normally required for crop production.

777. Nilson, D. J., R. L. Williamson, J. C. Thompson, and J. E. Shultz. Techniques Used To Establish, Maintain and Enhance Grassland Seasonal Variety on the Glenharold Mine in North Dakota. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 144-152.

Revegetation techniques used in reestablishing diverse and seasonally balanced native grasslands in North Dakota are summarized. Techniques used to establish grasslands included late spring seeding, improved seed mix ratios, and the use of native hay mulch. Data on frequency, productivity, and cover support the use of these techniques. A combination of management techniques is necessary to reduce cool-season grass competition in order to allow warm-season species to become established. These management techniques include prescribed burning, time-specific applications of nonselective herbicides, and interseeding with warm-season grass species.

778. Nimmo, J. R., and K. C. Akstin. Hydraulic Conductivity of a Sandy Soil at Low Water Content After Compaction by Various Methods. Soil Sci. Soc. Am. J., v. 52, No. 2, 1988, pp. 303-310.

The influence of soil compaction on the unsaturated hydraulic conductivity of a sandy soil was determined in the laboratory using the steady-state centrifuge method. The soil was packed to various densities by dry-soil deposition with variable vertical drop impacts. This procedure was followed by centrifuged compression, with the soil being wet to approximately one-third saturation. Results show that compaction brings the fine particles closer together and decreases soil porosity, particularly the large pores. The pore-size distribution is disrupted, which causes an increase in water retention and a decrease in unsaturated hydraulic conductivity. This paper is a good reference on the effects of soil compaction in sandy soils, on porosity and water retention, and unsaturated hydraulic conductivity.

779. Noble, A. D., M. E. Sumner, and A. K. Alva. The pH Dependency of Aluminum Phytotoxicity Alleviation by Calcium Sulfate. Soil Sci. Soc. Am. J., v. 52, No. 5, 1988, pp. 1398-1402.

A nutrient solution experiment was conducted to evaluate the effects of varying levels of $CaSO_4$ on the alleviation of aluminum toxicity to soybean (*Glycine max* (L.) Merr.) roots at two pH levels. Increasing $CaSO_4$ in solution (625-10,000μM) increased soybean root length by threefold and twofold in solutions at pH 4.2 and 4.8, respectively. Increasing $CaSO_4$ additions resulted in a decrease in the predicted activity of Al^{3+}, while the activity of $AlSO_4^+$ increased. The magnitude of alleviation of aluminum toxicity by $CaSO_4$ was smaller at pH 4.8 because less $AlSO_4^+$ was formed and more $Al(OH)_2^+$ was formed. Increasing $CaSO_4$ additions to solutions alleviated aluminum phytotoxicity in soybean, reflected in an increase in root length. This alleviation was, however, dependent on solution pH.

780. Norem, M. A., and A. D. Day. Managing Copper Tailings Slopes for Revegetation in the South-Western United States. Reclam. & Reveg. Res., v. 4, No. 1, 1985, pp. 83-92.

Two methods of incorporating barley (*Hordeum vulgare* L.) residue into copper tailings slopes to enhance the growth of perennial grass species were compared at an Arizona open-pit copper mine. Tailings slopes were capped with desert soil to a depth of 8 to 10 cm or left uncapped (control); these were the main plots. Plots were then hydroseeded with barley and a mixture of wood fiber and ammonium phosphate. Following hydroseeding, the slopes were mulched or left unmulched (split-plot) with wheat (*Triticum aestivum* L.) straw. Sprinkler irrigation, with liquid nitrogen fertilizer injected every 2 weeks, was utilized.

The following growing season, barley residue was treated in one of three ways: (1) incorporated with a sheepsfoot roller, (2) incorporated with a spike-tooth chain drag, or (3) not incorporated. Four perennial grass species were then hydroseeded: (1) Lehmann lovegrass (*Eragrostis lehmanniana* Ness.), (2) buffelgrass (*Pennisetum ciliare* (L.) Link.), (3) blue panicgrass (*Panicum antidotale* Retz.), and (4) bermudagrass (*Cynodon dactylon* (L.) Pers.). The hydroseeded mixture contained ammonium phosphate and wood fiber. Irrigation was used, with liquid nitrogen fertilizer injected as before. The soil chemical characteristics of the materials studied, both the desert soil and tailings, were determined.

Barley growth was greatest on capped slopes regardless of aspect, while the growth of the perennial grasses was greatest on capped southern aspects compared with uncapped tailings. Forage yield was also higher for capped plots than for uncapped plots. The mulching of uncapped slopes did not improve barley growth. Incorporation was done to improve seedbed conditions; of the methods tested, the spike-tooth chain drag method produced greater growth in all treatments than did the other two methods.

781. Norem, M. A., A. D. Day, and K. L. Ludeke. An Evaluation of Shrub and Tree Species Used for Revegetating Copper Mine Wastes in the SW United States. J. Arid Environ., v. 5, 1982, pp. 299-304.

The purpose of this study was to evaluate tree and shrub species survival, growth, and reproductive potential on copper tailings and overburden material on northern and eastern slope aspects at the Cyprus Pima Mine near Tucson, AZ. Ten tree species and seven shrub species were evaluated. The planting rates for the trees and shrubs were 20 tree seedlings per 900 m^2 and 15 shrub species per 900 m^2. Two of the seven shrub species had 100-pct mortality, and 3 of the 10 tree species had 100-pct mortality. Hopseedbush (*Dodanea viscosa* (L.) Jacq.) was the only shrub that survived on the north aspect. For the trees, paloverde (*Cereidium microphyllum* (Torr.) Rose & Johnst.) survived best on the east slope and tree tobacco (*Nicotiana glauca* Grah.) survived only on the north slope. The remaining tree species were not affected by aspect. The authors conclude that in the arid areas of the Southwestern United States plant survival depends on the chemical composition of the mine waste material, slope exposure, and the suitability of a species to an arid environment.

782. Nowicki, M. L. Fly Ash for Sanitary Sewage Sludge Stabilization/Disposal. Paper in Proceedings: Eighth International Ash Utilization Symposium, Volume 1 (Washington, DC, Oct. 28-31, 1987). Electr. Power Res. Inst., Palo Alto, CA, 1987, p. 29-1.

Abstract of a paper presented at the Eighth International Ash Utilization Symposium. An overview of a long-term sewage sludge stabilization-disposal project using 200,000 tons of fly ash per year is presented. Background information, project development processes, and the status of current operation are given.

783. Nuttall, W. F., H. Ukrainetz, J. W. B. Stewart, and D. T. Spurr. The Effect of Nitrogen, Sulphur and Boron on Yield and Quality of Rapeseed (*Brassica napus* L. and *Brassica campestris* L.). Can. J. Soil Sci., v. 67, No. 3, 1987, pp. 545-559.

Several greenhouse and field experiments were conducted to determine (1) the effect of nitrogen, sulfur, and boron fertilizers on yield and quality of rapeseed (*Brassica napus* L. and *Brassica campestris* L.), (2) whether these cultivars respond differently to the added nutrients, and (3) the nutrient-nutrient interaction effects of five rates of nitrogen, sulfur, and boron in a composite rotatable design on yield and quality of *Brassica napus* L. Rates of application varied, but up to 200 kg ha^{-1} N, 50 kg ha^{-1} S, and 2.8 kg ha^{-1} B were applied. Sulfur and a combination of sulfur and boron application resulted in an increased yield of rapeseed. Oil concentration and protein content of rapeseed was increased by sulfur additions. Nitrogen additions also resulted in increased protein contents of rapeseed, but when nitrogen was combined with boron, protein content decreased and oil percentage increased. The yield response of rapeseed to sulfur and boron fertilization was related to soluble soil sulfur and boron. Sulfur fertilizer additions resulted in improved seed set in rapeseed, while boron fertilizer enhanced yield by decreasing the number of sterile florets and improving pod development.

784. Oberle, S. L., and L. G. Bundy. Ammonia Volatilization From Nitrogen Fertilizers Surface-Applied to Corn (*Zea mays*) and Grass Pasture (*Dactylis glomerata*). Biol. and Fertil. Soils, v. 4, 1987, pp. 185-192.

A 2-year field experiment was conducted to determine the extent of ammonia (NH_3) loss from surface-applied

urea-containing fertilizers. The effects of NH_3 loss on corn (*Zea mays* L.) and orchardgrass (*Dactylis glomerata* L.) yield and nitrogen uptake were assessed. Experimental sites used in the corn trials were fertilized with ammonium nitrate (NH_4NO_3), urea, or a urea-NH_4NO_3 solution at rates of 0, 56, and 112 kg ha^{-1} N after planting, but prior to seedling emergence. In the orchardgrass experiment (grass pasture), urea and NH_4NO_3 were broadcast at rates of 0 and 67 kg ha^{-1} N to plots in an established orchardgrass pasture.

First-year results from the corn experiment showed that when the influence of rainfall was eliminated, respective NH_3 losses from the NH_4NO_3, urea-NH_4NO_3, and urea treatments were 2, 12, and 24 pct of the nitrogen applied. During the first year there was severe moisture stress, which limited corn yields in all treatments and resulted in no significant yield or nitrogen uptake differences between nitrogen treatments. Second-year results show that when little rainfall occurred for 7 days following application of the various nitrogen fertilizers, significant amounts of NH_3 were volatilized from the urea- and urea-NH_4NO_3-treated plots. Losses of NH_3 were greatest in the urea treatment, followed by the urea-NH_4NO_3 and NH_4NO_3 treatments. Corn yields and nitrogen uptake during the second year were increased by nitrogen fertilization and influenced by the rate and source of applied nitrogen. Grain yields increased when the rate of nitrogen applied increased from 56 to 112 kg ha^{-1} N; however, this response occurred only with urea-NH_4NO_3 and urea treatments. At 56-kg-ha^{-1} N, grain yields of urea- and urea-NH_4NO_3-treated soils were lower than yields of NH_4NO_3-treated soils, which is consistent with higher NH_3 losses in the urea and urea-NH_4NO_3 treatments. The NH_3 losses from urea and urea-NH_4NO_3 influenced nitrogen uptake when these nitrogen sources were used at the 56-kg-ha^{-1} N rate.

In the grass pasture experiment, first-year results show that NH_3 volatilization from the urea treatment was equivalent to 19 pct of the urea-nitrogen applied. During the second year, rainfall occurred within 3 days of application and NH_3 loss from the urea treatment was equal to 9 pct of the nitrogen applied. Loss of NH_3 was significantly lower, 1 pct of nitrogen applied, when NH_4NO_3 was applied. Forage yield and nitrogen uptake were significantly increased by both nitrogen sources; however, yields with urea were significantly lower than yields with NH_4NO_3, and nitrogen uptake by the forage crop was significantly lower with urea treatment than with NH_4NO_3. These results show that NH_3 volatilization from urea-containing fertilizers resulted in significant NH_3 losses under climatic conditions that favored these losses.

In this study, when at least 2.5 mm of rainfall occurs within 4 days after urea application, NH_3 loss will be limited and corn yields will not be significantly reduced. In grass pastures, however, rainfall must occur within 24 h to prevent significant NH_3 loss. The more rapid NH_3 loss from urea applications in grass pastures, compared with corn, may be due to higher temperatures, more plant residues of the soil surface, or to high urease activity in the grass pasture. A good method for determining the amounts of NH_3 volatilized is presented in the "Materials and Methods" section of this paper.

785. O'Connor, G. A., K. L. Knudtsen, and G. A. Connell. Phosphorus Solubility in Sludge-Amended Calcareous Soils. J. Environ. Qual., v. 15, No. 3, 1986, pp. 308-312.

The effects of sewage sludge amendments on phosphorus solubility relationships were determined using calcareous New Mexico soils. Soils from field and greenhouse soil-fertility and crop-production experiments were used. Phosphorus solubility was expressed using solubility diagrams for secondary calcium-phosphorus compounds found in soils. The field and greenhouse studies showed that sludge amendments increased phosphorus levels in the calcareous soils used. The increased solubility of phosphorus was not due to the phosphorus in the sewage sludge, but to the secondary effect of decreasing soil pH slightly.

786. Odom, J. W., and G. L. Mullins. Evaluation of a Brass Recycling Plant Slag as a Micronutrient Fertilizer. Am. Soc. Agron., Agron. Abstr., 1988, p. 44.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. This greenhouse experiment was conducted to determine the effectiveness of slag from a brass recycling plant as a micronutrient. Hybrid sorghum (*Sorghum bicolor* (L.) Moench C.V. Summergrazer-3) was grown in an acid sandy loam soil. Slag was added at rates comparable to 0 to 6 mg kg^{-1} Zn. Using this soil, slag additions were effective in increasing the boron and zinc contents of sorghum tissue.

787. Ogle, P. R., and E. F. Redente. Plant Succession on Surface Mined Lands in the West. Rangelands, v. 10, No. 1, 1988, pp. 37-42.

A literature review is presented on plant succession and reclamation practices that can induce succession on mined lands in the West. Successional factors that can be manipulated to induce succession include organisms, parent material, and relief. The organism factor includes the soil biota, vascular plants, and animals. Parent material or soils can affect plant species composition in a particular area, while relief or topography influences plant community development through effects on microclimate and pedogenesis. Reclamation techniques that can accelerate

or direct plant community development on mined lands include grading, topsoil replacement, species selection, mulching, planting methods, irrigation, and postreclamation management.

788. O'Hagan, M., and F. T. Caruccio. The Effect of Admixed Limestone on the Rates of Pyrite Oxidation in Low, Medium, and High Sulfur Rocks. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, p. 155.

Abstract of a paper presented at the National Symposium. A leaching experiment was conducted using three rock types (alkaline shale with a total sulfur content of 0.25 pct, nonalkaline shale with a total sulfur content of 1.07 pct, and a preparation plant refuse with a total sulfur content of 4.40 pct) to simulate conditions with an admixed gob pile or reclaimed backfill. Limestone was admixed to each rock type at rates of 1, 2, 3, and 5 pct by weight. The samples were leached for 12 weeks and analyzed for pH, specific conductance, alkalinity, sulfate, iron, calcium and magnesium, and the presence of *Thiobacillus ferrooxidans*. In the alkaline shale, leachates were neutral to alkaline, which was attributable to a low sulfur (pyrite) content, a high intrinsic neutralization potential, and the absence of *Thiobacillus ferrooxidans*. The noncalcareous shale produced leachates that ranged from acidic (0 pct limestone) to neutral or slightly acidic (1 and 2 pct limestone) to alkaline (3 and 5 pct limestone). Limestone was effective in neutralizing oxidation products and delaying acidification in this medium-sulfur sample. The high-sulfur rock produced highly acidic, iron-rich leachates throughout the experiment. Limestone additions had little effect on these samples compared with the nontreated high-sulfur rock.

789. Ohlsson, K. E., A. E. Robb, Jr., C. E. Guindon, Jr., and L. J. Slaski. Management Practices for Fish and Wildlife on Surface Mined Lands in Northern Appalachia. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 517-520.

The authors provide a summary of a handbook (entry 790) that identifies and describes the management practices available for protecting and enhancing fish, wildlife, and their habitats during surface mining and reclamation in northern Appalachia. Each management practice described in the handbook contains information on the purpose, description, construction, materials needed, maintenance, and an evaluation of the practice utilized. Each of the major sections of the handbook is reviewed in this paper, and it is stressed that fish and wildlife habitat is a viable postmining land use, either alone or in conjuction with other land use plans.

790. Ohlsson, K. E., A. E. Robb, Jr., C. E. Guindon, Jr., and R. L. Smith. Best Current Practices for Fish and Wildlife on Surface Mined Land in the Northern Appalachian Coal Region. U.S. Fish and Wildl. Serv., FWS/OBS-81/45, 1982, 305 pp.

This handbook was designed to provide ideas for simple, cost-effective methods of improving fish and wildlife resources on reclaimed surface coal mines in the northern Appalachian coal regions. It covers wildlife enhancement methods for both aquatic and terrestrial environments. It provides an extensive review of methods of revegetating land for wildlife purposes. Subjects covered include species selection, methods of soil modification to create vegetated areas suitable for wildlife, soil amendments necessary to establish vegetation, and methods of obtaining and planting seed, cuttings, and transplants for wildlife purposes. The discussion includes methods of planting areas with trees, shrubs, and herbaceous vegetation to create "edge" habitat necessary for wildlife diversity. Selecting and planting aquatic vegetation is also reviewed. This is an excellent document for anyone interested in enhancing fish and wildlife resources in the northern Appalachian coal region.

791. O'Keefe, B. E., J. Axley, and J. J. Meisinger. Evaluation of Nitrogen Availability Indexes for a Sludge Compost Amended Soil. J. Environ. Qual., v. 15, No. 2, 1986, pp. 121-128.

This study evaluated the biological and chemical methods of assessing nitrogen availability through correlation and regression analysis with total nitrogen uptake by field-grown corn (*Zea mays* L.) and the residual nitrogen effects of composted sewage sludge additions. Composted, lime-stabilized raw sludge was applied at 0, 56, 112, and 224 Mg ha^{-1} over a 4-year period. The biological method used to assess nitrogen availability was an aerobic incubation, while the chemical methods used included total Kjeldahl nitrogen, autoclave-extractable nitrogen, KCl-extractable NH_4-nitrogen, and acid permanganate ($KMnO_4$)-extractable nitrogen. The cumulative net nitrogen mineralized, as assessed by the biological method, showed that there was an initial rapid mineralization phase during the first 28 weeks followed by a slower, constant phase over the remaining weeks to week 73. All chemical indexes of nitrogen availability indicated that there is a linear relationship between sludge application rate and nitrogen availability. The chemical methods and the aerobic incubation method were equal in their assessment

of nitrogen availability over a wide range of total soil nitrogen. These results showed that chemical indexes of nitrogen availability can be used to assess soil nitrogen availability if the soil-crop-climate conditions are known.

792. Olem, H. Coal and Coal Mine Drainage. J. Water Pollut. Control Fed., v. 60, No. 6, 1988, pp. 886-890.

This article reviews recent literature on coal and coal mine drainage topics. The article is divided into discussions on the following topics: (1) environmental regulation, (2) coal mine drainage characterization, (3) coal mine drainage process and mitigation studies, (4) coal mine drainage models, (5) coal cleaning, and (6) coal transportation and storage. A total of 67 references are included in the literature review. This article was included in the review process because it contains references on environmental regulation and mitigation studies of acid coal mine drainage.

793. Olsen, F. J., and J. H. Jones. Characterization of Organically Amended Parent Materials on Reconstructed Prime Farmland for Corn Production. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 84-93.

The chemical and physical properties of four parent materials amended with animal manure were compared with those of replaced topsoil for corn (*Zea mays* L.) production at a southern Illinois surface mine site. The four parent materials used were (1) the original B horizon, (2) loess, (3) glacial till, and (4) a mixture of the entire profile minus the A horizon. Each of the four soil mediums was treated with (1) unamended spoil (control), (2) 50 Mg ha^{-1} cattle manure, (3) 100 Mg ha^{-1} cattle manure, (4) 200 Mg ha^{-1} cattle manure, and (5) 30 cm of replaced topsoil. Surface bulk densities decreased with increased rates of added cattle manure. The organic matter levels of soils treated with 200 Mg ha^{-1} cattle manure approached the organic matter content of the replaced topsoil. Average corn grain yields over a 2-year period indicated that all manure treatments resulted in corn yields that were comparable to those obtained on replaced topsoil. The authors state that it is not the level of organic matter that is important for optimal yields, but the addition of fresh organic matter annually through the use of organic amendments. Manure treatments resulted in better soil physical conditions because of increased organic matter and decreased bulk densities.

794. Olsen, F. J., J. H. Jones, D. M. Curnock, B. Davies, and R. J. Christ. Corn Production on Different Parent Materials Amended With Cattle Manure Compared to Topsoil Replacement on Strip Mined Prime Farmland. Am. Soc. Agron., Agron. Abstr., 1984, p. 32.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. The effects of incorporating various rates of cattle manure into four different parent materials compared with topsoil replacement on corn (*Zea mays* L.) growth and production were evaluated. The soil materials studied were B horizon, loess, glacial till, and a mixture of these materials. Cattle manure was applied at 0, 50, 100, and 200 Mg ha^{-1} on a dry-weight basis. No nutrient deficiencies were found, and corn yields on cattle manure treatments were comparable to those on replaced topsoil.

795. Olsen, S. H., and S. J. Henning. Nitrogen Fertilization of Corn on a Reconstructed Soil at a Surface Coal Mine. Paper in 1980 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 1-5, 1980). Univ. KY, Lexington, KY, 1980, pp. 23-25.

This article presents data from a 2-year study on the effects of nitrogen fertilizer application and deep tillage treatments on corn (*Zea mays* L.) yields in Mahaska County, IA. The Lester Pfister 75 hybrid was planted at a rate of 47,000 seeds per hectare. Maximum yields were obtained with nitrogen application rates of 250 to 300 kg ha^{-1}. This rate is approximately 25 pct higher than the rate recommended for undisturbed land in the area, but is justified because of the low fertility status and poor soil physical conditions of mined land. When deep tillage treatments are used, less nitrogen fertilizer may be needed to obtain maximum corn yields. Information on herbicide and pesticide application rates and the nutrient status (nitrogen, phosphorus, and potassium) of corn leaves is also presented.

796. Olson, C. The Alaska Department of Natural Resources and Soil Productivity. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 8-10.

This paper discusses the policies of the Alaska Department of Natural Resources (DNR) concerning soil management, the rationale for this management, and the objectives of the established policies. Maintaining or enhancing soil productivity are two soil management objectives stated by the Alaska DNR. Activities to achieve these goals are presented.

797. Olson, G. L., D. W. Maunder, and J. C. Burdick. Western Coal Conservation: Unique Problem, Unique Solutions. Coal Min., v. 24, No. 5, 1987, pp. 36-40.

The article discusses the successful reclamation techniques utilized at the Jacobs Ranch Mine located near Gillette, WY. The goal of the reclamation program is to return the land to native rangeland for cattle grazing. Techniques used include topsoiling regraded backfill, mulching and stubble mulching, and permanent revegetation using a mixture of native perennial grasses and shrubs. Other reclamation techniques discussed include duplicating contours, piling of large rock (which provides wildlife habitat), erosion control, sediment control, slope stabilization, and wildlife land uses. This article provides good background information on a successful reclamation program.

798. Olson, K. R., and R. L. Jones. Agronomic Use of Scrubber Sludge and Soil as Amendments to Lake Springfield Sediment Dredgings. J. Soil and Water Conserv., v. 42, No. 1, 1987, pp. 57-60.

This greenhouse study was conducted to evaluate the agronomic potential of scrubber sludge and lake sediments and the main effects and interactions of various combinations of eroded soil, sediment, and scrubber sludge on sudangrass (*Sorghum sudanense* (Piper) Stapf.) yields. Soil and sediment were mixed at five different ratios, ranging from 0:100 soil to sediment, to 100:0 soil to sediment, and placed in 20-cm-diameter pots. Pots were then treated with 0, 1, 2, 4, or 8 pct scrubber sludge. None of the soil-sediment-sludge treatments received fertilizer. Sudangrass was seeded and harvested at 30-day intervals for a total of three cuttings. At the first cutting, sediment treatments (100 pct) had an agronomic advantage over soil (100 pct) at all levels of scrubber sludge owing to the more favorable physical and chemical characteristics of the lake sediments. Additionally, mixing soil into sediments reduced sudangrass yields in the absence of scrubber sludge. The highest yields occurred when 2 pct scrubber sludge was added to all combinations of soil and sediment, while 8 pct scrubber sludge dramatically reduced yields for all combinations of soil and sediment. The results show that sudangrass grew better in lake sediments than in eroded soils. If the objective is to use scrubber sludge and lake sediments as amendments to eroded soils, the authors recommend that the optimum combination would be 75 pct sediment, 25 pct soil, and 2 pct scrubber sludge, based on the results of this study.

799. Olson, K. R., and R. L. Jones. Effects of Scrubber Sludge on Soil and Dredged Sediment Aggregation and Porosity. Soil Sci., v. 145, No. 1, 1988, pp. 63-69.

A greenhouse study was conducted to evaluate the effect of scrubber sludge, in the form of calcium sulfate ($CaSO_4$), on the aggregation and porosity of various combinations of dredged sediments and topsoil in the presence of sudangrass (*Sorghum sudanense* (Piper) Stapf.) roots. Both pore-size classes and corresponding volumes were evaluated, along with their impact on water storage and transmission. Dredged lake sediments and the top 20 cm of soil (a fine-silty, mixed, mesic Typic Agriudoll) were mixed at 0, 25, 50, 75, and 100 pct with each other, and various applications (0, 1, 2, 4, and 8 pct) of dried scrubber sludge were added.

Applications of scrubber sludge resulted in decreased aggregation and increased total porosity for all combinations of topsoil and lake sediment. The scrubber sludge had a flocculating effect on sediment particles, which prevented them from packing together. Transmission (>50 μm), water storage (0.5 to 50 μm), and residual (<0.5 μm) classes and pore-size volumes differed between topsoil and sediment, and with the addition of scrubber sludge. The scrubber sludge decreased the residual pore volume and water storage capacity of the sediments, but increased the transmission and total porosity, resulting in higher rates of saturated flow, compared with results for sediments without scrubber sludge. For the topsoil, the residual and transmission pore volumes decreased, while water storage pore volume increased. This article is an excellent reference on the effects of scrubber sludge on soil aggregation and porosity.

800. Olson, R. A. Ecology of Wetland Vegetation on Selected Strip Mine Ponds and Stockdams in the Northern Great Plains. Ph.D. Thesis, ND State Univ., Fargo, ND, June 1979, 493 pp.

This thesis reports the results of an extensive examination of the wetland plant communities of strip mine ponds and stockdams in five geographical locations in the Northern Great Plains Coal Mining Region. Density, frequency, relative density, relative frequency, relative canopy coverage, and an importance value were calculated for plant species encountered in randomly located 0.25-m^2 quadrats to characterize each major wetland community. Stockdams were found to be floristically richer than strip mine ponds. Plant communities were distributed in narrow concentric bands around strip mine ponds, compared with the wider, complex mosaic patterns of vegetation associated with stockdams. The magnitude of summer drawdown and basin slope were found to be major factors determining wetland community attributes. The author recommends contouring existing rangeland strip mine ponds to reclaim wetland community ecosystems. Extensive species composition, production, and plant cover data are presented. The publication is an excellent reference for revegetation planning in the Northern Great Plains Coal Mining Region and with prudent

consideration could find application over a broader geographical area.

801. Olson, R. A. Wetland Vegetation, Environmental Factors, and Their Interaction in Strip Mine Ponds, Stockdams, and Natural Wetlands. U.S. For. Serv., Gen. Tech. Rep. RM-85, July 1981, 19 pp.

This publication offers a concise review of the water regime, chemical features, temperature factors, light penetration, substrate properties, and physical characteristics for strip mine ponds and stockdams in the Northern Great Plains Coal Mining Region. The author discusses how these parameters interact to determine wetland plant community composition and the consequent wildlife habitat quality for consumptive and nonconsumptive resource utilization. This publication is a good general reference for revegetation planning in the Northern Great Plains Coal Mining Region and with prudent consideration could find application over a broader geographical area.

802. Opeka, T., and R. Morse. Use of Green-Manure Amendments and Tillage To Improve Minesoil Productivity (U.S. EPA-IAG contract DG-E762 and U.S. SEA-CR contract 684-15-26, VA Polytech. Inst. and State Univ.). U.S. EPA, Rep. EPA-600/7-29-257, Dec. 1979, 85 pp.

This report relates the results of a 2-year study conducted in Buchanan and Wise Counties, VA. The purpose of study was to examine the effects of green-manure crops and tillage treatments on vegetable crop growth and yield. Normal and deep tillage treatments produced the best yields on calcareous soils, whereas minimum and normal tillage treatments produced the best results on acid soils. The differences appeared to be moisture related. The normal and deep tillage treatments on calcareous soils tended to have higher moisture levels and the highest infiltration rates. On the acid mine soils, minimum tillage plots tended to have higher moisture content throughout their profiles than did the other treatments. Increased depth of tillage and incorporation of lime plus green-manure crops tended to improve the mine-soil productivity by improving some of the physical and chemical characteristics. This report is of particular importance to reclamation planning in the Appalachian area. It indicates that, with favorable economic and climatic conditions, the production of certain horticultural and agronomic crops is a potential alternative.

803. Orr, H. K. Reestablishment of Wooded Waterways and Associated Upland Shrub Communities in Surface Coal Mining Areas of the Northwestern Great Plains. Paper in Fifth Symposium on Surface Mining and Reclamation (NCA/BCR Coal Conf. and Expo IV, Louisville, KY, Oct. 18-20, 1977). Natl. Coal Assoc. and Bitum. Coal Res., 1977, pp. 235-244.

This study examined suitable methods and species for reestablishment of woody vegetation along waterways and associated upland sites. Various combinations of cultural treatments and plant species can be used for planting in waterways depending on slope, aspect, and spoil characteristics. Low shrubs such as big sagebrush (*Artemisia tridentata* Nutt.), rubber rabbitbrush (*Chrysothamnus nauseosus* (Pall.) Britt.), four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.), and winterfat (*Eurotia lanata* (Pursh) Moq.) can be established on south-facing slopes and adjacent uplands. On these sites erosion can be minimized and moisture conserved by contour furrowing. On north-facing slopes, taller species such as green ash (*Fraxinus pennsylvanica* Marsh.), cottonwood (*Populus sargentii* Dode), Russian olive (*Elaeagnus angustifolia* L.), Siberian pea shrub (*Caragana arborescens* Lam.), and silver buffaloberry (*Shepherdia argentea* (Pursh.) Nutt.) are adaptable. On these aspects and selected locations on other aspects, Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) and ponderosa pine (*Pinus ponderosa* Dougl. ex P. & C. Laws.) can also be established. Establishment and survival of these species may be enhanced if supplemental water and moisture conservation measures, such as contour furrowing and/or mulching, are applied. No given species was consistently successful in terms of initial establishment. Container-grown stock was reported superior for the conifer species. Initial survival rates were higher for bare-root stock for the deciduous species. This paper is a good reference for planning revegetation and stock selection of deciduous species in the Northern Great Plains Coal Mining Region and may find application in the Rocky Mountain Coal Mining Region as well.

804. Ostler, W. K., K. L. Allred, and D. J. Hansen. A Field Survey of Reclamation Practices in the Overthrust Belt. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam, 1985, pp. 190-195.

The most common reclamation problems of oil and gas disturbances in the Overthrust Belt (WY, UT, and ID) were determined, and successful and unsuccessful reclamation practices were identified. Disturbances included wellsites, roads, and pipelines. At each of the 101 sites studied, descriptive information was collected concerning location, elevation, types and extent of disturbance, topography, land use ownership, vegetation types and dominant vegetation, and special problems such as erosion.

Erosion occurrence was determined using a modification of BLM's Erosion Condition Classification. Factors influencing erosion, such as slope steepness, length, and soil texture, were determined. Vegetation cover, cover of perennial species, cover of litter, and cover of rock and bare ground were visually estimated. The factor most influential in determining the erosion condition was slope, a positive correlation. Other factors contributing included rock cover, vegetation cover, and silt percentage of the soil, all negatively correlated.

Proper reclamation procedures can greatly decrease the amount of erosion that takes place. Proper erosion control on steep slopes (31 to 70 pct) included topsoiling, seeding, and mulching, with netting to keep the mulch in place. Water control methods were also used effectively to divert water around or down the slopes. Vegetation reestablishment was dependent on precipitation and on reclamation techniques such as seeding, mulching, and netting. The most important variable in predicting perennial cover was age, followed by silt content (more silt implied higher vegetative cover), and slope (more gentle slopes having greater perennial cover). Examples of mulches used are presented. The use of mulch and netting does not preclude the use of water control devices. The use of topsoil also enhanced vegetation reestablishment; the topsoiled areas had higher perennial cover, total cover, number of species present, and a better erosion condition classification.

805. Oyler, J. A. Evaluation of Sludge/Fly Ash Mixtures and Herbaceous Species Performance To Reclaim Metals Contaminated Site Near a Zinc Smelter. Am. Soc. Agron., Agron. Abstr., 1987, p. 32.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Sludge and fly ash mixtures, lime, and potash were used to amend a zinc smelter site in Pennsylvania. Three ratios of sludge and fly ash were used, blown onto the site (no incorporation), and the site was planted using metal-tolerant species. For all species tested, the 1:1 ratio was superior.

806. Oyler, J. A. Reclamation of Site Near a Smelter Using Sludge/Fly Ash Amendments: Herbaceous Species. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 22-31.

The author discusses the results of a remedial investigation undertaken at an EPA Superfund site located at Blue Mountain, Carbon County, PA. A brief history of the zinc smelting operations and resulting effects of SO_4 emissions on the vegetation and particulate metal buildup in the soil is presented. Greenhouse and field studies were conducted to determine the feasibility of reclaiming the site using applications of limestone, potash, sewage sludge, and powerplant fly ash followed by the hydroseeding and mulching of adapted species. It was determined that smelter-affected soils could be ameliorated by treating the site with the appropriate sludge and fly ash mixture and planting suitable herbaceous species.

The greenhouse study was conducted to evaluate the proposed amendments and to screen herbaceous species. Treatments consisted of five sewage sludge and fly ash mixtures and a control. Prior to application, contaminated soil was limed (10 tons per acre) and fertilized with 80 lb $acre^{-1}$ K. The mix ratios used were 1 sludge; 1 sludge to 1 fly ash; 2 sludge to 1 fly ash; 3 sludge to 1 fly ash; 3 sludge to 1 fly ash with humus from the site added; and a control. Twelve species, grasses and legumes, were evaluated based on germination and height growth, root development, total plant biomass, foliar and root nutrient, and metal concentration.

Based on the greenhouse evaluation, five grasses and two legumes were evaluated in the field. The species tested were switchgrass (*Panicum virgatum* L.), tall fescue (*Festuca arundinacea* Schreb.), intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), big bluestem (*Andropogon gerardi* Vitman.), perennial ryegrass (*Lolium perenne* L.), birdsfoot trefoil (*Lotus corniculatus* L.), and flatpea (*Lathyrus sylvestris* L.). Lime and potassium fertilizer were applied to all field plots at the same rates as were used in the greenhouse study. The sludge and fly ash mix ratios used were 1 sewage sludge (105 tons per acre) to 1 fly ash (105 tons per acre); 2 sewage sludge (105 tons per acre) to 1 fly ash (52.5 tons per acre); 3 sewage sludge (105 tons per acre) to 1 fly ash (35 tons per acre); and a control. Plant performance data were collected for each treatment and species. Data collected included number of plants per foot, height, vigor rating, root development, number of invading species, and plant uptake of nutrients and metals. Any overland movement of the sludge and fly ash mixtures was also noted. Germination and plant performance of the legume species were poor, while the responses of grasses and those legumes that did germinate were generally best on the 1:1 amendment ratio, followed by the 2:1 ratio. Based on these results the author states that either the 1:1 amendment ratio or the 2:1 amendment ratio have the most merit for use on the zinc smelting contaminated soils studied.

807. Packee, E. C. Correlation of Forest Growth and Yield With Soil Characteristics. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 37-42.

Forest site quality is defined, and the approaches used to estimate site quality are discussed. Methods discussed

include site index, soil-site correlations, and the relationship of site quality to the soil unit. The advantages and disadvantages of each method are presented. The methods discussed to estimate site quality may be useful in determining site quality of reforested surface-mined sites.

808. Packer, P. E., C. E. Jensen, E. L. Noble, and J. A. Marshall. Estimating Revegetation Potentials of Land Surface Mined for Coal in the West. Paper in Ecology and Coal Resource Development, Volume 1 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 396-411.

The primary objectives of this investigation were to develop capabilities for predicting the degree of revegetation success to be expected under a wide variety of climatic conditions, soil and spoil properties, and revegetation treatments, utilizing site-specific revegetation data and information from many of the major coal surface mines in North Dakota, Montana, Wyoming, Colorado, Utah, New Mexico, and Arizona. It was assumed that, unless some other revegetation objective is defined, the primary goal of revegetation on surface-mined coal in the interior West is to establish a productive and protective cover of durable plants consisting predominantly of needed species adapted to and characteristic of these areas or other, similar areas before mining. It was further assumed that differences in the degree of success of revegetation efforts to date on surface-mined coal lands of the West should be related to variations in natural climatic components, changes in site-specific physical and biological characteristics, and differences in the revegetation methods. Multiple regression models were developed for estimating forage production and plant cover densities as functions of climatic environmental components, growth medium characteristics, and revegetation treatment alternatives.

The results of the study indicate that the amount of forage produced and the density of plant cover developed are significantly affected by at least two major climatic factors that are not readily susceptible to alteration—annual precipitation and length of growing season. Three properties of spoil materials were found to be significantly related to production and cover: potassium and sodium content and pH. Seven revegetation treatments, including tilling, seeding methods, topsoiling, fertilizing, supplemental irrigation, mulching, and time of seeding, were also found to be related to forage production and ground cover. Finally, the age of the vegetation also significantly affected forage cover and production. All of these factors together accounted for about one-half to three-fourths of the variations experienced in forage production and plant cover density.

809. Packer, P. E., C. E. Jensen, E. L. Noble, and J. A. Marshall. Models To Estimate Revegetation Potentials of Land Surface Mined for Coal in the West. U.S. For. Serv., Gen. Tech. Rep. INT-123, Aug. 1982, 25 pp.

The objectives of this research were to develop methods to estimate the degree of revegetation success obtainable under a wide variety of climatic conditions, soil and spoil properties, and revegetation treatments, using site-specific data and information from most of the surface coal mines rehabilitated through 1976 in the interior West. A strong conceptual framework was developed in the form of FORTRAN IV regression models to estimate forage production and vegetative cover for native and introduced species. Maps were also developed depicting precipitation and growing season. Seven revegetation treatments and the age of vegetation completed the list of major controlling factors, accounting for 50 to 75 pct of the total variance in forage production and plant cover density.

810. Padley, E. A., and C. C. Trettin. Vegetative Growth on Mine Tailings Following Applications of Municipal Sludge. Am. Soc. Agron., Agron. Abstr., 1984, p. 32.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. Sewage sludge was applied to iron mine tailings in a greenhouse study to determine if the growth of alfalfa (*Medicago sativa* L.) and creeping red fescue (*Festuca rubra* L.) would be improved. Applications of sludge at 22.4 Mg ha^{-1} increased yield to an average of 16.7 kg ha^{-1}, while 56.0 kg ha^{-1} of sludge resulted in yields of 3.6 kg ha^{-1}. The control treatment had average yields of 3.2 kg ha^{-1}. Fertilizer (12-12-12) applications at 336 kg ha^{-1} to the 22.4-Mg-ha^{-1} sludge treatment increased average yields to 19.8 kg ha^{-1}. Uptake of nutrients by planted species was related to the characteristics of the tailings rather than to sludge or fertilizer applications.

811. Paganelle, D. J., J. N. Hockman, and J. A. Durger. Phosphorus Distribution in Three Loblolly Pine Plantations After Different Site Preparation. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 384-388.

The effects of three site preparation methods on site phosphorus distribution, tree size, total biomass, and overall nutrition of planted, genetically improved loblolly pine (*Pinus taeda* L.) were studied after three growing seasons at three plantations located in the Virginia Piedmont area. The site preparation methods used were (1) shear, rake, disk, (2) chop and burn, and (3) shear-disk. The shear, rake, disk treatment (most intensive) resulted in the greatest total biomass and phosphorus content of the planted

pines. Biomass and phosphorus content of the native vegetation were greatest in the shear-disk treatment (least intensive), indicating lower control of competing vegetation, but greater nutrient conservation. Forest floor biomass and phosphorus content were also greatest in this treatment, indicating phosphorus conservation. The phosphorus content of the upper 15 cm of soil was greatest in the shear-disk treatment. The more intensive treatments resulted in more pines per hectare, taller trees with larger root collar diameters, and larger volume index values. These intensive treatments also resulted in a redistribution of site phosphorus, while the shear-disk treatment resulted in little loss of site phosphorus. Regardless of treatment, no apparent phosphorus deficiency was present in any of the plantations after three growing seasons.

812. Palkovics, W. E., L. D. Hepner, and T. D. Cordrey. The Effects of Lime Stabilization on Viral and Bacterial Levels in Sewage. Am. Soc. Agron., Agron. Abstr., 1986, p. 35.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. The effects of lime additions to raw sewage on microbial forms were studied. Conclusions are presented.

813. Parady, F. E., III. Reclamation Techniques in Southwestern Wyoming. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 87-93.

The reclamation techniques used at the Bridger Coal Co. surface coal mine in southwestern Wyoming are described. Soil management techniques include segregation of the soil horizons into the surface 6 in and the subsoil (the balance). Unsuitable soil materials are identified. Direct application of soil is used to achieve diversity when native species are included in the revegetation plan. Plant establishment techniques are described. Fertilization has been used, but the utility of fertilization is limited to years with average or above-average precipitation.

814. Parady, F. E., III. Reclamation Techniques in Southwestern Wyoming. Environ. Geochem. Health, v. 7, No. 1, 1985, pp. 26-27.

Information is presented on the reclamation techniques, based on local conditions, used by the Bridger Coal Co. located in southwestern Wyoming. Typical soils are coarse textured, with an average pH of 7.5 to 8.0 and electrical conductivity ranging from 4.0 to 6.0 mmho cm^{-1}. There are elevated levels of salinity, sodicity, and boron. Unsuitable native soils are identified and are not moved onto recontoured areas unless soil heterogeneity is desired. During the mining operations, soil horizons are segregated into topsoil (surface 6 in) and subsoil (the rest). Replaced soil depth ranges from 6 to 60 in, with an average of 15 in. Soil that is removed during mining is either stockpiled or hauled directly (direct application) onto a recontoured area. Associated costs of direct application (longer hauls) are offset by eliminating double handling of the stockpiled topsoil. Information is given on the seeding systems and shrub establishment techniques used at the minesite. General information is given on the fertilizer program utilized.

815. Parker, L. W., N. Z. Elkins, E. F. Aldon, and W. G. Whitford. Decomposition and Soil Biota After Reclamation of Coal Mine Spoils in an Arid Region. Biol. and Fertil. Soils, v. 4, 1987, pp. 129-135.

The authors hypothesize that the development of the soil biota should parallel the development of a plant community on mine spoils and that the decomposition rates and soil biota of older reclaimed sites would be more similar to those of unmined sites than to those of newly reclaimed sites. These hypotheses were tested on reclaimed areas in northern New Mexico by comparing an unmined pinon juniper site to four adjacent mined sites reclaimed by the same procedures and amended with the same topsoil. The sites had been reclaimed 1, 2, 3, and 4 years prior to the initiation of this study. The soil microflora was compared across sites by taking five replicate soil samples on each site. Litterbags containing 10 g of fresh barley straw (*Hordeum vulgare* L.) were buried at a depth of 5 cm at each site. Bags were removed 37, 85, and 127 days after burial to estimate nematode, microarthropod, and microbial populations, as well as nitrogen concentration and decomposition rates. Plant standing crop was estimated at the end of each growing season at each site.

Numbers of denitrifiers were highest in the 1- and 2-year-old sites and lowest in the 3- and 4-year-old sites, which had numbers that were not significantly different from those of the unmined site. Nitrifying bacteria were higher on all reclaimed sites than on the unmined site, with no significant differences among reclaimed areas of different ages. *Azotobacter* spp. decreased as the time since reclamation increased. Total bacteria were greatest on the 1-year-old reclaimed site and unmined site and lowest on the 3-year-old reclaimed site. Rates of decomposition were highest on the unmined site. On reclaimed sites the decomposition rates of buried straw were significantly higher on the 1- and 2-year-old sites than on the 3- and 4-year-old sites. Population densities of bacteria, fungi, and protozoans on buried straw were similar in older reclaimed and unmined sites. The population

densities of these taxa were higher on younger reclaimed sites. Density and number of microarthropod taxa were greater in the unmined site on all sampling dates than in reclaimed sites. Standing crop biomass was highest on the 4-year-old reclaimed site and lowest on the unmined site. The addition of straw and topsoil to reclaimed areas resulted in initially large heterotrophic microbial populations. As the straw decomposed, however, the organic matter reserves were depleted and bacterial numbers decreased. As a result the bacterial-based food web was reduced in the decomposing straw and contributed to the lower rates of decomposition in the 4-year site. The input of new organic matter was essential for the continuation of the fungal-based detrital food web. Large differences existed between reclaimed sites and the undisturbed area in terms of soil process and populations of soil biota. Qualitative and quantitative data on soil fauna provide an index of the relative success of reclamation procedures in restoring soil microflora and soil processes. The authors found that relationships exist between species composition and densities of soil microarthropods and decomposition.

816. Parker, L. W., and W. G. Whitford. The Detrital Food Web and Surface Mine Reclamation. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 319-321.

The detrital food web, a complex mixture of microflora and microfauna that decompose dead organic matter, recycles the energy and nutrients immobilized in detritus. A detrital food web must be established as quickly as possible on disturbed sites through inoculation. Topsoiling and mulching are two amendments that can be used as an inoculant of detrital food web organisms, topsoil, and as an energy and nutrient pool to maintain detrital food web organisms until sufficient carbon input occurs. This article reviews the current knowledge on detrital food webs and the establishment of detrital food webs on reclaimed mine spoils.

817. Parkinson, D. Microbes, Mycorrhizae and Mine Spoil. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 634-642.

This paper provides a succinct literature review of soil microbiology and mycorrhizae as they pertain to mine-land reclamation. The paper provides good background reading that would be useful to individuals with little or no experience in the subject.

818. Parmenter, R. R., and J. A. MacMahon. Early Successional Patterns of Arthropod Recolonization on Reclaimed Strip Mines in Southwestern Wyoming: The Ground-Dwelling Beetle Fauna (Coleoptera). Environ. Entomol., v. 16, No. 1, 1987, pp. 168-175.

The recolonization and early successional patterns of ground-dwelling beetle fauna in a 7-year sequence of reclaimed surface coal mines were compared with those on an undisturbed site in southwestern Wyoming. The seven reclaimed sites were sequentially revegetated at 1-year intervals; the three oldest sites did not receive any topsoil during reclamation, while the younger sites were covered with 10 cm of stockpiled topsoil. All mined sites were drill seeded with a native seed mix. The ground-dwelling beetle fauna was sampled using pitfall traps and was characterized by species richness, diversity, evenness, species-dominance curves, and trophic groups. Comparisons of beetle assemblages among sites were made using Jaccard's species similarity index and the Bray-Curtis similarity coefficient.

A total of 12,196 beetles representing 98 species in 19 families were captured during this study. Beetle assemblages on all plots were dominated by a few species, with the reclaimed mine plots containing more dominant species than the undisturbed plot. Cluster analyses indicated that beetle assemblages on reclaimed mine plots were within two groups, those plots with topsoil and plots without topsoil. Beetle assemblages on reclaimed mine plots were different from beetle assemblages on undisturbed mine plots with less than 30 pct similarity. Of the total species collected, 53 of the 98 were not found in the undisturbed area. Initial beetle colonization of minesites was by species that were either rare in the undisturbed area or by species that immigrated from similarly disturbed habitats. On young topsoiled plots the number of species and beetle diversity increased with maturity, while on older plots without topsoil the reverse is true. The beetle fauna may be tracking the changes in organic resources rather than soil type, however, the differences in species richness and diversity, through time, may be the results of the presence or absence of topsoil. Topsoil may have provided a more suitable substrate, allowing for greater survivorship and increased numbers of immigrant species. There was no significant relationship between total beetle species numbers or diversity and measured vegetation parameters. There was, however, a significant positive correlation between plant and herbivorous beetle species richness. There were differences between the beetle assemblages on reclaimed mine and undisturbed plots in the proportions of the different trophic groups. Reclaimed mine plots had significantly fewer herbivores, predators, and dung feeders than undisturbed plots and

significantly more fungivores and insect carrion feeders. On reclaimed plots there were significantly more omnivorous species on replaced topsoil plots than on undisturbed plots, but the mean number of omnivorous individuals was not significantly different. The colonizing species were mostly generalist feeders, feeding on seeds, weedy plants, and living and dead insects present on the reclaimed mine plots. The reorganization of the trophic structure was due to the severity of the mining disturbance. There are different food resources available on reclaimed mine plots, causing a restructuring of beetle fauna.

819. Parton, W. J., J. E. Ellis, and D. M. Swift. The Impacts of Strip Mine Reclamation Practices: A Simulation Study. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 584-591.

This computer model provides an excellent starting point for reclamation studies and planning in the Northern Great Plains and Rocky Mountain Coal Mining Regions.

820. Patra, D. D., M. S. Sachdev, and B. V. Subbiah. Forms of Fertilizer Nitrogen Residues in Soil After Intercropping of Maize-Cowpea. Biol. and Fertil. Soils, v. 4, 1987, pp. 155-161.

Field and greenhouse experiments were conducted to assess the effect of various types of cropping systems on the fate of residual fertilizer nitrogen as well as indigenous soil nitrogen and crop residues. In the field experiment, urea was applied to corn (*Zea mays* L.) at a rate of 120 kg ha^{-1} N, to corn-cowpea (*Vigna sinensis* (L.) Engl.) intercropping at 60 kg ha^{-1} N, and to cowpea with no fertilizer nitrogen applied. In the greenhouse experiment, urea was applied to corn at a rate of 120 kg ha^{-1} N, to corn-cowpea intercropping without inoculation at a rate of 60 kg ha^{-1} N, to corn-cowpea intercropping with *Rhizobium* inoculation at a rate of 60 kg ha^{-1} N, to cowpea without inoculation and fertilization, and to cowpea with inoculation, but no fertilization. After the crops were harvested, soils were analyzed for total nitrogen, NH_4-nitrogen, organic nitrogen, and fertilizer ^{15}N residues.

Growing cowpea alone or intercropping with corn resulted in an increase in the relative amounts of acid hydrolyzable organic nitrogen fraction in the soil in both experiments. For cowpea the amount ranged from 81 to 85 pct, while for corn it ranged from 58 to 73 pct. The cropping system had a significant effect on the total nitrogen content of the soil and the distribution of nitrogen into the various organic fractions. The contribution of crop residues toward total nitrogen content of the soils was significantly higher after cowpea alone than with corn-cowpea intercropping of corn alone. Growing legumes alone or intercropping resulted in increases in the relative amounts of acid hydrolyzable and identifiable organic nitrogen fractions in the soil.

821. Payne, G. G., D. C. Martens, and L. W. Zelazny. Crop Response to Long-Term Copper-Enriched Swine Manure Applications. Am. Soc. Agron., Agron. Abstr., 1985, p. 29.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. The potential environmental hazards associated with long-term copper applications as either copper sulfate or copper-enriched swine manure on corn (*Zea mays* L.) were evaluated. Yields were not reduced and the copper concentration of the grain was not increased, even though copper was applied seven times yearly. Copper concentrations in corn ear leaves did not significantly increase, and there was little downward movement of applied copper in the soils studied.

822. Peach, J. D., J. Duffus III, B. Robinson, E. E. Young, Jr., M. R. Keppel, R. G. Kleigleng, and F. W. Imbrogno. Surface Mining: State and Federal Use of Alternative Enforcement Techniques (Report to the Chairman, Committee on Interior and Insular Affairs, House of Representatives). U.S. Gov. Account. Off., GAO/RCED-87-160, Aug. 1987, 21 pp.

State and Federal use of alternative enforcement techniques, provided under the Surface Mining and Control Reclamation Act (SMCRA), are reviewed. Injunctions, individual civil penalties, criminal action, and suspension or revocation of the mining permit are possible alternative enforcement techniques. This report focused on determining (1) whether States that have been granted primacy for regulating mining activities in their States have statutory authority to use, and are using, alternative enforcement techniques to enforce State mining requirements, (2) whether OSMRE is using such techniques in those States and areas where it retains regulatory authority, and (3) the extent to which OSMRE monitors the States' use of these techniques. The study found that although States have the authority to use SMRCA's alternative enforcement technique against operators who do not correct violations, none have developed a comprehensive system for enforcing alternative techniques.

823. Pederson, T. A., A. S. Rogowski, and R. Pennock, Jr. Comparison of Some Properties of Minesoils and Contiguous Natural Soils (U.S. EPA contract EPA-IAGD5-E763). U.S. EPA, Rep. EPA-600/7-8-162, Aug. 1978, 141 pp.

This document reports the results of investigations to evaluate soil changes due to surface coal mining and reclamation operations in Clearfield County, PA. Four mine-soil pits located within the disturbed area and four natural soil pits located in adjacent undisturbed areas were sampled and described. Mine soils exhibited a high degree of coarseness and high rock content. Roots were generally found to concentrate along soil-coarse fragment interfaces. Few roots penetrated the massive mine-soil material in the C horizons. Significantly more extractable aluminum was found in the natural soils than in the mine soils. The clay minerals present in the mine soils were less weathered than those in natural soils. Bulk densities of surface mine soils averaged 1.70 g cm^{-3} compared with 1.26 g cm^{-3} for adjacent soils.

824. Pederson, T. A., A. S. Rogowski, and R. Pennock, Jr. Comparison of Morphological and Chemical Characteristics of Some Soils and Minesoils. Reclam. Rev., v. 1, No. 3/4, 1978, pp. 143-156.

This publication is a summary of the completed EPA-600/7-8-162 contract report by the same authors. This study was conducted to determine the effects of surface mining and reclamation on mine-soil properties in Clearfield County, PA. Four mine-soil pits within a disturbed area and four natural soil pits located in an adjacent undisturbed area were sampled, described, and compared. Pedogenetic development in mine soils was minimal, and their most prominent feature was a high degree of coarseness and rock fragment content. Plant roots tended to concentrate along the coarse fragment interfaces. The concentration of chemical constituents in mine soils was similar to that found in natural soils. Significantly higher extractable aluminum content was found in the natural soils owing to prolonged weathering of the material. The carbon-nitrogen ratios of mine soils indicate that nitrogen is a limiting factor for microbial activity. The clay mineralogy of the native and mine soils indicates that the mine soils were derived from the same material as the native soil. The authors concluded that the high coarse fragment content and low cation-exchange capacity of the minesoils suggest that agronomic use of these soils is questionable without fertilization and special cultivation equipment.

825. Pederson, T. A., A. S. Rogowski, and R. Pennock, Jr. Physical Characteristics of Some Minesoils. Soil Sci. Soc. Am. J., v. 44, No. 2, 1980, pp. 321-328.

The physical properties of spoils resulting from coal surface mining and reclamation were studied at a mine in Clearfield County, PA. The objectives of the study were to determine mine-soil characteristics such as specific surface area, bulk density, moisture, water retention, hydraulic conductivity, infiltration rates, and evapotranspiration at 10 sites located within the 4-ha experimental area. The results show that the surface mining and reclamation operations at this mine have produced mine soils with an average specific area of 31 $m^2 g^{-1}$ and an average bulk density of 1,763 kg m^{-3}. The bulk density of the area first decreased and then increased with depth. Evapotranspiration, determined using microlysimeters, could be approximated by either class A pan evaporation (1.8 mm d^{-1}) or by model results (1.3 mm d^{-1}). There were large spatial variations in the infiltration rates, water retention, and hydraulic conductivity. The hydrologic implications of these physical properties are also discussed.

826. Penrose, K. D., and D. J. Hansen. Planting Techniques for Establishment of Container-Grown or Bareroot Plants. Paper in Shrub Establishment on Disturbed Arid and Semi-Arid Land (Proc. Symp., Laramie, WY, Dec. 2-3, 1980). WY Game and Fish Dep., 1981, pp. 37-46.

The authors discuss the use of container-grown and bare-root plants for rapid establishment of plant cover, productivity, and species diversity. Careful planning of all aspects of the revegetation effort is stressed. Topics discussed include (1) species and plant materials selection, (2) scheduling considerations, (3) holding facilities for planting material, (4) methods of planting and avoiding poor planting, and (5) monitoring programs for the assessment of revegetation efforts. The article is focused on revegetation of disturbed areas of the arid and semiarid regions of the Western United States.

827. Pentecost, E. D., and R. C. Stupka. Wildlife Investigations at a Coal Refuse Reclamation Site in Southern Illinois. Paper in Addendum to Proceedings of a Symposium on Surface Mining and Fish/Wildlife Needs in the Eastern United States (WV Univ., Dec. 1978). U.S. Fish and Wildl. Serv., FWS/OBS-78/81 A, 1979, pp. 107-118.

This article discusses the revegetation of a coal refuse pile near Staunton, IL, with respect to wildlife. Attempts were made to determine if wildlife colonized the site during secondary succession. Surveys were made to determine the population of mammals, birds, amphibians, and reptiles at the site. The mammalian and avian species observed were typical of old-field communities in southern Illinois. Revegetation was completed prior to the study, and little information is given on the methods used to establish vegetative cover.

828. Perel, T. S. The Nature of Eurytopy in Polyploid Earthworm Species in Relation to Their Use in Biological Soil Amelioration. Biol. and Fertil. Soils, v. 3, 1987, pp. 103-105.

Polyploidy in the earthworm family Lumbricidae is discussed. Ecological differentiation between chromosomal races of various species can be wide, enabling species to coexist in the same habitat and occupy different ecological niches. Polyploidy must be considered when using earthworms for biological soil amelioration.

829. Perry, E. F. Minesoil Properties That Influence Fish and Wildlife Habitats. Paper in Symposium on Surface Mining and Fish/Wildlife Needs in the Eastern United States (WV Univ., Dec. 1978). U.S. Fish and Wildl. Serv., FWS/OBS-78/81, 1978, pp. 223-231.

This article presents data on mine-soil classification in the Appalachian and Midwestern Coal Regions. A variety of mine soils are analyzed for chemical and physical properties. Data are given on how these properties influence postmining land use. The author has attempted to identify key mine-soil properties that influence fish and wildlife habitats.

830. Perry, E. F. Overburden Analysis: An Evaluation of Methods. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 369-375.

Four methods of assessing overburden chemical properties were reviewed: (1) acid-base account, (2) various leaching techniques, (3) computer modeling, and (4) statistical predictions. The assumptions, strengths, and limitations of each method are discussed. All methods are simplified representations of the geochemical-hydrologic systems that exist at any mine type; none of the methods are precise or exact indicators of the overburden chemical properties. Assumptions of each method must be understood in making judgments on permitting decisions and mining and reclamation plans.

831. Perry, H. M., E. F. Aldon, and J. H. Brock. Reclamation of an Asbestos Mill Waste Site in the Southwestern United States. Reclam. & Reveg. Res., v. 6, No. 3, 1987, pp. 187-196.

Asbestos wastes from a milling site near Globe, AZ, were covered (capped) with a sandy loam subsurface material (0.6 m) in an effort to prevent the movement of fibrils into the environment. Surface treatments included basin pits (1 by 1 m at 5-cm depth), contour furrows, and a control. Each surface modification was mulched with wheat straw at rates of 0, 0.5, and 1.0 Mg ha^{-1}. The experimental design was a split plot with mulching treatments nested within surface modification blocks. Treatment areas were drill seeded with indigenous species and interplanted with woody species. After two growing seasons the seeded grass species showing consistent successful establishment was Cochise lovegrass (*Eragrostis antherstonii* Stapf.), with an overall mean density of 5.3 plants per square meter. Total seeded plant density was lowest, 4.3 plants per square meter, on the contour-furrowed plots. The basin pit and no modification treatments had total seeded plant densities of 6.8 and 6.5 plants per square meter, respectively. The overall mean density of seeded plants on mulched plots after 2 growing seasons was 62 pct greater (6.6 plants per square meter) than areas without mulch (4.1 plants per square meter). After three growing seasons there were no significant differences in foliage cover or plant density as influenced by surface modification treatments. Mulching treatments continued to improve stand density and foliage cover after three growing seasons. Surface modification and mulching enhanced successful plant establishment on the capped asbestos waste. After two growing seasons, catclaw acacia (*Acacia greggii* Gray.) had a survival rate of 100 pct; however, velvet mesquite (*Prosopis velutina* Woot.), with 96 pct survival, showed greater vigor and growth. Plantings of foothill paloverde (*Cercidium floridum* Benth.) essentially failed, with only 2 of 27 plants surviving. After three growing seasons, the plantings of catclaw acacia and velvet mesquite continued to be successful. The authors state that surface modifications aided plant establishment by improving detention storage of rainfall, while mulching reduced soil temperatures and evaporation losses. When reclaiming areas in the upper Sonoran Desert, particular attention should be given to surface microtopography (enhanced infiltration and improved soil-water storage) and mulching should be used to reduce soil surface temperatures and evaporation rates.

832. Peterson, A. E., E. E. Schulte, and F. H. Gustin. Crop Response and Water Pollution Aspects of Land Application of Bottom Ash. Am. Soc. Agron., Agron. Abstr., 1987, p. 32.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Bottom ash was applied to a silty clay loam at rates of 225 and 450 Mg ha^{-1} and planted to corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.). Soil analysis to a 1-m depth indicated that there was no movement of heavy metals below the plow layer. Plant tissue analysis indicated no toxic effects from bottom ash applications.

833. Peterson, A. E., P. E. Speth, and L. R. Massie. Effect of Sewage Sludge on Crops, Soils, and Drainage Water From Tile Lines. Am. Soc. Agron., Agron. Abstr., 1986, p. 35.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. The tile lines from

two similar watersheds, one receiving applications of digested sewage sludge and the other normal farm fertilizer, were monitored along with soil chemical properties and corn (*Zea mays* L.) grain yields. After 3 years, there were no differences in the nitrate content of the drainage waters, grain yields were equal (11 Mg ha^{-1}), and no heavy metals had moved below the plow layer.

834. Petrikova, V. The Agronomical Effectivity of Manure After the Production of Biogas. Ann. Res. Inst. Crop Prod., Prague (Ruzyne), v. 24, 1986, pp. 245-259.

A pot study was conducted using fermented manure and composted manure as amendments to topsoil, overburden, and fly ash. Green maize was grown in each soil substrate that had been amended. Prior to use as a soil amendment, the fermented manure had been used to produce biogas, a supplementary energy source. Yields of green maize increased in pots amended with fermented manure compared with composted manure. In all three trial substrates, fermented manure increased the humus content and pH values compared with control and composted manure treatments. Treating the substrates with fermented manures also resulted in greater nutrient uptake by green maize compared with composted manure and control treatments.

835. Pfannenstiel, V. R., and G. W. Wendt. Enhancing Shrub Establishment by Utilizing Direct Haul Topsoil on Mine Spoils in Western Colorado. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 1-14.

The extent and composition of shrub regeneration on graded spoils with no topsoil, graded spoils with topsoil from stockpiles, and graded spoils with direct-hauled topsoil were evaluated on a western Colorado surface coal mine. Shrub establishment occurred at all study areas, but was variable within each reclamation type. Shrub establishment increased from older graded spoils with no topsoil to the younger direct-hauled topsoil areas. Big sagebrush (*Artemisia tridentata* Nutt.) and mountain snowberry (*Symphoricarpos oreophilus* Gray) contributed the highest numbers to total shrub composition on topsoiled areas, while big sagebrush and rubber rabbitbrush (*Chrysothamnus nauseous* (Pall.) Britt.) had the highest numbers on graded spoil. In areas where topsoil is replaced and direct-hauled topsoil is utilized, native shrub community reestablishment is greatly improved. The authors state that succession, begins as secondary succession on replaced topsoil, rather than primary succession, which occurs on unreclaimed spoil.

836. Phelps, L. B. Acid Mine Drainage. Ch. in Environmental Consequences of Energy Production: Problems and Prospects, ed. by S. K. Majumdar, F. J. Brenner, and E. W. Miller. PA Acad. Sci., 1987, pp. 131-140.

This chapter discusses the short- and long-term chemical effects of mining dealing with the formation of acid mine drainage. Short-term effects deal with the life of the mine, while long-term effects extend to time beyond the mine life. Acid mine drainage is produced by the oxidation of pyrite (FeS_2) and through a series of oxidation and hydrolysis reactions. As a result, ferric hydroxide, an insoluble precipitate, is formed. Acid mine drainage can be prevented if the pyrite liberated during mining is kept in an alkaline environment. Longer term control can be achieved by using calcium carbonate, while short-term control can be achieved using CaO. If the potential for spoil to generate acid mine drainage exists, it must be determined during the permitting process. An acid-base accounting of the overburden and interburden is used to determine this potential. Where potential acid-producing zones are identified, selective handling of the material can be used to place the spoil in a location not subjected to alternative wetting and drying cycles.

837. Phelps, L. B., and L. J. Holland. Soil Compaction in Topsoil Replacement During Mining Reclamation. Environ. Geochem. Health, v. 9, No. 1, 1987, pp. 8-11.

Soil compaction of stored and replaced topsoil, as influenced by soil moisture content and equipment used, was evaluated on a surface mine site in central Pennsylvania. Soil was moved and spread by either bulldozer or scrapers. As soon as the topsoil was replaced, soil moisture was analyzed gravimetrically and bulk density was measured using a sand cone. Samples were taken randomly within bulldozed plots, while half the scraper samples were taken from tire tracks and the other half from loose soil between the tires and scraper pan. All soil compaction values were compared with those obtained by the Standard Proctor laboratory compaction test. The compaction caused by each piece of equipment varied with moisture content; however, compaction was greatest under scraper tires, followed by bulldozer, and least under the scraper pans at all moisture contents.

Each level of compaction is lower than the bulk densities created by the Standard Proctor test. The fact that bulk densities in scraper tire tracks were significantly higher than bulk densities between tires is critical because tires occupy a large percentage of the scraper's swath and topsoil is replaced in long, straight passes. To the authors, the low values (1.17 to 1.21 g cm^{-3}) found under the scraper pan indicate that any compaction that occurred

when topsoil was stockpiled will be alleviated when it is respread. The authors recommend that soil should be stockpiled during the driest time of the year to reduce compaction due to soil wetness, and that the duration of storage should be kept to a minimum to reduce the amount of organic matter that decomposes during soil storage.

838. Phillips, J. M., and W. E. Sabbe. Forage Quality of Tall Fescue-Common Bermudagrass on Bauxite Minesoil as Influenced by Fertilization. Am. Soc. Agron., Agron. Abstr., 1984, p. 33.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. The influence of nitrogen, phosphorus, and potassium fertilization on the forage quality parameters of tall fescue (*Festuca arundinacea* Schreb.) and bermudagrass (*Cynodon dactylon* (L.) Pers.) were determined. Nitrogen was the most limiting nutrient in terms of forage quality.

839. Phillips, J. M., and A. E. Spooner. Dry Matter Production and Percent Ground Cover During Establishment of Selected Forage Species on Bauxite Minesoils. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 447-481.

This study was conducted to determine the adaptability of certain grass and legume species to bauxite mine soil in Saline County, AR. Brown lime was applied to the plots at a rate of 102.7 mt ha^{-1} to neutralize the acidic (pH 3.0) mine soil. The acidity problem was corrected 2 months after lime application. All cool-season species were planted in September 1980; the warm-season species were planted the following April. The forage yields obtained on the bauxite mine soils were very low compared with those observed in normal agricultural situations. The authors speculate that the low yields can be attributed to a restricted root zone, high soluble salts, and low micronutrient availability. Of the species planted, pearl millet (*Pennisetum typhoides* Burm. Stapf. & C. E. Hubb) (1,826 kg ha^{-1}) and hairy vetch (*Vicia villosa* Roth.) (1,406 kg ha^{-1}) had the highest yields for the forage grasses and legumes, respectively. The species having the best ground cover for the cool-season species were orchardgrass (*Dactylis glomerata* L.) and crimson clover (*Trifolium incarnatum* L.). The highest percent ground cover for warm-season species was found for pearl millet and common bermudagrass (*Cynodon dactylon* (L.) Pers.).

840. Philo, G. R., C. A. Kolar, and W. C. Ashby. Effects of Ripping on Minesoil Compaction and Black Walnut Establishment. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 551-557.

This study was conducted to evaluate the effects of ripping (subsoiling) graded mine soil on the survival and growth of direct-seeded black walnut (*Juglans nigra* L.) in Saline County, IL. The soil was ripped to a depth of 85 cm by a subsoiler attached to a D-8 caterpillar. Black walnut seeds were then planted in both the ripped and nonripped plots. Seedling survival in the ripped and nonripped plots during the first year was 88 and 66 pct, respectively; in July of the second season it was 85 and 64 pct, respectively. Ripping also resulted in greater stem diameter and height growth during the second growing season. Root excavations showed that root growth (length, depth, and radial spread) was significantly greater in the ripped plots than in the nonripped plots. Black walnut planted on nonripped plots had stunted taproot and lateral root development. Bulk density determinations during the second growing season indicated that ripping resulted in significant reductions in the bulk density at the 0- to 15-cm depth and 15- to 30-cm depth compared with nonripped spoil. This study showed that favorable establishment and enhanced tree growth can be achieved by ripping (subsoiling) graded surface mine spoil. It also illustrated the extent of soil compaction problems on reclaimed minesites. The authors conclude that grading standards should be altered to provide more favorable conditions for plant growth and eliminate the need for ripping.

841. Piccini, D., J. A. Ocampo, and E. J. Bedmar. Possible Influence of *Rhizobium* on VA Mycorrhiza Metabolic Activity in Double Symbiosis of Alfalfa Plants (*Medicago sativa* L.) Grown in a Pot Experiment. Biol. and Fertil. Soils, v. 6, 1988, pp. 65-67.

A greenhouse study was conducted to assess the possible effects of *Rhizobium* on VA mycorrhizae metabolic activity. Alfalfa (*Medicago sativa* L.) seeds were either uninoculated (control) or inoculated with *Rhizobium meliloti* (strain 102F28), with *Glomus fasciculatum*, or with a mixture of both micro-organisms. Nitrogenase activity, oxygen uptake, percentage VA mycorrhizal infection, plant root and shoot dry weight, and plant nutrient content were determined for each micro-organism treatment. Plants inoculated with *R. meliloti* alone or *G. fasciculatum* alone had significantly higher root and shoot dry weights compared with the controls. When both micro-organisms were used in combination, plants averaged the highest shoot dry weight. The root dry weight of alfalfa, however, was significantly higher when inoculated with only VA mycorrhizae than when both *R. meliloti* and *G. fasciculatum*

were used in combination. When plants were inoculated with both *R. meliloti* and *G. fasciculatum*, plants had a higher oxygen uptake and greater nodule nitrogenase activity than plants inoculated with either of the symbionts alone. Succinate dehydrogenase activity (indicator of metabolic activity) and percentage of VA mycorrhizae infection were similar between the mycorrhizae treatment alone and in combination with *R. meliloti*. The nutrient content of alfalfa plants was greatest in plants inoculated with both symbionts in combination than with either *R. meliloti* or *G. fasciculatum* alone. The results of this study suggest that *R. meliloti* may be affecting fungal metabolism in an undetermined biochemical pathway.

842. Pichtel, J., W. A. Dick, and P. Sutton. Comparison of Four Amendments for Long-Term Reclamation of Toxic Mine Spoil. Am. Soc. Agron., Agron. Abstr., 1985, p. 29.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. The effectiveness of municipal sewage sludge, fly ash, topsoil, and composted papermill sludge in maintaining a grass-legume mixture on mine spoil in southeastern Ohio were compared over a 7-year period. Percent ground cover, dry matter yields, and tissue analysis of the mixture were monitored. Final data indicate that the topsoiled plots had the greatest vegetative cover and the highest dry matter yields of any amendment.

843. Pierzynski, G. M., and L. W. Jacobs. Extractability and Plant Availability of Molybdenum From Inorganic and Sewage Sludge Sources. J. Environ. Qual., v. 15, No. 4, 1986, pp. 323-326.

This greenhouse study was conducted to evaluate the influence of soil pH on the uptake and extractability of molybdenum from inorganic and sludge sources. Sludge molybdenum additions were equivalent to increasing molybdenum concentrations by 0, 20, 44, and 94 mg kg^{-1} dry soil when sludge was applied at 0, 42, 94, and 200 Mg ha^{-1}. Soil not amended with sludge received molybdenum in the form of $NaMoO_4 \cdot 2H_2O$ at 0, 30, 60, and 120 mg kg^{-1} Mo. Organic and inorganic additions significantly increased molybdenum concentration in corn (*Zea mays* L.), soybeans (*Glycine max* (L.) Merr.), and alfalfa (*Medicago sativa* L.). Increasing soil pH also significantly increased molybdenum accumulation in each crop when amended with either molybdenum source.

844. Pierzynski, G. M., and L. W. Jacobs. Molybdenum Accumulation by Corn and Soybeans From a Molybdenum Rich Sewage Sludge. J. Environ. Qual., v. 15, No. 4, 1986, pp. 394-398.

This field study was conducted to evaluate the potential for molybdenum uptake by corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) when amended with molybdenum-rich sewage sludge. Two separate experiments were conducted. In the first, sludge was applied at rates of 0, 42, and 94 Mg ha^{-1}, and the potential for molybdenum uptake by corn and soybeans was monitored for 3 years. In the second experiment, corn was the only crop grown and sludge was applied at 194 (split application of 94 and 100 Mg ha^{-1}) and 200 (single application) Mg ha^{-1}. After three growing seasons, a total molybdenum analysis of the soil indicated that 97 pct of the molybdenum applied in the sewage sludge treatments was accounted for in the soil. There had been little molybdenum movement out of the plow layer. Corn and soybean yields were not significantly affected by molybdenum additions in sludge, but tissue and grain molybdenum concentrations were significantly increased in both crops. Lime treatments to all plots (4,290 kg ha^{-1}) increased soil pH from 4.8 to 7.1 and resulted in further molybdenum accumulation by both crops. Four soil extractants, along with soil pH, were evaluated as potential predictors of molybdenum accumulation by both crops. None of the extractants were proven to be better than the others.

845. Pierzynski, G. M., and L. W. Jacobs. Molybdenum Accumulation by Corn and Soybeans Grown on a Soil Amended by Mo-Rich Sewage Sludge. Am. Soc. Agron., Agron. Abstr., 1985, p. 29.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. Molybdenum accumulation by corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) grown on sludge-treated soil was evaluated over a 3-year period. Sludge was applied at rates ranging from 0 to 200 Mg ha^{-1}, with resulting molybdenum application rates ranging from 0 to 300 kg ha^{-1}. Plant tissue concentrations of molybdenum increased with sludge application. Lime present in the sludge resulted in increased soil pH's and further molybdenum accumulation by the plants. Four soil extractants were also evaluated in their ability to predict molybdenum concentration in plant tissues.

846. Pietz, R. I., J. R. Peterson, J. E. Prater, and D. R. Zenz. Metal Concentrations in Earthworms From Sewage Sludge-Amended Soils at a Strip Mine Reclamation Site. J. Environ. Qual., v. 13, No. 4, 1984, pp. 651-654.

The effect of sewage sludge amendments on the heavy-metal accumulations in earthworms was studied on Illinois mine soil and nonmined fields. Earthworms were sampled

at both sites to a depth of 20 cm, hand sorted, and analyzed for zinc, cadmium, chromium, copper, nickel, and lead. Composite soil samples were collected at each earthworm sampling site and analyzed for zinc, cadmium, chromium, copper, nickel, and lead. *Lumbricus terrestris* and *Aporrectodea tuberculata* were identified in the sludge-amended and nonamended nonmine soil, while *Aporrectodea tuberculata* was the only species found in the mine soils. During the 3-year sampling period, earthworm metal concentrations increased in all samples. The order of metal accumulation by earthworms in the sludge amended treatments was copper > cadmium > nickel > chromium > lead > zinc. Data analyses indicated that sewage sludge applications were the sources of cadmium, copper, and zinc in the earthworms. These metals are probably transferred to and may pose a potential hazard to predators.

847. Pietz, R. I., J. R. Peterson, D. R. Zenz, and C. Lue-Hing. Reclamation of Coal Refuse Material With Sewage Sludge and Other Amendments in Western Illinois. Am. Soc. Agron., Agron. Abstr., 1984, pp. 33-34.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. The effects of sewage sludge, lime, and gypsum amendments on the establishment of a vegetative cover and in improving the chemical characteristics of acidic coal refuse and percolate were determined. Treatments consisted of a control, 542 Mg ha^{-1} sewage sludge, 89.6 Mg ha^{-1} lime, 112 Mg ha^{-1} gypsum, and various combinations of the amendments. Sewage sludge and lime treatments were the most effective in maintaining refuse pH and reducing titratable acidity, water-soluble iron, and water-soluble alumimum. Forage cover increased with lime, sludge, and lime and sludge treatments. The sludge and sludge and lime treatments were the most effective in raising percolate pH and reducing zinc, copper, chromium, iron, lead, and aluminum concentrations.

848. Pionke, H. B., and A. S. Rogowski. Placement of Acid Spoil Materials. Reclam. & Reveg. Res., v. 1, No. 1, 1982, pp. 3-17.

This study evaluated how spoil placement may potentially affect the quality and quantity of drainage and ground water on reclaimed spoil located near Kylertown, PA. Two caissons were subjected to leaching by simulating field rainwater conditions. Water content was monitored for pH, total acidity, total salts, SO_4, calcium, magnesium, manganese, and iron. Results indicate that the placement of acid- and salt-containing spoils should be based on the chemical and physical spoil properties that may affect water percolation and O_2 diffusion rates. The deeper placement of acid spoil and coarser particle-sized materials can substantially reduce the amount of acid drainage.

849. Pitt, J. L., L. R. Hossner, and J. R. Melton. Nickel, Cadmium and Selenium Levels in Native Soil Overburden and Spoil Materials. Am. Soc. Agron., Agron. Abstr., 1984, p. 34.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. Nickel, cadmium, and selenium levels were compared between native soil, overburden core, and spoil materials obtained from four surface mining operations in Texas. No significant differences were found among samples for each element. The geological environments of deposition at each site did have a significant effect on the levels of nickel, cadmium, and selenium. Environments with slow deposition of fine materials had the highest concentrations of nickel and cadmium. Selenium was highest in the lignite and in deposits associated with lignite. This study indicates that no significant elevation of nickel, cadmium, or selenium would be expected from the mixing of overburden following surface mining operations in eastern Texas.

850. Pitt, J. L., L. R. Hossner, and J. R. Melton. Nickel, Cadmium, and Selenium Levels in Native Soil, Overburden, and Spoil Materials. J. Environ. Qual., v. 15, No. 2, 1986, pp. 113-116.

The variability in levels of nickel, cadmium, and selenium in native soil, overburden (premining), and spoil (postmining) materials of four surface mining sites in Texas were determined. Native soil is the surface soil to a depth of 2 m, overburden material is from surface soil that overlies the lignite seam to depths of 20 to 30 m, and spoil is randomly mixed soil and overburden material. Total composition of nickel, cadmium, and selenium was not significantly different over each sample type. Overburden had the highest concentration of nickel and cadmium. The spoil material had the next highest concentration, followed by the native soil with the lowest concentration. Selenium was highest in the lignite seams and in deposits associated with the seams. There was no significant difference in the selenium concentration between native soil, overburden, and spoil materials. The complete mixing of the overburden material is not expected to result in a significant elevation of the total nickel, cadmium, or selenium concentration.

851. Plantenberg, P. L. Factors Affecting Plant Succession on Mine Spoil at Colstrip, Montana. Pres. at 34th Annu. Meet. Soc. Range Manage. (Tulsa, OK, Feb. 9-13, 1981). MT State Univ., DOE/EV/70003-15, 1981, 16 pp.

This paper reports the results of a study designed to explain why major differences occur in dominance and succession on six naturally revegetated overburden sites originally formed in 1928 and 1930 near Colstrip, MT. The major factors affecting plant succession on overburden are reported to be overburden texture, the condition of adjacent rangeland, postmining management, and environmental modifications created by early successional plant species. This article provides an excellent reference for plant succession on naturally revegetated surface coal mine land.

852. Plass, W. T. The Establishment and Maintenance of Vegetation on Minesoils in the Eastern United States. Paper in Ecology and Coal Resource Development, Volume 1 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 431-437.

The author provides a discussion of reclamation practices in the Eastern United States summarizing technology at the time this article was written. Historical references are used to illustrate the development of specific technology. Future trends in reclamation technology are also discussed. The paper provides a concise literature review that could provide orientation and background for individuals with little or no prior knowledge of reclamation.

853. Plass, W. T. Organic and Inorganic Amendments Affect Vegetation Growth on an Acidic Minesoil. U.S. For. Serv., Northeast. For. Exp. Stn., Res. Paper NE-502, 1982, 7 pp.

This publication reports the results of a study that examined the potential of organic amendments in mine-soil revegetation treatments to produce high-density ground covers or increase the yield of pasture and forage crops. Shredded hardwood bark, composted municipal waste, and a tannery waste were applied to an acidic mine soil. Inorganic fertilizer, agricultural lime, and an alkaline waste from an SO_2 scrubber system were applied alone and in combination with the organic amendments. Mine-soil pH and specific conductance were significantly influenced by the organic amendments, but not by the inorganic amendments. Both organic and inorganic amendments reduced exchangeable acidity and exchangeable aluminum. Effective ground cover (more than 1,000 lb of green forage) was established within two growing seasons when composted municipal or tannery wastes were applied without fertilizer, lime, or scrubber waste. Where lime and fertilizers were used in combination with the various organic amendments, an effective vegetative cover was achieved in one growing season.

854. Plass, W. T. Reclamation of Coal Mined Land in Appalachia. J. Soil and Water Conserv., v. 33, No. 2, 1978, pp. 56-61.

This article reviews the sequence of reclamation operations, from mining to the establishment of vegetative cover, in Appalachia. Information is presented on overburden placement, topsoiling, soil amendments, species selection, site preparation, application of seed and fertilizer, and land management options. The goal of these operations is to return productivity to the land disturbed by surface mining.

855. Poissant, S. A., and F. T. Caruccio. The Occurrence and Viability of *Thiobacillus ferrooxidans* Under Varied Geochemical Conditions in Upshur and Lewis Counties, West Virginia. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 141-145.

The effect of two different geologic environments on the presence and viability of *Thiobacillus ferrooxidans* was evaluated. Sites were selected where the ground water emanating from the reclaimed areas was either acidic or alkaline and the differences could be attributed to the contrasting geologies, one acidic and the other neutral or slightly alkaline. At each site pH, specific conductance, temperature, calcium, magnesium, sodium, SO_4, total iron, acidity, alkalinity, net alkalinity, and the presence of *Thiobacillus ferrooxidans* (most probable number—MPN) were determined and compared. Obvious significant differences existed between the acid and alkaline sites. Positive correlations were found between MPN and acidity, total iron, SO_4, ferric iron, and the ratio of ferric to ferrous iron within a sample, while negative correlations were found between MPN and pH, alkalinity, and net alkalinity. These observations suggest that the addition of alkaline materials in reclamation may not only neutralize acidic components, but may suppress the bacterial catalysts as well.

856. Pole, M. W. Soil Salvage Requirements Based on Overburden Quality—Applying the Research. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 299-304.

This article describes the changes, along with the factors that led to the changes, that have occurred in the regulations governing the reclamation of North Dakota surface-mined lands since the first reclamation law was passed in 1969. Emphasis is placed on the requirements of topsoil salvage and respreading of suitable plant growth material to a specified depth based on overburden

characteristics. The approved regulations, adopted in 1986, represent a combined effort by regulatory agencies, independent researchers, and the surface coal mining industry to improve reclamation and reduce unnecessary reclamation cost. Several factors that contributed to the successful application of soil research to changes in the North Dakota reclamation regulations are presented.

857. Pommerening, E. Methods Used To Revegetate the Coeur d'Alene Mine District of Idaho. Paper in Proceedings: High-Altitude Revegetation Workshop No. 5 (CO State Univ., Fort Collins, CO, Mar. 8-9, 1982). CO Water Resour. Res. Inst., CO State Univ., Fort Collins, CO, Inf. Ser. 48, Dec. 1982, pp. 106-109.

This article describes the revegetation program of the Bunker Hill Co., operating in the Coeur d'Alene Mining District in northern Idaho. Elevation and aspect are critical factors affecting revegetation efforts in this area. An underground nursery was established in a ventilation drift where the temperature was a constant 74° F, and the CO_2 content in the air was 0.3 pct. Lighting was provided by 1,000-W, mercury-vapor discharge lamps. No insect or fungus problems were encountered. The company has found that a major advantage in having its own greenhouse operation is that trees and native shrubs can be grown and transplanted at the proper time of outplanting rather than when commercial nurseries are able to make seedlings available. The author reports that the greenhouse operation has helped reduce costs of reforestation efforts on the company's mined land. While this article specifically discusses a revegetation program for a heavy-metal mining operation, the description of the in-house, underground greenhouse operation provides an example of one company's unique method of meeting its specific needs.

858. Pommerening, E. Revegetation of the Coeur d'Alene Mining District. Min. Congr. J., v. 63, No. 3, 1977, pp. 20-23.

This article discusses the revegetation program initiated by the Bunker Hill Co. in the lead and zinc mining area of the Coeur d'Alene mining district in northern Idaho. Two types of disturbances are common within the district: (1) tailings deposits from the concentrators and (2) denuded mountain slopes. Research conducted on these areas has focused on vegetation establishment using herbaceous and woody species and the development of a greenhouse program to produce containerized seedlings underground. With the underground greenhouse the Bunker Hill Co. can now collect the seeds and grow its own conifers and native shrubs. The program has the advantage of being relatively inexpensive, and trees and shrubs can be grown and transplanted at the proper time rather than when they become available from commercial nurseries.

859. Ponder, F., Jr. Improving Tree Establishment and Growth With Nurse Vegetation. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll., Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 90-98.

This article provides a relatively brief literature review of the use of nitrogen-fixing plant species as a nurse crop, interplanted with preferred tree species. Several herbaceous and woody species are discussed. The article provides a good reference for this subject and is pertinent to potential land use considerations and to reclamation planning.

860. Popp, J. T., and R. S. Baker. Evaluation of Reclamation Techniques at Little Kyger Creek in Gallia County, Ohio. Paper in Proceedings 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 2-7, 1984). Univ. KY, Lexington, KY, 1984, pp. 479-484.

The effectiveness of different mine reclamation and sediment abatement techniques was investigated on an abandoned minesite in southeastern Ohio. The techniques were designed to control sedimentation through reduction of existing ground slopes, control of area drainage, protection of existing drainage courses, and the restoration of surface vegetation through the use of excavation, fill, and recontouring techniques, rock collars, rock and dirt terraces, rock and concrete drains, and the use of resoiling materials. The resoiling materials used for reclamation purposes included topsoil from a borrow pit, weathered mine spoil, fly ash, composted paper pulp, composted municipal wastes, composted municipal sewage, and combinations of these materials. Lime, fertilizer, seed, and mulch were applied to each resoiling area. Each area was evaluated in order to identify deformational features (slumps and gully erosion), percent cover, plant species, and root penetration. Soil and plant samples were collected and analyzed for soil chemical and physical properties (changes with time), and plant nutrient status and dry weight yield. All areas were compared with respect to sedimentation control, revegetation, soil and vegetation chemistry, and cost. Excluding cost, the areas reclaimed using composted municipal sludge and paper pulp sludge had the highest overall ranking. The lime and mine spoil treatment, however, had a low soil loss, high ground cover, and adequate vegetative yield at the lowest cost.

861. Poppleton, J. E., A. F. Clewell, and A. G. Shuey. Sand Pine Scrub Restoration at a Reclaimed Phosphate Mine in Florida. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec.2, 1983). Univ. KY, Lexington, KY, 1983, pp. 395-398.

This paper contains information on the methods that can be used to restore scrub vegetation on reclaimed phosphate mines in Polk County, FL. Bare-root seedlings of sand pine (*Pinus clausa* (Chapm.) Vasey) were planted on one set of plots, and height growth and survival were monitored. On two other sets of plots, a topsoil mulch, obtained from a natural sand pine scrub community, was applied and species composition and abundance were monitored. The results indicate that the planting of bare-root seedlings of sand pine was not worth the expense, considering their 68-pct mortality, as long as pine seeds were present in the mulch and established naturally. The mulched plots had the important tree and shrub species present in large numbers, and the growth of these species was substantial. The authors conclude that sand pine scrub communities can be restored on reclaimed lands using the mulching technique.

862. Porter, W. M., A. D. Robson, and L. K. Abbott. Factors Controlling the Distribution of Vesicular-Arbuscular Mycorrhizal Fungi in Relation to Soil pH. J. Appl. Ecol., v. 24, No. 2, 1987, pp. 663-672.

A series of experiments were conducted to determine the ability of vesicular-arbuscular (VA) mycorrhizal fungi from two adjacent soils (distinct populations) to infect and sporulate in soil from the other population and to identify the soil factors limiting fungal growth in each soil. When inoculum from soil I was introduced into soil II, no infection occurred. At the end of the experiment (8 weeks) inoculum from soil II had half as much infection in soil I as it did in soil II; however, no spores were produced. The dominant VA mycorrhizal fungi from adjacent soils were better able to infect and sporulate in their soil of origin than in the other soil. This inability appears to be related to the effects of soil pH on spore germination and the growth of hyphae; soil I had a pH of 4.8 and soil II, 7.5. Adjusting the pH of soils I and II affected germination and hyphal growth of both species of fungi. Spore germination of fungi found in soil I was depressed in soil II, however, liming soil I had a similar effect, while acidifying soil II overcame the depressing effect of this soil on the germination of fungal spores from soil I. The opposite trends were found for percentage germination and hyphal growth of spores from soil II. Acidifying soil II resulted in poor spore germination and hyphal growth that was similar to placing spores of soil II into soil I, while liming soil I overcame the effect of this soil on spore germination and hyphal growth of VA mycorrhizae from soil II. The hydrogen ion concentration appears to be the soil acidity factor that is limiting the germination of spores of the VA mycorrhizal fungi contrasted in this study.

863. Porter, W. M., A. D. Robson, and L. K. Abbott. Field Survey of the Distribution of Vesicular-Arbuscular Mycorrhizal Fungi in Relation to Soil pH. J. Appl. Ecol., v. 24, No. 2, 1987, pp. 659-662.

The results of a survey on the distribution and abundance of the vesicular-arbuscular (VA) mycorrhizal fungi *Acaulospora laevis* Gerd. & Trappe and *Glomus* spp. (WUM3) in relation to soil properties (pH, organic carbon, phosphorus, and clay content) are presented. Twenty-six sites from fields cropped to cereals were selected for study. These sites were within five different soil series. No spores of *Glomus* spp. (WUM3) were found in samples with a pH of less than 6.8, while only very acid soils (pH 4.5 to 4.9) contained large numbers of spores of *Acaulospora laevis*. No samples with a soil pH greater than 6.4 contained spores of *A. laevis*. The distribution of both species was related to soil pH; all other soil properties tested were not related to the distribution or abundance of either VA mycorrhizal fungus. Soil pH is the major determinant of the distribution of these fungi. The important implication of this study is that the commercial application (inoculation) of *A. laevis* into neutral or alkaline soil or the inoculation of *Glomus* spp. (WUM3) into acid soil would fail.

864. Postle, J. K., D. Taylor, A. E. Peterson, and R. B. Corey. Effect of Sewage Sludge Applications on the Inorganic Nitrogen Content of Soil and Ground Water. Am. Soc. Agron., Agron. Abstr., 1985, pp. 29-30.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. Sewage sludge was applied to a silt loam soil one time only and annually at rates of 6.6 and 13.2 Mg ha^{-1}. Levels of inorganic nitrogen in the soil increased at all sampling depths relative to the control when sludge was applied annually for 4 years. The one-time application had little residual effect on soil inorganic nitrogen levels. Ground water nitrate levels were monitored on the control and 13.2-Mg-ha^{-1} treatments. Nitrate levels were significantly higher in wells where soil was treated with sewage sludge. The time required for nitrate to affect the monitoring wells was 3 years.

865. Potter, K. N., F. S. Carter, and E. C. Doll. Physical Properties of Constructed and Undisturbed Soils. Soil Sci. Soc. Am. J., v. 52, No. 5, 1988, pp. 1435-1438.

Soil physical and hydrological properties of two mine soils of varying ages and an undisturbed soil were compared. The mine soils studied had been constructed with similar soil materials, one 4 years and the other 11 years after reclamation. The soils were also selectively characterized for particle size distribution, soil calcium, magnesium, and sodium ion concentrations, sodium absorption ratio, electrical conductivity, and soil pH. Soil physical properties of particular interest were bulk density, total porosity, macroporosity, and microporosity. Saturated hydraulic conductivity was the hydrologic property of interest.

Soil salvage and reclamation resulted in differences in texture and soil chemical properties in the constructed soils compared with unmined soil. The bulk density of constructed soils was greater than that of undisturbed soil. Bulk density was significantly greater in topsoil and subsoil materials of constructed soils compared with the bulk densities of undisturbed A and B soil horizons. The bulk densities of reclaimed topsoil materials were not significantly different, but the differences between reclaimed subsoil materials were significant, with the subsoil bulk density of the 11-year site being greater than the bulk density of the 4-year site.

Analysis indicated that there were significant differences in pore volume distribution between undisturbed and constructed soils and also between constructed soils. Macroporosity (>15 μm) was significantly lower in reclaimed topsoil than in undisturbed A horizon soil. The 11-year topsoil material had greater macropore volume than did the 4-year topsoil material. Small pore volume (4.5 to 0.1 μm) was not significantly different among the soils in the upper soil profiles. Macropore volume was greater in the undisturbed B horizon soil than in the reclaimed subsoils. Micropore space, however, was greater in the reclaimed subsoils than in the undisturbed B horizon. The saturated hydraulic conductivity (K_s) of constructed soils was reduced relative to the undisturbed soil; the K_s of the topsoil materials was always greater than that of the subsoil. The K_s of reclaimed topsoil was 25 pct that of the undisturbed A horizon, while the K_s of reclaimed subsoil was less than 10 pct that of the undisturbed B horizon. The differences in K_s between the 4-year and 11-year sites were not significant. The results suggest that soil physical properties in combination with soil chemical properties have potential for use as an index of reclamation success after soil construction. Advantages to using soil property-based indexes are given.

866. Potts, D. F. Snow and Soil Moisture Dynamics Under Various Lodgepole Pine Stand Densities. Paper in Future Forests of the Mountain West: A Stand Culture Symposium (Missoula, MT, Sept. 29-Oct. 3, 1986). U.S. For. Serv., Gen. Tech. Rep. INT-243, 1988, pp. 389-391.

The relationship between lodgepole pine (*Pinus contorta* Dougl.), at various stand densities, and snow accumulation and soil moisture dynamics were studied. A low-elevation lodgepole pine stand was divided into the following equal size treatments: a clearcut, a control (1,750 stems per hectare), and thinnings at 3- by 3-m, 4.5- by 4.5-m, and 6- by 6-m spacings. Mean snow depth by treatment, relative variability of snow accumulation, and mean soil moisture by treatment results are presented. Snow accumulation was found to be inversely proportional to basal area, with the relative variability in snow accumulation increasing with the increased number of tree stems per acre. The author states that understanding the relationships between managed lodgepole pine and the hydrometeorological environment may help to optimize wood production and water use in lower elevation semiarid environments. This article was included in the review process because it demonstrates the importance of forests (tree establishment) in maintaining the hydrologic cycle.

867. Powell, J. L., and R. I. Barnhisel. Reclaiming Surface-Mined Land In West Kentucky. Min. Congr. J., v. 63, No. 12, 1977, pp. 29-35.

This article discusses the factors that should be considered when planning an effective reclamation program in western Kentucky: climate, spoil testing, plant species selection, final grading, adequate fertility and lime amendments, seedbed preparation, mechanics of seeding, and the management of seeded areas. Examples are given of plant response to the various treatments, along with recommendations on nitrogen, phosphorus, and potassium fertilization rates, lime application rates, seeding rates, and grass-legume mixtures that have been used successfully in western Kentucky. The authors state that poor planning, incorrect choices, or failure to consider the factors listed above may result in total or partial failure of a reclamation project.

868. Powell, J. L., and R. I. Barnhisel. Reclaiming Surface Mined Land in West Kentucky. Paper in American Mining Congress, Mining Convention Session Papers, Set No. 3, Coal Mining I & II (San Francisco, CA, Sept. 11-14, 1977). Am. Min. Congr., Washington, DC, 1977, 28 pp.

This paper reviews contemporary methods for reclaiming surface-mined lands in western Kentucky. It provides an excellent summary of experimentation and observations made over the preceding 5 years. The major topics considered include the reclamation plan, grading, seedbed preparation, spoil testing, fertility amendments, climate and species selection, seed mixtures, the mechanics of seeding and postseeding management, and the potential

uses of reclaimed surface-mined land. The authors review results and comment on a broad spectrum of research findings.

869. Powell, J. L., R. I. Barnhisel, G. W. Aikin, and M. W. Ebelhar. The State of the Art of Reclaiming Land Surface-Mined for Coal in the Western Kentucky Coal Field. Paper in Fifth Symposium on Surface Mining and Reclamation (NCA/BCR Coal Conf. and Expo IV, Louisville, KY, Oct. 18-20, 1977) Natl. Coal Assoc. and Bitum. Coal Res., 1977, pp. 251-273.

This paper presents a summary of 5 years of research and observations conducted in western Kentucky coalfields. It was the intent of the authors to present this information so that it could be used as a guide in planning, implementing, and maintaining a sound reclamation program. Topics covered in their discussion include planning, grading, spoil sampling and testing, plant species selection, adaption characteristics of species, fertilizer and lime amendments, seedbed preparation, and the mechanics of seeding. Possible alternative postmining land uses are presented.

870. Powell, J. L., M. L. Ellis, R. I. Barnhisel, and J. R. Armstrong. Suitability of Various Cool Season Grass Species for Reclamation of Acid Surface-Mined Coal Spoils in Western Kentucky. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 503-526.

This study was conducted to determine the relative suitability of grasses for reclamation of surface-mined coal spoil in Ohio County, KY. Thirty-three selected cool-season grass species and/or varieties were evaluated in comparisons in which growth media, climate, and management techniques were similar. Each of the 33 species and/or varieties was established in a pure stand, with a legume mixture, or with Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.). The grasses seeded consisted of (1) four varieties of perennial ryegrass (*Lolium perenne* L.), (2) four combination mixtures of Kentucky-31 tall fescue and common perennial ryegrass, (3) three varieties each of Kentucky bluegrass (*Poa pratensis* L.), tall fescue, and annual winter wheat (*Triticum aestivum* L.), (4) two varieties each of western wheatgrass (*Agropyron smithii* Rydb.) and hard fescue (*Festuca ovina* var. *duriuscula* (L.) Koch), and (5) single species entries of meadow fescue (*Festuca rubra* L.), timothy (*Phleum pratense* L.), orchardgrass (*Dactylis glomerata* L.), redtop (*Agrostis alba* L.), reed canarygrass (*Phalaris arundinacea* L.), tall wheatgrass (*Agropyron elongatum* (Host) Beauv.), crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.), intermediate wheatgrass (*Agropyron intermedium* (Host) Beauv.), and smooth brome (*Bromus inermis* Leyss.). The establishment methods used were (1) liming at a rate of 17 mt ha^{-1} agricultural limestone and (2) fertilizing with 135, 450, and 225 kg ha^{-1} of ammonium nitrate, triple superphosphate, and muriate potash, respectively. All amendments were incorporated with a disk harrow. Data collection included yield determinations, ground cover evaluations, spoil chemistry, and plant tissues analyses. No "best" or "worse" choices of cool-season grasses were made based on ground cover or yield. The data do indicate that a broad selection of cool-season grasses exists that can be successfully utilized to achieve various goals in land reclamation programs.

871. Powell, J. L., M. L. Ellis, R. I. Barnhisel, and J. R. Armstrong. Suitability of Various Legume Species and Varieties for Revegetation of Acid Surface Mined Coal Spoils of Western Kentucky. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 121-129.

This study evaluated the yield of 25 selected legume species and varieties grown on the same spoil material, with identical fertility treatments, in Ohio County, KY. The legumes evaluated were (1) three varieties of birdsfoot trefoil (*Lotus corniculatus* L.), (2) seven varieties of alfalfa (*Medicago sativa* L.), (3) four varieties of red clover (*Trifolium pratense* L.), (4) four varieties of sericea lespedeza (*Lespedeza cuneata* (Dum.-Cours.) G. Don), (5) two varieties of annual lespedeza (*Lespedeza* spp.), and (6) single species of alsike clover (*Trifolium hybridum* L.), yellow sweetclover (*Melilotus officinalis* Lam.), white clover (*Trifolium repens* L.), hairy vetch (*Vicia villosa* Roth), and crownvetch (*Coronilla varia* L.). The listing given above is, in general, the order of their ranking with respect to yield. It was also found that spring seeding of legumes outyielded fall seeding. The authors recommend that birdsfoot trefoil and alfalfa be seeded if high yields are desired. The recommended varieties to use of these species are Dawn or Ferfus birdsfoot trefoil and Williamsburg alfalfa. If established in the spring, red clover has the potential to produce very high yields. No particular variety of red clover was superior for either planting season. None of the other legumes tested are recommended for seeding if the success standard of reclamation is to be judged by predetermined target level yields.

872. Powell, J. L., R. I. Barnhisel, and C. G. Poneleit. The Role of Corn Variety and Population in Meeting Target Yield Level for Phase III Bond Release. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 257-265.

The authors describe two experiments conducted in western Kentucky to evaluate the effects of varietal selection, plant population, and soil ripping on the yield of corn (*Zea mays* L.) growing on recently reconstructed prime farmland. A good literature review on the moisture requirements of corn is presented in the introduction. The amounts of fertilizer and lime and the incorporation method used are presented in the methods section of the paper. Yield responses of the various varieties tested are not related to the amendments applied. Yield results show that high populations (24,000 kernels per acre) are better than low populations, that ripping the soil prior to planting will increase yields, that 14 of the 42 hybrids tested exceeded target level yields for phase III bond release of 81 bu $acre^{-1}$, and that the yield ranking of hybrid corn evaluated on natural soils does not accurately predict hybrid performance on reclaimed prime farmland soils.

873. Powell, J. L., R. I. Barnhisel, W. O. Thom, M. L. Ellis, J. R. Armstrong, and F. A. Craig. Reclamation of Prime Farmland in Kentucky. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 1-12.

A progress report of research conducted in relation to the restoration of prime agricultural lands in western Kentucky is presented. The methods and results of four separate studies are presented. The research conducted included (1) soil reconstruction, (2) soil depth and ripping, (3) soil-handling methods, and (4) postreconstruction management studies. Crop yields were influenced by soil depth, ripping treatments, soil handling, organic amendments, and the crop varieties used. General conclusions of each study are presented.

874. Power, J. F., R. E. Ries, and F. M. Sandoval. Reclamation of Coal Mined Land in the Northern Great Plains. J. Soil and Water Conserv., v. 33, No. 2, 1978, pp. 69-74.

The authors discuss the reclamation of coal mined land in the Northern Great Plains. A short discussion is presented on the natural resources available in the region. Insufficient water is often the limiting factor for plant growth in the region. Reclamation technology must use the available natural resources to provide for efficient conservation of water by enhancing its infiltration and storage in the soil and the efficient use of stored water for plant growth. Through sound water conservation practices the productive potential of the land can be achieved.

875. Power, J. F., F. M. Sandoval, and R. E. Ries. Restoration of Productivity to Disturbed Land in the Northern Great Plains. Ch. in Reclamation of Disturbed Arid Lands. Univ. NM Press, 1978, pp. 33-49.

Information is presented on the potential for restoring agricultural productivity to land disturbed by strip mining in the Northern Great Plains. The authors discuss the basic resources involved in the reclamation of mined land: the climate, adapted vegetation, soil, and overburden. The successful revegetation of land disturbed by mining in the arid and semiarid regions in the Western United States depends primarily on the conservation and efficient utilization of the limited precipitation received and on storage and use of the water. The authors discuss how these natural resources can be used to return the land to a productive use. Successful revegetation can be achieved by creating a plant-rooting medium that will effectively store precipitation, conserving the water in the plant root zone in a way that would enable plant species to use it in the most efficient way.

876. Power, J. F., F. M. Sandoval, R. E. Ries, and S. D. Merrill. Effects of Topsoil and Subsoil Thickness on Soil Water Content and Crop Production on a Disturbed Soil. Soil Sci. Soc. Am. J., v. 45, No. 1, 1981, pp. 124-129.

This study was conducted to obtain quantitative data on how the thickness of subsoil (B and upper C horizons) and topsoil (A horizon) affect the water extraction, growth, and yield of several crops in the semiarid agricultural region of North Dakota. The site was located at the Glen Harold Mine near Stanton, ND. Wedge tests were used, incorporating the subsoil and topsoil at various thicknesses over the sodic mine spoils. Tested vegetation consisted of hard red spring wheat (*Triticum aestivum* L.), alfalfa (*Medicago sativa* L.), crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.), and a mixture of warm-season blue grama (*Bouteloua gracilis* (H.B.K.) Lag.), and sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.) grasses. Generally, all crops responded to increased soil thickness, with the greatest yields when total soil thickness was about 90 cm (75- to 120-cm range), including 20 cm of topsoil. Thicker or thinner soil layers decreased productivity. The crops extracted water from the upper 30 to 90 cm of spoils when the soil-spoil interface was within 90 cm of the soil surface. Depth of water extraction by crops generally was in the following relative order: alfalfa > crested wheatgrass > native grasses > spring wheat.

877. Powers, R. F., S. R. Webster, and P. H. Cochran. Estimating the Response of Ponderosa Pine Forests to Fertilization. Paper in Future Forests of the Mountain West: A Stand Culture Symposium (Missoula, MT, Sept. 29-Oct. 3, 1986). U.S. For. Serv., Gen. Tech. Rep. INT-243, 1988, pp. 219-225.

The response of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) to fertilization in the Pacific States was modeled. Sapling and pole-sized ponderosa pines were studied on 43 sites distributed through Oregon and California. Each site had at least 5 years of growth response. Plots had been treated with 0, 200, or 400 lb $acre^{-1}$ N. Results show that nitrogen response increases linearly with fertilization rate, with 5-year volume gains averaging 30 pct overall with fertilization. Plots free of weed competition grew twice as fast as unweeded plots following fertilization. Plots where site preparation involved scalping topsoil into windrow showed more than three times the fertilization response compared with unscalped plots where the topsoil remained intact. Scalped plots averaged less mineralizable soil nitrogen and lower nitrogen concentrations in current and 1-year-old foliage than did unscalped sites. Comparing the eight measurement variables, the variable most strongly correlated with growth response to fertilization was nitrogen concentration in 1-year-old needles. When foliar nitrogen concentrations were less than 1.1 pct, upper crown needles experienced nitrogen deficiency. The most effective model for predicting fertilization response was a four-variable equation with soil carbon-nitrogen ratio, foliar nitrogen, and site index as the independent variables. Seventy-six percent of the variation in relative growth response of ponderosa pine to fertilization could be explained by the predictive response model. This article was included in the review process because it contains good reference material on the growth responses of ponderosa pine, the most widely distributed commercial pine species in North America, to fertilization.

878. Pregent, G., C. Camire, J. A. Fortin, P. Arsen, and J. G. Brouillette. Growth and Nutritional Status of Green Alder, Jack Pine, and Willow in Relation to Site Parameters of Borrow Pits in James Bay Territory, Quebec. Reclam. & Reveg. Res., v. 6, No. 1, 1987, pp. 33-48.

The survival rates and growth of green alder (*Alnus crispa* (Ait.) Pursh), jack pine (*Pinus banksiana* Lamb.), and willow (*Salix planifolia* Pursh, *Salix bebbiana* Sarg.) planted in borrow pits in the James Bay Territory, PQ, Canada, were evaluated, and the factors limiting their growth were assessed. After three growing seasons the survival rates of green alder, jack pine, and willow were 90, 81, and 83 pct, respectively. Results may be explained by differences among study areas. At the end of the sixth growing season, mean total aboveground biomass of green alder was 349 g per tree, which is 3.5 and 12.5 times higher than the production of jack pine and willow, respectively. Phosphorus was the main nutrient limiting the growth and dinitrogen fixation of green alder. Alder grew better on stony soils than on sandy soils. The most important growth factors affecting jack pine were organic carbon, pH, phosphorus and nitrogen foliar concentration, extractable cations, and water supply. The best sites for jack pine growth were rich in organic matter (>0.14 pct) and slightly acidic (pH <5.6) with high extractable cations (Ca >30, Mg >3, and K >7$\mu g\ g^{-1}$). Willow grew best in plots rich with organic carbon. Nitrogen availability limited the growth of willow, with 66 pct of the plots having a foliar nitrogen concentration of less than 2 pct. Green alder is the species best suited for recolonization of these nitrogen-poor sites because of its rapid growth, high survival, and the nitrogen it supplies to the substrate through dinitrogen fixation.

879. Preve, R. E., J. A. Burger, and R. E. Kreh. Influence of Mine Spoil Type, Fertilizer, and Mycorrhizae on Pine Seeded in Greenhouse Trays. J. Environ. Qual., v. 13, No. 3, 1984, pp. 387-391.

A greenhouse study was conducted to evaluate the germination, survival, growth, and mycorrhizal colonization of eastern white pine (*Pinus strobus* L.), Virginia pine (*Pinus virginiana* Mill.), and loblolly pine (*Pinus taeda* L.) as affected by spoil type, fertilization, and mycorrhizal inoculation technique. The spoil types used were a gray siltstone and a brown sandstone from active strip mines in southwestern Virginia. The fertilization treatments consisted of a control and the equivalent of 100 kg ha^{-1} N, P, and K. The mycorrhizal inoculation techniques tested were a control, the equivalent of 56 kg ha^{-1} pine litter, and 250 g ha^{-1} *Pisolithus tinctorius* basidiospores. The experimental design was a completely randomized three-way factorial with three replications. The spoils were chemically and physically characterized.

Seedling emergence was greatest in nonfertilized siltstone, but the fertilization of sandstone significantly increased the shoot weight of all three species. Fertilization of siltstone spoil significantly decreased Virginia and loblolly pine emergence and survival. The overall low emergence on sandstone spoil compared with unfertilized siltstone reflects the pine seed sensitivity to moisture conditions; however, the sandstone spoil had better aeration and percolation, which offset its lower natural fertility. The extent of mycorrhizal colonization as affected by treatment was greater in sandstone than in siltstone spoil. In siltstone spoil, no significant differences were observed between inoculated and control seedlings in either the number of trees colonized or the symbiont species present. The sandstone spoil had fewer apparent physical and chemical limitations to mycorrhizal growth. Virginia pine responded the most to mycorrhizal inoculation, with both pine litter and basidiospores increasing the percentage of colonized trees. White and loblolly pine did not respond

to inoculation with pine litter. Mycorrhizal colonization did not significantly increase shoot weight of any of the species tested.

880. Price, R. A., J. G. Skogerboe, C. R. Lee, and D. L. Brandon. Effects of Various Soil Amendments on Plant Growth in Pyritic Soil. Am. Soc. Agron., Agron. Abstr., 1984, p. 34.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. A greenhouse study was conducted to evaluate the effects of soil amendments on the growth of Pensacola bahiagrass (*Paspalum notatum* (L.) cv. Pensacola) in pyritic soil. The soil was collected from a disposal area of the Tennessee-Tombigbee Waterway and was characterized as highly acidic, compacted, droughty, and easily eroded. Amendments tested were combinations of lime (51.6 Mg ha^{-1}) with 9.4, 18.6, 37.4, 74.6, and 149.5 Mg ha^{-1} of chicken manure, composted sewage sludge, pine tree bark, and 149.1 kg ha^{-1} NH_4NO_3 plus 257.8 kg ha^{-1} of 0-17-34 N-P-K fertilizer. The control treatment had no growth because of high soil acidity. Liming resulted in plant establishment, and growth doubled with fertilizer addition.

881. Pritchard, J. F. Superabsorbents, A New "Tool" for Mine Reclamation: An Introduction to a Valuable Technology. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 345-368.

This paper introduces superabsorbent technology and what has been learned in field applications. A superabsorbent is a material capable of absorbing many times its weight in liquid. Information is given on how superabsorbents work, factors affecting absorbency, effective life, the benefits from the use of superabsorbents, and how to use superabsorbents.

882. Purkable, T. L., M. S. McIntosh, and J. S. Angle. Effect of Composted Municipal Sludge on Hybrid Poplar Growth and Water Quality. Am. Soc. Agron., Agron. Abstr., 1985, p. 30.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. The effects of composted sewage sludge on hybrid poplar (*Populus* spp.) growth and water quality were determined. Composted sludge was incorporated into the soil at 0, 56, and 112 Mg ha^{-1}. Compost applications resulted in significantly taller trees with greater biomass than trees grown on control plots. Water quality was not affected by compost additions.

883. Quinn, J. J., and J. F. Pritchard. Superabsorbents, A New "Tool" for Mine Reclamation—An Introduction to a Valuable Technology. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 295-301.

Superabsorbents technology is introduced, and the major benefits of using superabsorbents are presented. A superabsorbent is capable of absorbing many times its weight in liquid (usually water) and is at times referred to as a "hydrogel." Superabsorbents are water management tools and can act to promote aeration and retention of water and nutrients. The material acts as a sponge; when water comes in contact with a particle, it swells, absorbing water with a capacity of expanding to 30 times its original volume. The effective life of superabsorbents is typically 6 months to a year. Superabsorbent benefits include (1) a more reliable water supply for plants, (2) improved aeration and drainage without promoting root rot, (3) more efficient water use, (4) improved nutrient availability, (5) increased effectiveness of herbicides, pesticides, and other chemicals, and (6) use as antitranspirants or antidesiccants. Application rates, costs, and uses of superabsorbents are presented.

884. Quinn, M. L. Tennessee's Copper Basin: A Case for Preserving an Abused Landscape. J. Soil and Water Conserv., v. 43, No. 2, 1988, pp. 140-144.

A detailed historical account of copper mining, environmental changes, and revegetation attempts in the Copper Basin Region in southeastern Tennessee is presented. Although this article does not contain any specific information on soil characterization or soil amendment use, it was included in the review process because it contains an alternative land use not often considered in revegetation planning—preservation of the current landscape for historical reasons. The author feels that it is necessary to preserve the unique qualities of the region for historical value.

885. Rafaill, B. L., and W. G. Vogel. A Guide for Vegetating Surface-Mined Lands for Wildlife in Eastern Kentucky and West Virginia (U.S. Fish and Wildl. Serv. contract FWS 14-16-0009-77-923, U.S. For. Serv., Northeast. For. Exp. Stn.). U.S. Fish and Wildl. Serv., FWS/OBS-78-84, July 1978, 99 pp.

This guidebook presents an extensive listing of plant species, with proven establishment potential on surface-mined sites, that are valuable for wildlife food and cover. Information is given on the requirements of specific species for pH tolerance limits, shade tolerance, time of

establishment, and growing season. General wildlife requirements and basic ideas on reclamation for wildlife on recently surface-mined sites are discussed. Specific wildlife species are considered with respect to plant species and planting patterns that have proven successful in West Virginia and eastern Kentucky. The purpose of this publication is to guide land managers, landowners, and mine operators in revegetating surface-mined land for wildlife in this area.

886. Rafaill, B. L., W. G. Vogel, and R. R. Hinchman. Guide for Revegetation in Eastern U.S. Coal Age, v. 86, No. 7, July 1981, pp. 76-86.

The authors present a concise discussion of revegetation methods applicable to reclaiming surface-mined lands in the Eastern United States. Topics include seedbed preparation, seeding techniques, planting of tree and shrub seedlings, recommended plant varieties and seed mixtures, seeding times and rates, fertilizer rates, liming rates, and mulches. Excellent lists of plant materials suggested for surface mine reclamation are included.

887. Raisanen, D. L. Survival of Selected Tree Species on Sites Reclaimed to Various Reclamation Standards. Paper in 1982 Seminar on Post-Mining Productivity With Trees (Carbondale, IL, Mar. 31-Apr. 2, 1982). South. IL Univ., Carbondale, IL, 1982, pp. 93-102.

This article details the results of a study to evaluate different methods of planting trees for forestry and wildlife purposes. Twenty-six plots were established at five mined sites in southern Illinois. Nineteen forest tree species and eight tree species for wildlife were planted, with four treatments. The treatments consisted of fertilizer, herbicide, planting seedlings into four different herbaceous cover mixtures, and ripping to a depth of 24 in. Data on survival after one growing season are given, showing that the herbicides increased survival by 80 pct, while a difference of only 10 pct separates the survival rates of trees on various herbaceous cover mixtures. The results of fertilization and ripping were inconclusive.

888. Ralston, D. S. Planning Prime Farmland Reclamation. Paper in Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains (Billings, MT, Mar. 1982). MT State Univ., Bozeman, MT, 1982, pp. C-6-1—C-6-16.

This general article deals with the planning that is involved when prime farmland is to be reclaimed. It discusses the elements of implementing a permanent program for prime farmland reclamation as required by Federal regulations. Equipment options available for moving overburden materials are presented. Two categories of equipment are discussed: direct-cast equipment, which is used for excavating and placement of overburden materials, and haul-back equipment, which transports overburden materials over longer distances. The general cost effectiveness and limiting factors of each piece of equipment are also discussed. The importance of overburden characterization is mentioned as a way of determining the suitability of the various soil materials for restoring crop productivity.

889. Ramani, R. V. Coal Refuse Piles: Problems and Prospects. Ch. in Environmental Consequences of Energy Production: Problems and Prospects, ed. by S. K. Majumdar, F. J. Brenner, and E. W. Miller. PA Acad. Sci., 1987, pp. 102-114.

This chapter outlines the current status of coal refuse generation and disposal, reviews the characteristics of coal refuse piles, discusses the environmental impacts from surface disposal of refuse, presents potential uses of refuse pile material, and summarizes procedures for safe disposal of coal mine refuse. In 1975, there were an estimated 3,000 to 5,000 refuse piles and impoundments in the eastern coal fields which contained 3 billion tons of refuse. Some reasons for the large volume of disposed refuse are given. The most important reason is the need to process run-of-mine coal. The chemical and physical characteristics of refuse material are dependent on the roof, floor, and seam conditions, and the methods used in the mining and processing of coal. In coal processing, two types of refuse are generated: coarse and fine wastes.

Adverse environmental impacts from abandoned coal refuse piles include air pollution (release of methane, dust and particle matter, and fines emitting toxic and noxious fumes), water pollution (turbidity, suspended solids, and chemical pollution due to leachates), and health and safety hazards (drinking water contamination and poor design and construction of refuse piles leading to their failure). Potential uses for the refuse in coal piles are given. The suitability for a particular use is dependent on the physical and chemical properties of the refuse material. Guidelines for the development of coal refuse disposal facilities are given.

890. Ramani, R. V. Environmental Planning for Surface Mining of Coal. Ch. in Environmental Consequences of Energy Production: Problems and Prospects, ed. by S. K. Majumdar, F. J. Brenner, and E. W. Miller. PA Acad. Sci., 1987, pp. 78-101.

This chapter outlines the methods of coal mining, discusses the environmental impacts of the mining activities, and presents a detailed procedure for environmental site planning for lands with surface-minable coal reserves. Surface mining methods discussed include contour mining,

area mining, open-pit mining (bench mining), and auger mining. Surface mining affects both the natural components (geomorphology, climate, and soil) and cultural components (demographic, economic, and market conditions) of the environment. The major phases in the life of a mine are (1) exploration, (2) development, (3) extraction, and (4) abandonment or return to other productive uses. The estimated number of years for each phase is given. The long-term environmental plan of a mining operation should preserve or enhance the value of mined lands. Steps that must be taken to achieve this long-term goal include (1) an inventory of the premining condition, (2) evaluation and decision on the postmining requirements of the region mined (these postmining requirements should be consistent with the needs and desires of the groups affected by the mining operation), (3) analyses of alternative mining and reclamation schemes to achieve the requirements, and (4) development of an acceptable integrated mining and reclamation scheme most suited for the technical, social, and economic conditions in existence. An environmental planning process is described.

891. Ramani, R. V., C. J. Bise, C. Murray, and L. W. Saperstein. User's Manual for Premining Planning of Eastern Surface Coal Mining, v. 2, Surface Mine Engineering (EPA grant R803882, PA State Univ.). U.S. EPA, Rep. EPA-600/7-80-175, Oct. 1980, 349 pp.

The purpose of the research reported in this document was to study the surface mining of coal in the Eastern United States and to establish guidelines for developing, evaluating, and selecting the most environmentally sound mining and reclamation practices. A comprehensive summary of the analyses required to lay out a surface mine is provided, while accounting for limitations imposed by geology, equipment, reclamation, economics, and environmental control requirements. Methods, techniques, and alternatives are recommended for selecting and designing mining systems that include soil handling and storage, overburden removal, and minimization of environmental effects of drilling, blasting, off-highway transportation, coal landing, and steep slopes. Reclamation procedures and planning constitute a relatively small portion of the material presented in this manual. This information, however, is usefully presented in the context of the overall planning of the surface mining operations.

892. Randall, G. W. Nitrogen Losses into Drainage Water and Corn Production as Influenced by Fertilizer N Rates. Am. Soc. Agron., Agron. Abstr., 1985, p. 30.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. The effects of nitrogen applied annually on nitrate-nitrogen in the soil, nitrogen loss via tile line discharge, and yield and nitrogen uptake in corn (*Zea mays* L.) were studied over a 6-year period. The first 2 years of the study were dry; no tile flow occurred, and corn yields were low. Nitrate-nitrogen accumulators in the 0- to 3-m profile totaled 241, 368, 495, and 814 kg ha^{-1} when nitrogen was applied at 0, 112, 224, and 336 kg ha^{-1} N, respectively. The third-year tile flow showed average nitrate-nitrogen concentrations of 13, 41, 58, and 85 mg L^{-1} and nitrogen losses of 16, 37, 46, and 92 kg ha^{-1} N for the respective nitrogen rates. After 6 years, total nitrate-nitrogen lost by tile lines was 12, 16, and 22 pct of the 112-, 224-, and 336-kg ha^{-1} N rates, respectively. Nitrogen applied at recommended rates for continuous-cropped corn resulted in tile losses of approximately 15 pct of the applied nitrogen.

893. Ransome, L. S., and R. H. Dowdy. Soybean Growth and Boron Distribution in a Sandy Soil Amended With Scrubber Sludge. J. Environ. Qual., v. 16, No. 2, 1987, pp. 171-175.

The effects of scrubber sludge additions to a loamy sand agricultural soil were evaluated for three growing seasons. Growth and elemental composition of soybean (*Glycine max* (L.) Merr.), plant-available boron status of the soil, and changes in soil-water electrical conductivity (EC) and boron levels were monitored. Scrubber sludge was applied at rates of 0, 10, 20, and 40 Mg ha^{-1} in a one-time-only application, prior to the first planting of soybean.

Plant populations exhibited a highly significant linear decrease with increasing rates of sludge application during the first two growing seasons. No decrease in plant population was associated with scrubber sludge rates in year 3. Plant populations did not differ significantly for any of the years at the 0- and 10-Mg-ha^{-1} rates, but were significantly lower for year 1 than for year 3 at the 20- and 40-Mg-ha^{-1} rates. Yields were significantly lower the first year with increasing sludge rates; no yield was obtained in three of the four replications at the 40-Mg-ha^{-1} rate. By year 3, however, yields increased with scrubber sludge application.

Leaf boron concentrations were significantly elevated with scrubber sludge amendments; for each successive crop there was a highly significant linear increase in leaf boron concentration with increased application rate. There was, however, a change from year to year in the response to the four rates. Leaf boron concentrations associated with all sludge rates during the first year were excessive, and visual symptoms of boron toxicity were observed. During succeeding years leaf boron concentrations remained high, but no visual toxicity symptoms were observed. Soil boron concentration increased as scrubber sludge rate increased. Scrubber sludge amendments of 20 and 40 Mg ha^{-1} increased soil boron levels to sufficiency. These levels were maintained in the upper soil depths for two to three growing seasons.

Soil-water boron concentrations and EC reached levels that were potentially detrimental to crop production during the first year at the application rate of 40 Mg ha^{-1}. This was probably due to the osmotic effects of salinity on seedling survival. Soil-water boron and EC levels were reduced after the first growing season because of leaching. Excess soluble salts were removed from the root zone by leaching. The authors state that suitable combinations of rate, timing, and placement of scrubber sludge should allow it to be used as an agricultural boron source.

894. Rappaport, B. D., D. C. Martens, R. B. Reneau, Jr., and T. W. Simpson. Heavy Metal Accumulation in Barley Silage Grown on Sludge-Amended Soils. Am. Soc. Agron., Agron. Abstr., 1985, p. 30.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. Heavy-metal accumulation in barley silage (*Hordeum vulgare* L.) grown on sludge-amended soil was evaluated. Application rates were 0, 42, 84, 126, 168, and 210 Mg ha^{-1}. Tissue concentrations of copper, nickel, and zinc were increased by sludge application, while the cadmium concentration was not.

895. Rappaport, B. D., D. C. Martens, R. B. Reneau, Jr., and T. W. Simpson. Metal Accumulation in Corn and Barley Grown on a Sludge-Amended Typic Ochraqualf. J. Environ. Qual., v. 16, No. 1, 1987, pp. 29-33.

There is a need to determine the accumulation of heavy metals in crops grown on sludge-amended soils under reduced (anaerobic) conditions. A 2-year field experiment was conducted on a poorly drained silt loam soil to determine if cadmium, copper, nickel, and zinc accumulations in corn (*Zea mays* L.) and barley (*Hordeum vulgare* L.) from sludge applications are limiting production and to evaluate the potential for ground water contamination from leaching of the heavy metals applied in the sewage sludge. Sewage sludge was applied to isolated plots at rates of 0, 42, and 84 dry Mg ha^{-1}.

Levels of heavy metals in the Ap horizon were increased by sludge rate over a 2-year period; however, there was no indication that the heavy metals had moved downward in the soil profile. Apparently the heavy metals were absorbed by the organic material added with the sludge and maintained in nonmobile forms. Additionally, the aluminum and iron hydrous oxides in the soil could have selectively removed the metals from the solution by sorbing the metals on the surfaces of the hydroxides, with the oxides becoming occluded and nonreactive. Yields of corn and barley were higher on control plots than on sludge-amended plots. The decreased yields on sludge-amended plots are attributed to nitrogen deficiency resulting from little mineralization of nitrogen because of the anaerobic conditions. All heavy-metal concentrations in plant tissues were within ranges considered to be normal for corn and barley growth. Phytotoxicity did not occur on these poorly drained soils as a result of sludge amendments.

896. Rappaport, B. D., D. C. Martens, T. W. Simpson, and R. B. Reneau, Jr. Prediction of Available Zinc in Sewage Sludge-Amended Soils. J. Environ. Qual., v. 15, No. 2, 1986, pp. 133-136.

The efficiency of DTPA (diethylenetriamine pentaacetic acid) and dilute HCl-H_2SO_4 (hydrochloric and sulfuric acid) extractants for predicting zinc uptake by corn (*Zea mays* L.) grown in sludge-amended soils was evaluated. Soil and corn tissue samples were collected from 14 sites in Virginia that were previously amended with one or more applications of sewage sludge. Multiple regression analyses were used to assess the forms of soil zinc extracted by DTPA and dilute HCl-H_2SO_4. The exchangeable and specifically adsorbed, organically bound, and noncrystalline oxide- and hydroxide-bound zinc fractions were tested to develop the regression equations. The organically bound zinc was the only zinc fraction that was related to the DTPA-extractable zinc ($r = 0.96$), while all three zinc fractions were related to the dilute HCl-H_2SO_4 extractable zinc ($R^2 = 0.98$). The dilute acid procedure extracts portions of zinc from each of the fractions. Ear leaf zinc concentration, however, was correlated more closely with DTPA-extractable zinc ($r = 0.64$) than with dilute HCl-H_2SO_4 extractable zinc ($r = 0.35$).

897. Rasmussen, P. E., and C. R. Rohde. Long-Term Tillage and Nitrogen Fertilization Effects on Organic Nitrogen and Carbon in a Semiarid Soil. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1114-1117.

The long-term tillage and nitrogen fertilization effects on soil organic nitrogen and carbon were evaluated in a winter wheat (*Triticum aestivum* L.) and fallow rotation. Tillage treatments (main treatment) consisted of a conventional (moldboard plow) system and two stubble mulch (offset disk and substrate sweeps) systems. Nitrogen treatment (subplots) consisted of 493, 728, 986, 1,221, 1,714, and 2,207 kg ha^{-1} N applied over a 44-year period. Soil samples were taken from each treatment and subplot at the 0- to 75-, 75- to 150-, 150- to 225-, 225- to 300-, 300- to 450-, and 450- to 600-mm depths; all soil samples were analyzed for total carbon and total nitrogen. Since inorganic carbon and nitrogen made up less than 1 pct of the total carbon and nitrogen present, all data are reported as organic carbon and nitrogen. Organic nitrogen and carbon in the upper 75 mm of soil were 26 and 36 pct higher, respectively, in the stubble mulch

than in the conventional tillage system. No differences were found below 75 mm. The beneficial effect of stubble mulch is dependent on shallow rather than deep incorporation. Nitrogen fertilization increased soil nitrogen linearly under both stubble mulch and conventional tillage. The level of nitrogen conservation was, however, greater with stubble mulch tillage. Stubble mulch tillage resulted in a conservation of 5.7 kg ha^{-1} yr^{-1} N. Of the nitrogen applied, it is estimated that 18 pct was retained in the soil organic matter. Nitrogen fertilization effects on soil carbon were similar to the effects on soil nitrogen; however, treatments with no previous sulfur additions ($(NH_4)_2SO_4$ applied the first 22 years and NH_4NO_2 the second 22 years) had higher organic carbon than comparable treatments with sulfur additions. Treatments with no previous sulfur application are marginally deficient, and this has altered the carbon-to-sulfur, but not carbon-to-nitrogen transformations.

898. Rastogi, V., R. J. Bohac, and A. Horowitz. Results From AML Sites Reclaimed Using Bactericides. Paper in 1987 Abandoned Mine Lands Conference (Little Rock, AR, Oct. 18-22, 1987). Am. Soc. Surf. Min. and Reclam., 1987, pp. 1-11.

A bactericide system consisting of a combination of liquid spray and controlled-release pellets to effectively reduce acid formation on two abandoned refuse areas is described. At both sites, bactericides were applied to one-half of the area and the other half was left untreated. Both the treated and untreated (control) areas were covered with topsoil and then limed, fertilized, seeded, and hay mulched. Treatment with bactericides effectively reduced acidity, total iron, sulfates, manganese, and aluminum in refuse moisture collected from lysimeters. Additionally, treatment with bactericides resulted in a more rapid growth of the heterotrophic bacteria population compared with untreated areas. The potential cost savings when bactericide treatments were used are presented. Treatment with bactericides resulted in a direct inhibition of *Thiobacillus ferrooxidans* activity, which reduced acid generation and solubilization of metals. Bactericide treatment also resulted in a greater heterotrophic micro-organism population on treated refuse, which helped to promote vegetation establishment.

899. Rastogi, V., and A. A. Sobek. The Economics of Using Bactericides in Active Mining and in Reclamation to Control Acid Mine Drainage. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 215-220.

The economic viability of using bactericides to inhibit acidophilic bacteria and control acid mine drainage is presented for an active operation (a 5-year-old refuse pile and a new refuse pile), the reclamation of a surface mining operation (reclaiming a previously untreated refuse pile and a previously treated refuse pile), and the reclamation of an abandoned mine-land site. All the examples presented are illustrative. The economic viability of using bactericides at each hypothetical site is based on site parameters (i.e., surface area), material costs, and cost offsets.

900. Rastogi, V., and A. A. Sobek. Reclaiming Abandoned Mine Lands Using Controlled Release Bactericides: A Case Study. Paper in Proceedings of the Eighth Annual National Abandoned Mine Lands Conference (Billings, MT, Aug. 10-15, 1986). MT Dep. State Lands, Helena, MT, 1986, pp. 140-150.

A general discussion on the use of bactericides to inhibit acid production in pyritic materials, along with other beneficial uses of bactericides, is presented. The results of a 2-year study on the use of spray and controlled-release bactericide pellets on a 5-acre abandoned coal refuse pile in eastern Ohio are presented. The refuse pile was divided in half; one-half was treated with bactericides and the other half was not. The entire refuse pile received the same lime, fertilizer, mulch, and topsoil replacement treatments, and was seeded to the same species. Rates of bactericides were determined by laboratory testing. Water quality, soil acidity, iron, manganese, aluminum, sulfates, microbial activity, and vegetation developed were monitored on both halves of the refuse pile.

Data indicate that there were significant reductions in acidity, sulfates, iron, manganese, and aluminum for the bactericide-treated side compared with the untreated side. Bactericides also suppressed the activity of *T. ferrooxidans* and benefited the heterotrophic bacteria population compared with the untreated side. The untreated half developed large barren areas from acid burnout, while the treated half had healthier vegetation. Controlled-release bactericides can be effective in acid control, promoting revegetation, and improving abandoned mine land aesthetically.

901. Rawajfih, Z., S. Gharaibeh, and F. Alkofahi. The Effect of Sewage Sludge on Wheat Growth and Nutrients Uptake. Am. Soc. Agron., Agron. Abstr., 1988, p. 45.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. This pot experiment evaluated the effect of sewage sludge applications on the dry matter yield and nutrient uptake of wheat (*Triticum aestivum* L.). Sludge and soil were mixed at various sludge-soil volume ratios, ranging from 1:8 to 4:1. Compared with the control, ratios of 1:8 and 1:6 produced the highest dry matter yields, while all other ratios resulted in

significantly lower yields. Sludge additions resulted in higher tissue phosphorus, iron, zinc, manganese, and copper contents, while tissue potassium content was higher in the control. The uptake of manganese and zinc was suppressed when the sludge-soil ratio was greater than 1.

902. Reddy, G. B., and G. A. Uzochukwu. Heavy Metals Accumulation in Selected Forages of Piedmont Region, North Carolina. Am. Soc. Agron., Agron. Abstr., 1986, p. 35.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. Heavy-metal accumulations in forages were investigated and compared with metal content of the soils in which they grew. The roots and shoots of the forages were higher in metal content than the soils.

903. Reddy, K. J., and V. R. Hasfurther. Chemical Equilibria of Molybdenum in Alkaline Mine Spoils and Soils. Am. Soc. Agron., Agron. Abstr., 1988, p. 46.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Research was conducted to collect thermodynamic data for molybdenum soil phases and solution species and to predict the chemistry of molybdenum in alkaline mine spoils and soils.

904. Reddy, K. J., and W. L. Lindsay. Availability and Plant Uptake of Trace Elements From Recarbonated Retorted Oil Shale. Am. Soc. Agron., Agron. Abstr., 1987, p. 32.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. A laboratory study was conducted to evaluate a method for lowering the alkalinity of oil shale solid waste. Retorted shale was exposed to pressurized CO_2 and moisture. This resulted in decreased pH values (11.6 to 8.6) and increased electrical conductivity (4.7 to 15.8 dS m^2). Plant tissues accumulated lower concentrations of arsenic, selenium, barium, cadmium, strontium and boron.

905. Reddy, K. J, and W. L. Lindsay. Availability and Plant Uptake of Trace Elements From Recarbonated Retorted Shale. J. Environ. Qual., v. 16, No. 2, 1987, pp. 168-171.

Preliminary results of laboratory and greenhouse studies on the recarbonation of retorted shales and the uptake of microelements by tall wheatgrass (*Agropyron elongatum* (Host) Beauv.) grown on recarbonated shales are presented. Lurgi retorted shale was used in this study. The CO_2 pressure system used in the laboratory to lower the pH of Lurgi shale through recarbonation is presented. The greenhouse pot experiment consisted of five treatments: (1) control (loam soil), (2) spent Lurgi shale, (3) recarbonated Lurgi shale, (4) spent Lurgi shale covered with soil (150 g of shale with 150 g of soil), and (5) recarbonated Lurgi shale covered with soil (150 g of recarbonated shale with 150 g of soil). Exposing Lurgi retorted shale to pressurized CO_2 (gas) (0.04 MPa CO_2 (gas) and moisture for 4 days) lowered the pH from 11.6 to 8.6 and increased electrical conductivity from 4.7 to 15.8 dS m^{-2}.

Recarbonation increased extractable zinc, iron, copper, molybdenum, and nickel and decreased extractable boron, chromium, strontium, and manganese. Tall wheatgrass did not germinate in the spent Lurgi retorted shale treatment. Tall wheatgrass grown on recarbonated shale had significantly lower dry matter yields than tall wheatgrass grown on retorted shale with soil cover, owing to higher salinity. With recarbonation, however, plants accumulated significantly lower concentrations of arsenic, selenium, barium, copper, strontium, and titanium than did plants grown on spent shale with soil cover. Concentrations of manganese and molybdenum in plant tissues were significantly higher in the recarbonated Lurgi shale treatments than in spent shale with soil cover only. The authors conclude that recarbonated retorted shales can be revegetated without soil cover.

906. Reddy, K. J., and W. L. Lindsay. The Solubility Relationships of Calcium and Magnesium Minerals in Processed Oil Shales. Am. Soc. Agron., Agron. Abstr., 1985, p. 30.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. The calcium and magnesium relationships of two processed oil shales at high pH's were examined. Processing oil shales at high temperatures destroyed the carbonate minerals and resulted in the formation of silicate minerals. The silicate minerals controlled the calcium and magnesium activities in solution and buffered the pH above 11.0.

907. Reddy, K. J., and W. L. Lindsay. The Solubility Relationships of Calcium and Magnesium Minerals in Processed Oil Shales. J. Environ. Qual., v. 15, No. 1, 1986, pp. 1-4.

The processing of oil shale results in the production of large amounts of waste material (spent shale). The literature concerning the chemistry of spent shale is not clear as to which minerals cause the high alkalinity associated with spent shale. Additionally, little has been done to understand the solubility relationship of calcium and magnesium minerals in spent shales at high pH values. This research was conducted to determine the solid phases

controlling the calcium and magnesium activities of two western Colorado oil shales and attempted to explain the high alkalinity of processed oil shales.

The different mineral phases were identified using X-ray diffraction analysis. Oil shale processing is done at high temperatures (1,273 K), resulting in the destruction of carbonate minerals and the formation of silicate minerals such as wollastonite, clinoenstatite, or diopside, depending on the processing method and the chemical composition of the raw oil shale. These silicate minerals buffer the pH above 11.0, and the alkalinity of spent oil shale is produced from the dissociation of silicate species in solution. These minerals are controlling calcium and magnesium activities in solution. The oxides and hydroxides of calcium and magnesium produced during the initial processing of oil shale do not persist, but they dissolve, and the products react with elements such as silica to precipitate stable minerals. It is thought that eventually, during recarbonation, calcium and magnesium silicates will dissolve. As the calcium and magnesium released reprecipitate as carbonates, the pH will return to 8.0.

908. Reddy, K. J., W. L. Lindsay, F. W. Boyle, Jr., and E. F. Redente. Solubility Relationship and Mineral Transformations Associated With Recarbonation of Retorted Shales. J. Environ. Qual., v. 15, No. 2, 1986, pp. 129-133.

The solubility relationships and mineral transformations associated with the recarbonation of two retorted shales from western Colorado were examined. Recarbonation was accomplished by bubbling CO_2 gas through the retorted shale. This was done to lower the pH of the waste material. The different mineral phases of retorted and recarbonated shales were identified using X-ray diffraction analysis. Recarbonation of the retorted shale resulted in the dissolution of the silicate minerals, the precipitation of calcite ($CaCO_3$), and lowering of the pH from 12.0 to 8.0. Solubility measurements showed that with recarbonation, the calcium activity of the two shales approached equilibrium with calcite ($CaCO_3$) and the measured CO_2 gas. Magnesium solubility approached that of diopside and antigorite (silicate minerals), but after 20 days of recarbonation, magnesium solubility decreased.

909. Redente, E. F. Reclaiming Oil-Shale Disturbances. West. Wildlands, v. 7, No. 3, 1981, pp. 35-37.

The author discusses the problems encountered when reclaiming spent oil shale in Colorado, Utah, and Wyoming. The four basic methods that can be used to mine and retort oil shale are (1) underground mining, (2) surface mining, (3) true in situ mining, and (4) modified in situ mining. Each method poses major reclamation problems. The most difficult disposal and revegetation problems are encountered on spent oil shale after retorting. Reclamation techniques that have proven to be successful are given. Native plant species have been shown to produce better stands over time than do introduced species. A mixture of native and introduced species may control the invasion of annual species during early stand development, but in the long run, a seeded native mixture may be more effective. Treatments that help to stimulate grass, forb, and shrub establishment are given; these include fertilization, mulching, and irrigation.

910. Redente, E. F., T. B. Doerr, C. E. Grygiel, E. Allerdings, J. M. Stark, and M. E. Biondini. Effects of Plant Species, Soil Materials, and Cultural Practices Upon Plant Establishment and Succession. Ch. in Revegetation Studies on Oil Shale Related Disturbances in Colorado (U.S. Dep. Energy contract DE-AS02-76EV04018, Range Sci. Dep., CO State Univ.). U.S. Dep. Energy, DOE/EV/04018-6, June 1982, pp. 1-25.

This study is part of a larger project evaluating the impact of and potential for reclamation following oil shale mining and retorting processes. This paper reports the sixth-year results of this study. The principal objectives of the research reported in this paper include (1) determining the proper seeding practices of potentially usable mixtures of plant species and their relationship to cultural practices such as fertilization, irrigation, and mulching, (2) determining the rate and direction of plant succession on disturbed topsoil, subsoil, overburden, retorted shale, and retorted shale overlain by soil, as influenced by natural invasion, species mixtures, and cultural practices, and (3) determining proper management procedures for long-term stabilization and reclamation of retorted shale materials.

The rate of natural plant succession was substantially influenced by the degree of soil disturbance. Mixing soil horizons increased the probability that annual weeds would be the prominent invaders of a site and decreased the probability of perennial species significantly contributing to the established vegetation communities. Introduced species were slightly more resistant to invasion by volunteer species. Fertilizer was found to be effective in increasing seeded grass and shrub production. Manipulation of topsoil depth and the use of a capillary barrier were shown to be the best treatments for supporting plant species over Paraho retorted shale. This paper is an excellent reference for planning revegetation establishment on spent oil shale in Colorado.

911. Redente, E. F., and N. E. Hargis. An Evaluation of Soil Thickness and Manipulation of Soil and Spoil for Reclaiming Mined Land in Northwest Colorado. Reclam. & Reveg. Res., v. 4, No. 1, 1985, pp. 17-29.

The effects of soil replacement thickness and mechanical treatment of northwestern Colorado mine soil and spoil on seeded range species were evaluated. Soil was replaced to depths of 15, 30, 45, and 60 cm, while the mechanical and fertilizer treatments were (1) disk spoil before soil replacement, (2) disk and fertilize spoil before soil replacement, (3) rip spoil to 60 to 90 cm before soil replacement, (4) rip spoil 60 to 90 cm and fertilize before soil replacement, and (5) rip soil and spoil to 30 cm below soil-spoil interface after soil replacement. The fertilizer was a single application of phosphorus applied at a rate of 52 kg ha^{-1} P. The experimental area was divided into four blocks; each was subdivided into twenty 10.7- by 10.7-m plots. The experimental factors (soil thickness and mechanical treatment) were arranged in a 4 × 5 factorial in a split-block design. Soil and spoil samples were characterized chemically and physically before fertilization. The area was seeded with a mixture of cool-season grasses, forbs, and shrubs. Density, canopy cover, aboveground biomass, and root biomass of the vegetation were sampled.

Seeded grass biomass (2,660 kg ha^{-1}) was significantly greater on 60 cm of soil than on the other three soil thickness, while seeded forb and shrub biomass was greatest on 15 cm of soil, with a decline as soil thickness increased. Biomass of the volunteer vegetation was significantly less on the 15 cm soil thickness than on the 30- to 60-cm thicknesses. The biomass of the seeded species did not differ significantly between the 60 and 15 cm of soil because the greater biomass of seeded grasses on 60 cm of soil was balanced by the greater biomass of seeded forbs on 15 cm of soil. Biomass of seeded and volunteer species was greater on 60 cm of soil than on 15 to 45 cm. With effective weed control, maximum usable herbage production would be expected on 60 cm of soil. Response of canopy cover to soil thickness was similar to that of aboveground biomass. Soil did not promote deeper root penetration even though it provided more nutrients than did the spoil. Seeded vegetation did not show a direct response to mechanical or fertilizer manipulation. Seeded range vegetation was more responsive to soil thickness changes than it was to manipulations of the soil and spoil. If the revegetation objective is maximum herbage production from a few perennial grass species, 60 cm of soil should be used.

912. Redente, E. F., N. E. Hargis, and M. E. Biondini. Revegetating Disturbed Areas To Protect the Environment, Final Report (Off. Surf. Min. and BuMines contracts G1115082 and G1105017, CO Sch. Mines; subgrant, CO State Univ.). Range Sci. Dep., CO State Univ., Fort Collins, CO, Jan. 1984, 104 pp.

The results and conclusions of a 3-year study at the Trapper Mine in northwestern Colorado are reported. The study examined vegetation response to four different topsoil thicknesses (15, 30, 45, and 60 cm) and five manipulations that included combinations of disking, ripping, and fertilizing. Wheat (*Triticum aestivum* L.) grain yields were highest when soil thickness was 45 cm and the soil and overburden were ripped. Alfalfa (*Medicago sativa* L.) yields appeared to be highest when overburden was disked and fertilized and the topsoil was replaced to a thickness of 60 cm. Standing crop biomass for range vegetation was highest when overburden was ripped and soil was replaced to 60 cm. However, maximum species diversity was obtained by disking overburden and replacing 15 cm of topsoil. Performance of most range plants improved over the 3 years of the study.

913. Redente, E. F., C. B. Mount, and W. J. Ruzzo. Vegetation Composition and Production as Affected by Soil Thickness Over Retorted Oil Shale. Reclam. & Reveg. Res., v. 1, No. 2, 1982, pp. 109-122.

This study was done to provide guidelines for topsoil thickness requirements for the reclamation of oil shale lands in the Piceance Creek Basin of northwestern Colorado. The study evaluated the effects of retorted shale properties, topsoil thickness, a capillary barrier, seed mixtures, and nitrogen and phosphorus fertilization. Six topsoil-shale profiles were constructed, consisting of (1) 60 cm retorted shale without topsoil covering, (2) 30 cm topsoil over 60 cm retorted shale, (3) 60 cm topsoil over 60 cm retorted shale, (4) 90 cm topsoil over 60 cm retorted shale, (5) 60 cm topsoil over 30 cm rock capillary barrier (barrier to salt migration) over 60 cm retorted shale, and (6) disturbed soil control with no retorted shale. Following profile construction, three mixtures of native and/or introduced species were drill seeded and fertilized with nitrogen and phosphorus at three different levels.

Vegetation did not establish on the nontopsoiled treatment owing to the adverse chemical and physical properties of the Paraho retorted shale. As topsoil thickness increased over the retorted shale, mean canopy cover of seeded species increased. The greatest canopy cover values were observed on the capillary barrier treatment. The 90-cm topsoil treatment had the second highest canopy cover values. Mean aboveground dry matter production was significantly greater on the 90-cm topsoil treatment than on all other treatments except the capillary barrier. Plants growing on the more shallow topsoil treatments were subject to the detrimental effects of retorted oil shale. Aboveground biomasses for the three seed mixtures were about equal; however, the native mixture had significantly greater canopy cover than the introduced or combination native and introduced seed mixtures. Grass production was significantly increased by nitrogen and phosphorus fertilizer application, while forb

production decreased significantly with fertilization. The results of this study indicate that topsoiling must be an integral part of the reclamation plan for retorted shale. Without soil coverings, wind and water erosion could result in serious air and water contamination.

914. Reeder, J. D. Fate of Nitrogen-15-Labeled Fertilizer Nitrogen in Revegetated Cretaceous Coal Spoils. J. Environ. Qual., v. 14, No. 1, 1985, pp. 126-131.

A greenhouse pot study was conducted to describe the short-term behavior of ^{15}N-labeled fertilizer nitrogen in cropped Cretaceous coal spoils compared with a cropped topsoil. Western wheatgrass (*Agropyron smithii* Rydb.) was used as the crop species. The effects of nitrogen fertilizer on seedling emergence and dry matter production, plant uptake of nitrogen, microbial immobilization and mineralization of nitrogen, and possible mechanism of fertilizer nitrogen loss were determined. Two coal mine spoils and one topsoil from northwestern Colorado were studied. Chemical and physical characteristics of the soil materials were determined. Fertilizer nitrogen was applied at 0, 60, 120, and 240 mg kg^{-1} N as $(^{15}NH_4)_2SO_4$. The fertilizer was enriched with 5.392 at. pct ^{15}N and was surface applied to simulate a broadcast application.

In the topsoil, complete emergence was noted 7 days after planting, while emergence was delayed in the spoil materials. The two highest rates of fertilizer nitrogen inhibited seedling emergence and establishment in the spoils because of NH_3 toxicity and the phytotoxicity caused by nitrite accumulation. Aboveground and total plant biomasses were significantly higher on nonfertilized topsoil than on nonfertilized spoil. Aboveground dry matter production increased on the spoil materials with the addition of 60 mg kg^{-1} N, and was not significantly different from the biomass at 120 mg kg^{-1} N; however, there was a significant decrease in aboveground biomass with the addition of 240 mg kg^{-1} N. Plants in topsoil took up significantly more indigenous nitrogen than did plants growing in spoils. There was a higher mineralization potential in the topsoil than in the spoil. Plants grown in topsoil also took up significantly higher levels of fertilizer nitrogen with increased application (luxury consumption). There was no luxury consumption of fertilizer nitrogen in plants grown in spoil; less fertilizer nitrogen was taken up. Balance sheets showed the location and recovery of fertilizer nitrogen in the soil-plant system at harvest.

915. Reeder, J. D. Transformations of Nitrogen-15-Labeled Fertilizer Nitrogen and Carbon Mineralization in Incubated Coal Mine Spoils and Disturbed Soil. J. Environ. Qual., v. 17, No. 2, 1988, pp. 291-298.

This laboratory incubation study quantified and compared carbon and nitrogen mineralization, nitrogen immobilization, and nitrification of five coal spoil materials and one soil (A and B horizons) collected from four coal mines in Colorado and Wyoming. The physical and chemical characteristics of the spoil and soil are presented, along with the analytical methods used. Two fertilizer treatments were applied to the samples: no addition of ammonium-nitrogen (NH_4-N) and the addition of NH_4-N at a rate of 40 mg kg^{-1} N as $(^{15}NH_4)_2SO_4$. Each sample was incubated for 3, 6, 12, or 24 weeks.

Carbon dioxide (CO_2) evolution was significantly higher in the soil sample than in the spoils, indicating that carbon mineralization was significantly higher in the soil than in any of the spoil samples. Most of the spoil samples contained larger quantities of organic carbon in inert forms that were resistant to microbial utilization. After 24 weeks of incubation the soil material had significantly higher accumulations of mineralized organic nitrogen than did any of the spoil materials. While a significant increase in mineral nitrogen concentration occurred in soil throughout the incubation periods, this did not occur in any of the spoil materials. In two of the spoils, the nitrogen mineralized did not accumulate, and in one case, shale material, mineral nitrogen declined significantly through the incubation period. Nitrogen was immobilized by the heterotrophic microbial population as rapidly as it was mineralized. The amount of plant-available nitrogen mineralized in the spoil material was found to be 20 pct of that mineralized in the soil, indicating that the amount of plant-available nitrogen mineralized was at least 5 times greater in the soil material.

These data suggest that under field conditions the spoil material evaluated will not be able to adequately supply the nitrogen requirements of seeded plant communities without supplemental nitrogen additions. When $^{15}NH_4$-N was added, the active microbial populations in the soil immobilized more of the added nitrogen than did microbes in any of the spoils except for the shale material. When $^{15}NH_4$-N was added to the spoil material, 51 to 62 pct of the added $^{15}NH_4$-N was nitrified and remained as nitrate in the spoils. The results show that under field conditions, microbial immobilization should protect added fertilizer, in the form of NH_4-N, from volatilization losses or from leaching losses following nitrification. In spoils with rapid nitrification, a larger proportion of added NH_4-N fertilizer will be susceptible to leaching losses. The author states that the information presented should be useful in deciding the form, amount, and time of application of nitrogen fertilizer in reclamation programs.

916. Reeder, J. D., and W. A. Berg. Nitrogen Mineralization and Nitrification in a Cretaceous Shale and Coal Mine Spoils. Soil Sci. Soc. Am. J., v. 41, No. 5, 1977, pp. 922-927.

This article reports the results of a study utilizing laboratory incubation techniques to examine the rates and amounts of nitrogen mineralization in geologic strata. Laboratory incubations were conducted to determine ammonification and nitrification rates in Cretaceous shale, two strip mine spoils, and an undisturbed soil collected from the Seneca Mine site near Hayden, CO. Net mineralization of nitrogen was significantly higher for the vegetated spoil material and the natural soil than for the shale and fresh spoil material. Nitrification of added NH_4-N resulted in significantly higher NO_3-N levels in the vegetated spoil and soil material. Rates and total amounts of CO_2 evolution from the geologic material resembled those from the natural soil. The results and discussion contained in this article are relevant to mine-land reclamation research and planning throughout much of the Rocky Mountain and Northern Great Plains Coal Mining Regions.

917. Reeder, J. D., and W. A. Berg. Plant Uptake of Indigenous and Fertilizer Nitrogen From a Cretaceous Shale and Coal Mine Spoils. Soil Sci. Soc. Am. J., v. 41, No. 5, 1977, pp. 919-921.

The significance to plant growth of indigenous nitrogen mineralization and utilization of added NH_4^+ was examined in a greenhouse study. Barley (*Hordeum vulgare* L.) was grown on incubated and nonincubated samples of a Cretaceous shale, two strip mine spoils, and a natural soil (Cryoboroll) collected from the Seneca Mine site near Hayden, CO. Plants grown on shale or fresh soil took up less indigenous nitrogen than did plants grown on vegetated spoil or on natural soil. The results indicated that initial plant recovery of fertilizer nitrogen from the geologic materials equaled that recovered from the soil. However, fertilizer nitrogen added to the geologic material may be less available to plants over time than the same amount of fertilizer nitrogen added to soil. The results also suggested that laboratory incubation tests could be used to estimate the plant-available nitrogen potentials of certain drastically disturbed lands prior to extensive revegetation programs. The results and discussion contained in this article are relevant to mine-land reclamation research and planning throughout major portions of the Rocky Mountain and Northern Great Plains Coal Mining Regions.

918. Reeder, J. D., and B. R. Sabey. Nitrogen. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 155-184.

Nitrogen deficiency can limit revegetation and long-term stability of land disturbed by surface mining. Disturbance drastically alters the flow of nitrogen through the soil-plant-microbial ecosystem. To achieve successful revegetation and maintain a self-sustaining plant community, it is necessary to reestablish an active biological nitrogen cycle. Another concern is the loss of nitrogen from disturbed land because of leaching, runoff, or soil erosion. This chapter discusses nitrogen in the environment in terms of nitrogen geochemical distribution, the nitrogen cycle in undisturbed grassland ecosystems (losses from and additions to nitrogen western soils), and the nitrogen cycle of a disturbed grassland ecosystem (topsoil nitrogen, geologic nitrogen, supplemental nitrogen, and potential toxicity hazards). Sampling and testing procedures for the determination of a site's nitrogen status are given.

919. Reeves, F. B., Jr., R. J. Reinsvold, J. Saboloni, and A. Park. Importance of Mycorrhizal Fungi in Revegetating Disturbed Soils and Retorted Shale. Ch. in Revegetation Studies on Oil Shale Related Disturbances in Colorado (U.S. Dep. Energy contract DE-AS02-76EV04018, Range Sci. Dep., CO State Univ.). U.S. Dep. Energy, DOE/EV/04018-6, June 1982, pp. 45-56.

This study is part of a larger project evaluating the impact of and potential for reclamation following oil shale mining and retorting processes. This paper reports the sixth-year results of this study. The main goal was to examine the ecology of the mycorrhizal association and to develop an understanding of how these fungi can be maintained or reestablished in disturbed, stored, or processed soil material. Topsoil storage for 3 years decreased the mycorrhizal inoculum potential of the topsoil when the soil was left unplanted. However, this potential was maintained in the upper 90 cm of the storage pile when the topsoil was planted with mycorrhizal-related plant species. Functional mycorrhizae did not form in decarbonized Paraho or Union shales after several growing seasons. No adverse effects on the mycorrhizal inoculum potential of the topsoil placed over these shales were reported. TOSCO II spent shale, when leached and fertilized, allowed the formation of mycorrhizae in the upper 30 cm of the profile but inhibited mycorrhizal formation at greater depths. This paper is an excellent reference for planning revegetation activities and for understanding the microbial plant ecology of revegetation of disturbed areas.

920. Reinsvold, R. J., and P. E. Pope. Use of Biological Dinitrogen-Fixers for Amelioration of Minesoils. Paper in Proceedings of the Fifth Better Reclamation

With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 69-83.

The effects of two dinitrogen (N_2) fixing trees, black locust (*Robinia pseudoacacia* L.) and European black alder (*Alnus glutinosa* (L.) Gaertn.), on mine-soil chemical properties were determined, along with the effects of phosphorus and potassium fertilization on plant growth and soil amelioration. Pure stands of each tree species were established using 1-0 bare-root seedlings and fertilized with either 0 or 50 kg ha^{-1} P and K in two applications (first and second growing seasons). Soil chemical properties (upper 30 cm) were determined prior to fertilization, during the first growing season, and after the first and second growing seasons. Soils were analyzed for pH, phosphorus, potassium, calcium, magnesium, sodium, NO_3-N, NH_4-N, total nitrogen, and percent organic matter. Trees were harvested after the first and second growing seasons to determine biomass production and nutrient content of the plant tissue.

There were no significant differences in soil chemical properties between plant species. After two growing seasons, the mean levels of NO_3-N, soil organic matter and total nitrogen within the plantations were significantly higher than preplanting values. Phosphorus and potassium fertilization also resulted in significantly higher levels of phosphorus and potassium (particularly available phosphorus and potassium) than in unfertilized plots. Soil acidity, calcium, magnesium, and sodium were not affected by fertilization or the presence of either tree species. Fertilization resulted in significantly higher nitrogen concentrations in locust foliage and in alder stem and foliage compared with tissues from unfertilized plots. The overall effects on soil chemical properties were similar for both N_2-fixing trees. Advantages and potential problems of growing N_2-fixing trees on reclaimed mine soils are presented. The greatest contribution to the soil-plant system by N_2-fixing trees is fixed nitrogen.

921. Reis, R. E., R. S. White, and R. J. Lorenz. Establishment of Range Plants in the Northern Great Plains. Paper in Impacts of the Conservation Reserve Program in the Great Plains, ed. by J. E. Mitchell (Symp. Proc., Denver, CO, Sept. 16-18, 1987). U.S. For. Serv., Gen. Tech. Rep. RM-158, 1988, pp. 29-34.

An overview of the principles and techniques used for establishing forage range species in the Northern Great Plains is presented. Information on range plant establishment includes planning for seeding, techniques for seeding, seedbed preparation, seeding methods, rates and dates, and early stand management. Controllable factors in range establishment are species and cultivar selection, seed quality, seedbed preparation, seeding method, and early stand management. Weather conditions, however, are uncontrollable. Information is also presented on the use of mulches and fertilizers in range plant establishment in the Northern Great Plains.

922. Reith, C. C., and L. D. Potter. Bare-Plot Analysis as a Tool for Diagnosing Impediments to Revegetation at Surface Coal Mines. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 268-274.

A variety of *post hoc* analyses on four revegetated coal surface mines in northwestern New Mexico were conducted to identify spoil and soil properties that may have impaired the germination, growth, or survival of the perennial grasses used for revegetation. Bare-plot analysis was used. This analysis involves determining soil properties of unvegetated areas on reclaimed surfaces and comparing them (pairwise comparisons) with soil properties of nearby successfully revegetated areas. Plots were analyzed for volumetric stoniness, bulk density, pH, electrical conductivity, sodium adsorption ratio, and soluble sodium, calcium, and magnesium. The results at each mine are presented; two of the mines had favorable results in the ability of bare-plot analysis to identify responsible factors, while at the other two mines the method was less successful. Bare-plot analysis works best on mines with relatively large reclaimed surfaces that have some successfully revegetated areas. The authors recommend bare-plot analysis as a useful tool for understanding the results of past reclamation.

923. Reith, C. C., and L. D. Potter. Geographic Variation Among Soil-Based Models of Reclamation Success. J. Arid Environ., v. 8, 1985, pp. 223-234.

The environmental variability expected for a regional model of reclamation potential based on soil properties for the San Juan Basin in northwestern New Mexico is examined. The geographic variation in the predictive power and composition of soil-based models of reclamation success at four surface mines is described. The geographic variation is interpreted in order to forecast the nature and feasibility of a regional model of reclamation potential. The soil properties likely to be reliable predictors of reclamation potential in the model are identified. Eleven soil properties were analyzed at each minesite, and factor analysis was performed on each property to reduce individual soil properties to fewer noncorrelated factors. Six general soil conditions were identified that represented gradients of stress to the vegetation. Multiple linear regression was used to find correlations between the soil condition and the revegetation indices (basal cover, foliar

cover, biomass, frequency) for the mines in combination and for each mine. Soil sodicity and texture were the most important factors in the models. Soil compaction and osmotic factors were negative, but were not significant negative factors at any mine. Stoniness and alkalinity were not significant in the basin-wide model and have no value as predictors of reclamation potential in a regional model.

924. Reynolds, J. F., M. J. Cwik, and N. E. Kelley. Reclamation at Anaconda's Open Pit Uranium Mine, New Mexico. Reclam. Rev., v. 1, No. 1, 1978, pp. 9-17.

This paper presents the reclamation activities used at Anaconda's uranium mine that show promise in revegetating critical areas in the semiarid climate of the Southwest. A three-step process is involved in the rehabilitation of critical areas for use as rangeland: step 1, overburden analysis to select against phytotoxic properties of the various materials on the waste dump; step 2, documentation of important phytosociological traits on overburden and comparison of the traits with those of surrounding plant communities on unmined land; and step 3, development of a revegetation project that includes intensive soil analysis and innovative seedbed preparation techniques. These steps indicated that the Tres Hermanos materials can support native vegetation that is comparable to that of surrounding grasslands. Long-term monitoring is needed to establish trends and determine the overall success of stabilization efforts.

925. Rice, C. W., R. I. Barnhisel, and J. L. Powell. The Establishment of Loblolly Pine (*Pinus taeda* L.) Seedlings on Mined Land With *Pisolithus Tinctorius* Ectomycorrhizae. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 527-534.

This study was conducted to assess the role of mycorrhizae in the establishment of loblolly pine (*Pinus taeda* L.) on surface mine spoil near Central City, in western Kentucky. A second objective was to compare the growth and survival of loblolly pine between nursery and field inoculations of mycorrhizae fungi. Four treatments were used in this study: (1) *Pisolithus* inoculant added to uninoculated seedlings in the field, (2) seedlings inoculated in the nursery with *Pisolithus tinctorius*, (3) control—uninoculated seedlings, and (4) control—uninoculated seedlings with vermiculite added. With the seedlings left over from this study, a demonstration study was established in eastern Kentucky on mined land near Quicksand, KY.

In the western Kentucky study, survival of loblolly pine was significantly greater when *Pisolithus* inoculant was added in the field (treatment 1). The survival of nursery-inoculated seedlings decreased significantly over the course of this study. By the end of the second growing season, the survival of these seedlings was only 10 pct. After four growing seasons there were no significant differences in height and root collar diameter among the surviving seedlings. Mycorrhizal infection was highly variable, with no apparent differences among treatments. After 4 years only one fruiting body of *Pisolithus tinctorius* had appeared on a plot; this plot had been field inoculated. However, the fruiting bodies of a native mycorrhizal fungus, *Thelephora terrestris*, appeared on several plots.

The survival and growth of loblolly pine planted at the demonstration site in eastern Kentucky were better than those of pine planted in western Kentucky. Mycorrhizal infection was also greater at the eastern Kentucky site. The authors conclude that the poor survival of nursery-inoculated seedlings suggests that the "tailoring" of loblolly pine with *Pisolithus tinctorius* may not always be the best approach on limed and fertilized surface-mined soils since field inoculation enhanced pine survival.

926. Richards, T. W., and D. H. Graves. Direct Seeding Study With Mulch Treatments After 5 Years. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 145-201.

Results reported are from a study of direct seeding of 15 tree species in barren mine spoils mulched with hardwood bark, waterborne fiber mulch, and a composted municipal garbage-sewage sludge product with the trade name of Real Earth. Germination rates averaged greater than 30 pct for northern red oak (*Quercus rubra* L.), bur oak (*Quercus macrocarpa*) Michx.), Ohio buckeye (*Aesculus glabra* Willd.), Chinese chestnut (*Castanea mollissima*) Blume), Virginia pine (*Pinus virginiana* Mill.), and loblolly pine (*Pinus taeda* L.). After 5 years, Virginia pine had decreased substantially, and most loblolly pine seedlings had died. Survival for the four hardwood species, which had the highest germination rates, ranged from 64 to 100 pct for the 5 years. The effects of the mulching treatments were not conclusive. By the end of five growing seasons, the control plot had the highest average stocking for all species tested. This report provides germination and survival data pertinent to revegetation activities involving the direct-seeding method. The study was conducted in Breathitt County, KY.

927. Richards, T. W., and D. H. Graves. Reclaiming Land With Trees: Costly but Effective. Am. Tree Farmer, v. 4, No. 2, 1985, pp. 18-19.

A cost comparison between pasture and forest land uses following mining is presented. Forest land uses cost as

much as $300.00 per acre more. Ways to reduce the cost of establishing forest are presented. Cost savings can result if grading is reduced, fertilization is eliminated, and trees are not established at the same time as the grass cover. Cost savings can also be expected if the proper tree species for planting on mined lands are used.

928. Richards, T. W., R. F. Wittwer, and D. H. Graves. Direct Seeding Oaks for Surface Mine Reclamation. Paper in 1982 Seminar on Post-Mining Productivity With Trees (Carbondale, IL, Mar. 31-Apr. 2, 1982). South. IL Univ., Carbondale, IL, 1982, pp. 57-62.

The results of four separate studies are summarized in this article. All four studies looked at the feasibility of direct-seeding oak tree species on mined land in Kentucky. Treatments included fertilization, mulches, and herbaceous cover, each considered separately and in combination. The oak species studied included northern red oak (*Quercus rubra* L.), pin oak (*Quercus palustris* Muenchh.), chestnut oak (*Quercus prinus* L.), bur oak (*Quercus macrocarpa* Michx.), and sawtooth oak (*Quercus acutissima* Carruth.). Data summarizing the stocking percentage and height growth for each treatment are given. Results show that mulching and fertilizing gave the best results, but herbaceous cover seriously impaired survival and growth.

929. Richards, T. W., R. F. Wittwer, and D. H. Graves. Feasibility of Direct Seeding Trees on Surface Mines in Kentucky. Paper in Vegetative Rehabilitation and Equipment Workshop, 36th Annual Report (Denver, CO, Feb. 4-5, 1982). U.S. For. Serv. Equip. Dev. Cent., Missoula, MT, 1982, pp. 39-44.

The authors discuss the development of a planting machine that is capable of planting (direct-seeding) large-seeded tree species on surface-mined land in Kentucky. Adaptations were made on a Cole multiflex unit planter. It was found that the planter was capable of planting large-seeded tree species in loose mine spoil but had limited ability on steep slopes. Further experimentation is needed to develop a planting machine suited to the variable site characteristics encountered on surface-mined land.

930. Richardson, B. Z., and E. E. Farmer. Changes in Sodium Adsorption Ratios Following Revegetation of Coal Mine Spoils in Southeastern Montana. U.S. For. Serv., Intermt. For. and Range Exp. Stn., Ogden, UT, Res. Pap. INT-287, May 1982, 4 pp.

The results of a 7-year study of the change in sodium adsorption ratios (SAR's) following revegetation of coal mine spoils in southeastern Montana are presented. SAR values decreased from greater than 12 to less than 3 within 5 to 7 years. Biomass production increased, further decreasing the relative proportion of sodium ions in sodic spoils. This study was conducted at the Decker coal mine. The results and discussion contained in the report are useful to planning reclamation activities in portions of the Northern Great Plains and Rocky Mountain Coal Mining Regions.

931. Richardson, B. Z., and T. P. Trussell. Species Diversity for Wildlife as a Consideration in Revegetation Mined Area. Paper in Shrub Establishment on Disturbed Arid and Semi-Arid Land (Proc. Symp., Laramie, WY, Dec. 2-3, 1980). WY Game and Fish Dep., 1981, pp. 70-80.

The methods used to promote vegetative diversity on reclaimed portions of five minesites are discussed. The mines used in the study were located in Idaho, Nevada, and Wyoming. The spoils at all of the test sites were amended with fertilizer. Mulch was applied to three of the sites. Rapid ground cover establishment was the initial objective at all five sites. Once ground cover was established, increasing species diversity and reestablishment of native shrubs became important. A constant ratio of shrubs to grasses over time was obtained by interseeding shrubs with grasses during direct-seeding operations. The authors feel that adding organic matter and ameliorating specific growth-limiting characteristics encourage natural succession and species diversity on reclaimed mined lands. The methods and discussions contained in this article are applicable to revegetation efforts on surface coal mine lands throughout major portions of the Northern Great Plains and the Rocky Mountain Coal Mining Regions.

932. Richardson, P. Federal Mining Law Endangers Usibelli's Reclamation Efforts. Alaska Constr. and Oil, v. 20, No. 5, 1977, pp. 20-26.

The author discusses several problems that exist with the Surface Mining Control and Reclamation Act of 1977 and the reclamation of Alaska's surface-mined land. Several of the regulations do not seem to apply to Usibelli Coal Mining Co.'s operations, which had field-proven reclamation success prior to the passage of Public Law 95-87. For example, the requirement that topsoil must be stockpiled and replaced does not apply in certain situations in Alaska. In Usibelli's case, topsoil was either very thin or nonexistent; yet using extracted overburden or innerburden, successful vegetation establishment was achieved. The author then discusses several of the strategies that have been used to successfully reclaim mined land in Alaska and reclamation projects that are planned for the future.

933. Richardson, S. G., and C. M. McKell. Salt Tolerance of Two Saltbush Species Grown in Processed Oil Shale. J. Range Manage., v. 33, No. 6, Nov. 1980, pp. 460-462.

This paper reports the results of a greenhouse study that evaluated the tolerance of four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) and cuneate saltbush (*Atriplex cuneate* A. Nels.) to salt in processed oil shale over an EC range of 4 to 38 mmho cm^{-1}. Both species survived and grew at salinities as high as 38 mmho cm^{-1}. However, cuneate saltbush was more salt tolerant than four-wing saltbush. The species exhibited differing growth responses dependent on the particular salt or salts in the soil solution. The results and discussion are applicable to surface coal mine revegetation efforts in major portions of the Rocky Mountain and Northern Great Plains Coal Mining Regions.

934. Rickard, W. H., and R. H. Sauer. Land Rehabilitation Research at Pacific Northwest Laboratories: A Brief Summarization for Presentation at Argonne National Laboratory. Battelle Pac. Northwest Lab., Richland, WA, Jan. 1977, 21 pp.

This publication provides brief descriptions of reclamation research conducted by the Pacific Northwest Laboratories. The four research projects included in the report are listed and briefly described:

1. *Primary Productivity and Grazing Potential of Undisturbed Sagebrush-Bluebunch Wheatgrass Communities.*—This study collected productivity data from an area in the sagebrush (*Artemisia* spp.) and bluebunch wheatgrass (*Agropyron spicatum* (Pursh.) Scribn. & Smith) region of the United States that has a long history of no grazing. These data are viewed in conjunction with data from a controlled cattle-grazing study to determine the capacity of this ecosystem to sustain moderate grazing pressure, to measure weight gains of cattle while on sagebrush-bluebunch wheatgrass pastures, and to study dietary preferences of the cattle. Reproductive capacity of the important cattle forage grasses was decreased by grazing. Gross changes in plant communities are anticipated under moderate grazing intensities. The study was conducted on the U.S. ERDA Hanford Reservation in south-central Washington.

2. *Response of Sagebrush-Bluebunch Wheatgrass Communities to Severe Soil Disturbance.*—This study examined secondary succession on abandoned dry land wheat fields on the U.S. ERDA Hanford Reservation. After 30 years native plants were still poorly represented. The fields were dominated by introduced weed species, especially cheatgrass (*Bromus tectorum* L.).

3. *Plant Cover on Stressful Habitats of Natural Origin.*—This study examined species composition and canopy cover on steep slopes having either a north or south aspect. The study was conducted in south-central Washington. Cheatgrass provided a significant portion of the vegetation on south-facing slopes. Native vegetation was more significant on north-facing slopes. It was concluded that south-facing slopes in this region are not conducive to establishment of native perennial grasses.

4. *Rehabilitation of Surface Mine Lands by Water Harvest.*—This study involved radical modification of the topography of a minesite to accumulate precipitation and placement of topsoil in sufficient depth to store adequate amounts of this water to enable growth of plants that exhibit higher productivity and higher economic value than those typically used under conventional land restoration practices.

The ratings assigned to keywords in the evaluation process refer to this publication as a whole and not to each individual research project. The information presented and the research discussed are useful to revegetation planning in portions of the Northern Great Plains, Pacific, and Rocky Mountain Coal Mining Regions.

935. Ries, R. E. Supplemental Water for the Establishment of Perennial Vegetation on Strip-Mined Lands. ND Farm Res., v. 37, No. 6, 1980, pp. 21-23.

This research was conducted to determine the density and dry matter production of perennial vegetation established on mined land in North Dakota that had natural precipitation supplemented by irrigation. Two separate studies are detailed in this paper. The first study utilized treatments consisting of two water levels (natural precipitation and natural precipitation plus irrigation), two planting dates (end of May and end of July), and two species mixtures (an introduced forage mixture and a native forage mixture). The second study utilized four water treatments and a single forage mixture. The water used for irrigation in the second study was of poor quality (EC of 3.0 to 4.0 mmho cm^2).

The results of the first study indicated that supplemental irrigation water can help ensure a fast and successful establishment of perennial vegetation, especially when natural precipitation is low. Supplemental irrigation will also permit planting later in the growing season, which may help to control weedy species. Supplemental water applied at different levels may also provide some control over the final species composition in newly established stands. The preliminary results from the second study indicated that the use of poor-quality water in the establishment of vegetation had no detrimental effects on the vegetation. The author concludes that supplementing

natural precipitation may provide protection against plant establishment failures and warrants consideration as a reclamation technique when water is available and the cost of failure is high.

936. Ries, R. E., and L. Hoffman. Pasture and Hayland: Measures of Reclamation Success. Paper in the Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 307-317.

This paper reviews information gained from 8 years of research on a reclaimed grassland in North Dakota. Several characteristics of the reclaimed grassland and two unmined grasslands used for tame pastureland were quantified and evaluated as measures for determining reclamation success. These characteristics included vegetation and animal productivity, ground cover, soil loss, species composition and numbers, and seasonality. The authors express the view that vegetative productivity and ground cover provide appropriate measures for documenting reclamation success for the postmine use of pasture and occasional hay production. The information conveyed is applicable to designing revegetation monitoring programs in major portions of the Northern Great Plains and Rocky Mountain Coal Mining Regions.

937. Ries, R. E., F. M. Sandoval, and J. F. Power. Reclamation of Disturbed Lands in the Lignite Area of the Northern Plains. Paper in Technology and Use of Lignite (Proc. Symp. cosponsored by U.S. Energy Res. Dev. Admin. and Univ. ND; Grand Forks, ND, May 18-19, 1977). U.S. Dep. Energy, GFERC/IC—77/1, 1977, pp. 309-327.

This article provides a good overview of the status of reclamation techniques and research in the Northern Great Plains Coal Mining Region. A review of some of the current reclamation research is provided, together with pertinent soil characterization and yield data. Trends of data and tentative conclusions are discussed.

938. Riley, R. K., and M. L. Brown. The Natural Invasion of Wildlife Food and Cover Species Onto Bituminous Coal Spoil. Paper in Symposium on Surface Mining and Fish/Wildlife Needs in the Eastern United States (WV Univ., Dec. 1978). U.S. Fish and Wildl. Serv., FWS/OBS-78/81, 1978, pp. 376-379.

This study reports on the natural invasion of mycorrhizae-deciduous tree species associations onto four different bituminous coal spoils in Allegany County, MD. A brief review of mycorrhizae-tree associations is given. Two fungi were identified that associated with several wildlife food and cover deciduous tree species—*Pisolithus tinctorius* and *Scleroderma aurantium*. The naturally occurring mycorrhizae were evaluated as soil amendments even though they were not added to the soil. This study suggests that deciduous tree species can be used for reforestation of bituminous spoil if *P. tinctorius* and *S. aurantium* are used as inoculum to form mycorrhizae associations. Recommendations on mycorrhizal use in revegetation of bituminous coal spoils are given.

939. Riley, R. K., and P. D. Curtis. Preliminary Results of the Occurrence of Endomycorrhizae on Surface Mine Top Soil Piles. Proc. WV Acad. Sci., v. 54, No. 1, 1987, p. 1.

The occurrence of endomycorrhizae on roots of grass was studied using 10 different surface mine topsoil piles ranging in age from 1 to 3.5 years. Eight of the study sites showed less than 5 pct endomycorrhizal infection, while the remaining sites showed 5 to 10 pct infection. Current topsoil storage procedures do not encourage mycorrhizal infection of species used to control erosion on topsoil storage piles. The results suggest that stored topsoil is a poor source of endomycorrhizal inoculum on reclaimed surface-mined soils.

940. Ringe, J. M., and D. H. Graves. Costs of Alternative Mulching Materials for Establishing Herbaceous Vegetation on Harsh Sites. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 19-23.

The effects of four fiber-mat mulching materials on herbaceous vegetation growth were compared with the effects observed for two hydromulches and a control. Establishment costs were calculated and benefit-cost relationships developed so that they could be compared among treatments. Herbaceous cover was measured using a point sampling technique. Establishment costs for mat mulches were calculated as the sum of material and labor costs incurred during placement. Establishment costs of hydromulches were calculated as the sum of material, labor, and equipment (hydroseeder and tandem-axle truck) costs. A modified benefit-cost ratio was used to compare the different mulch treatments by combining the biological results and the establishment costs.

Mulching had a beneficial effect on herbaceous cover, with the coverage in control plots being significantly lower than the cover in mulched plots. No differences could be detected among mulch treatments. During the second growing season no differences could be detected between

the control and mulch treatments. Although mat mulches were more expensive, they may be more suitable in drainage paths and in areas prone to erosion. In most applications hydromulches would be the best choice except where limited by equipment or site characteristics.

941. Ringe, J. M., and D. H. Graves. Economic Factors Affecting Mulch Choices for Revegetating Disturbed Land. Reclam. & Reveg. Res., v. 6, No. 2, 1987, pp. 121-128.

Comparisons were made among four fiber-mat mulching materials and two hydromulches, examining the amount of vegetative cover produced with each material and the associated installation costs so that cost-effectiveness relationships could be developed. The mulch treatments used were (1) control, (2) excelsior mat, (3) hydromulch with hardwood fiber, (4) paper mat, (5) hydromulch with fescue hay fiber, (6) jute fiber, and (7) straw mat. Herbaceous cover was significantly lower in the control than in the mulch materials. There were no significant differences in cover among mulch treatments. Hydromulches were more cost effective than mat mulches and would be the best choice for most situations. On sites such as drainage paths and other areas prone to concentrated water runoff, mat mulches may be more cost effective than hydromulches.

942. Ringe, J. M., D. H. Graves, and R. F. Wittwer. Effects of Soil Amendments and Severe Cattle Grazing on the Long-Term Survival and Growth of Tree Seedlings on Eastern Kentucky Surface Mined Land. Paper in Proceedings 1984 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 2-7, 1984). Univ. KY, Lexington, KY, 1984, pp. 209-213.

This study was originally designed to study the effects of bark mulch, diammonium phosphate (18-46-0) fertilizer, and herbaceous cover on the survival and growth of Virginia pine (*Pinus virginiana* Mill.), European black alder (*Alnus glutinosa* (L.) Gaertn.), and northern red oak (*Quercus rubra* L.) planted on freshly graded surface-mined land. Experiments were conducted at two sites, a flat area and a gentle slope. On the flat site, six treatment blocks were established and the entire area was fertilized with 500 lb $acre^{-1}$ of diammonium phosphate. No mulch was applied to two blocks; 1 in was applied to two blocks, and 2 in was applied to two blocks. One-half of each bark mulch treatment was seeded with a grass-legume mixture. On the slope site, all six blocks were covered with 1 in of bark mulch, and two blocks were fertilized with 18-46-0 fertilizer at a rate of 500 lb $acre^{-1}$, two at 250 lb $acre^{-1}$, and two were not fertilized. Tree survival and height measurements were made after the first, second, and fifth growing seasons. Following the fifth growing season cattle were allowed to graze the area. Tree survival and height measurements were taken again prior to the eighth growing season to assess the effect of this type of disturbance and the survival and growth trends of the trees.

Bark mulch improved the survival and height growth of Virginia pine and European black alder. The beneficial aspects of the bark mulch became more evident with time. Fertilization had more of an effect on the survival of black alder than on Virginia pine, but Virginia pine had more of a response in terms of height growth. Fertilizer and bark mulch amendments had no effect on the survival or height growth of northern red oak. Northern red oak had high mortality rates during the first growing season. Herbaceous competition had a detrimental effect on the survival of all species. Following grazing, the survival of Virginia pine and black alder decreased and grazing had a detrimental effect on tree form.

943. Roberts, D. R., and S. B. Carpenter. The Influence of Seed Scarification and Site Preparation on Establishment of Black Locust on Surface-Mined Sites. Tree Plant. Notes, v. 34, No. 3, 1983, pp. 28-30.

The effects of scarifying black locust (*Robinia pseudoacacia* L.) seeds and best scarification method for seeds to be sown on Eastern or Interior surface-mined land were studied. A field experiment was also conducted to determine what field procedures influence the germination potential of black locust.

Black locust seeds were placed in concentrated sulfuric acid for 10, 30, 60, and 90 min. After the seeds were rinsed, four different treatments were imposed in controlled-environment germination tests. For each acid treatment one-half of the seeds were planted; 50 pct of the seeds were watered immediately, and 50 pct had a 72-h water delay. The other half of the acid-treated seeds were dried at 34° C for 24 h and then either watered (50 pct) or subjected to a water delay (50 pct). The only significant effects found for increasing seed germination were the 60- and 90-min acid treatments. Germination was increased from 16 pct for nonscarified seeds to 56 and 46 pct for the 60- and 90-min treatments, respectively.

The field trial utilized seeds that were scarified for 60 min, rinsed, and oven dried at 34° C overnight. The field treatments consisted of 2.4 cm of bark mulch and bare spoil. None of the scarified seeds survived when seeded on the bare mine spoil. Seedling survival was significantly increased by using bark mulch. If the environment is unfavorable for the establishment of black locust, the authors recommend decreasing the seed scarification treatment. Their results indicate innate protection of the seed by the seed coat.

944. Roberts, H. A. (ed). Decision Analysis for Abandoned Mine Reclamation Site Selection and Planning. Decision Anal. Task Force, IL Inst. Nat. Resour., Project 90.012, Doc. 79/29, Aug. 1979, 256 pp.

The focus of this report is the application of decision analysis to the selection of abandoned minesites throughout Illinois for reclamation. The report consists of six independently written chapters treating various aspects of the problem. There is no overall unified methodology incorporating all categories of pertinent factors. The chapters discuss an overall modeling framework and handling social, political, economic, environmental, and regional water quality considerations within that decision analysis framework. The purpose of this report was to provide a framework within which to apply pertinent state-of-the-art theory and methods of decision analysis to making environmental management decisions at the State level.

945. Roberts, J. A. Mine Soil Genesis and Tall Fescue Nutrient Status as a Function of Overburden Type and Cultural Amendment. M.S. Thesis, VA Polytech. Inst. and State Univ., Blacksburg, VA, 1986, 181 pp.

The overall objective of this M.S. thesis was to provide soil-specific information to be used in planning postmine land uses. The author states that the results of this thesis should be applicable to controlled placement of mine spoil to return to approximate original contour sites, mountaintop removal sites, head-of-hollow fills, or other landforms in the Eastern Coal Mining Region. The specific objectives of this thesis were (1) study the controlled placement of overburden materials to form mine spoils of known composition with a minimum of compaction, (2) monitor the formation of mine soils from mine spoils as physical, chemical, and morphological changes occur with age as affected by parent material, cultural amendments, and vegetation, (3) assess Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) growth on the above-mentioned soil types, and (4) determine which mine-soil factor(s) are most likely to affect long-term productivity. This research was conducted at the Powell River Project area located near Norton, VA.

Two separate experiments were conducted as a part of this research. First, a rock mix experiment was conducted, which consisted of various rock mix combinations ranging from pure sandstone to pure siltstone with intermediate rock mixes of 2:1, 1:1, and 1:2 parts sandstone to siltstone. The second study was a surface treatment experiment consisting of a 2:1 sandstone-siltstone rock mix with a control and six amendment treatments.

This thesis contains information on the characterization and genesis of mine soils, changes with time, changes in parent material, additions of soil amendments, and establishment of a vegetative cover. Additionally, information is presented on which soil parameters are most likely to influence long-term productivity. Although the results are site specific, much of the information should have regional application on similar soils. In addition to the actual results of the thesis, the author presents a short review on each of the following topics: geological and climatological setting, overburden analysis and characterization, historical concepts of soil genesis studies, mine-soil genesis studies, mine-soil classification and mine-soil revegetation, particularly greenhouse studies using mine-soil materials, and field studies using inorganic fertilizers and organic amendments.

946. Roberts, J. A., W. L. Daniels, J. C. Bell, and J. A. Burger. Early Stages of Mine Soil Genesis as Affected by Topsoiling and Organic Amendments. Soil Sci. Soc. Am. J., v. 52, No. 3, 1988, pp. 730-738.

Changes in mine-soil chemical, physical, and morphological characteristics were monitored as a function of organic amendment addition and topsoiling on a surface mine site in Wise County, VA. These changes were related to pedogenic processes over time. A 2:1 sandstone-siltstone spoil mixture was used, and the treatments applied consisted of a fertilized control and six amendments: (1) sawdust (112 Mg ha^{-1}), (2) 30 cm of native topsoil (A + E + B + Cr horizons), and (3-6) sewage sludge applied at 22, 56, 112, or 224 Mg ha^{-1}.

After 3 years well-developed A horizons and transitional AC and C1 horizons were common. The depth and nature of the transitional horizons were influenced by the type of organic amendment applied. After 3 years water retention was greatest in plots receiving sawdust additions and lowest in plots with the topsoil treatment. Organic carbon increased over a 3-year period, and increases in soil carbon were equivalent to 700 kg ha^{-1} yr^{-1} C for the control to 1,500 kg ha^{-1} yr^{-1} C for the 22- and 56-Mg-ha^{-1} sludge treatments. Rates of surface total nitrogen accumulation ranged from 21 to 150 kg ha^{-1} yr^{-1} N, with the highest rates in the sludge treatments and the lowest in the sawdust treatment. Soil pH varied as a function of treatment, time, and depth; however, soil pH generally decreased with time. Electrical conductivity (EC) increased with the rate of sludge application; however, after the initial application there were decreases in EC in all treated soils, which reflected the rapid dissolution and leaching of soluble carbonates and base cations. These changes were also associated with the decrease in soil pH. Exchangeable calcium decreased with time in the surface soils of all treatments except sawdust. In all sludge treatments, the cation-exchange capacity (CEC) was dominated by calcium, while in the topsoil and sawdust treatments

25 to 50 pct of the CEC was composed of magnesium. Sludge additions increased the total CEC of the topsoil material. The sawdust treatment, in addition to having higher water retention, also had higher levels of exchangeable potassium. Exchangeable aluminum was low in all treatments. Extractable phosphorus increased as the rate of sludge applied was increased, and plots receiving large organic additions were also able to maintain higher levels of extractable phosphorus. In all treatments, values of extractable iron increased significantly, indicating that rapid oxidative weathering processes occur in these materials. The changes that occur in the mine-soil chemical and morphological characteristics reflect rapid pedogenesis. Processes such as dissolution, leaching, oxidation, and organic matter accumulation or decomposition rapidly change these newly constructed mine soils. The authors state that carefully selected and placed topsoil substitute materials can equal or surpass native soils in forage production, particularly where organic amendments are used.

947. Roberts, J. A., W. L. Daniels, J. C. Bell, and J. A. Burger. Early Stages of Mine Soil Genesis in a Southwestern Virginia Spoil Lithosequence. Soil Sci. Soc. Am. J., v. 52, No. 3, 1988, pp. 716-723.

Changes in mine-soil morphological, chemical, and physical characteristics in a young, rapidly weathering mine-soil system were documented. The effects of parent materials and initial pedogenic changes were observed over a 3-year period in five rock mix combinations over an underlying compacted mine bench in Wise County, VA. The mix combinations ranged from pure sandstone (SS) to pure siltstone (SiS) with intermediate rock mixes of 2:1, 1:1, and 1:2 ratios of SS to SiS. The average thickness of these spoil materials over the mine bench was 1.3 m.

After 3 years distinct A horizons had formed in both the SS and SiS plots to a depth of 0 to 5 cm. There was no difference in A horizon thickness between spoil types. The subsurface profiles contained differentiated C1 and C2 horizons, which were separated on the basis of weak, patchy structural development in the C1 and the presence of large (>25 cm) coarse fragments in the C2. Coarse rock fragments (>2 mm) made up a substantial portion (65 to 79 pct) of the initial mine soil since the mine spoils used were produced by blasting consolidated rock. Coarse fragment content increased as the SiS component increased; however, with time, the coarse fragment content of the 0- to 5-cm surface layer decreased as the rock fragments slaked and weathered.

The soil chemical and physical analyses focused on the fine-earth fraction (<2 mm) because it dominates soil solution chemistry even though it makes up only 21 to 35 pct of the soil by weight. Particle size distribution of these young mine soils was related to their parent material. Rock type affected moisture content, with the water-holding capacity increasing as the proportion of SiS in the spoil mix increased. Soil pH was found to vary as a function of treatment, time, and depth. As the proportion of SiS increased so did the pH value due to higher carbonate contents. The pH values of all spoil mixes decreased over the 3-year period because of the rapid leaching of carbonates and basic cations, and the nitrification of added ammonium-nitrogen fertilizers. Total nitrogen increased over the 3-year period as the proportion of SiS increased because of concentration of fertilizer nitrogen and organic nitrogen into the proportionally smaller fine-earth fraction of SiS mixes. Surface horizons contained greater total nitrogen than did subsurface horizons. Extractable phosphorus values were higher in the SS treatments. In the SiS soils phosphorus adsorption increased because soil iron was oxidized and formed insoluble iron-phosphorus complexes. Extractable iron increased as the SS content increased. Extractable calcium and magnesium increased as the SiS content increased; however, over the 3-year period both nutrients levels dropped. Exchangeable and soluble calcium and magnesium were removed, through leaching from the upper 30 cm of these mine soils, with magnesium being leached faster than calcium. Extractable potassium increased as SiS increased because of the higher mica content of the SiS. Potassium concentration was significantly higher in surface samples than in subsurface samples over the 3-year period, indicating the biological weathering of mica and cycling of potassium to the soil surface through plant uptake and litter decomposition. The supply of potassium should meet the long-term needs of plants without potassium fertilization as long as the vegetation is not removed. The authors conclude that the rapid changes in mine-soil properties are the result of active pedogenic processes acting on fresh geologic materials that, initially, are not in equilibrium with the soil environment.

948. Roberts, J. A., W. L. Daniels, J. C. Bell, and D. C. Martens. Tall Fescue Production and Nutrient Status on Southwest Virginia Mine Soils. J. Environ. Qual., v. 17, No. 1, 1988, pp. 55-62.

The growth and nutritional factors affecting the establishment, growth, and development of Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) were assessed in two experiments. Changes in tall fescue standing crop biomass over a 5-year period and nutrient status over a 3-year period were reported as affected by spoil type and soil amendments. In the first experiment, tall fescue growth and nutrient status were compared on five topsoil substitute mix combinations ranging from sandstone (SS) to siltstone (SiS) with intermediate rock combinations of 2:1,

1:1, and 1:2 SS to SiS. In the second experiment, tall fescue performance was compared over a constant 2:1 SS-SiS mix with a control and six soil amendment treatments. The amendments used were 112 Mg ha^{-1} sawdust, 30 cm of native topsoil (A + E + B + Cr horizons), and 22, 56, 112, or 224 Mg ha^{-1} municipal sewage sludge. Fertilizer was added to all experiment 1 rock mixes and to the control treatment of experiment 2. The topsoil amendment of experiment 2 received lime additions, and the sawdust amendment received two different fertilizer treatments.

After 1 year, the standing crop biomass of tall fescue in experiment 1 was highest in the SS treatment and decreased with increasing SiS content because of high pH values, low water availability, and restricted rooting volume. However, over time, treatments with SiS equaled or exceeded the standing crop biomass in the high SS treatments. This indicates that parent material effects on biomass diminished with time. All rock mix treatments maintained adequate fescue production and almost complete ground cover over the 5-year period of this experiment.

In experiment 2, tall fescue standing crop biomass increased as the rate of sludge applied increased. Amendments of 56 Mg ha^{-1} supported approximately two times the tall fescue standing crop biomass compared with other amendments. Control and topsoil treatments had similar standing crop biomasses, which were consistently lower than those for all other treatments. The results of both experiments indicate that nitrogen limits standing crop biomass over the short term, with phosphorus becoming limited over time. Soils amended with sludge tended to have higher tissue concentrations of nitrogen, phosphorus, and base cations. It was suggested that total phosphorus uptake was limited by soil nitrogen availability. Low soil nitrogen may decrease phosphorus availability by limiting total phosphorus uptake even when soil phosphorus is available. Potassium did not limit tall fescue growth; it would be expected to become limiting only if plant materials were harvested and removed from the site. Heavy-metal concentrations in the amendments did not result in toxic levels of iron, zinc, copper, or cadmium in the tissues of tall fescue.

The results of the two experiments demonstrated that organically amended topsoil substitutes are superior reclamation plant growth mediums compared with topsoil substitutes amended with topsoil that is fertilized and limed. This article contains useful information on the effects of topsoil substitutes on plant growth and on the usefulness of soil amendments for increasing plant yield.

949. Robertson, S. D., and R. F. Wittwer. The Effects of Slit-Applied Fertilizer Treatments on Growth and Survival of Sycamore and Cottonwood Planted on Minespoil. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 483-488.

This research examined the effects of slit-applied fertilizers on the growth and survival of eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.) and American sycamore (*Platanus occidentalis* L.) planted on mountaintop removal spoil in Bell County, KY. Two separate studies were conducted to evaluate both bulk and slow-release tablets.

The first study compared four levels of slow-release fertilizer in tablet form with a surface-applied bulk fertilizer and an unfertilized control. Fertilization had no effect on the survival of cottonwood or sycamore during the second or third growing season. However, there were significant treatment differences for height and root collar diameter. For cottonwood, control plots had lower heights and root collar diameters than the fertilized plots. Broadcast fertilizer was less effective in stimulating growth than the tablet-form fertilizers. Broadcast fertilizer treatments resulted in lower sycamore root collar diameters than did the other fertilizer treatments.

The second study utilized slit-applied slow-release fertilizer tablets. An untreated control was compared with low and high levels of nitrogen only, phosphorus only, and nitrogen plus phosphorus treatments. Survival of both species was significantly higher on control plots than on fertilized plots. The high phosphorus and the high phosphorus plus high nitrogen treatments resulted in the lowest survival rates for both species. The authors conclude that slit-applied, slow-release fertilizer tablets did not affect seedling survival; however, slit-applied bulk fertilizers decreased survival and should be avoided except with extremely acid-tolerant species such as black locust (*Robinia pseudoacacia* L.).

950. Rodriguez-Kabana, R., G. M. Jones, and I. Chet. Biological Control of Nematodes: Soil Amendments and Microbial Antagonists. Plant and Soil, v. 100, No. 3, 1987, pp. 237-247.

This article reviews the use of soil organic amendments in the control of soil nematode populations. Additions of organic matter to soil stimulates microbial activity resulting in increased enzymatic activities. Specific end-product compounds may be nematicidal. The magnitude of microbial stimulation depends on the nature of the organic matter added. The most effective amendments are those with narrow carbon-nitrogen ratios, those with high protein or amine contents, and those containing chitin or similar mucopolysaccharides. Chitin amendments to soil have been shown to be effective in the control of phytonematodes. Organic amendments may be selected

that stimulate the development of a specialized microflora that is antagonistic to nematodes.

951. Rogowski, A. S., H. B. Pionke, and J. G. Broyan. Modeling the Impact of Strip Mining and Reclamation Processes on Quality and Quantity of Water in Mined Areas: A Review. J. Environ. Qual., v. 6, No. 3, 1977, pp. 237-244.

The authors provide a concise literature review of the parameters affecting the hydrology of the spoil system. Studies of acid generation, neutralization, and transformation in strip mine spoil materials, spoil waterflow, oxygen diffusion, surface runoff, erosion, evapotranspiration, and temperature distributions within spoil banks are reviewed. The authors discuss the potential for modeling the hydrology and the acid-producing areas of a spoil system.

952. Rogowski, A. S., and B. E. Weinrich. Modeling the Effects of Mining and Erosion on Biomass Production. Ecol. Modell., v. 35, No. 1-2, 1987, pp. 85-112.

A productivity model derived from the literature and based on root distribution, bulk density, aeration porosity, and pH was modified and verified at a minesite in Pennsylvania. A soil loss model was also used to simulate the effects of mining and erosion on the productivity potential of the minesite. Projected productivity decreases due to mining ranged from 12 to 74 pct, while changes in productivity due to a single storm event, erosion, ranged from 1.0 to 6.5 pct. Based on the models, productivity appears to be more likely to decline because of mining than as a result of erosion.

953. Roll, J. L. Revegetation of Abandoned Coal Slurry in West Central Illinois. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 77-81.

This article describes a demonstration project on the revegetation of an inactive slurry impoundment (prelaw) without soil replacement in Illinois. The objective was to determine the limiting factors in vegetation establishment and to determine what species would survive without maintenance. The site was fertilized with N-P-K fertilizer over a 4-year period and planted to a variety of grasses, legumes, and tree species. Oats (*Avena sativa* L.) were used as a standing mulch. The primary limiting factors on the slurry were soil nitrogen, which limited vegetative growth, and slurry surface temperature, which limited germination and survival of young plants. Nitrogen fertilization ameliorates the nutrient deficiency factor, and mulching ameliorates the effects of high surface temperature. After 7 years bromegrass (*Bromus inermis* Leyss.), orchardgrass (*Dactylis glomerata* L.), reedgrass (*Phragmites australis* Trin.), and black locust (*Robinia pseudoacacia* L.) all had survival rates of 75 pct or better. There were also several species that had volunteered on the site.

954. Rosso, W. A. Revegetation Augmented by Reuse of Treated Acid Mine Drainage. Paper in 1980 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 1-5, 1980). Univ. KY, Lexington, KY, 1980, pp. 1-8.

The author evaluates the use of treated acid mine drainage (AMD) as irrigation water. The AMD was treated with limestone prior to irrigation. Four test programs were utilized: (1) irrigation with treated AMD containing sludge, (2) irrigation with treated AMD with sludge removal, (3) irrigation with untreated AMD, and (4) no irrigation. Prior to irrigation, spoil materials were characterized, and all plots were limed, fertilized, and seeded. Monitoring of the spoil material was conducted to document changes in soil chemistry during irrigation. Runoff was also monitored, and it was determined that irrigation with untreated AMD had no detrimental effects on water quality. The effects of the various irrigation treatments on vegetative cover and production were evaluated. Compared with the control, all three irrigation treatments enhanced the vegetation in terms of production and cover. There appears to be an advantage to both the vegetation and water quality when irrigating with acidic water on the types of spoils used.

955. Rosso, W. A., and B. H. Wolcott, Jr. Wildlife Option in Kentucky. Paper in Fifth Symposium on Surface Mining and Reclamation (NCA/BCR Coal Conf. and Expo IV, Louisville, KY, Oct. 18-20, 1977). Natl. Coal Assoc. and Bitum. Coal Res., 1977, pp. 20-23.

This paper presents a new wildlife option for Kentucky State reclamation regulations. Specific regulatory guidelines are presented. The plans and their initial implementation under these new regulations are evaluated. This project was located at the Ken Mine in Ohio County, KY. Few results are included.

956. Rothwell, F. M. Aggregation of Surface Mine Soil by Interaction Between VAM Fungi and Lignin Degradation Products of Lespedeza. Plant and Soil, v. 80, No. 1, 1984, pp. 99-104.

The occurrence of vesicular-arbuscular (VA) mycorrhizal fungi in a western Kentucky sandy loam mine soil

was determined, and their aggregating potential in a herbaceous legume ground cover was assessed. Roots of tall fescue (*Festuca arundinacea* Schreb.) and sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don.) were sampled and stained with lactophenol-aniline blue to detect the presence of VA mycorrhizal fungi. The periodic acid-Schiff reagent staining procedure was used to detect polysaccharide materials on the fungal hyphae and internal surfaces of sand grains making up the aggregates. Three *Glomus* spp. and a species of *Entrophospora* were found in association with root samples. *Glomus clarum* produced a highly branched external hyphae system that extended into the rhizosphere soil. Sand grains and small aggregates were bound by a network of fungal hyphae. The hyphal surfaces and sand grain surfaces in contact with the hyphae within the aggregates stained positive, indicating a polysaccharide binding material. The roots and fungal hyphae contributed to mine-soil stabilization as a result of the humic substances formed in the interaction between sericea lespedeza and *Glomus clarum*.

957. Rothwell, F. M. Transformation and Decomposition of Lignin-Related Compounds by Microbial Isolates From Mine Soils. Plant and Soil, v. 104, No. 1, 1987, pp. 143-147.

Mine-soil micro-organisms that are involved in the decomposition of raw organic matter have not been thoroughly characterized. Microbial transformation and degradation of lignin-related compounds were followed during incubation in liquid culture using spectrophotometric, chromatographic, and ion-exchange procedures. Cultures of mine-soil micro-organisms show the ability to modify the structural components of lignin-related compounds, such as methoxyl groups, carbon side-chains, and aromatic rings. Results show that the isolates used in this study are actively involved in the transformation and decomposition of aromatic residues under mine-soil conditions.

958. Rothwell, F. M., and D. Eagleston. Microbial Relationships in Surface-Mine Revegetation. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 94-113.

This article discusses various aspects of topsoiling and revegetation practices in the Eastern United States and their influence on the establishment and interrelationship of micro-organisms with plant and soil processes during reclamation.

959. Rothwell, F. M., and D. Eagleston. Microbial Relationships in Surface-Mine Revegetation. Environ. Geochem. Health, v. 7, No. 1, 1985, pp. 28-35.

This article discusses the various aspects of topsoiling and revegetation practices in the Eastern Coal Mining Region and the influence of these practices on the establishment and interrelationship of micro-organisms with plant and soil processes during reclamation. Topsoiling as a reclamation practice increases the availability of beneficial micro-organisms and improves the quality of plant growth medium where spoils are chemically or physically less desirable as a growth medium. Topsoil storage should be limited since with time there is a decrease in oxygen and moisture, a loss of organic matter and soil structure, and a reduction in the microbial population. The best practice is the direct-haul method, which eliminates topsoil stockpiling. The selection of vegetation or species to be used offers an opportunity to alter or modify soil development on surface-mined sites. Physiological differences exist between species and include levels of carbohydrate translocated to the root system or released into the surrounding soil (soil aggregation and food source for soil microbes), effectiveness as a mycorrhizal host, and rate of plant degradation. Organic amendments and mulches provide a source of water-soluble organic materials, which are utilized by micro-organisms (cellulose and lignin). The beneficial aspects of nitrogen-fixing bacteria and mycorrhizae fungi are discussed.

960. Rothwell, F. M., and W. G. Vogel. Mycorrhizae of Planted and Volunteer Vegetation on Surface-Mined Sites. U.S. For. Serv. Northeast. For. Exp. Stn., Gen. Tech. Rep. NE-66, 1982, 12 pp.

This publication reports the results of a study that examined the presence and type of mycorrhizae associated with planted and volunteer herbaceous and woody species on surface-mined sites in north-central Tennessee and southwestern Kentucky. An extensive list of host vegetation species is presented.

961. Rowell, M. J. Continued Studies of Soil Improvement and Revegetation of Tailings Sand Slopes (Syncrude Canada Ltd. contract 98-0051-R, Northwest Soil Res., Ltd.). Syncrude Canada Ltd., Edmonton, AB, Environ. Res. Monogr. 1977-4, 1977, 156 pp.

The second year (1976) of a study is reported, dealing with the improvement of a 5-year-old revegetated area on a tailings sand dike by implementation of different fertilizer treatments. Levels of available nitrogen, phosphorus,

potassium, and sulfur significantly decreased during the period between June and September. Good growth continued throughout the summer only when nitrogen, phosphorus, potassium, and sulfur fertilizers were added in June. The most efficient use of fertilizer occurred when nitrogen was added at a rate of about 80 kg ha^{-1} or less. At higher fertilizer application rates there was a tendency for bromegrass (*Bromus inermis* Leyss.) to replace creeping red fescue (*Festuca rubra* L.), the dominant grass in the sward. Root-shoot ratios ranging from 4:1 to 7:1 are reported, indicating an accumulation of root tissue over 5 years. Erosion on steep tailings sand slopes was minimized by rapid establishment of a plant cover. This was most effective where the surface was amended with peat, mine overburden, and nitrogen, phosphorus, potassium, and sulfur fertilizers. Between 13 and 34 pct of the intercepted rainfall was estimated to leach beyond the 30-cm depth while plants were being established during the first year of growth. Rapid infiltration rates of 24.0 to 30.5 cm h^{-1} were reported.

The seed mix used contained oats as a nurse crop, nine grasses, and four legume species. Dry weight production of oats was significantly greater than for either the grasses or the legumes. Dry weight production of root tissues approximated that of shoot tissues. Root growth was largely restricted to the surface 15 cm. Greater proportions of the roots in the 15- to-30-cm depth resulted from deeper tillage of peat and overburden. Total soil respiration, as well as total numbers of bacteria, fungi, and actinomycetes, was greater from the revegetation experiments than in samples of fresh or weathered tailings sand. The results reported in this publication are, to some extent, specific for reclamation of oil sand mining waste materials. However, they could find application in planning reclamation efforts for other materials possessing similar properties. The research reported was conducted at the Great Canadian Oil Sand, Ltd. (now Suncor) plant at Fort McMurray, AB.

962. Rowell, M. J. Revegetation and Management of Tailings Sand Slopes: 1977 Results (Syncrude Canada Ltd. contract 98-0145-EA, Northwest Soil Res. Ltd.). Syncrude Canada Ltd., Edmonton, AB, Environ. Res. Monogr. 1978-5, 1978, 141 pp.

This publication is the third annual report of an ongoing project investigating revegetation on a steeply sloping dike composed of tailings sand from tar sand extraction at the Canadian Oil Sand, Ltd. (now Suncor) plant, Fort McMurray, AB. The objectives of this research were to investigate methods for the establishment of vegetation for erosion control and to determine cost-effective methods for long-term management of these areas. Fourteen plant species were tested. Fertilizer rate was found to affect species composition of the reestablished vegetation. Seed washoff during snowmelt resulted in poor seed distribution for fall seeding trials. Aboveground vegetation production was related to the amount of fertilizer applied. The yield of plant roots was less affected by fertilization. Incorporation of peat or peat and overburden to deeper depths in the profile resulted in deeper penetration and yield of roots. Initial results of decomposition and microbial population and activity studies are presented and discussed. The results reported in this publication are specific for reclamation of oil sand mining waste materials in this area.

963. Rowell, M. J. Revegetation and Management of Tailings Sand Slopes From Tar Sand Extraction: 1978 Results (Syncrude Canada Ltd. contract 98-8021-CD, Northwest Soil Res. Ltd.). Syncrude Canada Ltd., Edmonton, AB, Environ. Res. Monogr. 1979-5, 1979, 131 pp.

Research results are reported for revegetation of two areas on a steeply sloping dike composed of tailings sand from tar sand extraction at the Great Canadian Oil Sand, Ltd. (now Suncor) plant at Fort McMurray, AB. The research objectives were to investigate methods for the establishment of a stable vegetative cover that would prevent erosion of the slope and possibly become self-maintaining. A comparison of two tillage depths was conducted for incorporation of soil amendments to depths of 15 and 30 cm, to promote deeper rooting.

Fertilizer additions significantly increased the uptake of nitrogen and potassium and to a lesser extent phosphorus and sulfur into the shoot tissues. Root mass production was not affected by fertilizer. Deeper incorporation of peat and overburden promoted deeper rooting. However, there appeared to be no advantage for the deeper tillage treatment over the 15-cm tillage treatment in promoting stable soil surface conditions. Soluble salt concentrations were reduced over the course of the study. Soil pH showed no significant change.

The effectiveness of different fertilizer treatments was assessed in terms of biomass production, nutrient uptake, and the efficiency of use of the fertilizer nutrients. On older established areas where no additional fertilizers had been added, erosion-free surfaces still existed. However, an annual fertilizer application of about 90 kg N, 25 kg P, and 40 kg K per hectare is recommended to maintain vigorous cover while efficiently using fertilizers. Where peat or peat and overburden are used on the tailings sand surface, it is recommended that fertilizer be added at a rate of 60 to 80 kg N; 40 kg P, and 60 to 80 kg K per hectare in the first year to obtain the most efficient use of the fertilizers.

Older revegetated sites exhibited more rapid rates of decomposition than areas revegetated later in the study. Decomposition rates were correlated with total soil respiration and to a lesser extent with numbers of aerobic micro-organisms. Analysis of decomposing litter residues indicated different patterns in the release of the major plant nutrients. The results reported in this publication are specific for reclamation of oil sand mining waste materials in this area.

964. Ruehle, J. L. Growth of Containerized Loblolly Pine With Specific Ectomycorrhizae After 2-Years on an Amended Borrow Pit. Reclam. Rev., v. 3, No. 2, 1980, pp. 95-101.

The purpose of this study was to use a combination of soil amelioration techniques and ectomycorrhizae to determine their effects on the establishment of loblolly pine (*Pinus taeda* L.) on a borrow pit located near Aiken, SC. Plots were amended with either processed sewage sludge or fertilizer and limestone. All plots were double-disked 10 to 15 cm deep to incorporate the amendments. Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) was then sown over the entire area to prevent erosion and retard nutrient loss. One year after site preparation, containerized loblolly pine seedlings inoculated with *Pisolithus tinctorius* (Pt.), *Thelephora terrestris* (Tt), or no ectomycorrhizae were planted on the site.

The results indicate that on fertilized plots, loblolly seedlings colonized with Pt ectomycorrhizae at planting had significantly better survival (96.0 pct) after 2 years than did seedlings colonized with Tt (88.0 pct) or nonmycorrhizal seedlings (89.6 pct). There were no differences in height, root-collar diameter, or seedling volume between Pt- and Tt-colonized seedlings, but Pt produced greater results than did the control. Survival of seedlings on sludge-amended plots was not affected by ectomycorrhizal treatment. However, the height, root-collar diameter, and seedling volume of loblolly pine on sludge-amended plots was greater with Pt ectomycorrhizae than with Tt or no ectomycorrhizae. Foliar nutrient contents were also affected by mycorrhizal and soil amendment treatments. The author concludes that loblolly pine seedlings tailored with *Pisolithus* ectomycorrhizae can be successfully established on borrow pits amended with either sewage sludge or fertilizer.

965. Rumble, M. A., and A. J. Bjugstad. Uranium and Radium Concentrations in Plants Growing on Uranium Mill Tailings in South Dakota. Reclam. & Reveg. Res., v. 4, No. 3, 1986, pp. 271-277.

The levels of uranium and radium in the vegetation growing on abandoned uranium mill tailings in southwestern South Dakota were evaluated. The mill tailings were covered with topsoil and seeded to a mixture of crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.), yellow sweetclover (*Melilotus officinalis* (L.) Lam.), and rye (*Lolium* spp.). Vegetation and soil samples from the mill tailings were analyzed and compared with vegetation and soil samples from control areas. All vegetation and soils were analyzed for radium and uranium; in addition, all soils were analyzed for EC, sodium, calcium, magnesium and pH. EC and pH values of control soils were lower than those of mill tailings soils, while magnesium concentrations were higher in mill tailings soils. Uranium and radium concentrations were higher in mill tailings soils than in control soils, but only the plant tissue uranium concentration was higher in all the vegetation growing on mill tailings compared with that on control sites. Concentration ratios (amount in plant to amount in soil) of both radionuclides indicate that the vegetation growing on the uranium mill tailings was not accumulating either uranium or radium.

966. Ruth, B. A., and J. N. Wade. Assessment and Treatment of Areas in Ohio Impacted by Abandoned Coal Mines. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 71-76.

This article discusses the assessment and treatment of 30 watersheds affected by coal-mine-related problems. Watersheds where reclamation is most needed were identified using a planning unit evaluation matrix in order to provide a ranking and priority system for each watershed.

967. Rutherford, G. K., D. Dimma, G. W., Van Loon, and W. G. Brech. The Pedological Properties of Tailings Derived From Three Mining Operations in the Sudbury Area, Ontario, Canada. J. Environ. Qual., v. 11, No. 3, 1982, pp. 511-518.

In this article the authors describe field and laboratory analyses of profiles in three different kinds of tailings in the Sudbury area, to evaluate their pedological properties. The analyses are excellent in relating chemical and physical properties to original conditions of the tailings, weathering, soil amendments (lime and fertilizer), and vegetative growth. On the basis of this research, absence of vegetation was determined to be due to (1) coarse material, which generally is a poor growth medium, (2) low pH, causing high concentrations of toxic elements, and (3) low organic matter and no source of N_2. This is an excellent article characterizing soils.

968. Sabey, B. R., J. T. Herron, D. G. Scholl, and J. Bokich. Particle Size Distribution. Ch. in Reclaiming

Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 59-73.

Particle size distribution of the soil affects many environmental factors that influence plant growth in developing ecosystems. Factors affected by particle size in the revegetation and management of disturbed sites include moisture, temperature, aeration, physical impedance of roots, chemical reactivity, and erosion. Each of these factors, as influenced by particle size, is discussed, as well as analytical methods.

969. Sabey, B. R., R. L. Cuany, N. Oleski, and J. Barry. Nitrogen Supply by Legumes and Other Fertility Sources for Disturbed Lands. Ch. in Revegetation Studies on Oil Shale Related Disturbances in Colorado (U.S. Dep. Energy contract DE-AS02-76EV04018, Range Sci. Dep., CO State Univ.). U.S. Dep. Energy, DOE/EV/04018-6, June 1982, pp. 67-85.

This study is part of a large project evaluating the impact of and potential for reclamation following oil shale mining and retorting processes. This paper reports on the sixth-year results of this study. The overall objective of this study was to determine the long-term fertility requirements and methods of meeting these requirements on nitrogen- and phosphorus-deficient soil materials used as plant growth media for land reclamation. Total biomass and total plant cover were significantly related to the fertility level of the soil. The maintenance of favorable fertility levels on the disturbed land included in this study depended on adequate and timely supplies of nitrogen either as fertilizer or through enhanced activity of natural elements of the ecosystem. The contributions of nitrogen to these disturbed plant-soil systems are referenced for planning revegetation activities.

970. Saeed, M. Use of Sorption Isotherms for Evaluating the Effect of Leonardite on Phosphorus Availability in a Coal Mine Spoil. Soil Sci., v. 126, No. 3, 1978, pp. 157-165.

This paper reports the results of a study that examined the effect of leonardite application on phosphorus availability in spoil material collected from the Glenharold coal mine area in North Dakota. There was greater phosphorus sorption by the leonardite, as indicated by comparison of the phosphorus isotherms of leonardite and the spoil. The addition of 10 pct leonardite to the spoil materials increased sorption by 21 pct. In growth chamber experiments the addition of leonardite depressed the uptake of phosphorus and the growth of thickspike wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.), but improved the growth of alfalfa (*Medicago sativa*) L.). A substantial increase in the utilization of indigenous zinc and manganese was observed with leonardite.

971. Safaya, N. M. Delineation of Mineral Stresses in Mine Spoils and Screening Plants for Adaptability. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 830-849.

This paper provides a concise literature review pertaining to the importance of mineral stresses in mine spoils, methods for their characterization, and the adaptability of plants to such stresses. A synchronized approach of identifying the site-specific nature of these stresses and screening plants for their specific tolerances to such stresses is emphasized by the author.

972. Safaya, N. M., J. E. McLean, and G. A. Halvorson. Cadmium and Zinc. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 283-311.

This chapter is concerned with the biological importance, geochemical abundance, and the chemistry and bioavailability of cadmium and zinc. Methods of measuring cadmium and zinc in soil and overburden are given. The activity of cadmium and zinc in soils is controlled by adsorption and chelation reactions. Solubility of both increases as the soil pH decreases. The authors state that the likelihood of cadmium or zinc toxicity occurring in western overburden materials is small, owing to the neutral to alkaline reactions of the overburden material. The amount of calcite present is sufficient to neutralize. However, the potential for acid generation, resulting in excessive levels of cadmium and zinc, does exist. There is a need to assess and predict the availability of zinc and cadmium in western coal mine overburden material.

973. Safaya, N. M., and M. K. Wali. Growth and Nutrient Relations of a Grass-Legume Mixture on Sodic Coal-Mine Spoil as Affected by Some Amendments. Soil Sci. Soc. Am. J., v. 43, No. 3, 1979, pp. 747-753.

The effects of fertilizers, gypsum, H_2SO_4, and leonardite (oxidized lignite) on the growth and nutrient relations of thickspike wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.) are described in this paper. Laboratory and greenhouse studies were conducted to investigate the effects of the treatments on (1) properties of a calcareous

sodic mine spoil, including phosphorus, zinc, and manganese availability, (2) the productivity of thickspike wheatgrass and yellow sweetclover grown as a mixture on the spoil, and (3) the mineral element composition of the two species. The spoil was from the Glenharold Mine in Mercer County, ND. The data and results are detailed in this paper.

974. Sander, D. H., and B. Eghball. Effect of Fertilizer Phosphorus Particle Size on Phosphorus Fertilizer Efficiency. Soil Sci. Soc. Am. J., v. 52, No. 3, 1988, pp. 868-873.

The effect of phosphorus fertilizer particle size, as influenced by phosphorus application rate, on winter wheat (*Triticum aestivum* L.) grain yield, head numbers, seeds per head, total phosphorus uptake, and fertilizer phosphorus efficiency was evaluated. Ammonium polyphospate (11-24-0, N-P-K) at particle weights of 0.00019, 0.0009, 0.025, 0.93, and 22 mg was applied at rates of 8.4, 16.8, and 25.2 kg ha^{-1} P on four different Nebraska soils.

Grain yield was significantly increased by applying phosphorus on the soils studied; however, phosphorus fertilizer particle size affected yield components on only two of the studied soils. These two soils had the greatest yield response to applied phosphorus. The optimum particle size for grain yield was found to be the 0.025-mg particle at the 8.4-kg-ha^{-1} P application rate. Grain yield was less with the smaller particle sizes because these small-sized particles provided a large surface area for reaction with soil and soil constituents, which reduced phosphorus availability. At larger particle sizes, grain yield decreased because of changes in root-phosphorus fertilizer contact probability as affected by the distribution of phosphorus fertilizer particles.

Total phosphorus uptake and the various other yield components paralleled the results of grain yield, with the exception of seed weight and seeds per head, where no effect of phosphorus fertilizer particle size was observed. Fertilizer phosphorus efficiency, as measured by how much of the applied fertilizer phosphorus was utilized by the plant in relation to the total applied, reached a maximum of 47 pct with the intermediate particle size applied at a rate of 8.4 kg ha^{-1} P. This was a 21-pct increase in efficiency over normal farm fertilizer (particle size of 20 mg). At the higher application rates, particle size had little effect on grain yield or fertilizer efficiency. This article contains good reference material on the effects of various fertilizer phosphorus particle sizes on phosphorus fertilizer efficiency.

975. Sandusky, J. Using Trees on Reclaimed Mined Lands in Southern Illinois. Paper in Trees for Reclamation (Lexington, KY, Oct. 27-29, 1980). U.S. For. Serv., Gen. Tech. Rep. NE-61, 1980, pp. 17-19.

The author discusses the planting of trees and the species used since 1956 on Peabody Coal Co.'s Will Scarlet Mine in southern Illinois. A review of the various Illinois reclamation laws and requirements is also presented. In 1974, a 10-year plan was implemented that would reclaim 2,600 acres of acid spoil; reforestation was part of the plan. Tree species were chosen based on (1) commercial desirability, (2) acid tolerance, (3) wildlife, and (4) esthetics. Both mechanical and manual planting of trees was done. Areas that were hand planted tended to have the highest survival rates. The most successful species were black locust (*Robinia pseudoacacia* L.), autumn olive (*Elaeagnus umbellata* Thunb.), sweetgum (*Liquidambar styraciflua* L.), European black alder (*Alnus glutinosa* (L.) Gaertn.), loblolly pine (*Pinus taeda* L.), and river birch (*Betula nigra* L.). The results of an attempt to aerial seed black locust are also presented.

976. Saperstein, L. W. Environmental and Legislative Consequences of Strip Mining. Ch. in Environmental Consequences of Energy Production: Problems and Prospects, ed. by S. K. Majumdar, F. J. Brenner, and E. W. Miller. PA Acad. Sci., 1987, pp. 419-430.

This chapter discusses the present legislative controls imposed on surface mining for coal and indicates strategies for improved reclamation performance on current mining operations. A brief history of mined land reclamation legislation is given. Prior to the passage of Public Law 95-87 (SMCRA) in 1977, 44 bills had been introduced into Congress between 1949 and 1970. The environmental performance standards for current surface mining operations (Title V) and abandoned mine reclamation (Title IV) of SMCRA are discussed. Important research needs are identified, including the need to establish techniques that minimize soil compaction as well as loosening techniques that help to reestablish structure.

977. Sauer, R. H. Reclaiming Mined Lands in Arid Environments. Battelle Pac. Northwest Lab., Richland, WA, PNL-SA-9661, Sept. 1981, 21 pp.

This report provides the rationale for the water-harvesting techniques under study by the Pacific Northwest Laboratories. These techniques have been implemented at three arid land sites in the Western United States: (1) Hanford Site in south-central Washington, (2) a mine-site near Kaenta, AZ, on the Black Mesa, and (3) a mine-site at Nucla, CO. The interim results obtained at each site are discussed generally. The author reports that the results obtained thus far indicate that water-harvesting reclamation techniques are technically and economically feasible. The information contained in this report may be useful to individuals planning reclamation activities in the arid portions of the Western United States.

978. Sauer, R. H. Restoration of Surface-Mined Lands. Paper in Pacific Northwest Laboratory Annual Report for 1980 to the DOE Assistant Secretary for Environment, Part 2 Ecological Sciences (U.S. Dep. Energy contract DE-AC06-76RLO 1830). Battelle Pac. Northwest Lab., Richland, WA, PNL-3700 PT2/UC-11, Feb. 1981, pp. 15-16.

This paper provides a progress report for a revegetation program designed to demonstrate the technical and economic feasibility of using water-harvesting techniques to provide irrigation water for useful crops on arid surface-mined land. The program is gathering information on optimum crops, slope angles, and slope treatments in an effort to reduce the costs of reclamation, reduce the consumption of soil and water, and establish productive, useful crops where only weed species would otherwise grow. Three demonstration sites have been established: the Hanford Site in Washington, the Black Mesa Mine on the Navajo Indian Reservation in Arizona, and the Nucla Mine in Colorado. The article describes the experimental design employed at each site but relates few or no results. The paper has been included in this bibliography to ensure that this type of research is represented.

979. Sauer, R. H., and W. H. Richard. Restoration of Surface Mined Lands With Rainfall Harvesting (U.S. Dep. Energy contract DE-AC06-76RLO 1830, Battelle Pac. Northwest Lab.). U.S. Dep. Energy, DE 83005890/PNL-4538, Dec. 1982, 41 pp.

This report provides an overview of research conducted by the Pacific Northwest Laboratory from 1976 through 1981 on an alternative method of restoring surface coal mine land in the arid Western United States. The studies examined the technical and economic feasibility of water harvesting, using partially leveled spoil banks at strip mines as catchment areas to collect and direct runoff to the topsoiled valley floor where crops were cultivated. Seven treatments were tested. The studies were conducted in arid areas of Washington, Arizona, and Colorado. Some treatments provided adequate runoff to produce a useful crop. Thus, it was concluded that it was technically feasible to use water-harvesting methods to replace or augment expensive and inadequate supplies of well and river water in arid regions. The authors further concluded that water harvesting could be made more effective with further information on catchment area treatments, the crops that are most adaptable to water harvesting, the optimum incline of the catchment areas, and the influence of climate. The authors report that water harvesting has the potential for reducing the cost and increasing the effectiveness of mine-land reclamation in the arid areas of the Western United States.

980. Scanlon, D. H., and J. C. Duggan. Growth and Element Uptake of Woody Plants on Fly Ash. Environ. Sci. and Technol., v. 13, No. 3, Mar. 1979, pp. 311-315.

Pulverized coal ash stored at the John Sevier Power Plant, Rogersville, TN, was tested as a substrate for eight woody plant species. Concurrent analyses of the substrate (fly ash and a soil control) and plant foliage in the second and third growing seasons were compared for concentrations of arsenic, boron, cadmium, chromium, copper, lead, mercury, nickel, nitrogen, phosphorus, potassium, selenium, and zinc. Boron, nickel, and selenium appeared more available to plants of all species. Chromium and lead showed no increases in foliar concentration in plants grown on fly ash as compared with soil. Plant survival was species dependent, ranging from 12 to 84 pct with a mean value of 53 pct. No improvement of plant performance resulted from the application of 10 cm of subsoil over the fly ash. Nitrogen-fixing species appeared best adapted for use in fly ash stabilization. This article would be pertinent to investigations of fly ash utilization in reclamation efforts. However, variability in elemental composition may limit the direct application of these results.

981. Schafer, W. M. Guides for Estimating Cover-Soil Quality and Mine Soil Capability for Use in Coal Strip-mine Reclamation in the Western United States. Reclam. Rev., v. 2, No. 2, 1979, pp. 67-74.

This paper discusses the findings of a National Cooperative Soil Survey Committee that assembled, reviewed, evaluated, and summarized available criteria for selecting cover soils throughout the Western States. Cover soils are materials placed on the surface of strip mine spoils to enhance the establishment of vegetation; they can be topsoil, subsoil, or overburden. Guidelines for rating the quality of cover soil and the agricultural capability of mine soils in the Western United States are proposed. Ratings are based on soil properties such as texture, rock-fragment content, water-holding capacity, pH, electrical conductivity, exchangeable sodium, soil depth, slope, permeability, and drainage. It is emphasized that these are guidelines only and must be updated and revised as more information becomes available.

982. Schafer, W. M. Minesoil Restoration and Maturity: A Guide for Managing Minesoil Development. Paper in Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min.; 1984, pp. 172-185.

The author outlines the basic concepts of soil development and presents a framework for managing postmine soil development based on these concepts. The author cites previous studies that found that mine soils can develop along different pathways than those followed by natural soils. This results in minesoils that are either more or less productive than the soils that existed prior to mining. The framework proposed for soil management in reclaimed systems has five steps: (1) set land use goals, (2) inventory soil and overburden materials, (3) create a landscape design, (4) create a soil-vegetation plan that complements the landscape design, and (5) apply proper postmining management to achieve previously set goals. The concepts contained in this article should be applicable nationwide.

983. Schafer, W. M. New Soils on Reclaimed Land in the Northern Great Plains. Paper in Symposium on Adequate Reclamation of Mined Lands? (Billings, MT, Mar. 26-27, 1980). Soil Conserv. Soc. Am., 1980, pp. 13-1—13-10.

The author presents guidelines for selecting cover soil suitable for mined-land reclamation and a procedural framework for managing cover soil in the overall mining operation. Specific methods are not suggested. However, a review of pertinent literature and interim results of current research are used to present basic principles and major factors to be considered in managing cover soil during reclamation of mined lands.

984. Schafer, W. M. Productivity of Mine Soils and Native Soils in the Northern Great Plains. Paper in 1981 Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 487-492.

This study evaluates the agricultural productivity capacity of five strip mine areas in the Northern Great Plains before and after mining. Results show that mining improved the agricultural productive capacity of three of the areas. The primary factors involved in the improvement of land capability were increased soil depth and decreased slope.

985. Schafer, W. M. Soils and Spoils. West. Wildlands, v. 7, No. 3, 1981, pp. 28-30.

The author discusses the differences that exist between native and surface-mined soils in Montana. Potential uses of the soil before and after mining are compared. For three out of five mines compared, the land capability class improved as a result of mining. Older surface mines showed a decrease in land capability, while new mines showed improved capability. Several soil factors that are limiting on Montana reclaimed lands are identified. These include compacted layers, disruption of nutrient cycles, sodium migration, and erosion.

986. Schafer, W. M. Variability of Minesoils and Natural Soils in Southeastern Montana. Soil Sci. Soc. Am. J., v. 43, No. 6, 1979, pp. 1207-1212.

This paper describes a study conducted near Colstrip, MT, to compare the spatial variability of mine soils with the variability of natural, undisturbed soils. The study sites were a 400-ha area mined and reclaimed using several mining techniques and an adjacent 300-ha unmined site. Each site was divided into 500-m cells. The sampling selection resulted in five randomly chosen sites spaced 10 cm, 1 m, 10 m, 100 m, and 500 m apart. Mine soils were found to be more variable at the 10-m lateral spacing, but natural soils were more variable at the 500-m spacing. Only 2 soil families were found on the mine area, while 14 were found on the natural area. It was concluded that order 1 (less than 1:10,000) or order 2 (1:10,000 to 1:30,000) soil surveys should be used on mined land because of local variability of the mine soils.

987. Schafer, W. M., D. W. Hedberg, D. J. Dollhopf, and J. E. Olson. Water Quality and Soil Water Movement in Western United States Minesoils as Influenced by Surface Manipulation. Reclam. & Reveg. Res., v. 2, No. 1, 1983, pp. 1-12.

This study evaluated the effects of three surface manipulation treatments on soil water movement under sprinkler irrigation, deep percolation, and leachate quality below the soil zone at the Dave Johnston Mine near Glenrock, WY. Although this article does not contain specific information on revegetation, the information that is given on surface manipulation and irrigation warrants review. The three surface manipulations evaluated in this study were chiseling, gouging, and dozer basins. Chiseling is a deep-cultivation treatment that serves as a temporary control for erosion and water conservation. It is temporary because the roughened surface is short lived. Gouging is an effective method for reducing runoff from moderate intensity storms. The basin that is created facilitates collection of plant-available water and provides protection from the wind. This creates a favorable microclimate for seedling establishment. Dozer basins are large depressions that are designed to restrict runoff and promote infiltration.

The authors feel that gouging is the most favorable surface treatment for general use in mine reclamation. A description is also given of the sprinkler irrigation system used in this study. The remainder of this article is devoted to describing the water quality of the mine as influenced by the three surface manipulations. Soil samples from the surface treatment plots were taken at 30-cm increments to

a depth of 210 cm and analyzed. Irrigation water was added, and leachate collected from lysimeters located in each of the surface treatment plots was analyzed and compared with the irrigation water that was applied to the plots. In general, the drainage from the lysimeters had a TDS value that was five times higher than that of the irrigation water. This increase was due to increased concentrations of SO_4, calcium, magnesium and HCO_3 ions.

988. Schafer, W. M., and G. A. Nielsen. Soil Development and Plant Succession on 1- to 50-Year-Old Strip Mine Spoils in Southeastern Montana. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 541-549.

Concurrent soil development and successional trends resulting from climate and parent materials typical of the Northern Great Plains were studied using a chronosequence of strip mine spoils ranging in age from 1 to 50 years and located near Colstrip, MT. Chemical, physical, and hydrological properties were compared with the production and composition of existing plant communities at these sites to determine how various soils enhance or limit reclamation potential. It was found that 50-year-old mine spoils can develop vegetation resembling that found on undisturbed sites if soil properties approximate those of native soils. However, only a small amount of the change required to form a native soil had occurred. Restoration of productive plant communities can be more effectively realized through proper reclamation on suitable material than by 50 years of succession on unfavorable soils. Reduced productivity and slow succession may result from excessive litter accumulation. Grazing or fire are suggested for reducing litter. This article is a good reference for those interested in studying plant succession and soil development processes on reclaimed surface coal mined lands.

989. Schafer, W. M., G. A. Nielsen, D. J. Dollhopf, and K. L. Temple. Soil Genesis, Hydrological Properties, Root Characteristics, and Microbial Activity of 1- to 50-Year-Old Strip Mine Spoils. U.S. EPA, Rep. EPA-600/7-79-100, Apr. 1979, 212 pp.

Soil development in mine spoils ranging from 1 to 50 years in age was evaluated to determine what changes take place in mine soil over time. Of interest were soil waterflow patterns, root growth and development, and soil physical, chemical, and microbiological properties of 15 sites on old spoil, new spoil and undisturbed native range (reference area) near Colstrip, MT. New mine soils (less than 10 years old) were found to support plant communities that were functionally more similar to native plant communities than were those on the older disturbed mine soils. The reclamation techniques that were used on the new mine soils were more effective in reestablishing productive grassland communities than was 50 years of succession on old spoils. The natural processes that were active in the development of native soils were found to occur in the 50-year-old mine soils; however, only a small amount of change had occurred and was confined to the top 5 cm of soil. Fifty years were required for organic matter and structure to reach equilibrium in the deeper soil layers. Up to 500 years may be required to achieve the levels found in natural soils. Topsoil replacement resulted in mine soils that were more similar to natural soils, but since topsoil replacement is human caused rather than a natural process, those soils will probably always remain different from natural soils.

Rapid infiltration rates were common on mine soils; even so, excessive runoff and erosion were common on poorly vegetated areas during intense storms. Because of this, rapid vegetation establishment is critical to protect mine soils during the first years after reclamation. Water use patterns also differed between natural soils, old mine soils, and new mine soils. Plant communities found on natural soils used soil water conservatively. Plant communities on old mine soils depleted nearly all of the available water in the root zone by July. This left little available water during a dry year compared with natural soils. Three to four years was required before root systems and microbiological activity on mine soils reached levels commonly found in natural soils. The authors recommend several suitable techniques to reconstruct mine soils.

990. Schafer, W. M., G. A. Nielson, and W. D. Nettleton. Minesoil Genesis and Morphology in a Spoil Chronosequence in Montana. Soil Sci. Soc. Am. J., v. 44, No. 4, 1980, pp. 802-807.

This paper reports the results of a study comparing selected soil chemical and physical parameters between mine soils from 1 to 50 years old and adjacent natural soils. Electrical conductivity, soil structure, and near-surface organic matter content were found to approach natural soil levels in decades. Organic matter content at depth will require hundreds of years. Carbonate distribution will require thousands of years. Some properties of mine soils such as texture, C-horizon color, rock fragment content, and depth to bedrock will remain different from those of natural soils. The authors feel that, while mine soils may differ from natural soils, they need not be inferior and opportunities exist in the mining and reclamation process for improving mine soils.

991. Scheib, R. H., K. R. Kelley, and P. M. Giordano. Effects of Sewage Sludge on N Transformations in Soil. Am. Soc. Agron., Agron. Abstr., 1987, p. 33.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. An incubation study using soil with ^{15}N-labeled humus-treated municipal sludge (450 kg ha^{-1} N) was conducted to determine the rate of sludge decomposition and net mineralization of sludge nitrogen. Additionally, the effects of sludge on microbial biomass and net mineralization of native organic nitrogen were determined. During the 12-week incubation period one-third of the sludge carbon was evolved as CO_2. Sludge-amended soils also had higher levels of microbial carbon. Sludge-amended soils had greater amounts of native organic nitrogen mineralization (5.6 pct) than did untreated soil (3.8 pct).

992. Schivley, W. W. Environmental Solutions for Ash Disposal. Pres. at Coal Technology '81 (Houston, TX, Nov. 17-19, 1981). Gilbert/Commonwealth, Reading, PA, 1981, 9 pp.

This paper presents two specific examples of ash disposal methods: (1) structural fill and (2) soil amendment and revegetation-reuse. Complete procedural descriptions of two representative examples are presented. The structural fill method involves burying the ash in "earth cells" (trenches), covering the deposited ash with the excavated material, contouring and grading, and revegetating. Specific seeding, fertilizing, and mulching prescriptions used in the example project are clearly described. Studies using a soil amendment are also reviewed. This is a good reference article for revegetation efforts in areas where ash is readily available, and/or its disposal and use are important considerations. The locations of projects described in this article were not given. Consequently, the article was evaluated for nationwide application.

993. Schmidtling, R. C. Relative Performance of Longleaf Compared to Loblolly and Slash Pines Under Different Levels of Intensive Culture. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 395-400.

The relative growth rates of longleaf pine (*Pinus palustris* Mill.), slash pine (*Pinus elliottii* Engelm.), and loblolly pine (*Pinus taeda* L.) were compared 25 years after intensive culture treatments. Culture treatments consisted of a control and four disking treatments with varied fertilization rates. Heights were measured at ages 1, 2, 3, 4, 5, 6, 9, and 25, and DBH was measured at ages 6, 9, and 25. Relative growth rates and height-age curves of each species varied with cultural treatment. At age 9, loblolly pine growth was superior to slash pine growth, which was superior to longleaf pine growth. After age 9, the growth of loblolly pine slowed on the control and less intensive plots. On control plots, the average height for loblolly, slash, and longleaf pines was 41.1, 47.7, and 51.9 ft, respectively, after 25 years. As the intensity of culture increased, so too did the relative growth rate of loblolly pine: at age 25, loblolly pine averaged 7 ft taller than slash or longleaf pines on plots that received the highest fertilization rates. Survival data indicate the need for early competition control for the survival of longleaf pine seedlings. Disking is not a desirable cultural treatment for longleaf pine establishment.

994. Schmieg, T. Strip Mining: Turning a Curse into a Blessing for Appalachia. Nature Scape, Wheaton, IL, Mar. 1981, pp. 14-25.

This article provides a general overview of surface coal mine reclamation in the Interior and Eastern Coal Mining Regions. The discussion contains nontechnical descriptions of the state of the art for several areas of reclamation and examines some of the impacts that the Surface Mining Control and Reclamation Act of 1977 has had on the coal mining industry. The article was reviewed and included in this bibliography for its value in providing good background information to individuals with little or no experience or knowledge of surface coal mine reclamation. Ratings for the keywords used in this evaluation indicate that these topics were considered in the article. However, this information was treated in a general manner. Few or no technical data were related in the article.

995. Schneider, K. R., R. F. Wittwer, and S. B. Carpenter. Trees Respond to Sewage Sludges in Reforestation of Acid Spoil. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 291-296.

The objectives of this study were to test sludge metal levels, fertilizer values, and application rates on the early growth of five tree species. European black alder (*Alnus glutinosa* (L.) Gaertn.), black locust (*Robinia pseudoacacia* L.), cottonwood (*Populus deltoides* Bartr. ex Marsh.), and loblolly pine (*Pinus taeda* L.) were established as 1-0 seedlings in the spring, while northern red oak (*Quercus rubra* L.) was direct-seeded in the spring. Four sludge treatments (high and low metals with either 100 or 200 kg ha^{-1} of soluble nitrogen present) were compared with two fertilizer treatments (100 or 700 kg ha^{-1} N in a slow-release fertilizer).

Survival of the tree species was highest in the plots with the high-metal sludge additions compared with the

fertilizer treatments. Growth and vigor increases were also found for the high-metal treatments, except for loblolly pine and cottonwood, where the growth responses were not very dramatic. Leaf samples analyzed for heavy-metal and nutrient concentrations showed significantly greater foliar nitrogen levels with fertilizer than with sludge, except for black locust. Visual metal toxicity symptoms were not observed during the first growing season. However, cadmium levels were within the phytotoxicity range for cottonwood and were very high for loblolly pine. Both species may be showing toxicity responses along with a growth stimulation from other metals and nutrients in the sludge. The authors conclude that growth and survival increases due to sludge applications were unexpected and may have been related to improvements in the soil condition.

996. Schoenholtz, S. H., and J. A. Burger. First Year Survival and Growth of Containerized Pine (*Pinus* spp.) Seedlings on Strip Mined Lands as Affected by Cultural Treatments and Edaphic Factors. Paper in Proceedings of the Second Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-5, 1982). U.S. For. Serv., Gen. Tech. Rep. SE-24, 1983, pp. 134-140.

This study evaluated the effects of ectomycorrhizal inoculation, chemical weed control, and slow-release fertilization on the first-year survival and growth of container-grown white pine (*Pinus strobus* L.), Virginia pine (*Pinus virginiana* Mill.), and loblolly pine (*Pinus taeda* L.) planted on two strip-mined sites in Wise County, VA. The two sites consisted of a flat bench site and a return-to-contour site. None of the cultural treatments used in this study had a significant effect on the survival of the planted pine species. However, mycorrhizal inoculation (*Pisolithus tinctorius* mycelia), weed control (glyphosate), and fertilization (21-g slow-release tablet) improved the growth of all three species. When fertilizer and weed control were combined, the most substantial growth response occurred. All of the treatments resulted in foliar nutrient concentrations that were above deficiency levels. This indicates that phosphorus, potassium, calcium, and magnesium, were not limiting seedling growth; however, the stimulatory effect of fertilization suggests that nitrogen may have been limiting. The authors conclude that cultural treatments can be used to improve the growth of pine species on strip-mined lands.

997. Schoenholtz, S. H., and J. A. Burger. Influence of Cultural Treatments on Survival and Growth of Pines on Strip-Mined Sites. Reclam. & Reveg. Res., v. 3, No. 4, 1984, pp. 223-237.

The effects of ectomycorrhizal inoculation, chemical weed control, and slow-release fertilization on the survival and growth of white pine (*Pinus strobus* L.), loblolly pine (*Pinus taeda* L.), and Virginia pine (*Pinus virginiana* Mill.) were evaluated on a recontoured site and a flat bench site in southwestern Virginia. Survival was not affected by sites, fertilizer treatments, or mycorrhizal inoculation during the first two growing seasons. Growth was not affected by site differences during the first year; however, after the second year, growth of all three species was significantly better on the bench site. Inoculation with *Pisolithus tinctorius* significantly increased the first- and second-year height and diameter growth of loblolly pine. First-year growth of all species and the second-year growth of loblolly pine were affected by a significant fertilizer-herbicide interaction. Average first-year height and diameter were greater with combinations of fertilizer and herbicide than when fertilizer or herbicide was used alone. This suggests that both treatments are important in mitigating nutrient and moisture deficiency on the sites studied.

998. Schoenholtz, S. H., J. A. Burger, and R. E. Kreh. Surface Organic Amendment and Nitrogen Fertilizer Effects on Subsurface Water Quality in Mine Soils. Am. Soc. Agron., Agron. Abstr., 1988, p. 47.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Impacts of reclamation treatments on subsurface water quality were evaluated. Concrete lysimeters containing mine spoil were seeded with grasses and legumes. Each lysimeter was amended with either 0 or 100 kg ha^{-1} nitrogen fertilizer and treated with either topsoil (5 cm), yellow poplar chips (50 mg ha^{-1}), or nothing. Prior to vegetation establishment, all treatments resulted in high leachate exports of nutrients. The highest leachate volume was obtained from the whole-tree wood chip amendment; it was 28 pct higher than from any other treatment.

999. Schoenholtz, S. H., J. A. Burger, and J. L. Torbert. Natural Mycorrhizal Colonization of Pines on Reclaimed Surface Mines in Virginia. J. Environ. Qual., v. 16, No. 2, 1987, pp. 143-146.

The effects of soil type, slow-release fertilization, and chemical weed control on the natural ectomycorrhizal colonization of container-grown white pine (*Pinus strobus* L.), loblolly pine (*Pinus taeda* L.), and Virginia pine (*Pinus virginiana* Mill.) on two strip-mined sites in southwestern Virginia were evaluated. A recontoured slope site composed of siltstone parent material was compared with a flat bench site composed of sandstone parent material. The experimental design was a split-plot design with three replications (one for each species) on each site. At each site a 21-g Agriform fertilizer tablet was placed 10 cm

deep within 10 to 15 cm of half of the seedlings planted in each main plot. In each fertilizer treatment, glyphosate was sprayed on half of the treatment before planting and again in the fall.

No ectomycorrhizae were present on the tree seedlings prior to planting. After one growing season 50 pct of the pine seedlings were colonized with ectomycorrhizal fungi. This suggests that there is a source of endemic mycorrhizal species present in the spoil materials tested. The number of seedlings colonized and the proportion of short-root colonization per seedling, however, were consistently higher on the sandstone spoil, 71 pct compared with 34 pct for seedlings on siltstone spoil. Both loblolly and Virginia pines had more ectomycorrhizal formation than white pine at both sites. Mycorrhizal colonization was positively correlated with foliar phosphorus for all three species on the sandstone spoil and for loblolly pine only on the siltstone spoil. This indicated the importance of mycorrhizal infection or formation for seedling nutrition on these disturbed sites. Neither slow-release fertilization nor glyphosate applications adversely affected ectomycorrhizal infection. These cultural treatments were compatible with mycorrhizal formation from naturally occurring fungal species.

1000. Schoenholtz, S. H., J. L. Torbert, and J. A. Burger. Factors Affecting Seedling Ectomycorrhizal on Reclaimed Surface Mines in Virginia. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 89-93.

Summaries of current research conducted to evaluate the need for ectomycorrhizal inoculation on reclaimed surface mines in southwestern Virginia are presented. The research was designed to evaluate the effect of *Pisolithus tinctorius* (Pers.) Coker & Couch (Pt) on the performance of planted pines and to evaluate the effect of spoil type and pine species on natural mycorrhizal development.

In the first study, containerized loblolly pine (*Pinus taeda* L.) and loblolly pine-pitch pine hybrids (*Pinus xrigitaeda*) were grown under greenhouse conditions for 16 weeks, and half were inoculated with Pt basidiospores, prior to outplanting. Each plot had been fertilized and mulched. After the second and third growing seasons, tree survival, height, and root collar diameter were recorded. Inoculation with Pt did not significantly improve seedling performance. The authors speculate that high soil fertility resulting from the broadcast of fertilizer, as well as limited moisture stress, depressed mycorrhizal benefits.

In the second study, nonmycorrhizal seedlings of loblolly pine, Virginia pine (*Pinus virginiana* Mill.), and white pine (*Pinus strobus* L.) were outplanted on plots under herbicide treatments (none or slow-release) at two sites: a flat bench and a recontoured slope of predominantly sandstone and siltstone, respectively. The frequency and extent of colonization were higher for all three species on the sandstone site (71 pct) than on the siltstone site (34 pct). This was attributed to the lower nutrient availability and better root penetration in the coarser soils on the sandstone site. The authors conclude that reclamation practices such as controlled overburden placement and fertilization, in combination with natural mycorrhizal formation, may be adequate to establish commercially valuable trees on these sites.

1001. Scholl, D. G. Vegetation and Soil Water Response to Contour Furrows, Dozer Basins, and Surface Additions of Topsoil or Power Plant Ash on Arid Coal Spoils. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 217-220.

The purpose of this study was to determine if plant establishment could be improved on northwestern New Mexico coal mine spoil using surface shaping or amendments in an area that received 15 cm of annual precipitation. Two shale spoil areas were studied. Treatments consisted of (1) controls, (2) contour furrows, (3) dozer basins, (4) topsoil (0.15 m), and (5) ash (0.07 m). Each treatment was drill seeded with range species. Furrow plots on both spoils had significantly better stands of vegetation than did the other treatment plots. Dozer basins showed no advantage over the control for most species. Topsoiled and ash-amended plots had species that emerged, but did not survive after 2 years.

1002. Scholl, D. G., and S. Miyamoto. Response of Alkali Sacaton and Fourwing Saltbush to Various Amendments on Coal Mine Spoils From Northwestern New Mexico. I. Acid Spoil. Reclam. & Reveg. Res., v. 2, No. 3, 1983, pp. 227-236.

Two greenhouse experiments were conducted to test chemical and physical amendments for use in revegetation of acid spoils. The spoil materials used in these experiments were collected from the Fruitland Formation of northwestern New Mexico. The response of alkali sacaton (*Sporobolus airoides* (Torr.) Torr.) and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) to the applied amendments was monitored. The chemical amendments used consisted of applications of phosphorus (CaH_2PO_4), lime ($CaCO_3$), and a wetting agent ("Soil Pen," linear sulfonate, anionic compound). The physical amendments and phosphorus application are essential, along with water and possibly nitrogen, for growing alkali sacaton and four-wing saltbush on acid spoil. The following amendments showed

promise for improving the growth of alkali sacaton and four-wing saltbush: (1) sand or ash mulch spread over the phosphorus- and lime-treated spoil, (2) shale or sand incorporation in the phosphorus- and lime-treated spoil, and (3) sand topdressing over phosphorus-amended spoil. Wetting agents may be necessary for treatments 1 and 3 if the spoils are strongly water repellent. Field tests are needed to make specific management recommendations.

1003. Scholl, D. G., and S. Miyamoto. Response of Alkali Sacaton and Fourwing Saltbush to Various Amendments on Coal Mine Spoils from Northwestern New Mexico. II. Sodic Spoil. Reclam. & Reveg. Res., v. 2, No. 4, 1984, pp. 243-252.

The potential of using chemical amendments in combination with sand amendments for revegetating northwestern New Mexico sodic mine spoils was evaluated. The spoils used were of sandstone and shale origin. Two separate experiments were conducted, a laboratory water penetration test and a greenhouse plant growth test. The chemical amendments used were concentrated sulfuric acid, gypsum, and phosphorus. These chemical amendments were applied in combination with physical amendments (sand mulching, sand topdressing, and sand incorporation) on the shale spoil. The water penetration tests involved packing spoil samples (both shale and sandstone) into acrylic plastic columns and applying concentrated sulfuric acid at 1, 2.5, and 5.0 Mg ha^{-1}. Additionally, treatment involved mixing aeolian sand at a weight rate of 50 pct. The advancement of wetting front was traced as a function of time. Shoot emergence and growth tests were conducted using alkali sacaton (*Sporobolus airoides* (Torr.) Torr.) and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) as the test species. Sandstone spoil amendments were sulfuric acid (2.5 or 5.0 Mg ha^{-1}) sprinkled over the spoil after seeding or gypsum (5.0 Mg ha^{-1}) or phosphorus (200 kg ha^{-1}) broadcast before seeding. For the shale-based spoil, the chemical amendments were imposed in combination with the physical treatments. Plant samples were analyzed for phosphorus, while spoils were analyzed for pH, EC, SAR, and extractable phosphorus.

Water penetration was slow, especially into the shale-based spoil. Sulfuric acid amendments increased the penetration rate into both spoils. Both gypsum and sand incorporation were less favorable than the acid treatment. Acid and gypsum treatments increased the rate of alkali sacaton germination in the sandstone spoil, but had little influence on the final count. In the shale-based spoil, sand mulching alone improved the emergence of four-wing saltbush, but not alkali sacaton. Acid application to both spoils reduced pH and SAR and increased soluble salts and available phosphorus.

1004. Scholl, D. G., and C. P. Pase. Wheatgrass Response to Organic Amendments and Contour Furrowing on Coal Mine Spoil. J. Environ. Qual., v. 13, No. 3, 1984, pp. 479-482.

The effects of organic amendments and contour furrowing (alone and in combination) on wheatgrass (*Agropyron* spp.) establishment in sodic and nonsodic western New Mexico spoil were determined. Organic treatments on the sodic spoil were partially decomposed pine bark (18 Mg ha^{-1}) and barley (*Hordeum vulgare* L.) straw. Contour furrowing was also utilized, with large furrows (0.2 m deep) through the amended plots and small furrows (0.1 m deep) through the raw spoil. Fertilizer was broadcast and applied at rates of 56 kg ha^{-1} N and 112 kg ha^{-1} P. Wheatgrasses were seeded and planted, and density and height were measured after the first and second growing seasons. Treatments on the nonsodic spoil included incorporation of pulverized barley straw (11 Mg ha^{-1}), addition of 0.15 m of topsoil to graded spoil, and the standard reclamation technique of furrowing (0.1 m deep), seeding, and broadcasting a mulch. All nonsodic treatments were fertilized.

The most important factor differentiating the two spoils was their SAR. Both SAR and soluble sodium were 18 times higher in the sodic spoil. Additionally, the EC was high in the sodic spoil, while spoil pH was 7 for all treatments and spoils. The major plant nutrients were low in both the sodic and nonsodic spoils. On the sodic spoil, the numbers of plants established did not differ among treatments, but grass height and production were greatest on plots with bark amendments that had been furrowed. On nonsodic spoil, the number of plants varied slightly among the treatments, but total grass plants were about four times as abundant as on sodic spoils. The height of individual species was similar among treatments, and total population was high on all treated areas. The wheatgrasses studied were found to respond well to the amendments utilized on both the sodic and nonsodic spoil.

1005. Schrandt, C. M., S. E. Feagley, and W. J. Shields, Jr. The Effect of Primary Papermill Sludge on the Growth and Nutrient Concentrations of Cottonwood Trees. Am. Soc. Agron., Agron. Abstr., 1988, p. 47.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The effects of papermill wastes, with and without nitrogen and phosphorus fertilizer, on the growth and nutrient concentration of cottonwood (*Populus deltoides* Marsh.) were evaluated. Papermill wastes were applied at rates of 0, 112, 224, and 448 Mg ha^{-1}, with nitrogen and phosphorus fertilizers the first year and without nitrogen and phosphorus fertilizers the second year. Applications of papermill wastes increased cottonwood heights and diameters. No differences

between fertilizer treatments were found. Foliar nutrient concentrations were affected by sludge and fertilizer treatments.

1006. Schrandt, C. M., S. E. Feagley, and W. J. Shields, Jr. Land Application of Primary Papermill Wastes: Effects on Soil Properties and the Growth of Cottonwood Trees. Am. Soc. Agron., Agron. Abstr., 1986, p. 36.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. Field-planted cottonwood cuttings (*Populus deltoides* Bartr. var. *deltoides*) were treated with three rates of papermill sludge plus fertilizer or fertilizer alone. Soils were analyzed 0, 2, 4, 8, 16, and 40 weeks after treatment, and tree heights and diameter were measured after 1 year of growth. Sludge amendments tended to increase soil pH, EC, and organic carbon, and decrease exchangeable acidity, exchangeable aluminum, and extractable phosphorus. Tree growth increased more with the fertilizer-alone treatment than with the sludge-plus-fertilizer treatment. Foliar concentrations of phosphorus, sulfur and calcium increased because of sludge application, and the sludge application decreased foliar concentrations of potassium, iron, aluminum, copper, manganese, and boron compared with the control or fertilizer-alone treatments.

1007. Schrandt, C. M., S. E. Feagley, and W. J. Shields, Jr. Papermill Waste Applications With and Without Added Fertilizers: Effects on Soil Properties. Am. Soc. Agron., Agron. Abstr., 1987, p. 33.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. The effects of applying primary papermill waste for 2 consecutive years on soil chemical properties were examined. Rates of application were 112, 224, and 448 Mg ha^{-1}. First-year treatments included wastes plus fertilizer nitrogen and phosphorus, fertilizer only, and a control. Second-year treatments included wastes, wastes plus fertilizer nitrogen and phosphorus, fertilizer only, and a control. First-year treatment effects included increases in soil pH, electrical conductivity (EC), and organic carbon and a decrease in exchangeable aluminum compared with the control. Second-year effects, in addition to the same first-year effects, included increases in extractable phosphorus, CEC, exchangeable calcium, and exchangeable sodium. Papermill waste treatment differences, with and without added fertilizer, were found for EC and extractable phosphorus.

1008. Schroeder, S. A. Effect of Crusting on Runoff and Erosion From Reshaped Spoil. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 205-210.

The effects of crusting on runoff and erosion losses were determined on graded spoil in order to develop a model to estimate K values for the Universal Soil Loss Equation. Artificially applied rainfall was used at two North Dakota mine locations to study the effects of crusting versus fallow surfaces (simulating freshly respread conditions) on reshaped spoil over a range of slopes. Soil losses generally increased as slope increased regardless of surface condition. In general, soil loss was greater for the fallow surface than for the crusted surfaces.

1009. Schroeder, S. A. Slope Gradient Effect on Erosion of Reshaped Spoil. Soil Sci. Soc. Am. J., v. 51, No. 2, 1987, pp. 405-409.

The applicability of the Universal Soil Loss Equation (USLE) slope function for predicting spoil erosion rates was evaluated at three reshaped spoil sites in North Dakota. Slope gradients ranged from 0.1 to 11.1 pct, and the effect of slope gradient on sediment was quantified using a rainfall simulator. Two spoil surface conditions were also included in the experiment: a crusted surface condition and a freshly respread condition. Spoil losses were greater from initially dry crusted spoils than from freshly respread spoils; however, under wet and very wet surface conditions spoil losses were less from crusted spoils than from freshly respread spoils. Increased soil loss from freshly respread spoil under wet conditions was due to greater scouring of the surface by overland flow. Regression-correlation analyses of total spoil loss from all sites exhibited linear tendencies for both surface conditions. Spoil loss increased linearly with increasing slope gradient. The USLE curvilinear soil loss ratio underestimated the slope gradient effect for slopes <9 pct and overestimated for slopes >9 pct compared with the developed spoil-soil loss ratio function. The author concludes that the developed spoil-soil loss ratio function and the USLE K values should provide adequate estimations of spoil erosion losses.

1010. Schroeder, S. A., and A. Bauer. Soil Water Variation in Spoil and Undisturbed Sites in North Dakota. Soil Sci. Soc. Am. J., v. 48, No. 3, 1984, pp. 656-659.

The authors present the results of a 7-year study conducted to compare the amounts of total water in a reclaimed spoil and nearby undisturbed grassland sites (reference area) in North Dakota. Soil moisture was measured in 30.5-cm increments to a depth of 244 cm using a neutron probe. Results indicate that water did not percolate beyond the rooting zone (0 to 122 cm) at either the reclaimed vegetated spoil or the undisturbed grassland sites. Total soil water below the rooting zone decreased with time because of the upward movement of unsaturated flow in response to gradients created in the rooting zone

by evapotranspiration (ET). At the beginning of the study the spoil site contained more total water than did the undisturbed sites, but greater ET losses due to the greater vegetation cover at the spoil sites decreased soil water to levels that were nearly equal to those of undisturbed sites.

1011. Schroeder, S. A., and G. A. Halvorson. Soil Water Depletion Under Crops on Reclaimed and Undisturbed Soils. J. Environ. Qual., v. 17, No. 1, 1988, pp. 130-134.

Changes in soil water depletion, water use efficiency, and total water used for small grains and corn (*Zea mays* L.) were compared between simulated reclaimed and undisturbed soils. Topsoil was spread over gravelly loamy sand spoil, clay loam spoil, and silty clay loam spoil to a depth of 0.23, 0.46, or 0.69 m. An additional treatment consisted of gravelly loamy sand spoil within 1.5 m of the surface and a clay loam subsoil placed over it to within 0.23, 0.46, and 0.69 m. Topsoil was then placed on the subsoil at thicknesses of 0.23, 0.46, and 0.69 m. All treatments had a uniform final soil surface.

Undisturbed soil consistently had greater total water usage and soil water depletion than did the reclaimed soils; however, the differences were significant in only 1 of the 4 years that the study was conducted. Grain yields from the reclaimed soil, averaged over three topsoil thicknesses on four spoil textures, were not significantly different than yields from undisturbed soil when total precipitation during the growing season was adequate and well distributed. Yield difference between undisturbed and reclaimed soils occurred when available soil water was inadequate or there was poorly distributed precipitation at the time of planting. Water use efficiency was found to be similar on both disturbed and undisturbed soils. If the mean total water use values for the reclaimed sites had approached the total water use values of the undisturbed soil and the water use efficiency values had remained the same, the authors speculate that grain and corn yield on the reclaimed soil would have equalled or exceeded yields on the undisturbed soil. However, because of shallower rooting depths and, as a result, less soil water depletion, reclaimed soils had water stress conditions, resulting in reduced productivity potential.

1012. Schroeder, S. A., M. W. Pole, and A. Bauer. Water Use Efficiency as Influenced by Topsoil Thickness and Fertility on Reclaimed Land. ND Farm Res., v. 37, No. 6, May 1980, pp. 24-26.

This article reports the results of a study conducted near Beulah, ND, that examined changes in water use efficiency (WUE) in response to increasing thickness of topsoil or first-lift material. WUE in corn (*Zea mays* L.) silage production increased with increased topsoil thickness in 2 out of 5 years. Similarly, WUE in wheat (*Triticum aestivum* L.) production increased in 3 out of 5 years. Application of nitrogen fertilizer increased WUE for corn silage production. The results and discussion contained in this report are pertinent to reclamation planning where the postmining land use is agricultural cropland.

1013. Schuller, R. M., I. G. Krapac, and R. A. Griffin. Evaluation of Laboratory-Produced Leachates Used for Environmental Assessment of Coal Refuse. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 123-128.

This study was conducted to compare field leachates with aqueous extracts from coal mining wastes produced in the laboratory using five accepted extraction procedures in order to evaluate the laboratory methods used. Samples of three coal-cleaning wastes were taken from an active operation in Saline County, IL, which included (1) fresh gob, (2) fresh slurry, (3) 20-year-old gob, and (4) gob from an abandoned deep mine site. The five extraction procedures used were (1) the proposed American Society for Testing and Materials (ASTM) method, ASTM-A, (2) proposed ASTM-B method, (3) proposed U.S. EPA extraction procedure, (4) carbonic acid technique, and (5) long-term equilibration in deionized water. Extract results indicate that the amount of leachate generated was dependent upon the extraction procedure used. Field extracts were found to have concentrations that were from 2 to 1,000 times greater than those in laboratory-generated extracts. The authors concluded that the differences in concentrations occurred because laboratory procedures did not duplicate the wetting-drying cycles and oxidation conditions responsible for the chemical composition of field leachates from coal refuse containing pyrite.

1014. Schumacher, N. A., C. E. Clapp, M. M. DuBois, M. T. Martindale, J. A. E. Molina, and W. E. Larson. Chemical Composition of Solid Waste Composts and Co-Composts. Am. Soc. Agron., Agron. Abstr., 1988, p. 47.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Nutrient and trace metal levels of solid waste composts and co-composts were analyzed from several sources. Trace metal concentration varied because of type and origin of feedstock materials, degree of preprocessing, and method and duration of composting process. Large differences existed in the composts' ability to supply nitrogen for plant growth.

1015. Schuman, G. E., E. J. DePuit, J. A. Smith, and L. A. King. Reclamation of Bentonite Mined Lands in

the Northern Great Plains. Paper in Proceedings 1984 National Meeting American Society for Surface Mining and Reclamation (Owensboro, KY, July 10-13, 1984). Am. Soc. Surf. Min. and Reclam., 1984, pp. 131-150.

The location and nature of bentonite deposits, mining methods, and current reclamation technologies are discussed. Topsoil replacement is used on areas currently mined, but is not an alternative for the reclamation of abandoned spoils.

Inorganic amendments that have been evaluated on both topsoil and spoil material include sulfuric acid, gypsum, calcium chloride, perlite, and vermiculite. These amendments have been used to reduce surface crusting (sulfuric acid and calcium chloride) and to increase hydraulic conductivity (sulfuric acid, calcium chloride, and gypsum). Generally, inorganic amendments have not shown consistent benefits to plant establishment and growth.

The effects of organic amendments on plant establishment and growth have also been evaluated. These amendments include wood residues, manure, and straw mulch. Organic amendments have been shown to provide the greatest benefits to bentonite spoils through improved physical characteristics of the spoil (increased water infiltration, reduced bulk density, and increased aggregation). Plant response to nitrogen and phosphorus fertilization has been variable. Information is also given on the tillage, and surface preparation techniques can be used along with the plant species adapted to the spoils. Long-term reclamation concerns are identified.

1016. Schuman, G. E., and J. F. Power. Plant Growth as Affected by Topsoil Depth and Quality on Mined Lands. Paper in Symposium on Adequate Reclamation of Mined Lands? (Billings, MT, Mar. 26-27, 1980). Soil Conserv. Soc. Am., 1980, pp. 6-1—6-9.

The authors discuss the benefits of topsoiling and review pertinent research results from Wyoming and North Dakota. Adequate depth of topsoil applications is very site specific, and such recommendations must be based on the availability of material and the quality of the subsoil and overburden. In some cases good-quality subsoil or overburden can be used to supplement limited topsoil resources. The major focus of the paper is the effect of topsoil depth on the water relations and plant productivity of the reclaimed mine soil. The information presented is primarily applicable in the Northern Great Plains Coal Mining Region.

1017. Schuman, G. E., F. Rauzi, and G. S. Howard. Vegetation Response to Soil Surface Modification in Mined Land Reclamation. Reclam. & Reveg. Res., v. 6, No. 1, 1987, pp. 49-54.

The effects of three surface modification treatments on forage production were evaluated. The site reclaimed was a topsoiled uranium mine located in south-central Wyoming. The surface modification treatments included (1) control, (2) pitting, (3) furrowing, and (4) soil ridges. The entire area was fertilized, mulched, and drill seeded to crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.). The surface modification treatments resulted in greater aboveground biomass than the control treatment in all years except one; in that year abnormally low (49 pct of normal) precipitation occurred. The greater yields in treated plots were attributed to increased water infiltration, snow trapping, and reduced evaporation. Over the 6 years of the study, crested wheatgrass aboveground biomass averaged 31, 37, and 31 pct greater on the pitted, ridged, and furrowed treatments, respectively, than on the control plot.

1018. Schuman, G. E., and T. A. Sedbrook. Sawmill Wood Residue for Reclaiming Bentonite Spoils. For. Prod. J., v. 34, No. 11/12, 1984, pp. 65-68.

The effectiveness of wood residue (sawdust, chips, and bark) on the establishment of a vegetative cover on an abandoned bentonite mine spoil in northeastern Wyoming was established. Wood residue was applied at rates of 0, 112, and 224 Mg ha^{-1}. The study area was fertilized with 90 kg ha^{-1} P and 5 kg N per megagram wood residue. After the residue was spread, it was incorporated into the spoil and the study area was drill seeded. Chemical analyses showed that the pH, EC, and extractable phosphorus content were similar across treatments, while total nitrogen values increased with increasing wood residue. The addition of 112 Mg ha^{-1} of wood residue doubled the amount of soil water in the 0- to 20-cm depth section. A benefit of the wood residue amendments is the improved water infiltration and storage of water by the bentonite spoil. The aboveground biomass of seeded species increased when amended with either the 112- or the 224-Mg-ha^{-1} wood residue treatment. There were no significant differences in seeded species biomass between the 112- and 224-Mg-ha^{-1} treatments. Control plot biomass decreased during the 4-year period and was significantly lower than biomass on both wood residue treatments. The improvement of the physical characteristics of the spoil by wood residue treatment is the main factor contributing to the successful revegetation of the abandoned bentonite mine spoil studied.

1019. Schuman, G. E., E. M. Taylor, Jr., F. Rauzi, and G. S. Howard. Standing Stubble Versus Crimped Straw Mulch for Establishing Grass on Mined Lands. J. Soil and Water Conserv., v. 35, No. 1, 1980, pp. 25-27.

This study was done to determine the feasibility and effectiveness of spring planting a small grain to help stabilize the soil and act as a mulch for establishing a permanent grass cover through fall seeding. This study was conducted on a topsoiled, regraded spoil dump at the Pathfinder Mines Corp.'s Shirley Basin uranium mine near Shirley Basin, WY. Twenty plots, each 5 by 45.7 m, were established and fertilized. Ten plots were seeded in the spring to Otis barley (*Hordeum vulgare* L.), while the other 10 plots were left fallow over the summer. The following fall, the barley stubble plots and fallow plots were seeded with a mixture of perennial grasses. Barley straw was scattered on the seeded fallow plots at a rate of 5 mt ha^{-1} and then crimped. Of the straw mulch applied in the fall, only 47 pct remained the following spring, while 94 pct of the stubble residue remained after the same period. Plant establishment along a 3.05-m transect was 54 plants and 48.6 plants for the stubble and crimped residue treatments, respectively. Stubble residue plots also showed a lower temperature fluctuation in the upper portions of the soil, had more soil moisture, and produced 25 pct greater cumulative water infiltration than did plots with crimped straw. Stubble residue costs were 75 to 95 pct lower than the costs for crimped straw or hay. The authors concluded that stubble mulch was statistically as good as or better than straw mulch for the establishment of perennial grasses.

1020. Schuman, G. E., E. M. Taylor, Jr., F. Rauzi, and B. A. Pinchak. Revegetation of Mined Land: Influence of Topsoil Depth and Mulching Method. J. Soil and Water Conserv., v. 40, No. 2, 1985, pp. 249-252.

The effects of topsoil depth and mulching method on the productivity of seeded native forage species, productivity of nonseeded species, and water infiltration and storage were determined at an open-pit uranium mine in south-central Wyoming. Overburden was graded and ripped. Topsoil was spread over the regraded overburden in a wedge slope, ranging in depth from 0 to 600 mm. Ten plots were seeded to barley (*Hordeum vulgare* L.) in the spring. The remaining plots were fallowed. In the fall, western wheatgrass (*Agropyron smithii* Rydb.), thickspike wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.), slender wheatgrass (*Agropyron trachycaulum* (Link) Malte), and green needlegrass (*Stipa virdula* Trin.) were seeded. The barley plots were direct seeded, while the fallow plots were mulched and crimped with 5 mt ha^{-1} barley straw after seeding. The following spring, seedling emergence was evaluated.

Forage yields were obtained over a 4-year period on sample sites at topsoil depths of 0, 200, 400, and 600 mm. Forage production by seeded species on the 400- and 600-mm topsoil depth plots was significantly greater for grass established with barley stubble than for that established with crimped straw mulch, a result of improved soil physical characteristics due to barley rooting habits. Nonseeded species production was greater at the 0- and 200-mm topsoil depth, and production of nonseeded species decreased as topsoil depth increased, particularly on stubble plots. Mulch type did not affect stored soil water. Results indicate that for forage production by native grasses, 400 mm of topsoil is adequate in revegetation. The use of stubble rather than crimped straw mulch will result in greater production by seeded species and lower production by nonseeded species, particularly when soil is replaced at 400- or 600-mm depths.

1021. Schuster, W. S., and R. J. Hutnik. Community Development on 35-Year-Old Planted Minespoil Banks in Pennsylvania. Reclam. & Reveg. Res., v. 6, No. 2, 1987, pp. 109-120.

A series of 35-year-old surface mine tree plantings were studied to examine the processes of invasion, succession, and community development in western Pennsylvania. A total of 169 plant species had invaded the sites, with black cherry (*Prunus serotina* Ehrh.) being the most common woody invader. Species richness varied with the tree species originally planted and site. After 36 years, most sites are dominated by trees characteristic of early to mid successional stages of a young woodland community. The invading species vary from site to site, and these differences may be attributable to site-specific factors. Spoil characteristics may be affecting the rate and composition of community development.

1022. Schuster, W. S., and R. J. Hutnik. Strip-Mine Test Plantings in Pennsylvania After 35 Years. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll., Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 119-128.

A reexamination of tree species trials made on bituminous spoil banks in Pennsylvania is reported. These spoil banks are composed primarily of shales and sandstones with pH varying between 4.0 and 6.7. Some piles had been partially or completely regraded, while others had been left as steep-sided piles. These piles are small compared with modern spoil banks. Mining had occurred between 1943 and 1948. After 35 years, 10 of the 22 original plantings remained intact and essentially undisturbed. Spoils were sampled at these 10 sites. Survival and basal area were determined for the 16 species planted. Wood production was calculated for the better stands.

Of the 10 conifers tested, red pine (*Pinus resinosa* Ait.) was most successful, whereas scotch pine (*Pinus sylvestris* L.) had significantly deteriorated. Wood production of the better stands compared favorably with that of natural stands. Tree survival was correlated with spoil acidity and degree of slope. Active soil formation processes were indicated by small changes in particle size distributions and potassium enrichment in surface spoil layers. While the most acidic spoils and the steepest slopes remained barren after 35 years, most of the banks have been successfully revegetated through the combination of tree planting and natural invasion. This report provides long-term data that are somewhat unique for reclamation literature. For that reason it has excellent potential application to reclamation planning. While the study is specific for Pennsylvania, application to a broader geographical area would be possible, particularly for spoil materials with similar characteristics.

1023. Scott, J. D., R. B. Reneau, Jr., D. C. Martens, T. W. Simpson, and B. D. Rappaport. Availability and Distribution of N and P in Four Virginia Soils Following Application of Sewage Sludge. Am. Soc. Agron., Agron. Abstr., 1985, p. 31.

Abstract of a paper presented at the 1985 Annual Meetings of ASA, CSSA, and SSSA. Nitrogen and phosphorus balances for corn (*Zea mays* L.) and barley (*Hordeum vulgare* L.) grown on sludge-amended soils were developed. The rates of sludge-borne nitrogen and phosphorus were evaluated using five treatments (667, 1,334, 2,001, 2,668, and 3,335 kg ha^{-1} N) of a digested sludge (1.6 pct N and 3.2 pct P) and two controls (no nitrogen and 200 kg ha^{-1} NH_4NO_3). Higher sludge application rates were needed before tissue nitrogen concentrations and yield were comparable to those on the inorganic nitrogen control. Phosphorus concentrations did not vary among treatments.

1024. Scott, M. D. Computerized Reclamation Planning System for Northern Great Plains Surface Coal Mines. Paper in Ecology and Coal Resource Development, Volume 1 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 412-420.

The paper provides a concise description of a computer-based reclamation planning system developed at Montana State University. The system, called CLAIM, summarizes relevant reclamation data and permits the reclamation manager to analyze available options quickly before developing the final reclamation plan. The program acts on the following general classes of data input: average slope, stage in mining sequence, dragline mine description, shovel and truck mine description, climatic parameters, topsoil parameters, subsoil parameters, overburden characteristics, surface water hydrology, ground water hydrology, vegetation community types, wildlife types, and socioeconomic parameters. The program ranks the critical environmental parameters by assigning feasibility rating units to them. The program then permits comparisons of reclamation costs based on the choice of postmining land use. The ratings for keywords used in the evaluation process represent the apparent treatment of these subject areas in the process of developing the model and the conceptual basis for the model.

1025. Scott, M. D. Northern Great Plains Reclamation Cost Projections by Computer. Paper in Conference on the Economics of Mined Land Reclamation (cosponsored by Land Reclam. Prog., Argonne Natl. Lab., and U.S. Dep. Energy; Chicago, IL, Sept. 1-2, 1981). Argonne Natl. Lab., ANL/LRP-TM-20, Sept. 1981, pp. 191-202.

This paper contains a description of a computer program called CLAIM that was designed to act as a reclamation planning tool. The program can predict the costs of reclaiming coal surface-mined land in the Northern Great Plains to any of five major land uses. The 10 most commonly used reclamation techniques are ranked according to general cost from highest to lowest: (1) toxic spoil rehandling, (2) topsoil stripping and replacement, (3) subsoil stripping and replacement, (4) spoil grading and contouring, (5) reclamation program administration, (6) ripping of compacted soils, (7) hand planting of shrubs and trees, (8) mulching, (9) fencing, and (10) purchasing seed. The relative costs of reclaiming minesites to the five major uses recognized in the computer model are, in decreasing order, costs for (1) high human use such as homes or industry, (2) cropland, (3) water-based recreation, (4) native revegetation (rangeland), and (5) wildlife management. The computer program described will allow the mine planner to evaluate different land use options and reclamation techniques in advance of the actual operation. Since this report deals with a computer model and not an actual field study, the ratings for the keywords used in the evaluation process represent the apparent treatment of these subject areas by the computer model.

1026. Scott, T. C., III. Water Relations of Plants Grown on Strip-Mine Spoils Treated With Sewage Sludge. Assoc. South. Biol., ASB Bull., v. 25, No. 2, 1978, p. 39.

This abstract contains no technical information on the techniques or rates used to apply sewage sludge on acidic mine spoil in southern Illinois. Root distributions of the four tree species and two grass species planted varied

little, but the roots of these species were severely distorted as a result of the soil profile caused by mining operations and the application of sewage sludge.

1027. Scott, T. C., III, and W. C. Ashby. Variable Performance of Black Walnut on Reclaimed Sites in Southern Illinois. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 15-23.

The growth responses of black walnut (*Juglans nigra* L.) were used to assess the suitability of three nontoxic mined sites and abandoned fields in southern Illinois. The minesites studied were cast overburden (ungraded site), cast overburden graded to 3- to 5-pct slope (graded), and graded cast overburden with 12 to 18 in of replaced topsoil (topsoil). Seedling survival was taken after the first growing season, and survival, stem diameter, and height were measured after the third growing season. Tree performance was much better on ungraded sites than on the graded or topsoiled sites, or abandoned fields. There was little difference in tree performance between graded or topsoiled sites.

1028. Seaker, E. M. Metals in Mine Spoil and Forage After Reclamation with Sewage Sludge. Am. Soc. Agron., Agron. Abstr., 1986, p. 36.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. The results of a 9-year program using compost and dewatered sewage sludge mixtures on mine spoil in Pennsylvania were reported. Potential leaching of metals into ground water and consumption of the forage growing on the sludge by grazing animals were concerns of local residents. Data indicated no significant leaching or downward movement of the sludge metals. All metals were within the proposed tolerance levels for agronomic crops.

1029. Seaker, E. M., and W. E. Sopper. Microbial Recovery in Minespoil Amended With Sewage Sludge. Am. Soc. Agron., Agron. Abstr., 1987, p. 33.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. This study assessed the effects of sludge and time on the populations of bacteria, fungi, and actinomycetes, and on microbial respiration and decomposition on surface-mined sites reclaimed with sludge or by conventional means. Sludge was applied at rates of 120 to 134 Mg ha^{-1} to minesites ranging in age from 1 to 5 years, while the control site was amended with fertilizer and was 5 years old. Grasses and legumes were planted on all sites. On the 1-year-old sludge site, levels of heterotrophic bacteria, fungi, and *Nitrobacter* and respiration rates were high; however, these values decreased to normal soil values with time. Actinomycetes increased with time on sludge sites, while the level of *Nitrosomonas* was not related to site age. Ecosystem recovery, as measured by microbial populations and activity, was more rapid and the degree of recovery greater on sludge-amended sites than on the control site amended with inorganic fertilizer.

1030. Seaker, E. M., and W. E. Sopper. Production and Quality of Forage Vegetation Grown on Municipal Sludge-Amended Mine Spoil. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 715-720.

The authors present the 5-year results of eight demonstration sites that were amended with various types of municipal sludges at various rates in the anthracite and bituminous coal regions of Pennsylvania. Each site was treated with a single application of sludge at rates ranging from 11 to 202 dry mt ha^{-1}. Following sludge application, the sites were broadcast seeded with Pennlate orchardgrass (*Dactylis glomerata* L.), Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), and Empire birdsfoot trefoil (*Lotus corniculatus* L.). Vegetation was sampled over a 2- to 5-year period for elemental analyses of plant nutrients and trace metals. Yields were determined from ten 0.09-m^2 samples collected along transects at each site. Over the 5-year period nitrogen, phosphorus, potassium, and copper concentrations remained constant; there were slight decreases in calcium, magnesium, and cadmium concentrations, and substantial decreases in manganese, iron, aluminum, zinc, chromium, cobalt, lead, and nickel concentrations. By the fifth year all metals except cadmium were within average ranges for agronomic crops. Cadmium was well below the tolerance level. Dry matter production was higher on the sludge-amended strip mine sites than on undisturbed farmland (reference area) in the same area. The authors conclude that by using good-quality sludges that are low in trace metals and have sufficient plant nutrients, strip-mined land can be successfully reclaimed with forage species of such quality that any potential risks to plant or animal health are minimal.

1031. Seaker, E. M., and W. E. Sopper. Reclamation of Bituminous Strip Mine Spoil Banks With Municipal Sewage Sludge. Reclam. & Reveg. Res., v. 3, No. 2, 1984, pp. 87-100.

Municipal sewage sludge was applied to an abandoned Pennsylvania coal mine to demonstrate its potential use as an amendment to return mined land to agricultural uses or

wildlife habitat. After the area was treated with agricultural lime, municipal sludge was applied at 11, 90, and 184 dry Mg and incorporated into the spoil material. The site was seeded with a grass-legume mixture and mulched with straw and hay at a rate of 3.8 Mg ha^{-1}. A monitoring system determined the effects of sludge applications on the quality and growth of the vegetation (percent cover, height growth, and dry matter production), soil chemical characteristics, and the chemical and bacteriological quality of ground water over a 5-year period. Vegetative cover improved over the five growing seasons, with no deterioration in vegetation quality or yield. Foliar analyses showed that nitrogen and phosphorus were higher in sludge-grown plants than in the controls, and that for seeded grass species potassium, calcium, and magnesium were higher in sludge plots than in the controls. Foliar concentrations of zinc, lead, and nickel in the grass and legume species decreased with time on sludge-amended plots, while concentrations of lead, cadmium, and nickel were sometimes higher in control plots than in sludge-amended areas. Sludge applications of 184 Mg ha^{-1} resulted in increased spoil nitrogen, phosphorus, calcium, and potassium, while magnesium concentration decreased. Extractable trace metals did increase, but were within the normal ranges established for these metals. Ground water quality was not adversely affected by sludge applications.

1032. Seaker, E. M., and W. E. Sopper. Root Growth and Organic Matter Accumulation in Sewage Sludge-Amended Minesoils. Am. Soc. Agron., Agron. Abstr., 1988, p. 47.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The effects of sewage sludge amendments on surface mine sites ranging in age from 1 to 5 years following reclamation were compared with those of a 5-year-old site reclaimed with chemical fertilizer in terms of soil regeneration and stabilization processes. Sludge was applied at rates of 120 to 134 Mg ha^{-1}. Sludge amendments resulted in positive correlations between yield, detritus accumulation, root growth, and organic matter content and site age. Organic carbon was significantly higher on the 5-year-old sludge-amended site, while total soil nitrogen remained constant over time. With sludge amendments, organic carbon and nitrogen surpassed that of the fertilizer-amended site the first year; yield and organic matter surpassed that of the fertilized site the second year; and detritus accumulation and root growth surpassed that of the fertilized site the third year. Compared with chemical fertilizer amendments, sewage sludge amendments to mine soils accelerate root growth and organic matter accumulation, which are necessary soil developmental processes.

1033. Segal, W., and R. L. Mancinelli. Extent of Regeneration of the Microbial Community in Reclaimed Spent Oil Shale Land. J. Environ. Qual., v. 16, No. 1, 1987, pp. 44-48.

This study examined the condition of microbial communities inhabiting various types of soil-reconstituted processed oil shale. Processed oil shale samples were taken from mining areas that had undergone different degrees of weathering, leaching, fertilization, and revegetation. Non-shale topsoil was used as a control. Two study sites had been fertilized, revegetated, and weathered for 6 years, one study site for 3 years, and one site had not been fertilized, revegetated, or weathered. Numbers of micro-organisms, bacterial diversity, and general richness, and the rate of cellulose decomposition were determined for each sample. These analyses would provide information on the regenerative potential of microbial communities in response to reclamation practices.

Compared with control samples, spent oil shale soils exhibited a significant decrease in viable numbers of bacteria, actinomycetes, and fungi; however, the longer the period of reclamation the greater the number of micro-organisms. The 6-year-old sites had the least reduction in micro-organism numbers. Bacterial diversity values ranged from a low of 2.10 for the nonrevegetated site to a high of 6.75 for the 6-year sites; the control had a diversity value of 7.89. Genus richness ranged from a maximum of nine for the control and eight for the 6-year-old sites, to a low of two for the nonrevegetated site. Complete decomposition occurred in 25-day incubations in the control and 6-year samples, while no decomposition occurred in the nonrevegetated site. Oil shale processing has negative impacts on the indigenous microbial communities; however, weathering, fertilization, and revegetation do have restorative effects. The degree of this effect increases with the length of time of environmental conditioning. The longer the soil is exposed to fertilization, leaching, and revegetation, the greater are the bacterial populations and diversity.

1034. Seifert, J. R., and P. E. Pope. Swamp White Oak Response to Various Levels of Nitrogen and Phosphorus—Surface Applied. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, p. 472.

Abstract of a paper presented at the Fourth Biennial Southern Silvicultural Research Conference. The nitrogen fertilizer source used and the rates of nitrogen and phosphorus applied are given; however, no results on the effects of the fertilizer amendments on diameter growth, height and leaf increment growth, soil nutrients, or leaf tissue analyses are given.

1035. Senkayi, A. L., J. B. Dixon, and L. R. Hossner. Todorokite, Goethite, and Hematite: Alteration Products of Siderite in East Texas Lignite Overburden. Soil Sci., v. 142, No. 1, 1986, pp. 36-42.

The manganese and iron oxide minerals formed on weathering of siderite in east Texas lignite overburden were characterized. The alteration products of siderite were investigated using X-ray diffraction and optical and scanning electron microscopy. When exposed to surface weathering conditions, siderite alters to either hematite or goethite. Cyclic wet and dry conditions are necessary for the release, concentration, and separation of the manganese and iron oxide phases, todorokite and goethite. Surface weathering favors the dissolution of siderite and precipitation of the hydroxylated phases of goethite and todorokite rather than the nonhydroxylated hematite. The weathering of siderite may release potentially toxic levels of manganese, which may have significant effects on the reclamation of east Texas surface-mined lands.

1036. Severson, R. C. Evaluating Chemical Character of Soil Material Suitability in Rehabilitating Mined Land in the San Juan Basin, New Mexico. Soil Sci. Soc. Am. J., v. 45, No. 2, 1981, pp. 396-404.

The author offers an excellent method of characterizing mine land (before and after mining) in the San Juan Basin of New Mexico, to determine which horizons would be best used as media for revegetation. He points out the importance of the form of elements contained in the soils. Although different soils may contain similar amounts of the same elements, if they are in different forms and/or associated with different constituents their effects on subsequent revegetation will vary.

1037. Severson, R. C. Soil and Overburden Sampling Needs and Programs. Paper in the Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min.; Billings, MT, Mar. 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, pp. 211-222.

The author outlines a sequence of steps that are necessary to develop a soil and overburden sampling program to characterize a minesite before development. The suggested sequence in this program is (1) problem statement, (2) sample design, (3) sample collection, (4) sample preparation, (5) laboratory analysis, and (6) data interpretation. The importance of each step is discussed, and some important considerations for each are pointed out. The concepts conveyed are relevant to the design of soil and overburden sampling programs nationwide.

1038. Severson, R. C., and L. P. Gough. Boron in Mine Soils and Rehabilitation. Plant Species at Selected Surface Coal Mines in Western United States. J. Environ. Qual., v. 12, No. 1, 1983, pp. 142-146.

The study assessed boron availability in mine soil and boron uptake by plant species used in strip mine rehabilitation at 11 minesites in North Dakota, Montana, Wyoming, and Colorado. The plant species tested were initially planted in a seeding mixture that consisted of a wheatgrass and a legume. The following species were used in the mixtures: crested wheatgrass (*Agropyron desertorum* (L.) Gaertn.) and intermediate wheatgrass (*Agropyron trachycaulum* (Link) Malte.) with either alfalfa (*Medicago sativa* L.) or four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.). The following evaluations were made at each site: (1) differences in boron concentration among similar rehabilitation plant species, cover soil, and spoil among mines, (2) differences among samples of mine soil and a single plant species within a mine, and (3) the potential boron phytotoxicity and deficiency conditions. Results indicate that except for one site, boron levels in both the mine soils and plants are not deficient or toxic over the region. The authors feel that soil electrical conductivity measurements should be the first step to determine if boron is deficient or toxic. If problem areas are indicated, the hot-water-soluble-boron analysis could confirm or reject the initial results. Using the boron results, along with electrical conductivity and pH, predictions can be made for boron accumulation in plants.

1039. Severson, R. C., and L. P. Gough. Rehabilitation Materials From Surface Coal Mines in Western U.S.A. 1. Chemical Characteristics of Spoil and Replaced Cover-Spoil. Reclam. & Reveg. Res., v. 2, No. 2, 1983, pp. 83-102.

This study evaluated the soil chemical characteristics of replaced cover soils and spoils of 11 mines located in the Fort Union (Montana and North Dakota), Powder River (Wyoming), and Green River (Wyoming and Colorado) coal basins. Three mines per State (two in Colorado) were selected based on the following criteria: (1) the area had been rehabilitated in the past 3 to 5 years, (2) cover soil had been used in the rehabilitation process, and (3) a wheatgrass-legume had been used in the seeding mixture. The specific objectives of the study were to (1) document the expected ranges in the soil chemical characteristics found at the mines, (2) assess the variability in soil chemical characteristics among the mines and among the samples collected at a single mine, and (3) compare the soil chemical characteristics of mine land with those of natural soils of the areas studied (reference area). DTPA-extractable cadmium, cobalt, copper, iron, lead,

manganese, nickel, and zinc, organic matter, and pH were the soil parameters measured at the 11 sites.

A large amount of variability was found for measurements taken among mines and among samples at a single mine. For example, pH ranged from 3.9 to 8.9. These results suggest the limited value that a simple average concentration would have for characterizing all mines or samples collected at a single mine. The authors suggest that an expected range in concentration is a better method for estimating the chemical characteristics of cover soil or spoil. The elemental concentrations of the metals analyzed for in the spoil and cover soil did not deviate much from the concentrations found in the natural A and C horizons of the area. Mine soils (youthful) and natural soils, however, represent different stages of soil development, and the authors feel that the comparison between the two may be inappropriate. Rapid changes in the chemical equilibrium of mine soils is expected.

1040. Shammas, A., N. Etaiby, and A. Shankiti. Properties of Reclaimed Sand Dune Soils Irrigated With Treated Sewage Effluent. Am. Soc. Agron., Abstr., 1987, p. 33.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. Sewage treatment effluent was used to irrigate leveled sand dunes. Treatment reduced the electrical conductivity and increased phosphorus, NH_4-nitrogen, and NO_3 in the 0- to 10-cm soil layer. Soil organic carbon was not built up, indicating rapid oxidation of added organics. There was no buildup of heavy metals in the soil.

1041. Sheets, P. J., V. V. Volk, and E. H Gardner. Plants and Soil Reaction to Nickel Ore Processed Tailings. J. Environ. Qual., v. 11, No. 3, 1982, pp. 446-451.

This article deals with greenhouse and laboratory experiments conducted to determine the effect of nickeliferous laterite ore tailings on plant growth and soil properties. Chemical analysis of the tailings revealed high soluble salts, low concentrations of phosphorus and calcium, and high conductivity. Soil was amended with the tailings, and tall fescue (*Festuca arundinacea* Schreb.) was planted in the greenhouse experiment. Plant establishment was slow on soils with high tailings amendment and on pure tailings; however, once plants were established, growth was fairly good and dry matter yields were comparable to those of soils treated with lower tailings rates. The serpentine tailings used in the experiment were from the Riddle, OR, area, where nickel and cobalt are recovered.

1042. Shellhorn, M. A., A. A. Sobek, and V. Rastogi. The Effect of Particle Size Distribution on the Rate of Mine Acid Formation and Its Mitigation by Bacterial Inhibitors. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 50-53.

A model predicting effective bactericide concentrations for field applications was developed. The procedures for and results of determining the relationships between acidity, bactericide concentration, and particle size, used to develop the model, are presented. High-pyritic-sulfur refuses were separated based on 24 particle size ranges, which spanned from 0.157 in to 0.0029 in. Three samples of each particle size were treated with bactericide at 100, 250, and 500 ppm by weight. Samples were incubated, then leached. Leachates were analyzed for pH, Eh, specific conductance, and acidity. Control samples showed an exponential increase in acidity with decreasing particle size (increased relative surface area). Treatment with bactericide resulted in a nonlinear decrease in acidity reduction with decreasing particle size. Increasing levels of acidity reduction for all particle sizes resulted with increasing concentrations of bactericides. The developed model provides a useful tool for determining the effective bactericide dosage.

1043. Shellhorn, M. A., A. A. Sobek, and V. Rastogi. Results From Field Applications of Controlled Release Bactericides on Toxic Mine Wastes. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 357-360.

The methods and results of two field studies using a two-phase bactericidal approach to controlling mine acid generation and acid mine drainage are reported. The approach involved a primary inhibition through spray application, followed by a lower maintenance level using controlled-release pellets. At each site, reclamation involved an initial grading and treatments with bactericide solution and controlled-release pellets, followed by topsoiling, liming, seeding, and fertilization. Control areas, without bactericides, were also established. Monitoring involved lysimeter and core sampling, iron-oxidizing bacteria enumeration, and visual inspection of the vegetation. Core data indicated a significant reduction in acidity, total iron, aluminum, manganese, and sulfate for treated areas compared with control areas. Most probable number data, used to determine bacterial density, indicated a 100-fold decrease in iron-oxidizing bacteria in treated areas. Lysimeter data indicated that after 1 year significant

reductions in acidity, specific conductance, total iron, ferrous iron, sulfate, manganese, and aluminum had occurred. Significant improvements in water quality resulted from the bactericide treatments. There were also significant reductions in vegetation on control areas due to burnout, while treated areas did not show acid burnout.

1044. Sherman, R. M., J. A. Kinkead, G. J. Campbell, and G. M. Alder. Irrigation for Reclamation of Strip Mined Lands (contract JO199088, Sherman and Sullivan, San Jose, CA). BuMines OFR 12-82, 1980, 127 pp.; NTIS PB 82-163395.

This report documents the results of a study that (1) investigated the environmental characteristics of coal mines in the arid and semiarid regions of the Western United States, (2) evaluated potential irrigation systems for use at these mines, and (3) identified those irrigation systems that are economically and technologically feasible. The authors recommend that the use of irrigation be temporary and limited to the germination and establishment of vegetative growth. A solid-set sprinkler irrigation system combined the most favorable characteristics by allowing efficient and frequent application of small quantities of water in the reclamation process. It is portable and adaptable to a range of field characteristics.

1045. Shipitalo, M. J., and R. Protz. Comparison of Morphology and Porosity of a Soil Under Conventional and Zero Tillage. Can. J. Soil Sci., v. 67, No. 3, 1987, pp. 445-456.

The effects of two tillage treatments on profile morphology and bioporosity in a southern Ontario, Canada, soil were examined. Micromorphometric analysis was used to assess the effects of tillage on pore size, shape, and orientation in the plow layer of the soils studied. No-tillage and conventional tillage treatments were compared on plots that had been established and planted to corn (*Zea mays* L.) for 7 years. In conventionally tilled plots the soil structure of the Ap horizon was granular, while in the no-tillage plots the Ap horizon contained compound aggregates consisting of subangular blocky aggregates breaking to granular aggregates. This resulted in a lower porosity and higher bulk density in the Ap of the untilled pedon. Tillage resulted in an abrupt boundary between Ap and Bm horizons, while no tillage allowed biological activity to obscure the boundary between the Ap and Bm; a 5-cm-thick AB horizon had formed. Micromorphometric analyses showed that porosity was greater in samples from tilled plots. In no-tillage plots, loss of macroporosity was characterized by a decrease in mean pore size and a tendency for the pores to become elongated with an orientation that was parallel to the soil surface. There were, however, more biopores in no-tillage plots than in conventionally tilled plots, two to nine times more depending on the horizons compared. In the conventionally tilled plots, bioporosity decreased with depth. Large biopores in the no-tillage plots were due to an abundance of root channels in the Ap horizon and a predominance of earthworm burrows lower in the soil profile. Earthworm activity was also responsible for increasing the distribution of organic carbon with depth in no-tillage plots. The authors state that the increased zoological activity in no-tillage soils may partially compensate for reduced porosity in Ap horizons by promoting more rapid gas and water movement to lower soil depths.

1046. Shoulders, E., and A. E. Tiarks. Slash Pine Shows Mixed Response to Potassium Fertilizer. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 425-428.

Two field fertilization trials were conducted in Louisiana. Potassium fertilizer was applied with and without nitrogen and phosphorus to slash pine (*Pinus elliottii* Engelm.). At the first site, slash pine was direct seeded and fertilized with potassium (0 and 62 lb $acre^{-1}$) on plots fertilized with 34 lb $acre^{-1}$ N and 44 lb $acre^{-1}$ P. There was no response to potassium fertilization through age 13. At the second site, an established plantation was thinned to 80 ft^2 basal area per acre and fertilized with potassium (0 and 50 lb $acre^{-1}$) on plots fertilized with 100 lb $acre^{-1}$ N and 22 lb $acre^{-1}$ P at age 25. When potassium was included in the fertilization treatment, tree height growth, diameter, and volume growth were increased. The major contributing factor to differences in potassium fertilization response between the two plantations is thought to be the level of exchangeable soil potassium prior to fertilization. The older, responsive plantation contained less exchangeable potassium than did the younger, unresponsive plantation. Other possible factors for response differences between the plantations to potassium fertilization included competition from herbaceous species for potassium in the younger plantation. The authors state that potassium fertilization should increase the growth of slash pine plantations if other nutrient deficiencies have been eliminated and if the soil contains less than 10 ppm exchangeable potassium in the 0- to 6-in surface soil layer.

1047. Shubert, L. E., and T. L. Starks. Diagnostic Aspects of Algal Ecology in Disturbed Lands. Ch. in Soil Reclamation Processes: Microbiological Analyses and Applications, ed. by R. L. Tate III and D. A. Klein. Marcel Dekker, 1985, pp. 83-106.

A review is presented on what is known on soil algae and their recovery process in semiarid and arid lands. Patterns of algal colonization and succession on mined lands are emphasized, along with an attempt to correlate soil algae with soil chemical and physical properties. Changes in one soil parameter may inhibit or eliminate one species, but enhance the growth of another.

1048. Shuman, L. M. Effect of Phosphorus Level on Extractable Micronutrients and Their Distribution Among Soil Fractions. Soil Sci. Soc. Am. J., v. 52, No. 1, 1988, pp. 136-141.

The effects of various phosphorus levels on the distribution of manganese, copper, iron, and zinc among soil fractions was determined, along with the extractability of these metals using common soil extractants. Eight Georgia topsoils were treated with 0, 30, and 60 mg kg^{-1} P as KH_2PO_4 and none or one level of manganese, copper and zinc. Soils were wet to saturation with deionized water and allowed to dry every 10 days to equilibrate phosphorus. The equilibration period was 22 weeks. Soils were sequentially extracted to determine manganese, copper, iron, and zinc in the exchangeable organic manganese oxide, amorphous iron oxide, and crystalline iron oxide fractions. Subsamples were also extracted for the same metals using the Mehlich-1, Mehlich-3, and DTPA (diethylenetriamine-pentaacetic acid) methods.

Increasing phosphorus rates had variable effects on metal concentrations in the different soil fractions. Manganese moved from less soluble fractions (crystalline iron oxide and residual) to the intermediately soluble fractions (manganese oxide and amorphous iron oxide). Increasing phosphorus had little effect on the plant-available, exchangeable, or organic fractions. In fine-textured soils, copper moved from the residual fraction to the exchangeable fraction, although these changes were small. In coarse-textured soils, copper moved from the exchangeable fraction into the crystalline iron oxide and residual fractions. Phosphorus treatments decreased iron concentration in the crystalline iron oxide and residual fractions in fine-textured soils and moved iron from the crystalline iron oxide and manganese oxide to the amorphous iron oxide fraction in coarse-textured soils.

In both soil types, increasing phosphorus rates resulted in increased zinc in the exchangeable and amorphous iron oxide fractions and decreased zinc in the crystalline iron oxide fraction. Of the added micronutrients, copper and zinc were evident in the exchangeable fractions for most soils, while added manganese was evident in the exchangeable fraction only in the coarse-textured soils. When the Mehlich-1 and DTPA extractants were used, increased phosphorus treatments caused increased manganese and iron extractability for all soils. These results are not consistent with the fraction data. Soil pH values increased with increasing phosphorus additions. This is a result of phosphate reacting with iron and aluminum oxides, with the hydroxyl ions produced causing the higher pH values. When phosphorus levels are increased, complex chemical reactions occur that affect both soil pH and redox conditions, resulting in micronutrient metals altering their chemical form, and becoming redistributed among the various soil fractions. The author also presents an excellent literature review on the processes that can disturb the equilibria of micronutrient metals when phosphorus is added to soils.

1049. Sidle, R. C., and R. W. Brown. Soil Water Availability for Seedling Establishment on Arid Mine Spoils. Am. Soc. Agron., Agron. Abstr., 1988, p. 48.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Soil water availability at various depths was determined during the first year of vegetation establishment on gold mine spoil material from western Nevada. Soil water potentials were compared among mine spoil, mulched mine spoil, and topsoiled material in the spring following a light snowfall and in early summer. Mulching and topsoil replacement benefited spring soil water availability. Mulched plots were significantly wetter than unmulched plots, and gravimetric water content was higher in topsoil material than in mine spoil. In the early summer, mulching effects were not significant at the 1- and 15-cm soil depths; however, topsoiled plots were wetter at these depths than mine spoil. Mulching appears to benefit seed germination, while topsoil replacement improves moisture relations through the summer.

1050. Sigua, G. C., and W. H. Hundall. P-Mo Interactions on the Yield and Nodulation of White Clover on Limed-Lignite Overburden. Am. Soc. Agron., Agron. Abstr., 1987, p. 34.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. This greenhouse study assessed the yield and nodule formation of inoculated and noninoculated white clover (*Trifolium repens* L.) in response to phosphorus-molybdenum interactions, when grown on limed-lignite overburden. Rates of phosphorus addition were 0, 90, and 180 kg ha^{-1} P_2O_5. Single applications of phosphorus and molybdenum resulted in significant yield and nodule counts in inoculated white clover. Noninoculated white clover responded significantly to phosphorus fertilization, but not to molybdenum fertilization. There were no significant phosphorus-molybdenum interactions in either inoculated or noninoculated white clover.

1051. Sikora, F. J., and J. Wolt. Effect of Cadmium- and Zinc-Treated Sludge on Yield and Cadmium-Zinc Uptake of Corn. J. Environ. Qual., v. 15, No. 4, 1986, pp. 340-345.

This greenhouse study determined the effect of cadmium and zinc on corn (*Zea mays* L.) yield and the cadmium-zinc uptake when applied in a manner that resembled actual sludge additions, and evaluated the interactions of cadmium and zinc in a sludge-plant-soil system. Sludge was treated with four levels of cadmium and zinc and applied to the soil used in the experiment. Zinc additions to the sludge increased the soluble cadmium in the treated sludges for all levels of added cadmium. Cadmium had no effect on water-extractable zinc. The dry matter weight of corn decreased with increased levels of cadmium addition to the soil. Corn dry weight at the highest level of cadmium addition was reduced by 19 pct compared with the lowest cadmium addition. Zinc additions resulted in a greater reduction in corn dry weight than did cadmium additions; at the highest level there was a 25-pct reduction in dry weight compared with the lowest rate of zinc addition. Cadmium added to the soil in sludge had no effect on root dry matter; however, when applied at the highest rate, zinc reduced root dry matter by 56 pct compared with the low rate of zinc, at the lowest level of cadmium. There was a significant cadmium-by-zinc effect on root dry weight. Zinc and cadmium applied in the sludge interacted to influence the cadmium content of both the aboveground and belowground tissues. Increasing the concentration of cadmium in sludge resulted in increased cadmium contents across all levels of sludge-applied zinc. The zinc treatment generally decreased cadmium content of roots as the level of applied zinc increased. This cadmium-zinc interaction influences the uptake and translocation of cadmium in plants.

1052. Simmons, G. L., and P. E. Pope. Compaction Alters Soil Physical Properties and Root Growth of Inoculated and Noninoculated Yellow-Poplar and Sweetgum Seedlings. Paper in Proceedings of the Fourth Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 4-6, 1986). U.S. For. Serv., Gen. Tech. Rep. SE-42, 1987, pp. 401-410.

Changes in soil physical properties associated with increases in compaction were characterized on an old field site and a marginal farmland site in Indiana. Additionally, root growth of inoculated (with endomycorrhizae fungi) and noninoculated yellow-poplar (*Liriodendron tulipifera* L.) and sweetgum (*Liquidambar styraciflua* L.) seedlings was determined. Two compaction treatments and a control were established at each site and 1-0 seedlings were grown for 1 year. As compaction increased, surface bulk density increased and total and air-filled porosities decreased. At the end of the first growing season, root growth of either species was not significantly influenced by mycorrhizal treatment at either site. At both sites, increasing surface bulk densities above 1.30 Mg m^{-3} resulted in reduced root growth and extension (horizontal and vertical) of both species, Sweetgum, because of it fibrous root system, did have a greater total root length and weight and more extensive distribution than did yellow-poplar.

1053. Simmons, G. L., and P. E. Pope. Influence of Soil Compaction on Physical Properties on Mineland Cast Overburden and Topsoil Media. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL., 1985, pp. 227-238.

The changes in the physical properties of overburden and topsoil materials as a result of compaction were characterized. Additionally, a greenhouse pot study was conducted to relate sweetgum (*Liquidambar styraciflua* L.) and yellow-poplar (*Liriodendron tulipifera* L.) establishment and root growth to changes in physical properties as a result of compaction. Soil materials were collected from a reclaimed surface-mined site (topsoil and graded cast overburden) and two reference sites (marginal farm-land and an abandoned old field). Topsoils were collected from the upper 20 cm at each site, and overburden was collected at a depth of 30 to 90 cm. Compactibility of each soil was determined at various moisture contents (from plastic limit to air dry) and surface pressures (15, 35, and 55 psi). Moisture retention, available water-holding capacity, total porosity, and macroporosity were determined at bulk densities of 1.25, 1.40, and 1.55 g cm^{-3} (low, medium, and high compaction). In the greenhouse, each soil type and compaction treatment was planted with newly germinated sweetgum and yellow-poplar seedlings. After 3 months, root systems were excavated to determine the depth of lateral and primary root penetration into the compacted soil mediums.

When a soil is compacted, the resultant bulk density depends on soil particle size distribution and water content. The compactibility curves for the minesite topsoil and marginal farmland soil were similar for each ground pressure tested because of similar particle size distributions. At 55 psi, bulk densities of 1.71 and 1.74 g cm^{-3} were attained for the mine topsoil and the marginal farmland, respectively. Even at lower pressures, maximum bulk densities were considered high. The cast overburden material had the highest bulk densities of any of the materials at all ground pressures tested. The maximum value was 1.93 g cm^{-3} at 55 psi and a soil moisture content of 15 pct. The abandoned old field was less compactible

than the other soils tested. The maximum density obtained was 1.53 g cm^{-3} at 55 psi. The total porosity and macroporosity decreased in each soil because of compaction. The degree of this decrease was related to the original pore size distribution and particle size distribution of the soil. The available water-holding capacity of each soil decreased, owing to a decrease in total porosity, as bulk density increased.

Sweetgum survival remained at 100 pct regardless of bulk density treatment; however, yellow-poplar survival decreased from 89 pct on the least compacted soil to 33 pct on the highly compacted soil. Differences in rooting habit of each species may be responsible for the changes that occurred. The extent of root penetration was affected by bulk density; the maximum number of roots for both species at a given depth was greatest on the least compacted soil and declined as bulk density increased.

1054. Simmons, G. L., and P. E. Pope. Using VA-Mycorrhizae To Enhance Seedling Root Growth in Compacted Soil. North. J. Appl. For., v. 5, 1988, pp. 65-68.

Yellow-poplar (*Liriodendron tulipifera* L.) and sweetgum (*Liquidambar styraciflua* L.) seedlings were grown in compacted soil in the greenhouse to determine if root growth was enhanced by inoculating the seedlings with the vesicular-arbuscular (VA) mycorrhizal fungi *Glomus macrocarpum* or *Glomus fasciculatum*. Root growth responses for each host-fungal association were also determined. Soils were compacted in pots in order to establish bulk densities of 1.25, 1.40, and 1.55 g cm^{-3} which represented low, medium, and high compaction conditions, respectively. Seedlings of both species were transplanted into each bulk density treatment at the two-leaf stage.

As bulk density increased, the root growth of both species was significantly reduced. At the lowest bulk density, inoculated yellow-poplar seedlings had significantly greater root weight and length than control (uninoculated) seedlings. At the higher bulk densities, root length in yellow-poplar was not affected by mycorrhizal treatment. Fibrosity of the yellow-poplar root system was not significantly influenced by increased bulk densities, and fibrosity response to mycorrhizal treatment varied at each density. Sweetgum total root length decreased significantly with each increase in bulk density.

Sweetgum seedlings inoculated with *G. fasciculatum* resulted in significantly greater root weights and length than did uninoculated seedlings or seedlings inoculated with *G. macrocarpum*. This result was valid at each bulk density. The total number of sweetgum lateral roots was significantly reduced as bulk density increased; however, seedlings inoculated with *G. fasciculatum* had the greatest number of lateral roots at the higher bulk densities. When yellow-poplar was inoculated with either fungal species, mycorrhizal dependency (degree to which a plant is dependent on the mycorrhizal association to produce maximum growth) was the same. This indicates that at high bulk densities, mycorrhizal colonization may not improve root growth of yellow-poplar. When inoculated with *G. fasciculatum*, sweetgum seedlings had the greatest root weight, length, and fibrosity, and the highest mycorrhizal dependency values at each bulk density treatment. This indicates that inoculating sweetgum seedlings with *G. fasciculatum* may help to mitigate the effects of compaction on tree growth.

This article was rated as a good reference only because it was a greenhouse study; however, it does contain useful information on the influences of mycorrhizae on root growth of hardwood seedlings in compacted soils. This research should be expanded to include field studies on more than one soil series. Although the authors do not state that the information presented has direct application to coal surface-mined sites, soil replacement during reclamation often leads to compaction and the results presented in this study would be applicable in this situation.

1055. Sindelar, B. W. Establishment, Succession, and Stability of Vegetation on Surface Mined Lands in Eastern Montana. Three Year Project Summary (U.S. Dep. Energy contract EY-76-5-06-2228 No. 3, MT State Univ.). U.S. Dep. Energy, TID-28791, July 1978, 14 pp.

This publication is an interim report summarizing the activities, progress, major findings, and preliminary conclusions resulting from an ongoing long-term study of revegetation success near Colstrip, MT. Other interim reports, together with the final report, are included in this bibliography (entries 1056-1058). The study examined plant succession on revegetated plots ranging in age from 0 to 50 years. Preliminary conclusions contained in this report are based on 2 years of field data collection.

1056. Sindelar, B. W. Successful Development of Vegetation on Surface Mined Land in Montana. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 550-556.

The purpose of this paper was to report successional development and plant community characteristics observed during the first year of a long-term study on sites ranging in age from 1 to 50 years and located near Colstrip, MT. The study monitors plant cover, yield density, frequency, species composition, soil moisture content, soil temperature, and weather conditions at biweekly intervals throughout the growing season from 14 exclosures. Comparisons are made on individual sites over time as well as

simultaneously among sites. Preliminary analyses indicate that some early successional stages associated with soil formation might be bypassed in reclamation by topsoiling, fertilization, mulching, and seeding mixtures of plant species. Species seeded, initial seeding success, cultural practices, and weather strongly influence plant succession. This article is an excellent reference for those interested in studying plant succession on reclaimed surface-mined lands in the Northern Great Plains Coal Mining Region.

1057. Sindelar, B. W., and P. L. Plantenberg. Establishment, Succession, and Stability of Vegetation on Surface Mined Lands in Eastern Montana (U.S. Dep. Energy contract EY-76-5-06-2228 No. 3, MT State Univ.). U.S. Dep. Energy, Annu. Prog. Rep., July 1979, 55 pp.

This is an annual progress report for a study initiated in 1975. The study was conducted on strip-mined land near Colstrip, MT, to examine the development, stability and performance of plant communities established on semiarid mined land. Areas studied included native range, 48- to 50-year-old naturally revegetated coal spoil, and 2- to 9-year-old seeded spoil. Density, frequency, cover, biomass, and species composition data were taken on each plot. Results showed that the 50-year-old naturally revegetated areas were either highly advanced or locked into a lower sere, depending on spoil texture and management practices. Success of younger seeded communities was influenced by using introduced species, cover crops, and fertilization, as well as by weather. Problems with declining yield, limited success of native species, limited species diversity, and soil functioning are discussed, along with suggestions for improving reclamation in semiarid areas of the Western United States.

1058. Sindelar, B. W., and P. L. Plantenberg. Establishment, Succession, and Stability of Vegetation on Surface-Mined Lands in Eastern Montana (U.S. Dep. Energy contract DE-AT06-76 EV70003). U.S. Dep. Energy, Final Rep. DOE/EV/70003/17, 1982, 33 pp.

This study examined and documented the development, stability, and permanence of plant communities established on 15 semiarid sites near Colstrip, MT. Thirteen sites were located on mine spoil, one on unmined native range (reference area), and one on a pipeline construction site. Reclamation sites had been seeded between 1969 and 1977, and naturally revegetated sites had been abandoned in 1928 and 1930. The specific objectives of the study were (1) plant establishment and succession on mined land, (2) stability and permanence of artificial and natural communities on mined land, and (3) the kind and rate of concurrent soil and vegetation establishment on mined land.

The authors found that the migration of native plants from surrounding plant communities was common. The most common migrants were the forbs, which enhanced species diversity. Migration of native grasses was slow. The migration or invasion by volunteer species onto spoil material was dependent upon the density of the seeded cover crops: the less dense the cover crop, the greater the variety of grasses and forbs that invaded an area. The natural revegetation of spoil material indicates that the potential for reclamation success at Colstrip is very good. The results of this study are intended to enable reclamation workers to develop a better understanding of the revegetation process on mined lands and the primary and secondary succession that occurs.

1059. Singh, Y., B. Singh, M. S. Maskina, and O. P. Meelu. Effect of Organic Manures, Crop Residues and Green Manures (*Sesbanis aculeata*) on Nitrogen and Phosphorus Transformations in a Sandy Loam at Field Capacity and Under Waterlogged Conditions. Biol. and Fertil. Soils, v. 6, 1988, pp. 183-187.

This non-coal-related pot experiment examined nitrogen and phosphorus transformations in a calcareous sandy loam soil amended with different organic manures and crop residues at both field capacity and saturation. Organic amendments used were cattle, poultry, and green manure and wheat and rice straw. The various organic amendments were incubated for 1, 2, 4, 8, 12, and 16 weeks prior to analyses of mineral nitrogen, Olsen phosphorus, and moisture contents.

With soil moisture at field capacity, the nitrogen mineralized from poultry manure and green manure at 4, 8, and 16 weeks was 45, 60, and 85 pct and 59, 74, and 100 pct of the total nitrogen, respectively. Additions of cattle manure resulted in nitrogen immobilization during the first 4 weeks of incubation, followed by nitrogen mineralization; however, only 19 pct of the total nitrogen contained in the cattle manure was mineralized during the 16-week period. Additions of wheat and rice straw resulted in the immobilization of nitrogen. After 4 weeks, mineralization began, but the amount of mineral nitrogen released was less than that mineralized in the untreated, control soil. The kinetics of nitrogen mineralization of poultry and green manure and of untreated soil exhibited an initial fast reaction, followed by a slow release of inorganic nitrogen. At saturation, mineralized nitrogen was lost through nitrification-denitrification reactions under anaerobic conditions.

At field capacity, the largest amount of phosphorus mineralized occurred in the soils amended with poultry and cattle manure, with about 15 pct of the phosphorus in poultry manure being released during the first week. Under saturated conditions, there was a large increase in

the phosphorus released in soils amended with green manure and crop residues compared with the same soils amended at field capacity. The authors speculate that this may have resulted from enhanced reduction leading to increased phosphorus availability in these soils.

This article was included in the review process because of the information presented on the nitrogen and phosphorus transformations that occur under various soil moisture regimes using different organic amendments.

1060. Singleton, P. C., and D. A. Barker. Soil Development and Nitrates in Minesoil. Paper in Symposium on Adequate Reclamation of Mined Lands? (Billings, MT, Mar. 26-27, 1980). Soil Conserv. Soc. Am., 1980, pp. 14-1—14-14.

Chemical and physical properties of 16- and 40-year-old mine spoils from the Hanna Basin in south-central Wyoming were analyzed to determine the extent of pedogenesis over that period of time. Potassium enrichment in the upper 2 in. in both the 16- and 40-year-old mine soils, together with some downward movement of soluble salts, indicated incipient pedogenesis had occurred. Mine soils used in the study exhibited nitrate levels higher than those found in surrounding undisturbed soils. These amounts, however, were within the range normally expected in natural soils. Nitrate levels in the mine soils appeared to decrease with age.

1061. Skelly and Loy. A Compliance Manual. Methods for Meeting OSM Requirements. McGraw-Hill, 1979, 705 pp.

This manual is designed to arm the mine planner and operator with some concepts, design procedures, and operating techniques to help them meet the requirements of the 1977 Surface Mining Control and Reclamation Act. It includes interpretive summaries of most of the Federal permit requirements and performance standards. It reviews revegetation regulations in detail. Information is included on soil testing and sampling, fertilization, liming, and mulch requirements. There is an extensive discussion concerning species selection, including a list of Soil Conservation Service Plant Materials Centers. Tables of herbaceous and woody species recommended in the temperate East and Midwest as well as in arid and semiarid climates are given. Methods of planting and stand management are outlined. Various methods of measuring productivity, ground cover, and the use of reference areas are given.

1062. Skogerboe, J. G., C. R. Lee, and R. A. Price. Long-Term Restoration of Pyritic Soils for Erosion Control. Am. Soc. Agron., Agron. Abstr., 1984, p. 36.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. Long-term restoration techniques were demonstrated for an area characterized as acidic, droughty, and severely compacted. Soil amendments utilized included combinations of agricultural lime (100 Mg ha^{-1}), coarse limestone (100 Mg ha^{-1}), rock phosphate (6.5 Mg ha^{-1}), and chicken manure (78 Mg ha^{-1}). All amendments were incorporated to a depth of 45 cm to reduce compaction and neutralize potentially oxidizable pyrite.

1063. Skogerboe, J. G., C. R. Lee., and R. B. Sneel. Quantification of Erosion Control and Runoff Water Quality From Pyritic Soil Restoration Demonstration Plots. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 149-154.

Field rainfall simulations were conducted at the Tennessee-Tombigbee Waterway, Divide Section, to verify laboratory lysimeter data and to evaluate the effects of different soil amendments on runoff water quality from pyrite soil restoration plots. The soil amendments used were (1) lime, (2) lime and rock phosphate, (3) lime and chicken manure, and (4) lime, rock phosphate, and chicken manure. Plant species used were Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don.), weeping lovegrass (*Eragrostis curvula* (Schrad.) Nees), and Pensacola bahiagrass (*Paspalum notatum* Flugge).

Significant differences in biomass, runoff water quality, and erosion control were found for different combinations of soil amendments and plant species. The effects of different biomass and plant species were determined using the laboratory rainfall simulation and lysimeter system. In this system the best erosion control was obtained from the Kentucky-31 tall fescue. The field simulation not only verified the lysimeter system, but measured the effects of different soil amendments on runoff water quality. Different soil amendments produced wide ranges in biomass, but the use of organic matter as a soil amendment significantly increased vegetation biomass and erosion control. A decrease in soil loss by 50 pct was observed when chicken manure was used. The nutrient concentrations and loads observed in the runoff water from chicken-manure-amended plots were, however, higher during the first year following application. Yearly monitoring is needed to determine if these trends will continue.

1064. Skousen, J. G. Effects of Sewage Sludge Application on a Revegetated Minesoil in West Virginia. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 214-220.

The effects of a one-time application of municipal sewage sludge on the vegetation, mine soil, and surface water quality of a sparsely vegetated surface mine in West Virginia were investigated. The sewage sludge was applied onto the existing vegetation, by surface application, at rates of 0, 22.4 44.8, and 78.4 Mg ha^{-1} on a dry-weight basis. Total plant cover, bare ground, and litter cover were estimated visually. Plant species were identified, and their cover was estimated. The aboveground biomass was separated into grass, legume, and weed components. Mine soils and surface water samples were also collected and analyzed for chemical characteristics.

The surface application of sewage sludge initially smothered the existing vegetation, resulting in a decrease in total plant cover and biomass in plots receiving heavy applications of sewage sludge. After 6 months, sewage sludge applications resulted in increased plant cover and grass aboveground biomass, while legume biomass and number decreased because of increased grass growth and competition. Surface applications of sewage sludge did not significantly increase soil pH values, organic matter content, or macronutrient concentrations in the mine soil. Concentrations of iron, copper, lead, and zinc were all significantly higher in mine soils that received the heaviest applications of sewage sludge. No visual symptoms of stress or reduced growth of plants in the sludge-treated mine soils were evident. Surface water quality was not adversely affected by sewage sludge applications. The one-time application of sewage sludge resulted in significant improvements in plant cover and biomass for two growing seasons following application. No other significant effects were found concerning established vegetation or the mine soils studied.

1065. Skousen, J. G. An Evaluation of Methods for Determining Pasture and Hay Production on Reclaimed Surface Mines. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 277-284.

Although this article does not contain any information on soil characterization of surface-mined lands or on the use of soil amendments, it was included in the review process because of the useful information presented on regulatory policy, standards for reclamation success. The precision and suitability of nine techniques commonly used for evaluating plant cover, composition, and aboveground biomass were assessed as possible methods that could be used to predict aboveground biomass in areas reclaimed for forage production. An effective accurate prediction could assist regulatory agencies in determining revegetation success and granting bond release. Eight measurements were made on eight surface-mined areas in West Virginia by three observers. The measurements, or estimates, were Rennie-Rarmer Cover, Quadrat Cover, Quadrat Botanical Composition (grass percentage and legume percentage), Estimated Yield, Quadrat Height, Pasture Probe Reading, Disk Meter Reading, and Quadrat Weight. Visual techniques used to assess aboveground biomass were found to be highly variable. Of the methods tested, the Disk Meter Reading estimates showed good correlation between vegetation height and weight. The author states that Disk Meter Reading should be studied further as a method for evaluating aboveground biomass on reclaimed surface-mined land.

1066. Skousen, J. G., and C. A. Call. Grass and Forb Species for Revegetation of Mixed Soil-Lignite Overburden in East Central Texas. J. Soil and Water Conserv., v. 42, No. 6, 1987, pp. 438-442.

A 3-year field study was conducted to evaluate the establishment and productivity (aboveground biomass) of 10 grass species and 7 forb species on a mixed soil-lignite overburden material in east-central Texas. No soil amendments were used. Density, aerial cover, and aboveground biomass of these 17 species were compared with that of Coastal bermudagrass (*Cynodon dactylon* (L.) Pers.), a species that is commonly sprigged on mixed soil-lignite overburden materials that have been graded, disked, limed, and fertilized.

Most of the 17 species tested have potential for use in low-maintenance revegetation programs incorporating no lime or fertilizer additions. Coastal bermudagrass provides excellent ground cover and high forage production under high rates of fertilization, but does not support multiple land uses. The authors suggest that low-maintenance species could be seeded at the time of bermudagrass sprigging. Without further fertilization and management the bermudagrass would decline and the low-maintenance species would fill the vegetation gaps. Coastal bermudagrass would provide short-term site stabilization, and low-maintenance species would follow with a more diverse, self-sustaining community capable of supporting multiple uses without soil amendments. Information on the density, aerial cover, aboveground biomass, and uses of each of the 17 species studied is presented.

1067. Skousen, J. G., and C. A. Call. Sod-Seeding To Modify Coastal Bermudagrass on Reclaimed Lignite Overburden in Texas. Reclam. & Reveg. Res., v. 6, No. 3, 1987, pp. 163-176.

This study investigated the establishment and growth of low-maintenance, perennial grass and forb species sod-seeded in different-aged Coastal bermudagrass (*Cynodon dactylon* (L.) Pers.) swards on reclaimed mixed soil-lignite

overburden in east-central Texas. The two study sites had Coastal bermudagrass swards that were 2 and 8 years old. Both sites were fertilized with N-P-K fertilizer and limed prior to sprigging. Glyphosate was applied to one-half of each bermudagrass sward, and eight, low-maintenance, perennial species were seeded into untreated and herbicide-treated bermudagrass sod. At each site, one-half of the herbicide-treated and untreated swards were fertilized with 44-44-44 kg ha^{-1} N-P-K at the time of seeding, while the other half was not fertilized. Seeded species were Indiangrass (*Sorghastrum nutans* (L.) Nash), kleingrass (*Panicum coloratum* L.), side-oats grama (*Bouteloua curtipendula* (Michx.) Torr.), switchgrass (*Panicum virgatum* L.), the leguminous forbs Illinois bundleflower (*Desmanthus illinoensis* (Michx.) MacMill.) and sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don), and two nonleguminous forbs, Engelmann daisy (*Engelmannia pinnatifida* T. & G.), and Maximilian sunflower (*Helianthus maximiliani* Schrad.). Fertilizer and herbicide were applied once. Density and aboveground biomass of all species, including bermudagrass, were determined for 3 years after sod-seeding. Light measurements were taken during the first growing season, mixed overburden samples were taken for soil chemical and physical analyses prior to seeding, and root biomass and distributions of each species were determined from soil cores after the second growing season.

The four sod-seeded grass species were not observed in any of the treatments in either sward during the first 2 years. By the third year, all four grasses were observed in both swards in areas where vegetation gaps had developed. During the first year sod-seeded leguminous and nonleguminous forbs were observed only in plots that had been treated with herbicide. Englemann daisy was not observed in any treatment. Fertilizer treatment had varied effects on forb species. The density and aboveground biomass of sod-seeded species increased during the second year. The authors noted three trends in the establishment of sod-seeded species: (1) 50-pct sod suppression with glyphosate herbicide is necessary for first-year establishment of forbs, while grasses require more intensive suppression, (2) establishment of sod-seeded species was greater in the less competitive 8-year-old bermudagrass sward, and (3) establishment was greater in nonfertilized treatments.

1068. Skousen, J. G., C. A. Call, and R. W. Knight. A Chronosequence of Vegetation and Minesoil Development on a Texas Lignite Surface Mine. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 79-88.

Changes in mine soils and vegetation that naturally established on a series of different-aged mined areas were evaluated and compared with those on an adjacent unmined area in east-central Texas. The unreclaimed sites ranged in age from 1 to 50 years since mining. Information is presented on the vegetative changes that have occurred on the different-aged sites. Significant changes have occurred in soil pH and bulk density over time. Soil pH values are initially high on younger unreclaimed sites. With time, unoxidized pyrite reacts with the air and water, releasing acid and decreasing the soil pH on intermediate sites (5 to 20 years old). As the mine soils continue to weather and age, soil pH gradually increases. Bulk density values decreased significantly from 1.30 Mg m^{-3} on 1-year-old mine soil to 0.93 Mg m^{-3} on 50-year-old mine soil. These reductions are attributed to differences and changes in mining equipment and procedures and to a significant increase in litter cover on the older (20-, 30-, and 50-year-old) mined areas. Increased organic matter and humus in the older mine soils resulted in lower bulk densities.

Soluble salt concentrations have also increased over time after disturbance, owing to the weathering and oxidation of minerals that were in a reduced state in the overburden prior to mining. Mineral weathering has released ions that have accumulated at the surface, and high surface soil temperatures and evaporation rates have caused water to move upward with these ions to the surface. The authors state that whether the different-aged mined sites represent a soil and vegetation chronosequence is difficult to determine. The mine soils that developed on the 5-, 10-, and 15-year-old sites are similar in chemical properties, and the mine soils on the 20- and 30-year-old mined sites are chemically similar; the mine soil on the 50-year-old mined site is different from all the other mine soils studied and different from the native, undisturbed soils of the area. Several models of ecological succession appear to apply to the different-aged mined sites; initial floristics model, tolerance model, and relay floristics (fascilitation) model.

1069. Skujins, J. J., and B. Z. Richardson. Humic Matter Enrichment in Reclaimed Soils Under Semiarid Conditions. Geomicrobiol. J., v. 4, No. 3, 1985, pp. 299-311.

Changes in humic and fulvic acid components of surface soils 9 years after the reclamation of overburden and replaced topsoil at a minesite in Montana are described. Two soils were treated; overburden spoil material and topsoil originating from the surface 1 m were placed over the overburden to a depth of 20 cm. Four soil treatments were used on each soil type: (1) no treatment (control), (2) fertilization with 50 kg ha^{-1} N, 135 kg ha^{-1} P, and 17 kg ha^{-1} K, (3) an organic amendment consisting of surface-spread *Sphagnum* moss cover with jute netting, 5,600 kg ha^{-1}, and (4) fertilization and mulching at rates used in treatments 2 and 3. All plots were seeded with

mixtures of native and introduced grass species. Humic matter was extracted using a sonication-chelating resin extraction method. The humic and fulvic acid components were analyzed for nitrogen and carbon content. Soils that received the mulch amendment had the greatest increase in organic carbon compared with the control. Fertilization also increased organic carbon, but to a lesser extent. The highest total soil nitrogen increases were observed in the fertilized soils. The increased organic matter content of treated soils is due to the increased productivity and increased aboveground and belowground litter production. Humic and fulvic acid components are also influenced by the organic and inorganic amendments.

1070. Slick, B. M., and W. R. Curtis. A Guide for the Use of Organic Materials As Mulches in Reclamation of Coal Minesoils in the Eastern United States. U.S. For. Serv., Gen. Tech. Rep. NE-98, 1985, 144 pp.

The purpose of this guide is to direct the reader on and familiarize the reader with the application of organic mulches as an aid in preventing excessive soil loss and in revegetating lands disturbed by coal surface mining in the Eastern United States. Information presented applies mainly to active mining operations. Four major categories of organic waste are considered: (1) agricultural (crop and livestock residues), (2) silvicultural (logging and wood-manufacturing wastes), (3) municipal (refuse and sewage sludge), and (4) industrial. Information is given on the quantity generated, usage, problems, and constraints affecting usage for each waste type. The most readily available organic materials are evaluated for erosion control and on-site physical, chemical, biological, and climatic variables that may influence soil stabilization, vegetation establishment, and the cost of achieving desired results. Information is also given on surface preparation, application rates, time of application, methods, anchoring techniques, and equipment used when mulches are a part of the reclamation plan.

1071. Smith, J. A., E. J. DePuit, and G. E. Schuman. Wood Residue and Fertilizer Amendment on Bentonite Mine Spoils: II. Plant Species Responses. J. Environ. Qual., v. 15, No. 4, 1986, pp. 427-435.

This study evaluated the effects of varied species mixtures, wood residue rates, and nitrogen fertilization rates on the revegetation of orphan (abandoned) bentonite mine spoils in northeastern Wyoming. Four wood residue rates (0, 45, 90, and 135 Mg ha^{-1}), four nitrogen fertilization rates (0, 2.5, 5.0, and 7.5 kg N per megagram wood residue), and two seed mixtures (native and introduced, with six species each) were established on regraded spoil. Aboveground biomass of the seed mixtures was collected near the end of the second growing season. There were significant wood residue treatment effects on the aboveground biomass of certain plant species, however, no effects of fertilization treatments were evident. There were significant interactions among wood residue and fertilization treatments for some species. Individual species responses are presented along with community responses. In general, native species had peak biomass values at lower residue rates (90 Mg ha^{-1}) than did introduced mixtures (135 Mg ha^{-1}).

1072. Smith, J. A., G. E. Schuman, E. J. DePuit, and T. A. Sedbrook. Wood Residue and Fertilizer Amendment on Bentonite Mine Spoils: I. Spoil and General Vegetation Responses. J. Environ. Qual., v. 14, No. 4, 1985, pp. 575-580.

The effects of varied wood residue rates, nitrogen fertilization rates, and species mixtures on the revegetation of orphan (abandoned) bentonite mine spoils in Wyoming were evaluated. Changes in soil properties and vegetation due to amendments were monitored over a 2-year period. Wood residues (main treatment) were applied at rates of 0, 45, 90, and 135 Mg ha^{-1}. Nitrogen fertilizer was applied on the basis of wood residue rates to maintain uniform carbon-nitrogen ratios across wood residue treatments. On plots treated with wood residue, ammonium nitrate was applied at 0, 2.5, 5.0, and 7.5 kg N per megagram of wood residue. On control plots, nitrogen was added at rates equivalent to those applied on the 45-Mg-ha^{-1} wood residue treatment; rates of application were 0, 112, 224, and 336 kg ha^{-1} N. Phosphorus was applied to all plots at 90 kg ha^{-1} P. Subplots were drill seeded with either a native or an introduced grass mixture. Soils were characterized prior to amendment application and in each of the monitoring years to establish chemical edaphic changes due to amendments. Seedling density, canopy cover, and aboveground biomass were determined.

Spoils were characterized by high clay, EC, and soluble sodium. Wood residues at 90 and 135 Mg ha^{-1} significantly increased the soil water content in the top 30 cm of spoil. This increase is a result of reduced bulk densities, improved soil structure, and increased water infiltration and storage. Soil nitrogen and phosphorus decreased with increasing depth because of the concentrating of nitrogen and phosphorus near the spoil surface. Wood residue treatments significantly increased the density of both native and introduced grass species. The 90-Mg-ha^{-1} wood residue treatment resulted in significantly higher biomass of native species, while the biomass of introduced species increased significantly through the 135-Mg-ha^{-1} residue treatment. No significant differences in biomass were observed for native and introduced species mixtures at the 0- or 45-Mg-ha^{-1} residue treatments. At each residue treatment, second-year biomass increased significantly from the nonfertilized to the 2.5-kg-Mg^{-1} N fertilized

treatment, but no significant differences due to fertilization were noted above that rate. Cover data followed the same pattern as aboveground biomass data.

1073. Smith, J. H., and T. L. Jackson. Decomposition of Wheat and Barley Straw Treated With Urea-Sulfuric Acid. Biol. and Fertil. Soils, v. 4, 1987, pp. 199-203.

Laboratory and field experiments were conducted to study the effects of urea-sulfuric acid treatments on the decomposition of two cereal straws, winter wheat (*Triticum aestivum* L.) and winter barley (*Hordeum vulgare* L.), and on the total numbers of micro-organisms and actinomycetes. In the laboratory, winter wheat straw was treated with no acid or 1:1 v/v urea-sulfuric acid in water at 0.5 or 1.0 mL g^{-1} straw and mixed with a silt loam soil at 0.5, 1.0 or 1.5 g straw per 100 g soil. Samples were incubated for 12 weeks. Acid-treated straw initially decomposed faster than nontreated straw; however, final decomposition was 25 to 45 pct greater for the nontreated straw than for acid-treated straw.

Winter wheat and barley straws (25 g) were treated with 0, 0.5, or 1 mL urea-sulfuric acid (1:1 v/v) with water, placed in mesh bags, and buried (20 cm) in a silt loam soil in the field. Straw treated with urea-acid decomposed significantly faster than nontreated straw. After 160 days, 58 pct of the straw decomposed with urea-acid treatments, while 48 pct decomposed with no treatment.

Total counts of micro-organisms in soil with no straw were 1.8 million per gram soil, while urea-sulfuric acid treated straw had counts of 15.7 million per gram soil after a 14-day incubation period. Actinomycete counts increased from 0.3 million to 6.7 million per gram soil for the no-straw and straw-treated soils, respectively. Results show that in the field, urea-sulfuric acid treatments can accelerate cereal straw decomposition rates without adversely affecting soil micro-organisms. Additionally, experiments show that care must be used when extrapolating laboratory experimental results to field conditions.

1074. Smith, J. R., and W. D. Klimstra. Establishment and Succession of Vegetation on Pre-Law Coal Surface-Mined Land in Perry County, Illinois. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 331-339.

Vegetation composition and structure were investigated on a prelaw coal surface-mined area in Perry County, IL. The successional studies were conducted on lands mined between 1932 and 1950. Plants recorded included representatives of 191 species from 51 families. Information is given on plant cover, density, species richness, plant life form, and duration. Environmental influences on vegetation composition and structure included spoil age, topography, aspect, and spoil chemical and physical factors. Plant establishment was not inhibited by the spoil chemical and physical characteristics.

1075. Smith, J. W. The Beneficial Use and Disposal of Coal Ash on Active Mine Sites in Pennsylvania. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 285-293.

This article discusses the regulatory policies of the State of Pennsylvania concerning the permitting of fly ash disposal sites and approval of beneficial reuse of fly ash. Surface mining sites, coal refuse disposal sites, and coal refuse reprocessing sites are examples of places where ash disposal or beneficial use of fly ash can take place in Pennsylvania. Different sections of this paper discuss fly ash disposal, the permitting process (including the chemical characteristics and leachability of the fly ash), the beneficial use of fly ash (plant nutritional benefits, proper application and mixing rates, and metal loading rates), the interim policy for the beneficial use of residual waste, and two case studies. The author states that the new statutory and regulatory procedures for fly ash are useful in order to identify environmentally acceptable disposal sites and beneficial use sites. This is an excellent article concerning state regulatory policy of a soil amendment that can be applied to coal surface-mined lands.

1076. Smith, P. L., E. F. Redente, and E. Hooper. Soil Organic Matter. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 185-214.

In mined land reclamation, soil organic matter content is important in terms of its nutritive and physical effects on topsoil. A general literature review on the formation, nature, and analysis of soil organic matter is presented. The effects of organic matter on plant growth and the growth media are also reviewed. In revegetation planning there is no single set of levels for organic matter to use in rating topsoil as good, fair, poor, or unsuitable. Suitability levels vary with location (climate) and the postmining land use. Organic matter additions mitigate several adverse soil properties or site conditions including texture, reaction, sodicity, salinity, nutrient levels, undesirable organic matter levels, and erosion. The reestablishment of a functional soil system is critical to successful reclamation in the arid and semiarid West, with organic matter formation having an integral part in this functional ecosystem.

1077. Smith, R. K. The Effects of Mulches and Fertilizer on Vegetation Establishment in Southwestern Wyoming. Paper in Shrub Establishment on Disturbed Arid and Semi-Arid Land (Proc. Symp., Laramie, WY, Dec. 2-3, 1980). WY Game and Fish Dep., 1981, pp. 123-137.

The study evaluated the effectiveness of seven combinations of mulch and fertilizer treatments in aiding seedling establishment and biomass production. Native grass hay mulch in a 2 tons per acre application was superior to fabric mulch and nonmulch treatments for seedling establishment of grasses and some species of *Atriplex*, but was detrimental to shrub biomass production. Fertilization increased the establishment of grass and weedy species, but not the establishment of seeded shrubs. Individual weights of all species planted were, however, increased with fertilizer applications. Fabric mulch reduced the establishment of winterfat (*Ceratoides lanata* (L.) C.A. Mey.), did not affect the establishment of grasses and *Atriplex*, and improved the establishment of weed species.

1078. Smith, R. M. Update on Overburden Characteristics. Paper in 1977 Coal Convention Session Papers Set No. 3 (Am. Min. Congr. Coal Conv., Pittsburgh, PA, May 1-4, 1977). Am. Min. Congr., Washington, DC, 1977, 17 pp.

Methods of sampling and physically and chemically characterizing coal mine overburden are outlined in this article. The author briefly describes sampling approaches for soil (top 5 ft) and overburden properties that are useful for designing a mining and reclamation plan. These tests include methods for determining liming requirements and available plant nutrients. A discussion of costs for overburden sampling versus potential benefits is included.

1079. Smolander, A., C. Van Dijk, and V. Sundman. Survival of *Frankia* Strains Introduced Into Soil. Plant and Soil, v. 106, No. 1, 1988, pp. 65-72.

Conditions important for the successful introduction of the nitrogen-fixing actinomycete, *Frankia*, into the soil and for the nodulation of alder hybrids (*Alnus incana* × *Alnus glutinosa*) were studied. Two *Frankia* strains were used, and the survival of the strains was examined in two different soil conditions along with the effect of pH and temperature on nodulation. Each *Frankia* strain was introduced into soils that did not contain *Frankia*, a peat and fine sand. *Frankia* survival, the persistence of nodulation capacity using the plant infection technique, was similar despite the morphological differences between the two strains. Nodulation capacity declined at both 14° and 22° C over time; however, survival was better in soils limed to pH values above 6 than in soils at their original pH, 2.9 for peat and 4.2 for the fine sand. Nodule formation was affected by pH. Nodulation was fastest and the number of nodules highest at pH 5.8, while nodulation was inhibited at pH 3.5. Nodule numbers were significantly different over the pH range of 3.5 to 5.8, with nodules increasing linearly over this pH range. The authors state that the optimal *Frankia* strain for forestation purposes would be one that is adapted to the prevailing soil conditions.

1080. Snarski, R. R., J. B. Fehrenbacher, and I. J. Jansen. Physical and Chemical Characteristics of Pre-Mine Soils and Post-Mine Soil Mixtures in Illinois. Soil Sci. Soc. Am. J., v. 45, No. 4, 1981, pp. 806-812.

The authors report an evaluation of the chemical, physical, and mineralogical properties of the Sable soil series (Typic Haplaquoll) from west-central Illinois and the Darmstadt soil series (Albic Natraqualf) from southern Illinois to determine the value of solum and subsolum material as plant growth media. The B2 horizon of the Darmstadt soil was the least suitable for plant growth. Incorporation of A horizon into a mix of the top 3 m of the soil profile did not significantly enhance the chemical or physical properties of the mix in the case of either soil. By comparing tested and calculated soil chemical and physical values, the authors found that many of these parameters could be reasonably predicted for solum and subsolum mixtures.

1081. Snow, P. G., B. Gehrmann, and R. L. Carrasquillo. Production and Utilization of Scrubber Sludge. Paper in Proceedings: Eighth International Ash Utilization Symposium, Volume 1 (Washington, DC, Oct. 28-31, 1987). Elect. Power Res. Inst., Palo Alto, CA, 1987, pp. 6-1—6-13.

A flue gas desulfurization system is described, along with applications for the utilization of the resultant scrubber sludge. The marketability of scrubber sludge is based on its structural properties for pavement design and its ability to improve soil stabilization. The use of scrubber sludge in soil stabilization, as a base material, and as a wearing surface is described.

1082. Sobek, A. A. Characterizations of Minesoils Developing in Coal Refuse. Reclam. Rev., v. 3, No. 1, 1980, pp. 61-64.

Abstract of a paper presented at the Annual Meeting of the American Council for Reclamation Research. The author compares the soil and vegetative development of

(1) a 53-year-old coal-cleaning refuse material, (2) a 3-year-old portion of the refuse that had been regraded, amended to adjust pH, and covered with 30 cm of glacial till, and (3) an undisturbed soil near Staunton, IL. The old refuse exhibited little soil development, lacked vegetation, had a low pH, and had a high sulfur content. The treated refuse had a 95-pct cover of a grass-legume mix, a higher pH level, lower sulfur, and soil development in the upper 30 cm due to the action of the plants. The reclaimed mine soil compared favorably with the undisturbed soil.

1083. Sobek, A. A., and J. E. Bogner. Using the Acid-Base Account To Predict Acid Potential of Coal Overburden. Paper in the Third Biennial Symposium on Surface Coal Mining and Reclamation on the Great Plains (cochaired by Reclam. Res. Unit, MT State Univ., and U.S. Off. Surf. Min., Billings, MT, Mar 19-21, 1984). MT State Univ. and U.S. Off. Surf. Min., 1984, 21 pp.

This paper evaluates methods for determining the acid-generating potential of unweathered rock and sediments. The component parts making up the acid-base account are reviewed. Weathering methods used to estimate the acid potential are briefly described. Examples are given of two coal mines in Pennsylvania and two mines in Wyoming to illustrate the potential problem in using these methods. The authors conclude that the acid-base account is still the best available technique for characterizing acid potential of coal overburden materials.

1084. Sobek, A. A., L. R. Hossner, D. L. Sorensen, P. J. Sullivan, and D. F. Fransway. Acid-Base Potential and Sulfur Forms. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 233-258.

The geochemical data base that defines overburden acid-generating characteristics is important to the management of western reclamation. The acid-generating potential of sulfur minerals in overburden is the result of iron sulfide oxidation. Laboratory procedures are based on the oxidation of sulfide compounds in exposed coal and overburden materials. The best available technique for evaluating acid potential of overburden materials is the acid-base account method. This method consists of five components: (1) acid potential, (2) neutralization potential, (3) pH, (4) rock type, and (5) depth below the land surface. The most important part of this method is to balance maximum potential acidity against total neutralizers. Examples of acid-base accounting are given, along with management recommendations.

1085. Sommerfeldt, T. G., and D. G. MacKay. Utilization of Cattle Manure Containing Wood Shavings: Effect on Soil and Crop. Can. J. Soil Sci., v. 67, No. 2, 1987, pp. 309-316.

Repeated annual applications of cattle manure containing softwood shavings, compared with inorganic fertilizer and cattle feedlot manure without wood shavings, were incorporated into a southern Alberta, Canada, Chernozemic soil. The effects of these applications on soil productivity and yield and protein content of barley (*Hordeum vulgare* L.) cropped under a continuous cropping program were determined. Five treatments were applied annually for 7 years: (1) control, (2) nitrogen fertilizer (34-0-0 at 67 kg ha^{-1}), (3) manure only (50 mt ha^{-1}), (4) manure plus wood shavings (50 mt ha^{-1}), and (5) manure plus wood shavings plus fertilizer (same rates as used in treatments 4 and 2, respectively).

After 7 years, soil electrical conductivity (EC), organic matter (OM), total nitrogen, nitrate-nitrogen (NO_3-N), total phosphorus, and available phosphorus in the upper 30 cm of soil were significantly greater in manured than control plots. Total nitrogen, total phosphorus, and available phosphorus of manured soils were significantly greater than in the fertilized plots. In control plots the fertility of the land decreased over the 7-year period. In the fertilized and manure plus wood shavings treatments barley straw yields showed a decrease over time. Yield data indicate that nitrogen was tied up in the decomposition of the wood shavings in the manure. Straw yields remained constant for the manure and manure plus shavings plus fertilizer treatments. Grain yields were inconsistent. The highest protein levels occurred with the manure treatments and the lowest with the control and manure plus wood shavings treatments. The study shows that manure containing wood shavings can be utilized on these soils without decreasing barley production; however, if supplemental nitrogen is applied (to compensate for nitrogen immobilization) productivity can be increased to levels attained with manure without shavings.

1086. Sopper, W. E. Reclamation of the Palmerton Superfund Site. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 171-178.

This paper reports on the greenhouse and field experiments developed in an effort to alleviate the environmental damage caused by emissions from a zinc smelting operation. The greenhouse experiment was conducted to evaluate proposed sludge and fly ash mixtures and to screen 12 grass and legume species and 12 tree species.

Contaminated soil was treated with various mixtures of (1) sludge alone, (2) one part sludge to one part fly ash (1S:1FA), (3) two parts sludge to one part fly ash (2S:1FA), (4) three parts sludge to one part fly ash (3S:1FA), (5) three parts sludge to one part fly ash plus black humus detritus (3S:1FA:H), and (6) control. Results confirmed the feasibility of using the three sludge and fly ash mixtures; tree, grass, and legume species germinated and grew satisfactorily in the mixtures tested. Field results are the same as in entry 1087 below.

1087. Sopper, W. E. Reforestation of a Zinc Smelter Superfund Site. Paper in Mine Drainage and Surface Mine Reclamation Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 68-73.

A general review of the causes and revegetation problems associated with the Blue Mountain, PA, EPA Superfund site are presented. This paper reports on the research efforts to develop a restoration program to alleviate the environmental damage caused by emissions from a zinc smelting operation. Field studies were conducted to determine the efficacy of using mixtures of municipal sludge and fly ash as soil amendments to aid in the establishment of trees on soils that are highly contaminated with zinc, cadmium, copper, and lead. The mixture ratios evaluated, on a volume basis, were one part sludge (1S) to one part fly ash (1FA), 2S to 1FA, and 3S to 1FA. Other amendments applied to each plot included potassium fertilizer, lime, and fiber mulch. Seedlings of 10 species and hybrid poplar (*Populus* spp.) were planted on the plots. Owing to poor initial survival, the same species were replanted the following year at an earlier planting date.

Survival for each species ranged from 44 pct to 91 pct across all treatments. For all the tree species combined, the highest survival rate was found on the 2S:1FA treatment, 80 pct. The species with the highest survival rates across all amendments were alder (*Alnus glutinosa* (L.) Gaertn.) (91 pct), black locust (*Robinia pseudoacacia* L.) (86 pct), black cherry (*Prunus serotina* Ehrh.) (84 pct), white pine (*Pinus strobus* L.) (83 pct), larch (*Larix decidua* Mill.) (81 pct), and hybrid poplar (77 pct). Foliar analyses of these species showed that concentrations of copper, nickel, chromium, cobalt, and boron were below the suggested tolerance level for growth suppression in all species on all treatments. The concentrations of manganese, iron, aluminum, zinc, lead, and cadmium in the foliage were all above the suggested tolerance level in most species on each treatment; however, the author did not observe any phytotoxicity symptoms after 1 year in any of the tree species planted. The results of this study indicate that each of the sludge and fly ash mixtures used was successful in improving tree seedling establishment on the highly contaminated soils studied. Further monitoring of tree survival and growth is necessary to determine if the sludge and fly ash treatments can facilitate long-term revegetation success on disturbed areas.

1088. Sopper, W. E., L. T. Kardos, and S. N. Kerr. Revegetation of Anthracite Refuse Banks Treated With Municipal Sewage Effluent and Sludge: Phase II (grant GO166049, Inst. Res. Land and Water Resour., PA State Univ.). BuMines OFR 53-78, 1978, 80 pp.; NTIS PB 283 394.

This study was designed to evaluate the overwinter survival and second- and third-year growth responses of planted tree species and seeded grass and legume species on sludge-amended anthracite refuse banks located near Scranton, PA. Tree seedling survival was higher at lower sludge application rates, while greatest height growth was obtained at higher sludge application rates. Hardwood tree species were superior to conifers in terms of survival and growth responses. During the first growing season, dry matter production and vegetative cover were highest for the lower sludge application rates. Of the grasses and legumes tested, the best overall response was obtained from reed canarygrass (*Phalaris arundinacea* L.), tall fescue (*Festuca arundinacea* Schreb.), orchardgrass (*Dactylis glomerata* L.), birdsfoot trefoil (*Lotus corniculatus* L.), and Penngrift crownvetch (*Coronilla varia* L.). The higher sludge rate (150 mt ha^{-1}) produced the best overall herbaceous vegetation growth response. Water quality was not impaired by the sludge application by the third growing season.

1089. Sopper, W. E., and S. N. Kerr. Revegetation of Mined Land Using Wastewater Sludge. Public Works, v. 111, No. 9, Sept. 1980, pp. 114-116.

This article describes demonstration projects in which different types of municipal sewage sludge were incorporated into surface mine reclamation and revegetation activities. The sites of these demonstration projects were in Pennsylvania. This is a very good, somewhat technical paper on the subject and could be useful to individuals with little background in the use of sewage sludge as a soil amendment, as well as acting as a reference for proposed reclamation activities.

1090. Sopper, W. E., and S. N. Kerr. Revegetating Strip Mined Land with Municipal Sewage Sludge (Project Summary). U.S. EPA, Rep. EPA-600/52-81-182, Oct. 1981, 7 pp.

The authors summarize sludge demonstration projects initiated on three sites that were representative of abandoned bituminous strip-mined land and anthracite coal refuse in Pennsylvania. The types of sludge used were (1) liquid digested, (2) dewatered by centrifuge, vacuum filter, and sand-bed drying, and (3) compost (sludge-cake mix). Different rates of sludge were applied, and the sites were seeded with a mixture of grasses and legumes. Over a 3-year period the sludge applications ameliorated the harsh conditions of the test sites. Vegetative cover stabilized each site and has persisted and improved each year since establishment. Sludge applications did not cause a reduction in yield or quality of the vegetation. Sludge applications did increase the concentration of some metals in the vegetation, but all concentrations were below phytotoxic levels. There have been no adverse effects on the chemical or bacteriological quality of soil water because of sludge applications. The authors conclude that stabilized municipal sludges can be used to revegetate bituminous strip-mined land and anthracite refuse banks in an environmentally safe manner with no adverse effects on vegetation, soil, or ground water quality, and with little risk to animal and human health.

1091. Sopper, W. E., S. N. Kerr, and E. M. Seaker. The Pennsylvania Program for Using Municipal Sludge for Mine Land Reclamation. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 283-290.

The purpose of the article was to discuss the Pennsylvania program using municipal sewage sludge for mineland reclamation in both the anthracite and bituminous regions. Federal and State guidelines and regulations for land application of sludge are discussed. A series of demonstration sites were established, and the results indicate that stabilized municipal sewage sludge can be used to revegetate land disturbed by mining with few adverse effects on vegetation, soil, or ground water quality.

1092. Sopper, W. E., and E. M. Seaker. A Guide for Revegetation of Mined Land in Eastern United States Using Municipal Sludge. Sch. For. Res. and Inst. Res. Land and Water Resour., PA State Univ., State College, PA, Mar. 1983, 93 pp.

This document presents discussions of pertinent State and Federal legislation, site investigations, vegetation selection and management, sludge analysis, sludge transportation and application methods, sludge application rates, and monitoring methods. An appendix containing a literature review of land reclamation projects using municipal sludge is included. The research reviewed and the discussions and recommendations contained in this document are principally relevant to the Interior and Eastern Coal Mining Regions. It is highly recommended as a reference manual for reclamation planning in areas where municipal sludge application is an alternative.

1093. Sorensen, D. L., and P. R. Fresquez. Patterns of Denitrification in Reclaimed Minespoils in the Arid Southwest. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 327-331.

The denitrification potentials of spoils and revegetated soil materials were evaluated to determine possible loss of nitrogen through denitrification and as an indicator of general microbial activity. Samples were taken from 2- to 3-year-old spoil piles, 3- to 4-year-old topsoil stockpiles, areas that had been revegetated, and an undisturbed area. Potential denitrification was determined using the acetylene inhibition technique. Potential denitrification rates were low and similar in spoil material, stockpiled topsoil, revegetated spoil, and revegetated replaced topsoil regardless of age. This was true even under conditions favorable for denitrification, anaerobic and moist soil conditions. Whole-core samples of revegetated spoil indicated relatively high rates of denitrification when high amounts of nitrate and total nitrogen were present. Denitrification was highest where levels of nitrate were high and spoil material was less permeable. In general, nitrogen losses through denitrification will be limited by microbial activity and the semiarid environment for the New Mexico mine soil studied.

1094. Sorenson, D. L., D. A. Klein, W. J. Ruzzo, and L. E. Hersman. Enzyme Activities in Revegetated Surface Soil Overlying Spent Paraho Process Oil Shale. J. Environ. Qual., v. 10, No. 3, 1981, pp. 264-371.

Several key microbiological parameters related to soil development and biogeochemical cycling processes were monitored to evaluate possible relationships between surface soil management and soil microbiological responses in surface soil used in covering Paraho retorted oil shale. Appreciable reductions in nitrogenase (acetylene reduction), dehydrogenase, and phosphatase activities were found in surface soil at the 30-, 61-, and 91-cm depths when it was placed directly over the processed shale, compared with surface soil not in contact with the processed shale. Nitrogenase and phosphatase activities were comparable to those of the control soil when a 30-cm coarse rock capillary barrier was placed between the 61-cm soil layer and the processed shale. The authors suggest, based on these field results, that better maintenance of microbial processes in soils placed over Paraho retorted shale during revegetation may be obtained by incorporating a capillary

barrier in the reclaimed profile. This paper reports the results of a 2-year study conducted in the Piceance Basin of Colorado.

1095. Sorenson, D. L., W. A. Kneib, D. B. Porcella, and B. Z. Richardson. Determining the Lime Requirement for the Blackbird Mine Spoil. J. Environ. Qual., v. 9, No. 1, 1980, pp. 162-166.

The objective of this research was to develop a procedure for determining the total lime requirement of the copper-cobalt Blackbird Mine spoil near Salmon, ID. The approach and methodologies used in this study have application to other mineral mine revegetation efforts. The reason the lime requirements of a spoil are important to revegetation is that the production of acid from the oxidation of pyrite may prevent the revegetation of a spoil. A total lime requirement must be determined to control existing acidity and to prevent reacidification as the oxidation of pyritic material continues. The total lime requirement consists of the amount of ground limestone needed to neutralize the acidity present because of the buffering capacity of the soil, as well as the acidity generated from the oxidation of sulfide-sulfur in the fine, highly reactive fraction of the soil and the oxidation of sulfide-sulfur exposed by weathering of larger diameter soil material. At the Blackbird Mine both the soil-buffering capacity and potential acid production due to sulfide mineral oxidation contribute significantly to the lime requirement. The total lime requirement has to be met before revegetation can begin. Once a plant community is established and the respiration of roots and micro-organisms begins, the concentration of oxygen in the soil water system available for sulfide oxidation will decrease. This would cause a slowing of the soil acidification process. The authors conclude that adequate lime application combined with revegetation will assure control of spoil pH.

1096. Southard, R. J., and S. W. Buol. Subsoil Saturated Hydraulic Conductivity in Relation to Soil Properties in the North Carolina Coastal Plain. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1091-1094.

The influence of several soil properties on the saturated hydraulic conductivity (K_{sat}) of nine deep, weakly structured Ultisols was assessed. Vertical K_{sat} was measured in the laboratory using a constant-head permeameter. Saturated hydraulic conductivity decreased with increasing soil depth, while the grade of structure became stronger. The soil property most highly correlated with K_{sat} was the percentage of pores with diameters greater than 30 μm (r^2 = 0.81). The coefficient of linear extensibility (COLE) measured on soil pastes (COLE paste) was the second best predictor of K_{sat} (r^2 = 0.50). Total porosity showed a weak negative correlation with K_{sat}, while bulk density, clay content, silt content, and sand content showed no significant correlation with K_{sat}. Additionally, no significant correlation was found between the weighted mean ped diameter and K_{sat}, which suggests that much of the water-flow is occurring in intra-peds rather than along inter-ped planes of weakness. Large pores are the dominant means for saturated water movement in these soils.

1097. Spackman, L. K., M. E. Essington, and P. J. Sullivan. Detailed Mineralogical Characterization of a Retorted Oil Shale. Am. Soc. Agron., Agron. Abstr., 1986, p. 36.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. A mineralogical characterization of Colorado retorted oil shale was conducted using linear density gradients, magnetic susceptibility fractionation, X-ray diffraction, scanning electron microscopy, and elemental analyses. Results indicate that there are mineralogical alterations in the retorted shales due to recarbonation.

1098. Staley, T. E., W. M. Edwards, C. L. Scott, and L. B. Owens. Soil Microbial Biomass and Organic Component Alterations in a No-Tillage Chronosequence. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 998-1005.

In general, conservation tillage (no-tillage) has been reported to result in a surficial accumulation of biological activity and biomass, major soil organic components (carbon, nitrogen, phosphorus), increased soil moisture and bulk density, and decreased soil temperature, aeration, and surface pH. In this study, the effects of tillage method (conventional or no-tillage) on biological and chemical properties of similar soils were determined and related to any changes due to time under no-tillage in a 0-, 1-, 2-, 4-, 7-, 9-, 15-, and 20-year chronosequence that had been continuously cropped to corn (*Zea mays* L.). Any changes were compared with those of two pasture agroecosystems (improved and unimproved) on the same soil type. The 0-year no-tillage site was considered the conventional tillage site. Microbial biomass carbon, total and soluble organic carbon, and organic nitrogen, phosphorus, and sulfur were determined in the surface (0 to 7.5 cm), 7- to 15-cm, 15- to 30-cm, and 30- to 45-cm soil layers. The plow zone in the soils studied extended to 15 cm.

Microbial biomass carbon levels in the soil surface layers under no-tillage averaged 60 pct greater than under conventional tillage; however, the level under conventional tillage in the 7.5- to 15-cm layer averaged 57 pct greater than those under no-tillage. Within tillage systems, biomass carbon in the 0- to 7.5-cm layer under no-tillage

averaged 19 pct greater than those of the 7.5- to 15-cm layers, while biomass carbon in the 0- to 7.5-cm layers under conventional tillage was 50 pct of that found in the 7.5 to 15 cm layer. Biomass carbon generally decreased under no-tillage with soil depth.

Total carbon levels in the soil surface layers under no-tillage averaged 83 pct greater than those under conventional tillage, but levels under conventional tillage at the 7.5- to 15-cm and 15- to 30-cm layers averaged 39 and 19 pct greater, respectively, than no-tillage at the same depths. Total carbon in the 0- to 7.5-cm layers under no-tillage averaged 94 pct greater than in the 7.5- to 15-cm layers, while total carbon in these layers under conventional tillage differed by 13 pct. Total carbon decreased with depth for all no-tillage sites.

Soluble organic carbon in the 0- to 7.5-cm surface layer under no-tillage averaged 51 pct greater than under conventional tillage, while soluble organic carbon in the 7.5- to 15-cm layers averaged 70 pct greater under conventional tillage than under no-tillage. In the no-tillage system, soluble organic carbon in the 0- to 7.5-cm layer was two times greater than in the 7.5- to 15-cm layer, while in the conventional tillage system there was little difference between these layers. Soluble organic carbon in the no-tillage system decreased with soil depth.

Organic nitrogen, phosphorus and sulfur in the surface 0- to 7.5-cm layers were all greater in the no-tillage system than in the surface layer in the conventional tillage system. Additionally, organic nitrogen, phosphorus and sulfur were generally higher in the surface 0- to 7.5-cm layers than in the 7.5- to 15-cm layers in the no-tillage system. All soil components for the two pasture systems resembled those found in the 1-year no-tillage site. In the surface layer, biomass carbon reached a maximum after 1 year of no-tillage, then gradually equilibrated in about 10 years to a level approximately 30 pct greater than that under conventional tillage. All other soil components in the soil surface layer were significantly correlated with years under no-tillage. The authors state that management practices designed to improve nutrient use efficiency by controlling microbial mineralization and immobilization activity should take into consideration not only tillage method, but years under the tillage method.

1099. Stanley, M. A., G. E. Schuman, F. Rauzi, and L. I. Painter. Quality and Element Content of Forages Grown on Three Reclaimed Mine Sites in Wyoming and Montana. Reclam. & Reveg. Res., v. 1, No. 4, 1982, pp. 311-326.

This study was conducted to determine the nutritional quality of forage grasses grown on unmined (reference area) and mined land in Wyoming and south-central Montana. Three sites were chosen for this study: (1) Decker Coal Co.'s mine near Decker, MT, (2) Glenrock Coal Co.'s mine near Glenrock, WY, and (3) Shirley Basin uranium mine near Medicine Bow, WY. Forage samples were clipped within a randomly placed 30.5- by 58.4-cm metal frame and then air dried for production estimates and element analysis. The plant material was analyzed for protein, phosphorus, potassium, calcium, magnesium, aluminum, iron, sodium, manganese, zinc, copper, boron, nickel, chromium, and cadmium. Statistical analysis was limited to those species occurring on both sites at each mine. The results indicate that the forage species had higher concentrations of nonnutrient metals when grown on native soils than when grown on reclaimed mine spoil. Of the elements analyzed, only iron was consistently higher in forage species grown on reclaimed sites. Mineral deficiencies rather than toxicities appear to be of greater concern on the reclaimed sites. Both phosphorus and protein were often found to be deficient in forage species, and sodium was below the requirement for cattle in all forage. The authors recommend mineral supplements to alleviate these problems on reclaimed sites.

1100. Stanton, N. L., and D. K. Remmentz. Nematode Densities on Reclaimed Sites on a Cold Desert Shrub-Steppe. Reclam. & Reveg. Res., v. 1, No. 3, 1982, pp. 233-241.

This study was done to determine if there were any host species or reclamation treatment effects on nematode densities and trophic diversity at the Bridger Coal Co.'s mine in the southwestern part of the Red Desert in Sweetwater County, WY. Samples were taken under halogeton, shadscale, and grass species growing on four different sites: (1) undisturbed native vegetation (reference area), (2) native vegetation from which 15 cm of topsoil had been removed, (3) a reclaimed area spread with topsoil removed from site 2, and (4) a reclaimed site which was spread with stockpiled topsoil. Of the four soil-plant treatments, the native undisturbed soil-vegetation supported the highest densities of all trophic groups of nematodes. Both the plant parasites and microbivores were significantly higher in the undisturbed shadscale. The four soil-plant treatments exhibited a gradual progression from high to low nematode densities in the following order: (1) native vegetation, (2) disturbed native vegetation with fresh topsoil, (3) under shadscale, disturbed native vegetation with fresh topsoil, (4) under halogeton, disturbed vegetation with stockpiled soil replacements, and (5) under halogeton. On all sites, the native shrub, shadscale (*Atriplex confertifolia* (Torr. & Frem.) S. Wats.), supported the highest densities, while the introduced annual, halogeton (*Halogeton glomeratus* (Bieb.) C.A. Mey), supported the lowest. The results indicate that immediate topsoil replacement provides a better habitat

for the nematode component of the microfauna. It may also be possible to use nematodes as indicators of the extent of disturbance and the successional status of the soil.

1101. Stark, J. M., and E. F. Redente. Trace Element and Salt Movement in Retorted Oil Shale Disposal Sites. J. Environ. Qual., v. 15, No. 3, 1986, pp. 282-288.

The extent of salt and trace element movement within seven different soil and retorted shale disposal piles was determined after 6 years. Six plots were constructed by filling pits with 60 cm of Colorado retorted oil shale and covering with (1) no topsoil (exposed retorted shale), (2) 30 cm of topsoil, (3) 60 cm of topsoil, (4) 90 cm of topsoil, and (5) 60 cm of topsoil over a 30 cm rock capillary barrier over the retorted shale. The control (6) consisted of disturbed soil with no retorted shale. After 6 years, soil and retorted shale samples were analyzed for arsenic, boron, cadmium, copper, fluorine, iron, lead, manganese, molybdenum, nickel, selenium, and zinc; electrical conductivity and SAR were also determined.

Results show that sodium and soluble salts have moved out of the upper portions of the shale layer. Shale layers in the 30-, 60-, and 90-cm topsoil treatments have lower SAR values than the topsoil layer immediately over them. Processes that may be responsible for these movements are upward movement by diffusion or capillary rise, or downward movement by leaching. Fluorine also had considerable movement and redistribution within the soil-retorted shale profiles studied. The redistribution pattern was explained by the same processes mentioned previously. Molybdenum showed only slight redistribution within the profiles; most of the molybdenum remained within the shale itself. Arsenic, boron, cadmium, copper, iron, lead, manganese, nickel, selenium, and zinc remained almost entirely within the shale; no movement out of the shale layer into the soil was detected.

Surface soil samples did not show elevated levels of salts or trace elements; however, plants growing on the plots did have higher trace element concentrations than did those on control plots. Plant uptake may become an important mechanism for the redistribution of trace elements and salts to the soil surface in future years. Of the treatments utilized, the capillary barrier treatment was the most effective in preventing upward salt and trace element migration. In general, retorted shale covered with the greatest topsoil depths had the least amount of salt and trace element movement. The deeper the shale is buried, the less it is affected by leaching and capillary effects.

1102. Stark, N. A Tree For All Seasons. West. Wildlands, v. 7, No. 3, 1981, pp. 18-21.

The author discusses the factors that limit the growth of ponderosa pine (*Pinus ponderosa* Laws.) on eastern Montana coal spoils. If ponderosa pine are to be grown on regraded mine soils, it is essential to know how mine soils and native forest soils differ physically and chemically. The author discusses how ponderosa pine, an acid-loving species, has adapted to the alkaline soil of eastern Montana. Two possible reasons are given: (1) the ponderosa pine growing in eastern Montana is an ecotype or subpopulation adapted to calcareous spoils, or (2) it is close to its limit of tolerance for alkaline conditions. The remainder of the paper is devoted to a discussion of the physical and chemical properties of eastern Montana mine soils. The author concludes that if trees are to be grown on regraded mine soils, they will have to be selected for the physical and chemical characteristics of the mine soil.

1103. Starks, T. L., and L. E. Shubert. Algal Colonization on a Reclaimed Surface-Mined Area in Western North Dakota. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 652-660.

The purpose of this study was to identify and quantify the soil algae present on an experimental revegetation test site north of Beulah in Mercer County, ND, as well as to describe their succession and relationships to the abiotic components of the soil. Several amendments to the spoil were tested for their effect on plant growth. These treatments included leonardite, scoria, fertilizer, and combinations of these treatments. Algal populations were monitored over three growing seasons (1975-77). Algal variety increased from year to year regardless of the type of soil amendment. The number of algal species, chlorophyll a, and pharophytin (a content of the algae) were correlated with the soil amendments used and selected soil nutrients over time in a trend analysis. Sodium, manganese, and potassium contents of the spoil, as well as time, were significantly correlated to the algal parameters measured. This article provides a unique perspective of the ecological processes occurring during surface mine reclamation.

1104. Starnes, L. B., J. B. Maddox, and T. G. Zarger. Effects of Remedial Reclamation Treatments on Terrestrial and Aquatic Ecosystems—A Progress Report. Paper in Symposium on Surface Mining and Fish/Wildlife Needs in the Eastern United States (WV Univ., Dec. 1978). U.S. Fish and Wildl. Serv., FWS/OBS-78/81, 1978, pp. 276-285.

This research involved remedial treatments to a 162-ha site in Campbell County, TN, after previous revegetation

attempts had failed. Treatments to the area included liming, disking, seeding grasses and legumes, and planting trees and shrubs. Increases in percent ground cover and number of woody stems per hectare resulted from the treatments. Owing to the vegetative cover, the water quality of the 2,800-ha Ollis Creek Watershed, in which the site is located, was improved. There were decreases in the total acidity, turbidity, sulfates, and certain metals within the watershed. Major responses by wildlife to the improved water quality were limited to aquatic invertebrates, where both numbers of individuals and taxa increased.

1105. Starr, G. L., and J. M. Geist. Soil Bulk Density and Soil Moisture Calculated With a FORTRAN 77 Program. U.S. For. Serv., Gen. Tech. Rep. PNW-211, 1988, 6 pp.

This program offers a simple way to save computing time and reduce errors when monitoring soil bulk density. If weights of moist samples are obtained, moisture percentages by weight and volume can also be calculated using this program. The program will compute mean, standard deviation, and confidence intervals for user-selected observations. This report also contains information on file preparation (data, program, and auxiliary files) and program execution.

1106. Stecker, J. A., D. H. Sander, F. N. Anderson, and G. A. Peterson. Phosphorus Fertilizer Placement and Tillage in a Wheat-Fallow Cropping Sequence. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1063-1068.

This study was conducted to determine how tillage systems affect the performance of different methods of phosphorus application in a winter wheat (*Triticum aestivum* L.) and fallow cropping sequence. Tillage treatments evaluated were plow (moldboard), stubble mulch (chisel), and no-till (chemical). Ammonium polyphosphate was applied at rates of 0, 8.4, and 16.8 kg ha^{-1} and placed by broadcast-, knife-, or seed-applied methods. Plots had either 13.5 Mg ha^{-1} residue or no residue. Plowing resulted in the highest grain yield and phosphorus uptake by winter wheat, while no-till resulted in the lowest grain yield and phosphorus uptake. The lower yields may have been due to the cool spring temperatures during this experiment. When residue was not applied, phosphorus placement with seed and knife methods increased grain yield more than did the broadcast method. When residue was applied, knife placement was less effective and broadcast application more effective than seed placement at the low phosphorus rate. At the high phosphorus rate, seed placement resulted in the highest yield in all treatments. The results show that residues can affect the performance of phosphorus placement methods in terms of grain yield and phosphorus uptake.

1107. Stevenson, D. S. Effects of Three Soil Conditioners on Water Content in Two Soils at Three Pressure-Plate Matric Potentials. Can. J. Soil Sci., v. 67, No. 2, 1987, pp. 395-397.

Soil water contents of a sandy loam and a silt loam soil were determined at three matric potentials after treatment with soil conditioners, which were supposed to increase the soils' ability to retain water for plant use. Matric potentials of -1,500, -100, and -30 (silt loam) or -20 (sandy loam) kPa were determined using a pressure-plate test. Only one of the soil conditioners, Aquaprotect, increased the soil water contents at each matric potential over the control for both soils. All three conditioners increased the soil water content of the silt loam at -1,500 kPa compared with the control. The effect of the Alcosorb treatment was to widen the difference in water content between the high and low potentials.

1108. Steward, D. G. The Effect of Soil Horizon Combination on the Production of Blue Grama and Western Wheatgrass. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 265-269.

A greenhouse study was conducted to evaluate three soil horizons (A, B, and C) and unconsolidated overburden material (D) for their suitability as plant growth material. The soil materials used for this study were taken from the Powder River Basin in northeastern Wyoming and consisted of three soil series: Decolney, Fort Collins, and Olney soils. The suitability of the soils as plant growth material was evaluated using blue grama (*Bouteloua gracilis* (H.B.K.) Lag.) and western wheatgrass (*Agropyron smithii* Rydb.). The soil combinations used were (1) all horizons combined, (2) A plus B horizons combined, (3) A plus B plus C horizon combined, (4) C horizon, (5) C plus D horizon combined, and (6) D horizon. Each treatment was amended with 1.51 lb $acre^{-1}$ active N, 1.44 lb $acre^{-1}$ active P, and 1.35 lb $acre^{-1}$ active K.

In general, blue grama established more readily and grew more rapidly than western wheatgrass. The most productive soil, averaged over all horizon combinations, was the Olney series. The least productive soil was the Fort Collins series. The A plus B horizon was the most productive, while the C horizon was the least productive. The A plus B plus C combination was less productive than the A plus B, while the C plus D combination was a little more productive than either the C or D alone. Approximately 52 pct of the variation in blue grama biomass can

be attributed to the effects of soil horizon combination; pH and clay content explained the greatest amount of variation. Of the variation in western wheatgrass biomass, 31 pct was explained by soil horizon combination; pH, clay, and organic matter were the most significant variables. The author concluded that the best possible plant growth material can be obtained by paying attention to changes in soil texture, pH, and calcium carbonate accumulation.

1109. Stiller, D. M., G. L. Zimpfer, and M. Bishop. Application of Geomorphic Principles to Surface Mine Reclamation in the Semiarid West. J. Soil and Water Conserv., v. 35, No. 6, 1980, pp. 274-277.

The authors discuss the need for a more rigorous application of geomorphic and hydrologic concepts in the design of postmining topography in the semiarid West. The concepts should provide a valuable addition to erosion control and enhance revegetation efforts. Several reclamation problems are discussed, and attention is given to minimizing erosion through topographic design that has incorporated geomorphic and hydrological concepts. The authors conclude that successful reclamation in the semiarid West depends on precise planning of the reclaimed surface and the integration of the reclaimed surface and drainage network into the surrounding landscape.

1110. Stout, W. L., G. A. Jung, and J. A. Shaffer. Effects of Soil and Nitrogen on Water Use Efficiency of Tall Fescue and Switchgrass Under Humid Conditions. Soil Sci. Soc. Am. J., v. 52, No. 2, 1988, pp. 429-434.

This study was conducted on non-coal-mined land, but will serve as a good reference on the interactive effects of soil water availability and nitrogen fertilization on yield and water use efficiency of two forage grasses under humid conditions in south-central Pennsylvania. A C_3 grass (tall fescue (*Festuca arundinacea* Schreb.)) and a C_4 grass (switchgrass (*Panicum virgatum* L.)) were grown on three soils derived from red acid shale with available water-holding capacities of 25, 15, and 5 cm. The grasses were fertilized with 0, 90, and 180 kg ha^{-1} N, with the nitrogen applied in split applications (in April and after the first cut) on the tall fescue and in a single application (April) on switchgrass. All treatment plots received 50 and 75 kg ha^{-1} P and K, respectively, each spring over the 3 years of this study. Grasses were harvested at early heading and in the late fall for nitrogen analysis and yield determinations. Precipitation, temperature, and soil water (measured using a neutron probe at 30-cm increments, biweekly, to lithic or paralithic contact) were monitored.

When precipitation was adequate and well distributed, nitrogen was the major factor controlling forage yield and water use efficiency of both species. Eighty percent of the variation in yield and water use efficiency could be accounted for by nitrogen. When precipitation occurred as one large storm event or when it was sparse or poorly distributed, soil water-holding capacity was the main factor controlling yield and water use efficiency. This factor accounts for 40 pct of the variation in the yields of tall fescue and switchgrass under these conditions. The authors state that soil properties related to water-holding capacity (texture, bulk density, thickness, etc.) can be used with weather data to develop yield potentials for similar soils with and without nitrogen fertilization.

1111. Stout, W. L., H. A. Menser, O. L. Bennett, and W. L. Winant. Cover Establishment on an Acid Mine Using Composted Garbage Mulch and Fluidized Bed Combustion Residue. Reclam. & Reveg. Res., v. 1, No. 2, 1982, pp. 203-211.

This study was conducted to determine the effectiveness of fluidized-bed combustion residue (FBCR), alone and in combination with composted garbage mulch, on the establishment of Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) on acid mine spoil. Fertilizer was applied during the second season at a rate of 560 kg ha^{-1} of 10-10-10 fertilizer. Fertilization was delayed in order to observe the contribution of plant nutrients by the mulch and FBCR. Plant materials were harvested for yield determinations and nutrient analyses. Soil samples were also analyzed for macronutrients, micronutrients, and the presence of heavy metals.

Prior to fertilization, only the plots with composted garbage mulch had a satisfactory yield. Cover was improved with fertilization, but the cover on control plots and plots with only lime and FBCR was still inadequate. Plots that had composted garbage mulch with or without lime or FBCR had adequate vegetative cover. Yields were also larger on plots treated with composted garbage mulch, owing to higher nutrient inputs. Yields on plots treated with lime or FBCR alone were not significantly different from those on control plots. Plant analyses indicated, however, that lead levels exceeded the safe level in plant materials in several treatments that received composted garbage mulch. The authors conclude that composted garbage mulch and FBCR are useful materials in establishing vegetative cover on acid mine soils and this use also provides a means of disposing of these waste materials.

1112. Stringer, J. W., and S. B. Carpenter. Energy Content of Black Locust Growing on Surface Mined Land. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 243-248.

This study was conducted to determine the total energy content and usable energy content of the aboveground portion of black locust (*Robinia pseudoacacia* L.). Biomass sample plots were established in 84 black locust stands, ranging in age from 2 to 10 years, located in eastern Kentucky. The aboveground portion of each tree within a 10-m^2 plot was harvested and divided into four parts (leaves, current growth, wood, and bark), which were weighed, dried, and reweighed. Heat of combustion values of each plant part were determined using a Parr 1241 adiabatic oxygen bomb calorimeter. Heat content was determined using heat of combustion and biomass data. The specific gravity of the wood was also calculated.

The total biomass ranged from 4,365 kg ha^{-1} for 2-year-old stands to 34,878 kg ha^{-1} for 9-year-old stands. Average whole-tree heats of combustion ranged from 8,600 Btu lb^{-1} for 2-year-old stands to 8,539 Btu lb^{-1} for 10-year-old stands. The average energy content of 2-year-old stands was less than that of 10-year-old stands, 8,357 and 8,440 Btu lb^{-1}, respectively. Two-year-old stands contained the lowest total energy contents, averaging 82.5 and 50.9 MBtu ha^{-1} for aboveground and woody biomass, respectively. Nine-year-old stands had the highest amount of energy upon combustion, 655.3 and 576.9 MBtu ha^{-1} for aboveground and woody biomass, respectively. Nine-year-old stands also had the highest usable heat content for whole-tree biomass, 483.4 MBtu ha^{-1}, and woody biomass, 432.8 MBtu ha^{-1}. Annual usable energy contents for the 9-year-old stands were the highest for total and woody biomass, 53.7 and 48.1 MBtu ha^{-1}, respectively. This study shows the advantages of using black locust, grown on surface-mined land, as a fuel source.

1113. Stroo, H. F., and E. M. Jencks. Effect of Sewage Sludge on Microbial Activity in an Old, Abandoned Minesoil. J. Environ. Qual., v. 14, No. 3, 1985, pp. 301-304.

The effects of applying lime, fertilizer, lime plus fertilizer, and sewage sludge to lime plus fertilizer on the microbial activity and growth of tall fescue (*Festuca arundinacea* Schreb.) on an old (18 years since initial reclamation), acidic (pH 4.6), infertile mine soil were evaluated. Sewage sludge was applied at 50 and 100 kg ha^{-1} plus lime plus fertilizer. The indices of microbial activity analyzed were respiration rate and activities of amylase, urease, and phosphatase.

Respiration rates were significantly increased by all treatments. The fertilizer treatment resulted in significantly higher respiration rates than did the lime treatment. Lime did not enhance the effect of fertilizer in promoting microbial activity. Sludge at both application rates significantly increased the rate of respiration. Amylase activity was related to the respiration rate data, with liming having no effect on the activity of amylase. Activity of both the urease and phosphatase was poorly related to respiration rate. Tall fescue yield was increased by all treatments. The results show that microbial populations do exist in these mine soils and that their activity can be increased by liming and fertilization. Sewage sludge applications enhance the effect of lime and fertilizer. Respiration rate and amylase activity are reliable indicators of microbial activity, while urease and phosphatase activities appear to be of little value for evaluating mine-soil microbial activity.

1114. Stucky, D. J., J. H. Bauer, and T. C. Lindsey. Restoration of Acid Spoils With Sewage Sludge: I. Revegetation. Reclam. Rev., v. 3, No. 3, 1980, pp. 129-139.

The authors' purpose was to study several critical factors that are necessary to provide guidelines for further applications of large quantities of sewage sludge to acidic strip mine spoil. The site of this study was the Palzo tract in southern Illinois. The objectives of this study were to determine differences among plants in their ability to (1) become established and tolerate adverse parameters such as pH and soluble salts, and (2) exclude or accumulate metals.

Reed canarygrass (*Phalaris arundinacea* L.), switchgrass (*Panicum virgatum* L.), and orchardgrass (*Dactylis glomerata* L.) were the most successfully established species after three growing seasons. From the time of initial planting to the end of the third growing season, reed canarygrass, switchgrass, and orchardgrass increased their percent aerial cover from 27 to 94, 14.5 to 73, and 36.5 to 63.5 pct, respectively. Each species had a minimum pH that their roots would tolerate; for reed canarygrass it was 3.5, for switchgrass it was 3.7, and for orchardgrass it was 4.2. All three species were also able to establish themselves in the presence of potentially toxic quantities of cadmium, copper, lead, manganese, nickel, and zinc. For example, after one growing season the cadmium contents in the tops of reed canarygrass, switchgrass, and orchardgrass were 6.5, 10, and 2.8 ppm, respectively. By the end of the third growing season, however, all elements in the plant tops were within ranges that are not considered to be toxic or harmful. In general, when the pH was greater than 5.5, quantities of metals in the plants were lower than when the mean pH was less than 5.5. The authors conclude with a list of suggested guidelines for future applications of sewage sludge on acidic mine spoils.

1115. Stucky, D. J., R. J. Christ, and R. L. Holmes. Greenhouse Studies of Growth and Yield of Soybeans in Sub-Surface Horizon Materials. Reclam. & Reveg. Res., v. 5, No. 4, 1986, pp. 461-481.

This greenhouse study was conducted to assess the subsoil and parent materials from six Alfisols and two

Entisols from southern Illinois as growth mediums for soybean (*Glycine max* (L.) Merr.). This study was in response to Public Law 95-87 (SMCRA), which requires the separate removal and replacement of A (topsoil), B (subsoil), and C (parent material) horizons to construct a final rooting medium of not less than 122 cm; however, B and C horizons can be mixed or parent material may be used alone if equal or greater productivity can be achieved compared with the soil that existed prior to mining. For each of the eight soils, five single or combination horizon treatments were developed at two fertility levels: amended with lime, phosphorus, and potassium, and nonamended. The soil horizon treatments for the Alfisols were (1) B-horizon material, (2) C_1-horizon material, (3) a 1:3 ratio of B- to C_1-horizon materials, (4) II C_1-horizon material, and (5) a 1:3 ratio of B- to II C_2-horizon materials. The five horizon treatments for the Entisols were (1) B-control-section material, (2) C_1-horizon material, (3) 1:3 ratio of B-control to C_1-horizon materials, (4) C_2-horizon material, and (5) a 1:3 ratio of B-control to C_2-horizon materials. Soils were analyzed for texture, CEC, pH, phosphorus, potassium, magnesium, calcium, zinc, manganese, copper, iron, sodium, boron, and organic matter. Planted soybeans were measured at maturity for yield, height, and tissue concentrations of nitrogen, phosphorus, potassium, calcium, copper, iron, magnesium, manganese, zinc, sodium, sulfur, and boron.

Yield data from the amended and nonamended treatments indicate that the productive potential of the subsurface horizons would be equivalent to that of topsoil or increased if (1) soil other than nonamended B- or B-control-horizon material alone were used, or (2) if the B-C, the B-, or B-control-horizon material were amended with lime and fertilizer. Reduced plant growth and yields were related to an accumulation of excessive quantities of minor elements.

1116. Stucky, D. J., and T. C. Lindsey. Effect of Soil Compaction on Growth and Yield of Soybeans Grown in a Greenhouse on Several Reconstructed Soil Profiles From Prime Farmland in Southern Illinois. Reclam. & Reveg. Res., v. 1, No. 4, 1982, pp. 297-309.

This greenhouse study evaluated the effect of soil compaction on the ontogeny and yield of soybeans (*Glycine max* (L.) Merr.) on reconstructed prime farmland soil horizons. A Proctor test was used to gain information that might help maximize the yield of prime farmland soils reconstructed after surface mining. Soil materials used in this study were collected from two potential surface mine sites in Perry and Jackson Counties in southern Illinois. Soil from each horizon (A, B, C, and C_2) plus a 1:3 ratio mixture of B-C_1 and B-C_2 horizons was fertilized and compacted into pots at three different bulk densities. The bulk densities were (1) not compacted (1.2 g cm^3), (2) moderately compacted (1.4 g cm^3), and (3) severely compacted (1.6 g cm^3).

The results indicate that yields decrease as soil compaction increases. In all cases plants grown in soil compacted to 1.4 g cm^3 outyielded plants grown in severely compacted soil (1.6 g cm^3). By blending the B- and C-horizon material at a 1:3 ratio, significantly higher plant yields were obtained compared with plants grown in B-horizon soil material. Yields of plants grown in the C horizon were not significantly different from yields of plants grown in the A horizon. Potentially, the most useful information derived from the Proctor test was the determination of the soil moisture percentage at which soils are least susceptible to compaction. The Proctor test can also be used to determine the effect of blending horizons or adding organic matter on the compactibility of reconstructed mine soil.

1117. Stucky, D. J., and A. L. Zoeller. Restoration of Acidic Mine Spoils With Sewage Sludge: II. Measurement of Solids Applied. Reclam. & Reveg. Res., v. 3, No. 3, 1980, pp. 141-147.

A greenhouse study was conducted at Southern Illinois University in Carbondale, IL, prior to the reclamation of an acid mine spoil. The objectives of the study were to (1) identify the critical soil parameters, (2) provide information so an equation could be computed to determine approximate quantities of sewage sludge needed to be incorporated into the spoils to achieve the desired spoil pH, and (3) provide information for an equation so that, following sludge incorporation, measured quantities of critical parameters could determine the approximate amount actually applied in the soil profile. Sewage sludge, at equivalent rates of 0, 224, 336, and 448 dry mt ha^{-1}, was mixed with acidic mine spoil and placed in pots in the greenhouse. Orchardgrass (*Dactylis glomerata* L.) was then seeded into the pots 48 h after incorporation of the sludge. Orchardgrass was the species chosen because it had been successfully established at the Palzo tract in southern Illinois. Parameters measured were pH, organic matter, cation-exchange capacity, electrical conductivity, and yield. The parameters were measured at the time of seeding and 5 months after planting.

The data collected at the time of planting had the greater predictability value. Spoil pH was the most important parameter measured in order to predict the rate of applied sewage sludge. Additional accuracy was obtained by including the cation-exchange capacity in the equation. The authors conclude that soil properties can be used to estimate the amount of sewage sludge solids that are needed to reclaim acid mine spoils and to estimate the quantities incorporated.

1118. Stypa, M., A. N. Barrios, D. A. Barry, M. H. Miller, and W. A. Michell. Effects of Subsoil Bulk Density, Nutrient Availability and Soil Moisture on Corn Root Growth in the Field. Can. J. Soil Sci., v. 67, No. 2, 1987, pp. 293-308.

Influences of subsoil bulk density, nutrients, and soil-plant water relations on corn (*Zea mays* L.) growth were determined over a 4-year period. A silt loam soil with a well-structured, but compact B horizon was compared with an artificially created soil (soil-peat-perlite) without subsoil compaction. Despite the high bulk density and penetrometer resistance in the 15- to 45-cm depths (1.5 Mg cm^{-3}) of the silt loam soil, corn roots developed as well, with little morphological differences, in the natural soil as in the artificially created soil. Natural structural cracks and biopores allowed for root development with minimum restriction. Roots did not develop below 45 cm because of the high bulk density, 1.80 Mg cm^{-3}. Roots were found, however, at greater depths in the artificially created soil. Shoot dry matter and yield were the same in all years in both soils. Fertility treatments had little influence on root distribution, but phosphorus and potassium availability was increased in the 0- to 15-cm layer of the silt loam soil, with high levels of fertilization resulting in greater shoot dry matter. Irrigation did not alter root length or root distribution in the silt loam soil.

1119. Sullivan, P. J., M. E. Essington, and L. K. Spackman. Equilibrium Analysis of Retorted Oil Shale. Am. Soc. Agron., Agron. Abstr., 1986, p. 37.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. A retorted oil shale was subjected to several equilibrium evaluations ranging in length from 24 h to 6 months. Total soluble inorganic and organic components, pH, and Eh were determined for each extract.

1120. Sullivan, T. E. Monitoring Soil Physical Conditions on a National Forest in Easter Oregon: A Case Study. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 69-76.

Guidelines developed by the Pacific Northwest Region, USDA Forest Service, for sampling physical conditions of surface soil were used to monitor the impact of tractor logging and machine piling (cleanup of logging slash) on soils in 24 different cutting units in eastern Oregon. There was concern that excessive soil resource damage was occurring on these units. Results of the monitoring program confirmed that machine piling and multiple entries onto a particular unit were causing excessive soil compaction. Recommendations are given to help alleviate the compaction problem on these units.

1121. Sundstrom, F., and R. D. Morse. Legume Inoculation Following Seedling Establishment in Mine Soils. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 13-19.

The objectives of this study were to determine the influence of nitrogen availability and time of inoculation on nodulation, N_2 fixation, and growth of snap bean (*Phaseolus vulgaris* L.) in 4-year-old mine soil from Wise County, VA. Treatments used were (1) fertilization and inoculation at planting, (2) fertilization at planting and inoculation delayed 21 days, (3) fertilization at planting and no inoculation, (4) inoculation at planting and fertilization delayed 21 days, and (5) appropriate controls. Fertilization rates were 0, 25, 50, and 100 kg ha^{-1}. All treatments were duplicated in a growth chamber study and a field study. Nitrogen fixation was measured by nitrogenase activity using the acetylene reduction method. At maturation both studies were terminated, and plant shoot, root, and nodule dry weights were determined along with percent total nitrogen in the roots and shoots.

The nitrogen fixation responses to nitrogen fertilization and treatment were found to be complex and interrelated. The highest amount of nodule mass and gaseous nitrogen fixed, however, occurred at a fertilization rate of 25 kg ha^{-1} N. No significant differences were found between nitrogen fertilizer rate and percent nitrogen in the shoots and roots. This indicates that the plants were receiving adequate nitrogen regardless of the nitrogen source (fertilizer or fixed) or the fertilization rate.

1122. Sutton, P. Influence of Amendments on Acid Mine Spoil Properties and Plant Cover. Am. Soc. Agron., Agron. Abstr., 1988, p. 49.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The long-term effects of composted papermill sludge, fly ash, sewage sludge, and topsoil on the chemical properties of acid mine spoil and vegetative cover were studied. Rates of application were (1) composted papermill sludge, 67, 90, and 112 Mg ha^{-1}, (2) fly ash, 448 Mg ha^{-1}, (3) sewage sludge, 224 Mg ha^{-1}, and (4) 20 cm of topsoil. Ground cover of a grass-legume mixture was initially 100 pct. After nine growing seasons, cover (plant plus litter) was 88, 95, 95, and 99 pct for fly ash, papermill sludge, sewage sludge, and topsoil treatments, respectively. Additional phosphorus and potassium fertilization did not increase ground

cover. Application of lime (4.5 Mg ha^{-1}) to the fly ash and sludge treatments did not affect soil pH values after 6 years. Fertilizer applications of phosphorus and potassium did increase phosphorus and potassium concentrations in fertilized subplots over unfertilized subplots.

1123. Tackett, E. M. Boissevain Reclamation Project—A Multidisciplinary Approach to Abandoned Mineland Reclamation. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 32-38.

This article describes an abandoned mine-land reclamation project conducted in northwestern Virginia. The project area consisted of coal refuse stored in piles and along the banks of a local stream. The reclamation project followed a series of steps, beginning with an environmental assessment of the site. The major environmental problems identified were potential hazards associated with flooding and refuse sliding, erosion, and aesthetics. Four reclamation alternatives were developed, along with their estimated costs and impacts on the environment. The reclamation alternatives included grading refuse piles and fill to new contours, removing coal refuse from the stream banks, installing permanent drainage features, and direct revegetation of the recontoured coal refuse. Revegetation activities included the heavy application of lime, fertilizer, and wood fiber mulch, seeding of grass and legume species for erosion control and site protection, and the planting of white pine (*Pinus strobus* L.) and autumn olive (*Elaeagnus umbellata* Thunb.). Herbaceous cover and woody species survival percentages are presented for data collected 1 and 4 years after plant establishment. The author relates the success of this project to an effective approach to problem assessment, including determining reclamation goals, formulation of a cost-effective reclamation plan, and the successful implementation of the plan.

1124. Tackett, E. M., and D. H. Graves. Evaluation of Direct-Seeding of Tree Species on Surface Mine Spoil After Five Years. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 28-Dec. 2, 1983). Univ. KY, Lexington, KY, 1983, pp. 437-441.

The authors present the 5-year results of a study designed to evaluate the effects of aspect, mulch, fertilization, and competition on five tree species direct seeded on mine spoil near Jackson, KY. Three large-seeded tree species, northern red oak (*Quercus rubra* L.), pin oak (*Quercus palustris* Muenchh.), and bur oak (*Quercus macrocarpa* Michx.), and one small-seeded species, paulownia (*Paulownia tomentosa* (Thunb.) Steud.), were spot seeded, while European black alder (*Alnus glutinosa* (L.) Gaertn.) was broadcast seeded. The treatments consisted of five mulch treatments (a control, hydromulch, shredded bark, shredded bark plus chicken manure, and Real Earth—a composted municipal waste and sewage sludge mixture), three fertilizer treatments (0, 200, and 400 lb $acre^{-1}$ of 16-32-8 fertilizer), and a 1:1 mixture of yellow sweetclover (*Melilotus officinalis* Lam.) and tetrablend ryegrass (*Lolium perenne* L.) broadcast seeded at either 0, 10, or 20 lb $acre^{-1}$.

First-year growth was not affected by the treatment variables tested. After 5 years, however, the variation in percent stocking (survival) was a function of aspect and competition. Mulching and fertilization had no significant effects on the stocking rates. Competition from ground cover plants had a significant effect on the growth of direct-seeded trees after 5 years. Grasses and legume competition resulted in a 35-pct reduction in the average height growth of the seeded species. The results indicate that direct seeding of trees on mine spoil can be successful if the proper materials and techniques are used.

1125. Tackett, S. L., E. R. Winters, and M. J. Puz. Leaching of Heavy Metals From Composted Sewage Sludge as a Function of pH. Can. J. Soil Sci., v. 66, No. 4, 1986, pp. 763-765.

The relative short-term leaching rates of cadmium, copper, iron, lead, and zinc from commercially composted sewage sludge as a function of pH were determined. The pH range examined was 2.5 to 7.0 in 0.5-pH-unit intervals. Zinc and cadmium showed large increases in concentration with decreased pH; the greatest concentration increase for both occurred between pH 6.0 and 5.5. Iron, copper, and lead did not show any significant change in concentration as a function of pH under the experimental conditions imposed.

1126. Tackett, S. L., and A. M. Yadvish. Heavy Metals in Soil From Land Reclamation With Sludge. J. Water Pollut. Control Fed., v. 59, No. 5, 1987, pp. 294-298.

Heavy-metal concentrations of surface-mined soils amended with sewage sludge were determined at three sites in Pennsylvania 4 to 5 years after application. These concentrations were compared with those measured before and immediately after sludge application. The sludge was applied at each site at a rate of 12.8 kg m^{-2} as a dry compost-cake mix (60 pct sludge and 40 pct wood chips). The sludge was incorporated into the top 4 in of soil.

At each site the concentrations of lead, copper, and zinc were significantly higher 4 to 5 years following application than before application or 1 year after application. There was a relationship between metal buildup in the soil and

the metal concentrations of the original sludge applied. The higher than expected concentration of heavy metals in the sludge-reclaimed soils may have resulted from the high metal concentration in the soil before sludging, the use of sludge rates greater than 12.8 kg m^{-2}, or the use of sludge containing higher metal contents than the stated analysis. The authors conclude that the high and variable metal concentrations found in the sludge-reclaimed soil resulted from the variability in the amount of sludge used, variability in the evenness of spreading, and variability in the metal concentrations of the sludges used. The authors recommend that total metal concentrations of soils should be determined, not just extractable metal concentrations.

1127. Taki, S. K., M. H. Rowell, W. B. McGill, and M. Nyborg. Reclamation and Vegetation of Surface Mined Areas in the Athabasca Tar Sands. (Syncrude Canada Ltd., contract 5-39619, Dep. Soil Sci., Univ. AB). Syncrude Canada Ltd., Edmonton, AB, Canada, Environ. Res. Monogr. 1977-1, 1977, 170 pp.

A growth-chamber study was used to determine the performance of a number of native and cultivated plant species on oil sand mining waste materials under different salinity, soil reaction, fertility, soil mix, and oil conditions. An accompanying field trial was conducted on a vegetated area of a tailings pond dike to determine responses of the established vegetative cover to different fertility levels and to determine the fate of added fertilizer nutrients. Both studies were conducted over a 1-year period.

It is recommended that the oil-sand-bearing materials be mixed with fertilizer and a good soil material and left for one growing season before seeding, at which time fertilizers should again be applied. Where salinity levels are extreme, normal chemical means of reclaiming saline soils prior to planting should be applied. Where salinity is low to moderate, tolerant plant species could be seeded without chemical reclamation. Acidification is recommended in areas of high pH (about 10). This treatment should be accompanied by correction of salinity problems where appropriate. Legumes can be grown successfully in the soil mix in near-neutral soils; the seeds are inoculated with the proper inoculant, and plant nutrients are provided in the soil mix. Balanced stands of legumes and grasses may be obtained by using seeding mixtures consisting of species of grasses and legumes that would compete on an equal basis or by using a larger percentage of legume seeds in the seeding mixture and by ensuring soil conditions favoring legumes in competition with grasses. Initial fertilizer rates should not be less than 80 lb N, 40 lb P, and 80 lb K per acre per year after the establishment of vegetation. A seedbed allowing deeper root penetration is of high priority in establishing greater slope stability. Cultivated species grew at least as well as the native species in the short-term experiments. An important consideration in revegetation is the capacity of soils to withstand acidification. Tailings sand and both lean and heavy oil sands are extremely poorly buffered against acidity. Under conditions likely to prevail near an extraction plant, they could be expected to be acidified to levels at which plant growth would be eliminated with 10 years of exposure. The buffering capacity of this material could be increased to acceptable levels by mixing with peat and overburden materials. No material tested was devoid of microbial activity. High populations of sulfate-reducing organisms were reported. Tailings materials and overburdens were shown to have a limited ability to supply available forms of nitrogen and phosphorus to plants. Natural levels of atmospheric nitrogen fixation by free-living microorganisms were low.

The results reported in this publication are to some extent specific for reclamation of oil sand mining waste materials; however, they could find application in planning reclamation efforts for other materials possessing similar properties. The research reported was conducted 22 miles north of Fort McMurry, AB, Canada.

1128. Tate, R. L., III. Microorganisms, Ecosystem Disturbance and Soil-Formation Processes. Ch. in Soil Reclamation Processes: Microbial Analyses and Applications, ed. by R. L. Tate III and D. A. Klein. Marcel Dekker, 1985, pp. 1-33.

Examples are presented of the types of microbial transformations that are important to soil development. Long-term plant community structure, as well as successful establishment of vegetative cover, depends on the development of a functional soil microbial community. The development and activity of the functioning microbial community are limited by the physical and chemical conditions of the mine soil. Carbon mineralization and the nitrogen cycle are discussed to provide background information on microbial processes.

1129. Taylor, E. M., Jr., and G. E. Schuman. Element Levels of Barley (*Hordeum vulgare*) Grown on Flyash and Lime Amended Acidic Coal Spoils. Am. Soc. Agron., Agron. Abstr., 1984, p. 37.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. Fly ash and calcium carbonate, each at five levels, were applied to acidic coal spoils to increase the pH of these spoils. Three topsoil treatments were applied to the above amendments and fertilized with 90 kg ha^{-1} N and P. Barley (*Hordeum vulgare* L.) was used as the test species. Results indicate that fly ash or lime can be used to alleviate acidic conditions, but boron toxicity may result at high levels of fly ash additions.

1130. Taylor, E. M., Jr., and G. E. Schuman. Fly Ash and Lime Amendment of Acidic Coal Spoil To Aid Revegetation. J. Environ. Qual., v. 17, No. 1, 1988, pp. 120-124.

Acid spoil material was collected at the Glenrock Coal Co. Mine near Glenrock, WY, and used in a greenhouse study to evaluate the effect of fly ash and lime on ameliorating the low pH (2.7) of the spoil. Amendment rates were 0, 10, 20, 30, and 40 g fly ash per kilogram of spoil and 0, 10, 20, 40, and 80 g of lime per kilogram of spoil. Topsoil depths of 0, 10, and 20 cm were placed over each of the amended spoil treatments. Both the topsoil and spoil materials were chemically and physically analyzed prior to the addition of the amendments, and the soil and spoil were analyzed for water-soluble boron and pH as affected by each amendment. Barley (*Hordeum vulgare* L.) was used to evaluate the effects of soil amendments and topsoil on aboveground and belowground plant biomass, root distribution, and concentration of plant elements in the aboveground tissues.

The pH of the spoil material was significantly increased by applying lime and fly ash, regardless of the rate of application. Fly ash amendments resulted in significantly greater aboveground biomass when topsoil was not used; however, when 10 or 20 cm of topsoil was placed over the spoil, amending the spoil with fly ash had no effect on aboveground biomass. Lime additions to spoil not covered with topsoil resulted in higher aboveground biomass than did nonlimed spoil. There were, however, no significant differences in plant aboveground biomass among liming rates within the no-topsoil treatment. When 10 or 20 cm of topsoil was placed over the spoil, lime additions did not affect plant aboveground biomass. Topsoil alone also increased plant aboveground biomass. The application of fly ash significantly increased root biomass when no topsoil was used. When topsoil was placed over an unamended spoil, root growth and biomass were limited to the depth of the topsoil. When the topsoil was placed over amended spoil (lime or fly ash), root biomass and distribution patterns were more uniformly spread throughout the soil-spoil profile. Lime amendments did not result in any toxicity symptoms in the test plant. Fly ash amendments, however, resulted in boron toxicity symptoms and elevated boron concentrations in the barley aboveground tissues. Even though boron was present at potentially toxic levels, no significant yield reductions occurred.

The authors conclude that fly ash is a feasible alternative to lime for ameliorating acid mine spoils in the Northern Great Plains Coal Mining Region. Site-specific conditions need to be considered, however, because of the variability in spoil and fly ash characteristics. Since this was a greenhouse study, all keywords received a good evaluation, except for the chemical characterization of the spoil material. Although the research conducted was sound, field trials are necessary to support the results obtained in the greenhouse study. This article is an excellent reference and contains good background information for further research on the use of fly ash as a soil amendment on acidic spoil in the Northern Great Plains.

1131. Taylor, R. W., and I. O. Ibeabuchi. Heavy Metal Uptake by Four Forage Grasses at Various Clipping Dates on Acid Mine Spoils. Am. Soc. Agron., Agron. Abstr., 1986, p. 37.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. Heavy-metal uptake, aluminum uptake, and changes in metal levels at different clipping dates were investigated using four forage grasses growing on three different Alabama acid mine spoils. Bermudagrass (*Cynodon dactylon* (L.) Pers.) grew best on all spoils; clipping intervals did not influence dry matter yield or metal uptake. Oat (*Avena sativa* L.) growth was reduced after the second clipping, and there were significant differences in dry matter yield and metal uptake at the various clippings. Both triticale (X. *Triticosecale* Wittmack) and perennial ryegrass (*Lolium perenne* L.) had insufficient growth to clip at the first and second clippings.

1132. Taylor, S. L., M. McDonnell, and W. A. Niering. Recycled Industrial Wastes Aid Revegetation. Compost Sci./Land Util., v. 21, No. 3, 1980, pp. 18-20.

The authors evaluated the potential value of recycled mycelium, an industrial residue produced from the fermentation processes of organic acids and antibiotics, in rehabilitating an unused gravel pit in Ledyard, CT. The experimental treatments were (1) fresh citric acid mycelium, (2) composted mycelium, (3) fresh mycelium mixed with topsoil, (4) sandy loam topsoil only, and (5) untreated control plots. The mycelium and mycelium-topsoil mixtures were spread by hand to a depth of 5 to 8 cm and covered any existing herbaceous plants. At the end of two growing seasons, percent cover of plants was estimated on all plots. The results indicate that plant cover, particularly annual species, increased in plots treated with mycelial residues compared with topsoil-treated and control areas. The greatest increase in plant cover occurred on composted mycelium plots. Approximately 90 pct of the ground was covered with newly established plants by the end of two growing seasons. The authors conclude that the use of mycelial residues in the revegetation of sparsely vegetated or unvegetated, well-drained, nutrient-poor, gravelly sites appears to be a sound land use practice. The application of mycelial residues hastens the natural revegetation process.

1133. Tester, C. F. Comparison of Tall Fescue Grown in Greenhouse, Growth Chamber and Field Plots of Evesboro Soil Amended With Either Sewage Sludge Compost or Fertilizer. Am. Soc. Agron., Agron. Abstr., 1987, p. 34.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. The effects of sewage sludge compost and complete fertilizer amendments on yields, nitrogen content, and phosphorus content of tall fescue (*Festuca arundinacea* Schreb.) were evaluated. Rates of compost application were 0, 44.8, 89.6, and 134.4 Mg ha^{-1}. In each growth environment studied, compost amendments linearly increased fescue yields. Equivalent dry matter yields were obtained for greenhouse-grown fescue at 134.4 Mg ha^{-1} compost and complete fertilizer treatments. In the field, however, equivalent yields were obtained at a 61-Mg-ha^{-1} compost application rate.

1134. Thellier, C., B. Fritz, H. Paquet, J. Y. Gac, and N. Clauer. Chemical and Mineralogical Effects of Saline Water Movement Through a Soil During Evaporation. Soil Sci., v. 146, No. 1, 1988, pp. 22-29.

A column experiment was conducted to determine the chemical effects of evaporation of water from a simulated shallow aquifer through a homogenous sandy clay loam soil. Each of three columns (11, 11, and 51 cm in length) were exposed to different periods of evaporation (75 or 210 days). One 11-cm column was exposed to evaporation for 75 days, and the other 11-cm column and the 51-cm column were exposed to evaporation for 210 days. Each column was placed in a tank filled with water so that the lower 2 cm was permanently submerged. Oxygen isotopes were used to characterize the nature of water transfer in each column. Major soil elements (silicon, aluminum, iron, calcium, potassium, sodium, magnesium, and titanium) and the amount of soluble salts were also determined as a function of depth. The oxygen isotopic study showed the location in each column at which evaporation took place, at the surface in the shorter columns and lower in the profile when column length increased. Water moved upward by capillarity through the soil profile, resulting in the transfer of soluble ions (calcium, magnesium, and sodium) from the lower profile toward the soil surface where evaporation took place. Some of the soluble species precipitated at the soil surface. A thermodynamic computer simulation of direct evaporation of aquifer water and mass balance calculations of the mass transfer suggest that magnesium-rich minerals will form at the soil surface. This was confirmed by TEM observation.

1135. Thicke, F. E., R. G. Hoeft, W. L. Banwart, and L. V. Boone. Effect of Fly Ash and Flue Gas Desulfurization Sludge on Corn and Soybean Growth and Yield. Am. Soc. Agron., Agron. Abstr., 1986, p. 37.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. The effects of fly ash, flue gas desulfurization sludge (FGD-sludge), and a coal-fired powerplant discharge mixture of fly ash and FGD-sludge on corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) growth were investigated. Each material was applied at rates of 1,120, 11,200, 56,000, and 112,000 kg ha^{-1}. One-time applications of each material at rates of 11,200 kg ha^{-1} or less did not have any detrimental effects on the growth or yield of corn or soybeans. Fly ash rates of 56,000 kg ha^{-1} or more resulted in boron toxicity symptoms and elevated boron levels in both corn and soybeans and in reduced corn yields. Soybean yields were not reduced by rates of up to 112,000 kg ha^{-1} regardless of the material applied.

1136. Thicke, F. E., R. G. Hoeft, W. L. Banwart, and L. V. Boone. Effect of Scrubber Sludge and Fly Ash on Corn and Soybeans Grown on Three Soils in a Greenhouse. Am. Soc. Agron., Agron. Abstr., 1987, p. 35.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. A greenhouse pot study was conducted to evaluate soybean (*Glycine max* (L.) Merr.) and corn (*Zea mays* L.) growth in three soils (silty-clay loam, silt loam, and sand) amended with scrubber sludge or fly ash. The crops were grown sequentially. Rates of scrubber sludge and fly ash were 0.5, 5, 25, 50, and 100 g kg^{-1}. Corn grown on the silt loam or silty-clay loam had reduced dry matter yield and exhibited boron toxicity symptoms when the soils were amended with 50 g kg^{-1} or more of fly ash. In the sandy soil the same results occurred with 25 g kg^{-1} or more of fly ash. Soybeans had boron toxicity symptoms and reduced dry matter production when fly ash was applied at rates of 25 g kg^{-1} on any of the soils tested. Scrubber sludge did not produce any toxicity symptoms in either of the crops tested, but rates of 50 g kg^{-1} or more resulted in reduced yields in both crops in all three soils.

1137. Thicke, F. E., R. G. Hoeft, W. L. Banwart, and L. V. Boone. Effect of Scrubber Sludge and Fly Ash on Soil Physical and Chemical Properties. Am. Soc. Agron., Agron. Abstr., 1988, p. 49.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The effects of scrubber sludge, fly ash, and Poz-O-Tec (mixture of scrubber sludge and fly ash with 2 to 3 pct CaO added) on soil physical and chemical properties were investigated. All amendments were moldboard plowed into field plots at 0, 1.12, 11.2, 56, and 112 Mg ha^{-1}. Scrubber sludge and

Poz-O-Tec applications reduced penetrometer readings at the 5- and 10-cm depth; fly ash applications did not affect penetrometer measurements. Soil bulk density was reduced in the upper 30 cm of soil when scrubber sludge was applied. Fly ash and Poz-O-Tec treatments did not affect bulk density. Soil pH in the upper 15 cm of soil was increased from 6.8 to 7.3 when 112 Mg ha^{-1} of Poz-O-Tec was applied. Soil pH values were not affected by scrubber sludge or fly ash amendments.

1138. Thomas, D., and I. J. Jansen. Soil Development in Coal Mine Spoils. J. Soil and Water Conserv., v. 40, No. 5, 1985, pp. 439-442.

The effects of soil development (time) at eight surface-mined sites in Illinois were evaluated. Spoils ranged in age from 5 to 64 years old and had been surface mined prior to SMCRA of 1977. Soil physical, chemical, and micromorphological properties were measured. The original horizons had not been segregated or replaced at any of the sites. The reclamation methods used varied by site. Soil development was evident at all sites. The most apparent was the development of an A1 horizon darkened by organic matter. The zone below the A1 horizon was designated as a C1 horizon. No B horizon was described at any site because weak structure was the only evidence of soil development; there were no color changes, leaching, or clay translocation. Genetic soil structure was evident near the surface of all soils, ranging in depth from 3 cm at the 5-year-old site to 35 cm at the 55-year-old site. There was a general relationship between soil development and time since the most recent disturbance.

1139. Thompson, P. J., I. J. Jansen, and C. L. Hooks. Penetrometer Resistance and Bulk Density as Parameters for Predicting Root System Performance in Mine Soils. Soil Sci. Soc. Am. J., v. 51, No. 5, 1987, pp. 1288-1293.

A method is needed to predict root system performance in mine soils quickly and easily and to compare mine soils on their suitability for root growth. This study evaluated the effectiveness of penetrometer resistance and bulk density as parameters for predicting root system performance in mine soils. A model was developed that would predict the average root length density in the lower portion of the root zone (67 to 110 cm) using penetrometer resistance or average bulk density as the predictor variable. Penetrometer resistance and bulk density were highly correlated in the lower root zone, but poorly correlated near the surface. The results suggested that bulk density was a better predictor (R^2 = 0.81) of the effective rooting depth than penetrometer resistance (R^2 = 0.73). A model utilizing both penetrometer resistance and bulk density as independent variables resulted in the best fitting model investigated (R^2 = 0.90).

1140. Thompson, T. L., and L. R. Hossner. Effects of Drainage and Amendments on the Physical Properties of Bauxite Residue. Am. Soc. Agron., Agron. Abstr., 1986, p. 37.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. The effects of subsurface drainage, gypsum, and acid additions on the hydraulic conductivity of bauxite residue and on the pH and salt content of the leachate were studied. Leachate salt content decreased with time as soluble salts were leached, while the leachate pH remained high because of the presence of the alkaline salts and the hydrolysis of sodium. Wetting and drying cycles resulted in the formation of aggregates, which increased the hydraulic conductivity. General properties of bauxite residue, waste produced when aluminum is extracted from bauxite using the Bayer process, are given.

1141. Thornburg, A. A. Plant Materials for Use on Surface-Mined Lands in Arid and Semiarid Regions. U.S. Soil Conserv. Serv., SCS-TP-157, EPA-600/7-79-134, Jan. 1982, 88 pp.

This publication describes the characteristics, areas of adaptation, and performance of numerous herbaceous and woody plant species that have been found to have potential for use in revegetating surface-mined land in the arid and semiarid regions of the United States. Species selection, use, establishment, availability, and management techniques are discussed for a large number of native and introduced grasses, forbs, and woody plants. Sources of more specific information are suggested. This is an excellent publication and highly recommended as a reference manual to individuals considering potential species composition for surface mine revegetation.

1142. Thurman, N. C., J. C. Sencindiver, J. T. Ammons, and D. C. Adamo. Physical Properties of Minesoils and Their Effects on Root Growth. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 194-208.

Soil morphological and physical data were collected from 86 mine soils located in five Eastern and Midwestern States. The mine soils ranged in age from less than 1 year to more than 30 years old. Profiles were described using standard soil survey techniques, and the horizons were sampled for analysis. Data on bulk density, porosity, moisture retention, rock fragment content, texture, and root growth were reported. Twenty-seven of the mine soils had topsoil replaced. The predominant textures were loam, clay loam, and silty-clay loam. Total bulk density ranged from 1.11 to 2.07 Mg m^{-3} in the surface horizons

to 1.14 to 2.44 Mg m^{-3} in the subsurface horizons. Surface porosities ranged from 8 to 56 pct, while subsurface porosities ranged from 2 to 61 pct. The higher bulk densities (>2.1 Mg m^{-3}) and low porosities (<15 pct) were associated with horizons that had low rock fragment percentages and clay contents in excess of 27 pct. Water retention differences were higher in the surface horizons because of lower rock fragment percentages. Topsoiled mine soils had higher bulk densities, moisture retention, and water retention differences and lower rock fragment percentages in the surface horizons and higher porosities in the subsurface horizons than did nontopsoiled mine soils. Rooting depth extended below 100 cm in two-thirds (41) of the profiles that were 2 years or older, a total of 64 sites. Acidity was the major factor limiting root growth.

1143. Thurman, N. C., and J. C. Sencindiver. Properties, Classification, and Interpretations of Minesoils at Two Sites in West Virginia. Soil Sci. Soc. Am. J., v. 50, No. 1, 1986, pp. 181-185.

Soils on two minesites in northern West Virginia were classified using the proposed suborder Spolent. Nonagricultural land use interpretations were measured or estimated based on mine-soil properties, and the limitations for selected nonagricultural uses on the minesites were determined. Soil analyses were conducted using standard soil survey procedures. Mine-soil properties were compared with those of adjacent native soils. Mine soils had more rock fragments, lower erodibility estimates (K factors), higher overall bulk densities, lower porosity, and lower soil pH than native soils. Mine soils also had an irregular distribution of organic carbon with depth and a plasticity index that was rated as fair to good. The saturated hydraulic conductivity of mine soil was moderately low. Interpretations for selected nonagricultural uses for the minesites were based on the most limiting properties found. The major limiting soil features were slow percolation, large and small stones, droughtiness, and acidity; however, the site factors, rather than soil factors, may be the most limiting features for use. Classification using the suborder Spolent was useful in separating mine soils according to differences in management-related properties, and this classification can be used for general land use planning purposes.

1144. Tiedmann, A. R., and C. H. Driver. Snow Eriogonum: A Native Halfshrub To Revegetate Winter Game Ranges. Reclam. & Reveg. Res., v. 2, No. 1, 1983, pp. 31-39.

The objectives of this study were to (1) measure the frequency and cover of snow eriogonum (*Eriogonum niveum* Dougl. ex Benth.) relative to associated species in two habitats in north-central Washington, (2) determine seed characteristics and viability, (3) evaluate response to nitrogen, phosphorus, potassium, and sulfur fertilization, and (4) determine the ability of snow eriogonum to develop from direct seeding. This study was divided into three parts: a growth-chamber study, which was used to determine seed viability; a greenhouse pot study, which assessed response to fertilization; and a field study, which assessed coverage and success of direct seeding. Snow eriogonum is a pioneer plant on disturbed sites in north-central Washington. This study indicated that on such sites, snow eriogonum provides an average foliar coverage of 8.9 pct and makes up approximately one-sixth of the total vegetal cover. Germination tests revealed that the viability of the seed is within acceptable limits: 52 to 72 pct of the seeds tested germinated. Snow eriogonum responded favorably to nitrogen fertilization in the greenhouse pot trials, but did not respond to phosphorus, potassium, or sulfur fertilization. The direct-seeding trials indicated that snow eriogonum develops readily by this method. The authors conclude that snow eriogonum has a potential value for revegetating harsh sites.

1145. Toledo, M. V. M., J. G. Lopez, T. de la Rubia, J. Moreno, and A. R. Cormenzana. Effect of Inoculation With *Azotobacter chroococcum* on Nitrogenase Activity of *Zea mays* Roots Grown in Agricultural Soils Under Aseptic and Non-Sterile Conditions. Biol. and Fertil. Soils, v. 6, 1988, pp. 170-173.

The effects of inoculation with the bacterium *Azotobacter chroococcum* on nitrogenase activity of corn (*Zea mays* L.) roots grown in agricultural soil under aseptic and nonsterile conditions were reported. Acetylene reduction activity and microbial counts were determined 7 and 30 days after growth. *Azotobacter* spp. were isolated from four different soil types that were not inoculated and that had been under a corn monoculture for 10 years. Inoculation with a dense suspension of *A. chroococcum* on the roots of corn in nonsterile soils led to an increased number of *Azotobacter* associated with the roots. This effect diminished as plant growth proceeded. Nitrogenase activity on corn roots at 7 and 30 days increased in response to inoculation with suspensions of *Azotobacter* regardless of soil type. Nitrogenase activity was detected only on the roots of corn, never in inoculated soils without plants. These results show that inoculation of corn roots with *A. chroococcum* increases the nitrogenase activity associated with the roots, suggesting that this association is beneficial to the plant because fixed N_2 may become available. Further studies are necessary on this associative growth under natural conditions.

1146. Topper, K. F., and B. R. Sabey. Sewage Sludge as a Coal Mine Spoil Amendment for Revegetation in Colorado. J. Environ. Qual., v. 15, No. 1, 1986, pp. 44-49.

The effect of using sewage sludge as a coal mine spoil amendment to enhance vegetation establishment on a Colorado coal surface mine was evaluated. Since the lack of nitrogen and phosphorus commonly limits plant growth, vegetative responses to sewage sludge additions were compared with responses to inorganic nitrogen and phosphorus fertilizer amendments. Experimental treatments were (1) 0, 14, 28, 55, and 83 Mg ha^{-1} of dry sewage sludge, (2) 0, 40, 80, 120, and 160 kg ha^{-1} of inorganic nitrogen fertilizer (each rate had 160 kg ha^{-1} of elemental phosphorus), and (3) 0, 40, 80, 120, and 160 kg ha^{-1} of inorganic phosphorus fertilizer (each rate had 160 kg ha^{-1} of elemental nitrogen). A grass pasture mixture was broadcast seeded after all treatments had been partially incorporated. Vegetation response data included percent canopy cover, aboveground production, and tissue analyses for total nitrogen and total phosphorus. Spoil samples from sludge-amended treatments were also collected for chemical analyses.

Invading annual species dominated all treatments during the first growing season, making up 95 pct of the vegetation on sludge-amended plots and 90 pct of the vegetation on fertilizer-amended plots. The sludge and nitrogen fertilizer treatments significantly increased productivity during the first year. Total production on sludge-treated plots increased linearly to 4,300 kg ha^{-1} at the highest rate, while nitrogen fertilizer resulted in a quadratic response that leveled off at 1,800 kg ha^{-1}. Phosphorus fertilization had no effect on invading annual species.

During the second growing season, seeded grasses dominated stand composition, 61 to 94 pct. All treatments significantly increased seeded grass production over the control. Total nitrogen and phosphorus tissue concentrations indicated a linear increase in nitrogen concentration with increasing levels of nitrogen fertilization and sludge application. The higher sludge application rates resulted in higher nitrogen tissue concentrations than did inorganic fertilizers. Increasing phosphorus levels resulted in a decline in total nitrogen concentration; the zero phosphorus application treatment had significantly higher nitrogen concentrations than did the other phosphorus treatments. Beside increasing nitrogen and phosphorus availability, sludge applications improved the physical condition of the spoil, which may have contributed to the improved growth response on sludge-amended spoils. Seeded grasses performed best at the rate of 14 Mg ha^{-1} sludge. Sludge application at this rate was judged superior, in terms of plant growth response, to inorganic fertilization. The authors concluded that this was the most beneficial sewage sludge level.

1147. Topper, K. F., and B. R. Sabey. Use of Sewage Sludge as a Revegetation Amendment on a Colorado Coal Mine Spoil. Am. Soc. Agron., Agron. Abstr., 1984, p. 37.

Abstract of a paper presented at the 1984 Annual Meetings of ASA, CSSA, and SSSA. The effect of sewage sludge as an amendment for the revegetation of coal mine spoil in a semiarid environment was evaluated. Five levels of municipal sewage sludge and nine levels of inorganic nitrogen and phosphorus fertilizer were applied. Aboveground biomass, percent canopy coverage, and density increased significantly with sludge applications. The increase was more dramatic than when fertilizers were used. At low rates (<30 Mg ha^{-1}), sewage sludge can be used as an amendment for revegetating coal mined lands in semiarid environments.

1148. Torbert, J. L., J. A. Burger, and W. L. Daniels. Effect of Overburden Type and Organic Amendments on the Growth of Pines on a Reclaimed Surface Mine. Paper in Proceedings of the Third Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 7-8, 1984). U.S. For. Serv., Gen. Tech. Rep. SO-54, 1985, pp. 369-374.

The effects of various sandstone (SS) and siltstone (SiS) overburden mixtures, organic amendments, and *Pisolithus tinctorius* ectomycorrhizae on the growth of loblolly pine (*Pinus taeda* L.) and pitch-loblolly pine hybrid (*Pinus xrigitaeda*) seedlings were evaluated after 2 years on a reclaimed surface mine in southwestern Virginia. Two separate studies were conducted: a rock mix study and a surface amendment study. The rock mix study consisted of five overburden mixes; pure SS, 2:1 SS-SiS, 1:1 SS-SiS, 1:2 SS-SiS, and pure SiS. The surface amendment study consisted of seven surface treatments applied to a 2:1 SS-SiS mix: control, 12 in of topsoil, 25 mt $acre^{-1}$ sawdust, and four rates of sewage sludge (10, 25, 50, and 100 mt $acre^{-1}$). Each of the plots in the rock mix study and control plots of the surface amendment study received 1,000 lb $acre^{-1}$ of 15-30-15 granular fertilizer. The topsoil treatment was limed with 3.5 mt $acre^{-1}$ agricultural lime and fertilized. The sawdust plots were also fertilized and received an additional 300 lb $acre^{-1}$ urea nitrogen to compensate for nitrogen immobilization. The sludge plots were not fertilized. All plots were mulched with 80 lb $acre^{-1}$ straw and hydroseeded with 150 lb $acre^{-1}$ Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) and 750 lb $acre^{-1}$ wood fiber mulch. Pine seedlings were planted in half of each plot, and at the time of planting a 21-g fertilizer pellet was added. Half of the container-grown seedlings planted were infected with *Pisolithus tinctorius*. After two growing seasons, survival was assessed along with height and diameter of each seedling.

Overburden rock mix had no effect on survival, but seedling growth was affected, with the lowest growth occurring on the pure SiS plots. Growth improved as the SS component increased. The topsoil treatment resulted in poor pine performance. There was no significant difference in pine growth between seedlings planted in topsoil and those planted in unamended overburden. The best pine growth occurred in the sawdust plots. Municipal sewage sludge benefited seedlings at the two low application rates, but was detrimental to seedlings at the two high rates. The fertilizer pellet increased tree height by 50 pct, diameter by 70 pct, and volume index by 350 pct compared with the controls. Mycorrhizae infection, however, did not affect seedling growth, owing to the high soil fertility. Mycorrhizal trees not planted with a fertilizer pellet did have significantly greater diameter growth.

1149. Torbert, J. L., J. A. Burger, and W. L. Daniels. Effect of Overburden Type and *Pisolithus Tinctorius* on the Growth of Pines on a Reclaimed Surface Mine. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 144-147.

The effects of sandstone (SS) and siltstone (SiS) overburden mixtures and *Pisolithus tinctorius* ectomycorrhizae on the growth of loblolly pine (*Pinus taeda* L.) and pitch-loblolly pine hybrid (*Pinus xrigitaeda*) seedlings were evaluated after 2 years on a reclaimed surface mine in southwestern Virginia. Five overburden mixes were used: pure SS, 2:1 SS-SiS, 1:1 SS-SiS, 1:2 SS-SiS, and pure SiS. The entire area was fertilized with 1,120 kg ha^{-1} of 15-30-15 granular fertilizer, mulched with 90 kg ha^{-1} of straw, and hydroseeded with a water slurry containing 168 kg ha^{-1} Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.) and 840 kg ha^{-1} wood fiber mulch. One-half of each plot was planted with container-grown seedlings, half of which were infected with *Pisolithus tinctorius*. All seedlings were planted with a 21-g fertilizer pellet. Tree survival was assessed and heights and diameters were measured after two growing seasons. Overburden type had no effect on survival, but did affect seedling growth after 2 years. Growth was lowest on the pure SiS plots and improved as the SS component increased. Volume (D^2H) difference between trees on pure SS and the 2:1 SS-SiS mix was not significant. Mycorrhizal inoculation before planting had no effect on seedling growth due to the fertilizer treatment. In the cold climate of mountainous southwest Virginia, pitch-loblolly pine hybrids outperformed loblolly pine during the initial establishment phase.

1150. Torbert, J. L., J. A. Burger, and W. L. Daniels. Minesoil Factors Influencing the Productivity of New Forests on Reclaimed Surface Mines in Southwestern Virginia. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 63-67.

This article provides a summary of two studies that were conducted to identify mine-soil characteristics that directly influence forest productivity in southwestern Virginia. The first study examined the effect of overburden selection as a topsoil substitute on tree growth. Five overburden mixes ranging from pure sandstone (SS) to pure siltstone (SiS), with mixes of 2:1 SS-SiS, 1:1 SS-SiS, and 1:2 SS-SiS, were established to a depth of 1.2 m over a highly compacted underlying bench. Seedlings of a pitch-loblolly pine hybrid (*Pinus xrigitaeda*) were planted on each mix. After 4 years, tree growth had been affected by rock mix. Tree height, diameter, and volume increased as the amount of sandstone increased in the rock mix. Sandstone-derived mine soils were characterized as having lower soil pH values, lower levels of soluble salts, and fewer coarse fragments. These soil properties of sandstone mixes were more suited for pine growth than the chemical and physical characteristics of soils derived from siltstone.

The second study examined the effects of various mine-soil characteristics on the growth of 8-year-old white pine (*Pinus strobus* L.) on a series of reclaimed benches in southwestern Virginia. Results show that mine-soil depth to a restrictive layer and soluble salt concentration were the two most important soil factors affecting tree height. The results of these studies suggest that nonpyritic, brown sandstone is the best topsoil substitute for tree establishment and growth in the coal mining region of Virginia.

1151. Torbert, J. L., J. A. Burger, J. N. Lien, and S. H. Schoenholtz. Results of a Tree Species Trial on a Recontoured Surface Mine in Southwestern Virginia. South. J. Appl. For., v. 9, 1985, pp. 150-153.

The establishment performance of a variety of commercial tree species on a recontoured surface mine in southwestern Virginia was evaluated. The site was initially hydroseeded with a combination of Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), redtop (*Agrostis alba* L.), birdsfoot trefoil (*Lotus corniculatus* L.), ladino clover (*Trifolium repens* L.), and annual rye (*Lolium multiflorum* Lam.) in a mixture with 560 kg ha^{-1} 10-20-20 fertilizer and 1,681 kg ha^{-1} wood fiber mulch. Soils were chemically and physically characterized. Fifteen tree species were evaluated: European black alder (*Alnus glutinosa* (L.) Gaertn.), black locust (*Robinia pseudoacacia* L.), black walnut (*Juglans nigra* L.), chestnut oak (*Quercus prinus* L.), Chinese chestnut (*Castanea mollissima* Blume), cottonwood (*Populus deltoides* Bartr. ex Marsh.), red oak

(*Quercus rubra* L.), sycamore (*Platanus occidentalis* L.), yellow-poplar (*Liriodendron tulipifera* L.), white ash (*Fraxinus americana* L.), loblolly pine (*Pinus taeda* L.), scotch pine (*Pinus sylvestris* L.), shortleaf pine (*Pinus echinata* Mill.), Virginia pine (*Pinus virginiana* Mill.), and eastern white pine (*Pinus strobus* L.). The best growing hardwood species was black locust, with 90-pct survival after 3 years. Black alder was the second fastest growing hardwood species. Site-demanding hardwoods such as black walnut, red oak, yellow-poplar, and white ash performed poorly on the study site. When released, sycamore and cottonwood survived and grew well. Loblolly and Virginia pine survival and growth were better than those of all other pine species.

1152. Torbert, J. L., J. A. Burger, and R. E. Preve. The Effect of Ground Cover Species and Nitrogen Fertilizer Rate on the Successful Establishment of Hydroseeded Trees. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, 1986, pp. 83-88.

This paper describes an experiment to test the effect on pine establishment of four cover crops (a control and 30 kg ha^{-1} each of perennial ryegrass (*Lolium perenne* L.) and red fescue (*Festuca rubra* L.) with 56 kg ha^{-1} of either crownvetch (*Coronilla varia* L.), white clover (*Trifolium repens* L.), or birdsfoot trefoil (*Lotus corniculatus* L.)) and three fertilizer treatments (control and either 60 or 120 kg ha^{-1} N with 70 kg ha^{-1} P and 60 kg ha^{-1} K). A mixture of eastern white pine (*Pinus strobus* L.), Virginia pine (*Pinus virginiana* Mill.), and loblolly pine (*Pinus taeda* L.) was seeded (5 kg ha^{-1}) onto all test plots. At the end of the first and third growing seasons trees were counted and ground cover was estimated using the line intercept method. If the appropriate ground cover species are used and nitrogen fertilization rates are controlled, pines can be established by direct seeding. After three growing seasons, average tree density was 5,800 trees per hectare. Results indicate that birdsfoot trefoil and perennial ryegrass are desirable ground cover species and that nitrogen application rates should be less than 60 kg ha^{-1} for tree establishment.

1153. Torbert, J. L., J. A. Burger, and A. R. Tuladhar. Minesoil Property Effects on the Height of Eight-Year-Old White Pine. Am. Soc. Agron., Agron. Abstr., 1987, p. 35.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. The effects of minesoil properties on 8-year-old white pine (*Pinus strobus* L.) tree growth were evaluated. The combined effects of mine-soil chemical and physical properties on tree height were modeled using multiple regression techniques. Rooting volume index (rooting depth times soil size fraction) had the greatest influence on tree growth, followed by soluble salt content.

1154. Torbert, J. L., A. R. Tuladhar, J. A. Burger, and J. C. Bell. Minesoil Property Effects on the Height of Ten-Year-Old White Pine. J. Environ. Qual., v. 17, No. 2, 1988, pp. 189-192.

Important growth-limiting factors on reclaimed minesites were identified by examining the relationship between selected soil chemical and physical characteristics and the growth performance of white pine (*Pinus strobus* L.). Thirty-four 10-year-old white pines on a series of reclaimed benches in Virginia were selected for study. At the base of each tree a 1-m-deep soil pit was dug to determine rooting depth, while surface samples (0 to 10 cm) were collected for analysis of selected soil chemical and physical characteristics. Total height, establishment growth rate (average annual growth rate that occurred prior to the year that height growth exceeded the average of the two previous years by more than 100 pct—usually the first 3 or 4 years), and terminal 4-year increment (height increment that occurred during the last 4-years) were measured for each tree. Models to combine the effects of mine-soil properties on tree height were developed using multiple regression analysis.

No mine-soil characteristics were found to be correlated with the establishment growth rate. The terminal 4-year increment and total height measurements were, however, correlated with depth to the restrictive layer and electrical conductivity (soluble salts). Mine-soil depth was the property most strongly correlated with growth, particularly with terminal 4-year increment rather than with total height. This indicates that soil depth becomes more important when trees grow past the establishment phase. Site index estimates for each tree indicated that when soil depth was less than 30 cm, site index was less than 24 m. When soil depth was at least 72 cm, site index was 24 m. A negative correlation existed between electrical conductivity and tree height, indicating that tree growth was adversely affected by high levels of soluble salts. These high levels, however, are expected to decrease with time because of leaching, The most important mine-soil variable affecting terminal 4-year increment and total height was the rooting volume index (the product of depth and soil size fraction). The authors conclude that the ability of a mine soil to support tree growth is a function of rooting volume and total salt levels. Both properties can be controlled by mine operators by selecting nontoxic overburden and minimizing traffic over a site so that an adequate depth of uncompacted mine soil is formed.

1155. Tourbier, J. T., and R. Westmacott. A Handbook for Small Surface Coal Mine Operators (U.S. Off. Surf. Min. grant 14-34-0001-8900, Water Res. Cent., Univ. DE). U.S. Off. Surf. Min., 1980, 119 pp.

This publication interprets the regulations of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87) as they affect the operators of small surface coal mines. It is designed to aid these operators in bringing their mining operations into compliance with the regulations. The handbook contains information that can be used by operators in planning and conducting their operations. Chapter 2 presents a concise and regionally specific review of some of the problems encountered in surface mining and reclamation. Chapters 3 and 4 contain descriptive and graphic presentations of the principal surface mining methods and equipment used by small-mine operators. Chapter 5 presents information on the necessity of premining surveys, exploration, and planning. Chapter 7 contains an excellent, concise outline of accepted reclamation and revegetation techniques. Chapter 8 outlines necessary considerations for proposing post-mining land uses.

1156. Toy, T. J., and D. A. Shay. Comparison of Some Soil Properties on Natural and Reclaimed Hillslopes. Soil Sci., v. 143, No. 4, 1987, pp. 264-277.

Comparisons were made between natural and reclaimed hillslope soils for the following parameters: bulk density, particle size distribution, soil reaction (pH), and organic matter. No significant difference was found in soil bulk density comparisons between natural and reclaimed hillslopes. Bulk density increased with depth for both sites. No significant differences were found in gravel content between sites, but sand content was significantly higher on the natural hillslopes (72.34 pct) than on the reclaimed soil (56.97 pct). Silt and clay contents were 7 to 8 pct higher in reclaimed hillslopes than in natural hillslopes. This change may have a positive effect on revegetation by increasing the water-holding capacity of these soils, which is important in vegetation establishment in semiarid environments. There was no significant difference in average soil pH of the natural and reclaimed soils in the upper 10 cm of soil; however, there were significant differences between the two sites at the 10- to 20-, 20- to 30-, and 30- to 40-cm depth sections. In each case the reclaimed hillslope had lower pH values, which reflects the acid-forming characteristics of some of the overburden materials. The mean organic matter values were similar for the slopes of the sites; however, the reclaimed hillslope had a significantly higher organic matter content in the 10- to 20-cm depth section. This may have been related to the presence of coal materials in this depth section. The chemical and physical properties of reclaimed soils reflect the overburden characteristics, substantiating the need to evaluate overburden characteristics prior to mining.

1157. Trocme, M., J. Tarradellas, and J. C. Vedy. Biotoxicity and Persistence of Nonylphenol During Incubation in a Compost-Sandstone Mixture. Biol. and Fertil. Soils, v. 5, 1988, pp. 299-303.

Nonylphenol, a mixture of monoalkyl phenols, is a surfactant used in the manufacture of detergents, paints, inks, and pesticide formulations. In sewage sludge, 4-nonylphenols (4-NP) may appear in high concentrations. The persistence and biotoxicity of nonylphenol were studied in an incubation study using a reconstituted soil system, compost plus sandstone. The effect of nonylphenol on microbial activity was studied by monitoring CO_2 evolution and ATP content. Three treatments were used: a control, 100 ppm 4-NP, and 1,000 ppm 4-NP. The CO_2 evolution was not significantly different between the control and 100-ppm 4-NP treatments; however, the 1,000 4-NP significantly reduced CO_2 evolution by the fourth day. Respiration was depressed by 64 pct compared with that of the control. Biomass ATP also showed a progressive decrease from the fifth day on when treated with 1,000 ppm 4-NP. The 100-ppm 4-NP treatment did not result in any toxic effects. Over a 40-day period, 4-NP disappeared at the 100-ppm treatment after an initial lag phase, but persisted at the 1,000-ppm treatment. At the lower concentration, 4-NP disappeared because of biodegradation and residue binding. The authors conclude that at the concentrations expected (1 to 50 ppm) in the soil after sludge treatment, nonylphenol is not expected to be an environmental hazard.

1158. Tu, J. C., and S. C. Tan. Soil Compaction Effect on Photosynthesis, Root Rot Severity, and Growth of White Beans. Can. J. Soil Sci., v. 68, No. 2, 1988, pp. 455-459.

The effects of soil compaction on photosynthesis, root-rot severity, and growth of two white bean cultivars (*Phaseolus vulgaris* L.), one resistant and the other susceptible to root-rotting pathogens, were studied in a controlled environment. Sterilized soil and soil heavily infested with root-rotting fungi were used; both soils were either compacted (1.6 g cm^{-3}) or noncompacted (1.3 g cm^{-1}). Photosynthetic rates of plants grown in compacted soil were significantly lower than those of plants grown in noncompacted soil. Plant biomass and total leaf area were also significantly reduced in both soil types because of compaction. Plants grown in sterilized soil had little or no root-rot, while those grown in root-rot-infested soil

developed characteristic root-rot symptoms. Soil compaction increased the incidence of root-rot. The reduced plant growth that resulted from soil compaction was attributed to both decreased photosynthetic rates and increased root-rot severity in those soils compacted to 1.6 g cm^{-3}.

1159. Tucker, G. B., W. A. Berg, and D. H. Gentz. pH. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 3-26.

This chapter discusses soil, overburden, and water pH as it influences successful reclamation of mined land in the Western United States. Several analytical procedures for determining pH are presented, along with the role of pH in revegetation. The influences of pH on western mine-related water quality issues are discussed. Management implications and recommendations for determining soil, overburden, and water pH are given.

1160. Tuladhar, A. R., J. A. Burger, R. E. Adams, and J. L. Torbert. Identification of Mine Soil Properties Influencing White Pine (*Pinus Strobus* L.) Growth. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 24-30.

This study tested three hierarchical models and identified the mine soil, plant moisture, and foliar nutrients influencing white pine (*Pinus strobus* L.) growth on a series of reclaimed benches in Wise County, VA. The models hypothesized the relationships between (1) growth (biomass) and functional environmental factors (plant moisture and foliar nutrients), (2) functional environmental factors and mine-soil chemical and physical properties, and (3) growth and mine-soil chemical and physical properties. Models were constructed using maximum R^2 and stepwise regression methods. Thirty-six trees growing over a wide range of spoil origin, depth to restricted layer, stoniness, and bulk density were selected. At each tree, soil physical and chemical properties, plant moisture stress, nutrient content, and biomass were determined.

Model 1 showed a significant relationship between biomass and plant moisture stress and foliar nitrogen (biomass increased with increased foliar nitrogen and decreased plant moisture stress); however, the magnitude of R^2 was only 0.16, which indicated that limits to tree growth were a function of other factors. Model 2 revealed a significant relationship between functional environmental factors and soil physical and chemical properties. The soil physical factors that had the most effect on plant moisture stress were percent sand, soil depth to restricted layer, bulk density, and rooting volume. Foliar phosphorus was partially determined by soil acidity and total nitrogen, but no relationship was evident between foliar nitrogen and any of the soil chemical properties. Model 3 confirmed the importance of soluble salts. Soluble salts and rooting volume accounted for 64 pct of the variation in biomass, indicating that these variables were the most important mine-soil properties influencing white pine. It is recommended that salt-laden siltstone spoils be buried below sandstone spoils to maximize rooting volume and minimize the effects of soluble salts.

1161. Turner, G. D., R. R. Lau, and D. R. Young. Effect of Acidity on Germination and Seedling Growth of *Paulownia Tomentosa*. J. Appl. Ecol., v. 25, No. 3, 1988, pp. 561-567.

The effects of acidity on seed germination and primary root growth for royal paulownia (*Paulownia tomentosa* (Thunb.) Steud.) over a pH range of 1.5 to 7.0 were quantified in a laboratory study. This range represents the pH range present at acidic minesites in the Eastern United State. Additionally, the effects of acidic soils on seedling emergence and seedling growth were characterized in a greenhouse study using soils collected from an abandoned mine in Virginia.

Twelve pH treatments ranging from 1.5 to 7.0 were established. For each treatment, 100 seeds were placed on filter paper in petri dishes and the pH was varied by adding H_2SO_4 and NaOH. Seeds were checked for germination daily and were considered fully germinated when the radicle was >2 mm in length. The effects of acidity on primary root elongation were quantified using pH treatments of 4.0, 5.0, 6.0, and 7.0. After germination, primary root length was measured every 3 days from 15 randomly chosen seedlings from each treatment. Three soil treatments were used to examine the effect of soil acidity on seedling emergence and growth characteristics. The pH values used were 4.5, 5.5, and 6.5. Soils for the pH 4.5 and 5.5 treatments were collected from an abandoned mine, while the soil for the pH 6.5 treatment was a loam soil. Seedling emergence from the soil was studied in a greenhouse experiment. Seedling growth characteristics were monitored using the same soils. Three weeks after emergence, seedlings were harvested and for each seedling the number of leaves, and shoot and root lengths were recorded, and shoot and root dry weights determined.

No germination of paulownia seeds occurred below pH of 4.0. From 4.0 to 7.0 there was a gradual increase in seed germination, from 79 pct germination at pH 4.0 to 98 pct at pH 7.0. Ungerminated seeds from the pH treatments 3.0 and 3.5 were rinsed with distilled water and placed in petri dishes with a pH of 6.5. After 7 days, 59 pct and 74 pct of the seeds had germinated, respectively. Seeds from treatments below pH 3.0 did not

germinate at pH 6.5 even after rinsing, indicating that all seeds had been killed. Primary root growth was also affected by acidity. Total root length increased more slowly at pH treatments 4.0 and 5.0 than at pH treatments 6.0 and 7.0. There was no significant difference in seedling emergence for seeds grown in soils with pH's of 5.5 and 6.5, but seeds sown on soil with a pH of 4.5 showed significantly lower seedling emergence. Leaf number, root length, shoot dry mass, and root dry mass were also significantly lower in the pH 4.5 soil. The authors conclude that increased acidity has an adverse effect on the germination and seedling growth of royal paulownia.

1162. Ueckert, D. N. Establishment of Shrubs and Forbs in the Southern Plains Region. Paper in Impacts of the Conservation Reserve Program in the Great Plains, ed. by J. E. Mitchell (Symp. Proc., Denver, CO, Sept. 16-18, 1987). U.S. For. Serv., Gen. Tech. Rep. RM-158, 1988, pp. 47-51.

The potential use of four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.), littleleaf leadtree (*Leucaena retusa*), and winterfat (*Ceratoides lanata* (L.) C.A. Mey.) for conversion of cropland to Conservation Reserve Program (CRP) lands (for wildlife habitat and grazing lands) in the Southern Plains is discussed. For each species, general characteristics (such as growth form, height, rooting habit, range, and climatic tolerances), value of the species for grazing (crude protein content, digestible organic matter, and utilization), and establishment methods and management techniques (seeding, transplanting, and weed control) are presented. Perennial forbs that also have desirable characteristics for use on CRP lands are given. This article is a good reference for the shrub and forb species that can be established and provide adequate cover in the Southern Plains for wildlife habitat and grazing land.

1163. Ugolini, F. C. Effect of Podzolization on Soil Fertility. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 90-93.

The influence of podzolization on the movement and distribution of nutrient and nonnutrient elements in a forest soil is discussed. Three theories on the mechanics of podzolization are presented. The author concludes that podzolization occurs as a results of both pedogenic and biotic processes in cool to hyperhumid climates.

1164. U.S. Bureau of Land Management. Final Environmental Statement—Proposed Coal Leasing in Carbon Basin Area, Wyoming. July 1979, 205 pp.

General statements describing the environment and the impacts and mitigation for the proposed mining operation are contained in chapters 1-3. More specific and useful information is contained in chapters 4-7. Chapter 4 describes mitigating measures not included in the proposed action. Specific standard evaluation criteria listed include slope shaping; topsoil removal, storage, and replacement; seedbed preparation; and revegetation methods. Chapter 5 examines specific adverse impacts that cannot be avoided and includes statements on potential wind and water erosion, wildlife populations, and livestock grazing. Chapter 6 includes a comparison of short- and long-term productivity. Chapter 7 examines specific irreversible and irretrievable commitments of resources.

1165. U.S. Bureau of Land Management. Resource and Potential Reclamation Evaluation of Beulah Trench Study Area, West Renners Cove Coalfield, Mercer County, North Dakota. EMRIA Rep. 10, 1981, 290 pp.; summary, 27 pp.

This two-document set presents the results of an extensive study that provides information for establishing reclamation objectives and lease requirements. Detailed data are given on the geology, coal resources, overburden, vegetation, hydrology, climate, and physiography of this area. Greenhouse studies were conducted to identify potential toxicity and/or nutrient deficiency problems in the soils to be used during reclamation. A primary aim of the study was to provide data needed in the preparation of Environmental Impact Statements and Environmental Analysis Records and to aid in the review of reclamation plans for proposed mining activities in the area.

1166. U.S. Bureau of Land Management. Resource and Potential Reclamation Evaluation: White Tail Butte Study Area, Little Powder River Coal Field; Summary. EMRIA Rep. 13, 1977, 19 pp.

The White Tail Butte Study Area is in Campbell County, WY, 35 miles north of Gillette. This report summarizes a larger final report of the same title, dated 1981. Information is given on geology, coal reserves, overburden, soils, vegetation, and wildlife in the study area. Some recommendations for species selection, soil preparation, and seeding are given.

1167. U.S. Environmental Protection Agency. Elkins Mine Drainage Pollution Control Demonstration Project. Interagency Energy-Environ. Res. and Dev. Rep. EPA-600/7-090, Aug. 1977, 316 pp.

This report describes in detail a cooperative demonstration project in the Roaring Creek-Grassy Run watersheds near Elkins, WV, to control the pollution from

abandoned underground and surface mines. The main body of the report summarizes all aspects of the project and should be of value to private, State, and Federal agencies planning and conducting mine drainage and abatement projects. Scattered throughout the report are details on the revegetation of the areas under treatment, indicating that good vegetative cover was established on most disturbed areas, with legumes dominating after 8 years of establishment. Tree survival and growth were also good.

1168. U.S. Environmental Protection Agency. Environmental Impact Statement (Draft), Martin Lake D Area Lignite Surface Mine, Henderson, Rusk County, Texas. EPA 906/9-83-003, Mar. 1983, 10 ch., 325 pp.

Although quite general in nature regarding revegetation of disturbed coal mined lands, this publication is a good example of considerations necessary for an Environmental Impact Statement. Alternatives are presented along with company policy for establishing grazing land and forest land on disturbed areas.

1169. U.S. Environmental Protection Agency. Environmental Impact Statement: Henry W. Pirkey Power Plant, Unit-I/South Hallsville Surface Lignite Mine Project. Harrison County, Texas. EPA 906/9-82-004, Mar. 1982, 262 pp.

The proposed mine and powerplant in Harrison County, TX, is located in an area of farming, pastureland, and timber production. Included in this article is an analysis of existing soils and vegetation. The listing of land uses and types of associated vegetation that dominate on those lands could be useful for anyone developing a revegetation plan in the area.

1170. U.S. Forest Service. History of the Vegetative Rehabilitation and Equipment Workshop (VREW), 1946-1981. Equip. Dev. Cent., Missoula, MT, Rep. 8222 2805, 1982, 71 pp.

This publication reviews the organization and history of the Vegetative Rehabilitation and Equipment Workshop (VREW). VREW equipment development and test projects accomplished in conjunction with the U.S. Forest Service Equipment Development Centers at Missoula, MT, and San Dimas, CA, are reviewed. Short descriptions and excellent photographs of this equipment enhance the information contained in this document. The information and equipment described are primarily pertinent to range rehabilitation in the arid and semiarid areas of the Western United States.

1171. U.S. Forest Service. R-4 Reclamation Field Guide. U.S. For. Serv., Region 4 Miner. Manage., Ogden, UT, 1987, 81 pp.

This reclamation field guide was developed to compile existing information on the reclamation of disturbed lands in Region 4 of the National Forest System. The guide provides the user with (1) a statement of Forest Service reclamation policy, (2) a background of Forest Service authority, (3) a sequence of events for managing the reclamation process, (4) key reclamation principles, and (5) a reference and checklist of technical information to be applied. Ten steps that should be followed in reclamation are presented, along with standard reclamation practices and procedures for unique reclamation situations.

1172. U.S. Forest Service. Surface-Mined Lands... Hope for Future Forests? Northeast. For. Exp. St., NE-INF-77-88, 1988, 12 pp.

This article presents the 20-year results of a demonstration project established near Fonde, KY. Plantations of mixed hardwoods, mixed pines, loblolly pine (*Pinus taeda* L.), black locust (*Robinia pseudoacacia* L.), shrubs, and herbaceous species were established to provide forest products and wildlife habitat. Tree heights, diameters, and densities in the plantations were compared with the same measurements in unmined forested areas. Soils were also compared. Tree growth was as good or better on the mined site compared with the unmined site. Mine soils provided a deeper rooting zone and a greater water-holding capacity than did the unmined soils of the region.

1173. U.S. Forest Service. Wildlife User Guide for Mining and Reclamation. Intermt. For. and Range. Exp. Stn., Ogden, UT, Gen. Tech. Rep. INT-126, July 1982, 77 pp.

This publication is one of a series of guides that was prepared as part of the U.S. Forest Service Surface Environment and Mining (SEAM) program. It was designed to serve as a starting point for biologists to aid in the planning, evaluation, execution, and monitoring of reclamation work associated with mining and its ancillary facilities. Chapter 1 outlines the role of the wildlife or fisheries biologist in minerals management. Chapter 2 provides a synopsis of the laws and regulations governing minerals and mining that affect fish and wildlife management decisions. Chapter 3 explores fish and wildlife objectives in land management planning. Chapter 4 describes the phases of mineral activity. Chapter 5 presents a framework for analyzing the impacts and effects of proposed mining activities on fish and wildlife. Chapter 6

suggests potential effects and methods for mitigating those effects; included in this chapter are discussions on human and wildlife encounters and disturbance of habitat. Chapter 7 outlines methods available to the wildlife or fisheries biologist for coordinating efforts in achieving necessary reclamation procedure applications.

1174. U.S. Forest Service. User Guide to Vegetation. Mining and Reclamation in the West. Gen. Tech. Rep. INT-64, Nov. 1979, 85 pp.

This publication is offered as a guide covering planning for reclamation of mined lands. Topics include exploration and baseline data, species selection, plant materials, site preparation, planting methods, cultural treatments, and postmining management planning and monitoring. It will be especially useful to revegetation planning in the Western Coal Mining Regions. The information is presented in a discussion format and is supported by numerous graphs, photographs, references for additional information, a glossary, and an index.

1175. U.S. Forest Service. Vegetative Rehabilitation and Equipment Workshop, 35th Annual Report (Tulsa, OK, Feb. 8-9, 1981). Equip. Dev. Cent., Missoula, MT, Rep. 8122 2805, 1981, 84 pp.

This publication contains concise descriptions of equipment, plant materials, and revegetation concerns as presented at a workshop attended by representatives of Federal and State agencies, private industry, educational institutions, and foreign countries. Many of the projects described and much of the information presented is applicable to reclamation of surface coal mined land. The geographic focus of the workshop was the Western United States. Some of the equipment and problems discussed, however, are relevant to other regions of the United States.

1176. U.S. Geological Survey. Final Environmental Statement—Proposed Mining and Reclamation Plan, Coal Creek Mine, Campbell County, Wyoming, Federal Coal Lease W-3446. 1979, 200 pp.

General statements describing the environment and the impacts and mitigative actions for the proposed mining operation are contained in chapters 1-4. Adverse impacts that cannot be avoided if the proposals are implemented are described in chapter 5. Many of these comments pertain to natural vegetation production and site productivity for grazing and wildlife needs. Other comments on site productivity related to short- and long-term uses are contained in chapter 6. Discussions of irreversible and irretrievable commitments of resources contained in chapter 7 also include comments on site rehabilitation and revegetation and consequent site productivity for grazing and wildlife use. Chapter 8 contains a discussion of more specific rehabilitation alternatives and methods. The information and discussions contained in this document tend to be specific to this area of northwestern Wyoming.

1177. U.S. Geological Survey. Final Environmental Statement, Proposed Mining and Reclamation Plan, Pronghorn Mine Consolidation Coal Company Coal Lease W-58112, Campbell County, WY. 1979, 276 pp.

General statements describing the environment and the impacts and mitigation for the proposed mining operation are contained in part A, sections 1-6. More specific information appears throughout part B, in which impacts and mitigation measures are discussed. Much of the information and discussion contained in this document is specific for this area of Wyoming.

1178. U.S. Geological Survey and Montana Department of State Lands. Draft Environmental Statement—Proposed Expansion of Mining and Reclamation Plan, Big Sky Mine, Peabody Coal Company, Rosebud County, Montana, Federal Lease M-15965. 1978, 128 pp.

General statements describing the environment and the impacts and mitigative actions for the proposed mining operation are contained in chapters 1-4. Adverse impacts that cannot be avoided if the proposals are implemented are described in chapter 5. Many of these comments pertain to natural vegetation production and site productivity for grazing and wildlife needs. Other comments on site productivity related to short- and long-term uses are contained in chapter 6. Discussions of irreversible and irretrievable commitments of resources found in chapter 7 also contain comments on site rehabilitation and revegetation and consequent site productivity for grazing and wildlife use. Chapter 8 contains a discussion of more specific rehabilitation alternatives and methods. The information and discussions contained in this document tend to be specific to southeastern Montana.

1179. U.S. Geological Survey and Montana Department of State Lands. Final Environmental Statement—Proposed Expansion of Mining and Reclamation Plan, Big Sky Mine, Peabody Coal Company, Rosebud County, MT, Federal Lease M-15965. V. 2, 1979, 66 pp.

This document contains revisions in the mine plan as received through July 11, 1979. General statements describing the planned mining and reclamation activities, including proposed seeding and planting mixtures, subsoil contouring, and topsoil handling methods are contained

in chapter 1. The remaining portions of this volume deal with consultation and coordination with other government agencies and with private organizations and individuals. The information and discussions contained in this volume form an addendum to the Draft Environment Statement published in 1978 (entry 1178) and tend to be specific for southeastern Montana.

1180. U.S. Geological Survey and Montana Department of State Lands. Final Environmental Statement—Proposed Mining and Reclamation Plan, Spring Creek Mine, Spring Creek Coal Company (A Subsidiary of Northern Energy Resources Company, Inc.), Big Horn County, MT, Federal Lease M-069 782. 1979, 470 pp.

General statements describing the environment and the impacts and mitigation for the proposed mining operation are contained in part A, sections 1-6. More specific information appears throughout part B, where impacts and mitigation measures are discussed. Much of the information and discussion contained in this document is specific for this area of Montana.

1181. U.S. Office of Surface Mining Reclamation and Enforcement (Dep. Interior). Surface Coal Mining Reclamation: 10 Years of Progress, 1977-1987. Aug. 1988, 48 pp.

The accomplishments of the environmental protection regulatory program during the first 10 years of the Surface Mining Control and Reclamation Act (SMCRA) of 1977 are reported. Regulatory provisions that form the basis of SMCRA implementation are presented and include (1) performance standards, (2) permits, (3) performance bonds, (4) inspection and enforcement, and (5) lands unsuitable for mining. Three major surface mining methods are used in the United States: area mining (primarily in Western and Midwestern States), contour mining (Eastern States), and mountaintop removal mining (Eastern States). Examples are presented of the improved environmental protection as a result of SMCRA, including (1) erosion and sedimentation control, (2) surface and ground water protection, (3) acid and toxic drainage prevention and treatment, (4) topsoil replacement, (5) excess spoil disposal through careful engineering, (6) highwall elimination and return to approximate original contour, (7) better postmining land use, (8) revegetation, (9) less impact from blasting and explosives through careful planning, (10) wildlife restoration and enhancement, (11) mine waste disposal, (12) improved roads for postmining use, and (13) better planned remining.

1182. U.S. Office of Surface Mining (Dep. Interior). Southern Utah Petition Evaluation. Final 522 SMCRA Evaluation. OSM-PE-1 and OSM-EIS-4, Nov. 1980, 265 pp.

This document contains an evaluation of the suitability of certain lands in southern Utah for surface coal mining and reclamation. The document combines a petition to designate this Federal land as unsuitable for surface coal mining operations, with an evaluation of that petition and an environmental impact analysis of the effect of various potential Federal actions on the petition. The discussions pertaining to the affected environment, potential impact, and reclamation opportunities are some of the best that appear in documents of this type.

1183. University of North Dakota. Ecological Studies on the Revegetation Process of Surface Coal Mined Areas in North Dakota (contract JO295015). BuMines OFR 47-83, 1982, 13 v., approx. 850 pp.; NTIS PB 83-171-322, -330, -348, -355, -363, -371, -389, -397, -405, -413, -421, -439, -447.

This excellent minerals research contract report contains 13 volumes consisting of (1) executive summary, (2) physical and chemical properties of overburden and topsoil as affected by time and amendments, (3) soil and vegetation development of abandoned mines, (4) soil and vegetation development on topsoiled areas, (5) plant production on spoils and topsoil as affected by time and amendments (fertilizer and leonardite), (6) relationship between cover and aboveground biomass, (7) mineral analysis of plants grown on spoils and topsoil, (8) soil algae, (9) viability and diversity of the seed bank, (10) elements of macroclimate and microclimate, (11) effect of amendments on soil-plant-nutrient relations under controlled conditions, (12) screening plants for phosphorus requirements, and (13) statistical analysis. Excellent reference lists are included with each volume.

1184. Uribe, E., and F. R. Cox. Soil Properties Affecting the Availability of Potassium in Highly Weathered Soils. Soil Sci. Soc. Am. J., v. 52, No. 1, 1988, pp. 148-152.

Highly weathered soils were studied to determine if cation-exchange capacity (CEC) of humic matter (HM) could be used to develop potassium availability indices. Seventeen soils from the Coastal Plain, Piedmont, and Mountain regions of North Carolina and two soils from the Amazon Basin were studied. The potassium-buffering power of the soils tended to be positively correlated with the CEC. As the CEC increased, the potassium-buffering power also increased. Soils higher in HM, however, had a lower potassium-buffering power at any level of CEC, while soils low in HM had a greater ratio between potassium on exchange sites and that in solution. This indicates

a lower capacity to replace potassium removed from the soil solution when potassium is depleted. In equilibrium solutions, potassium concentration increased linearly with percent potassium saturation of the CEC, with soils high in HM having a higher concentration of potassium in equilibrium solutions at any given percent potassium saturation than low-HM soils. As HM increased and CEC decreased, a larger portion of extractable potassium was in solution. The soils tested were placed into two groups: (1) soils of low potassium-buffering power where HM > 1.9 pct and CEC < 4.6 cmol L^{-1} and (2) soils of high potassium buffering power where HM < 1.9 pct and CEC > 4.6 cmol L^{-1}. These groupings should help to improve potassium fertilizer recommendations for highly weathered soils.

1185. Vail, J. A., and R. F. Wittwer. Biomass and Nutrient Accumulation in 10-Year Old Eastern Cottonwood, Virginia Pine, and Black Locust Plantations on Eastern Kentucky Mine Soil. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, KY, 1982, pp. 237-242.

This study was conducted to compare the biomass production and nutrient accumulation in 10-year-old plantations of eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.), Virginia pine (*Pinus virginiana* Mill.), and black locust (*Robinia pseudoacacia* L.) in Bell County, KY. Two of the treatments that were used by the Forest Service in 1968 were investigated in this study: (1) tree species grown with grasses and legumes and (2) tree species grown alone. Total aboveground biomass and nutrient accumulation (nitrogen, phosphorus, potassium, calcium, and magnesium) were determined for each species treatment combination. Ten-year-old spoil and litter samples were also analyzed. No significant differences were found for total tree biomass; however, nutrient accumulations were found to be different among species. Black locust accumulated the greatest amount of nitrogen, while cottonwood accumulated the greatest amount of calcium and magnesium. There were no significant differences in the accumulation of phosphorus and potassium. Litter weights and nutrient content ranked in the general order of black locust > eastern cottonwood > Virginia pine. Spoil analysis showed no trends involving nitrogen, phosphorus, potassium, calcium, and magnesium. Even though there was more spoil nitrogen under the black locust, it was not significantly higher. The pH of the spoils under eastern cottonwood was significantly higher than the pH of spoils under either black locust or Virginia pine, probably because of the amount of calcium that accumulates in the foliage of eastern cottonwood and then is deposited on the forest floor each year. These results indicate that spoils have the potential to become productive soils in a relatively short time.

1186. Vance, S. L., I. J. Jansen, and C. L. Hooko. A Comparison of Soil Construction Methods Used After Surface Mining for Coal. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 149-152.

Several soil replacement methods used in prime farmland reclamation after surface mining for coal in Illinois were compared. The methods evaluated were (1) bucket-wheel excavation-conveyor-spreader system (soil horizons are blended with and without topsoil), (2) scraper-trucker comparison (scrapers replace 1 m of rooting media over graded cast overburden, dump trucks place 1 m of rooting media on base level and dozers level material, or truck traffic is on material with topsoil in windrows that are dozer pushed), and (3) cross pit wheel (topsoil is placed with scrapers on graded wheel spoil, scrapers windrow topsoil, which is pushed out by dozers, or dozers windrow topsoil and push it). The soil physical condition was evaluated using a constant-rate recording cone penetrometer to a depth of 112 cm, which measures soil strength. As soil strength increases, root penetration decreases. Soil strengths (penetrometer resistance) below 1.0 MPa were found in areas of minimal grading and traffic, while readings of 2.0 MPa or more were found in areas constructed with scrapers. Methods that used only dozers and limited the amount of grading resulted in the most favorable physical condition.

1187. Vandevender, J. C., and J. C. Sencindiver. The Effects of Three Forms of Nitrogen Fertilizer, Phosphorus, and Hydrated Lime on Abandoned Mine Land Reclamation. Paper in 1982 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 5-10, 1982). Univ. KY, Lexington, 1982, pp. 497-502.

This study evaluated the effects of lime, phosphorus, and three forms of nitrogen fertilizer on selected mine-soil properties and establishment of vegetation on two surface-mined sites in West Virginia. Nine treatments, replicated four times, were used: (1) control, (2) lime, (3) lime plus phosphorus, (4) lime plus phosphorus plus ammonium nitrate, (5) lime plus phosphorus plus sodium nitrate, (6) lime plus phosphorus plus nitroform, (7) lime plus ammonium nitrate, (8) lime plus sodium nitrate, and (9) lime plus nitroform. Each of the above treatments was seeded to the following mixture: Empire birdsfoot trefoil (*Lotus corniculatus* L.), 11.2 kg ha^{-1}; Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.), 16.8 kg ha^{-1}; redtop

(*Agrostis alba* L.), 3.4 kg ha^{-1}; Tioga deerstongue (*Panicum clandestinum* L.), 1.1 kg ha^{-1}; and Lathco flatpea (*Lathyrus sylvestris* L.), 1.1 kg ha^{-1}. Prior to treatment the experimental areas were devoid of vegetation and had the following spoil characteristics: an average pH of 4.1; low levels of calcium, magnesium, and sodium-bicarbonate-extractable phosphorus; medium to high levels of potassium and double-acid-extractable phosphorus; and total nitrogen of 0.18 to 0.36 pct.

Applications of hydrated lime significantly increased the neutralization potential, the pH (average value of 1.7), calcium levels, and the quantity of double-acid-extractable phosphorus and sodium-bicarbonate-extractable phosphorus. This indicates that liming increased the solubility of phosphorus in these mine soils. Nitrogen applied to limed plots, as either NH_4NH_3, $NaNO_3$, or UF, had no effect on the total nitrogen levels of the mine soils. Vegetation establishment was significantly enhanced by lime and the lime plus phosphorus treatments. However, the lime plus nitrogen treatments and the lime plus phosphorus plus nitrogen treatments did not cause a significant increase in percent ground cover over that produced in the lime or lime plus phosphorus treatments, respectively. These results indicate that vegetative ground cover is not increased by adding nitrogen to lime or lime plus phosphorus treatments. Lime, phosphorus, and mulch were more important than nitrogen for establishing vegetative cover on these mine soils.

1188. Van Epps, G. A., and C. M. McKell. Revegetation of Disturbed Sites in the Salt Desert Range of the Intermountain West. Coll. Nat. Resour., UT State Univ., UT Agric. Exp. Stn. Land Rehab. Ser., No. 5, Sept. 1980, 37 pp.

This publication reports the results of a study conducted in a major oil shale area near Vernal, UT. The study was designed to evaluate the effects of various propagation methods, planting seasons, and other treatments on shrub establishment and survival. The survival of bare-root stock was generally high in relation to that of container-grown plants. The authors state that it is advantageous to use bare-root stock for early-season plantings because it is faster, easier, and more economical. However, inexperienced planting crews, late-season planting, and the time when plant dormancy is broken can present situations that reduce the advantages of planting bare-root stock. Few or no survival benefits were obtained from applying additional moisture at the time of planting. Control of weed competition was found to be important to the survival of planted shrubs. The results of these studies indicate that plantings need to be observed for a minimum of 3 to 4 years before concluding that plants are in a permanent survival condition.

1189. Van Es, H. M., M. L. Thompson, S.J. Henning, and R. Horton. Effect of Deep Tillage and Microtopography on Corn Yield on Reclaimed Surface-Mined Lands. Soil Sci., v. 145, No. 3, 1988, pp. 173-179.

The effects of three methods of deep tillage on corn (*Zea mays* L.) yield on reclaimed surface-mined land in Iowa were investigated. The tillage treatments applied to the reclaimed mine soil were slip-plowing (0.7 and 1.0 m deep), subsoiling (0.7 and 1.0 m deep), moldboard plowing (0.5 m deep), and an untilled control. No significant differences in corn yield among the tillage treatments were detected. There were, however, strong associations between corn yields and the microtopography of harvested plots. In concave positions, yields were reduced to a mean value of 3.40 Mg ha^{-1}, compared with 5.34 Mg ha^{-1} for nonconcave positions. These yield reductions in concave positions were attributed to the standing water that collected in them during critical periods during the growing season. Geostatistical techniques were used to characterize the spatial variability of corn yield and to generate maps of distribution. The semivariograms for corn yields showed no significant observable tillage effects. The semivariograms also showed that there is no clear spatial dependence; the spatial variability patterns of yield varied for different regions of the site. Isarithmic maps of corn yield, produced by the kriging procedure, illustrated the effect of microtopography on corn yield. The authors concluded that in mine reclamation for agricultural production, the effect of microtopography should be considered, in that field variability should be kept to a minimum through careful grading.

1190. Van Hess, W. W. An Approach to Soil Productivity Assessment in Southeast Alaska. Paper in Proceedings of the Alaska Forest Soils Productivity Workshop, ed. by C. W. Slaughter, T. Gasbarro, and T. Lawson (Anchorage, AK, Apr. 28-30, 1987). U.S. For. Serv., Gen. Tech. Rep. PNW-219, 1988, pp. 81-83.

The problems associated with site index as a measure of site quality are presented. The author presents an alternative approach, which uses volume equations developed for individual trees on different forest ecosystem soils. The results are compared for significant differences. This approach does not identify the soil characteristics critical to site productivity, but it does quantify differences in site productivity.

1191. Van Luik, A. Mined Land Reclamation Using Polluted Urban Navigable Waterway Sediments: I. Trace Metals. J. Environ. Qual., v. 13, No. 3, 1984, pp. 410-414.

Sediments from the Calumet-Sag Channel, south of Chicago, IL, were assessed for suitability as a soil amendment on coal surface-mined land. The concentrations of 11 trace metals (all silt and clay content) were determined for 34 sediment samples from 10 cores taken at 2.4-km intervals along the length of the channel. Zinc levels may have to be monitored if the sediments are used as an amendment when certain agronomic crops are grown, owing to the potential for zinc phytotoxicity.

1192. Van Luik, A. Mined Land Reclamation Using Polluted Urban Navigable Waterway Sediments: II. Organics. J. Environ. Qual., v. 13, No. 3, 1984, pp. 415-422.

Levels of selected organic contaminants found in the sediments of the Calumet-Sag Channel in Chicago, IL, were determined in order to assess the suitability of the dredged material for use as an amendment on abandoned mined lands. Organic pollutants analyzed included volatile solids, oil and grease, total phenols, cyanide, total polychlorinated biphenyls (PCB's) and polycyclic aromatic hydrocarbons (PAH's). No significant correlations were found with sediment sample depth, location, or sediment silt or clay content. Each organic pollutant type is discussed.

1193. Van Luik, A., and W. Harrison. Mined Land Reclamation Using Polluted Urban Navigable Waterway Sediments: III. Experience at a Demonstration Site. J. Environ. Qual., v. 13, No. 3, 1984, pp. 423-431.

Dredged material from the Calumet-Sag Channel was used as a soil amendment on abandoned acidic coal mine spoils near Ottawa, IL. Treatments consisted of a control, mine spoil with 0.9 m of dredged material cover, 12 Mg ha^{-1} limestone incorporated into the top 15 cm of mine spoil with 0.9 m of dredged material cover, and 17 Mg ha^{-1} limestone incorporated into the top 15 cm of mine spoil with 0.9 cm of dredged material cover. All treatment plots were seeded with a mixture of six grasses. Water quality (pH, base cation concentrations, and trace metal concentrations) was monitored over a 4-year period. Water quality was monitored within the dredged material, the dredged material and mine spoil interface, and the underlying spoil at depths of 0.6, 0.9, and 1.5 m, respectively. Results show that in the control plots soil-water quality near the surface deteriorated with time with respect to pH. Deeper control-plot samples showed no significant changes in soil-water quality. Where dredged materials were used, the surface soil-water pH decreased slightly, while solutions collected at the dredged material and mine spoil interface were neutralized, with the dissolved trace metals dropping significantly. The authors state that the applied dredged materials have ameliorated the acidity and trace metal levels of the water found in the acidic mine spoil.

1194. Van Luik, A., and W. Harrison. Reclamation of Abandoned Mined Lands Along the Illinois Waterway Using Dredged Material. Argonne Natl. Lab., ANL/ES-127, Jan. 1982, 112 pp.

This report examines the feasibility of using river sediments from the Illinois, Kankakee, and Des Plaines Rivers in Illinois to reclaim abandoned surface-mined areas near those rivers. Sediments were sampled from 28 proposed or actual dredging sites. The samples were analyzed and found to be suitable topsoil and/or reclamation media. Problem abandoned surface-mined sites were identified, and three were designated as being particularly well suited for dredged material reclamation. Economic analysis showed that using the dredged material as a reclamation medium would be competitive with near-source confined disposal.

1195. Van Wesenbeeck, J. J., R. G. Kachanoski, and D. E. Rolston. Temporal Persistence of Spatial Patterns of Soil Water Content in the Tilled Layer Under a Corn Crop. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 934-941.

The spatial and temporal dynamics of surface water content under row crops affect many soil processes. The spacial distribution of surface water content can vary significantly with time and crop growth stage. This study describes the spatial and temporal dynamics of soil water content in the surface tilled layer (0 to 0.2 m) under a corn (*Zea mays* L.) canopy. Transfer function theory was used to describe the temporal change in the spatial variability of soil water content and the variability in the time of some hydrologic processes such as evapotranspiration and precipitation. Spatial coherency analysis was used to examine changes in the spatial pattern of soil water content at specific scales associated with row spacing. The transfer function and the coherency spectrum indicate that there is a highly time-dependent row-interrow pattern of soil water content caused by the crop, which is imposed on a large-scale pattern of surface soil water content.

1196. Vepraskas, M. J. Bulk Density Values Diagnostic of Restricted Root Growth in Coarse-Textured Soils. Soil Sci. Soc. Am. J., v. 52, No. 4, 1988, pp. 1117-1121.

Bulk density values related to both high mechanical impedance (where root growth is stopped) and to lower mechanical impedance (where root growth may be retarded, but with subsoiling increased root growth and yield

may occur) were determined. Mechanical impedance was determined and expressed as cone index. A model was developed to estimate cone index from bulk density and particle size distribution. Bulk density accounted for most of the variation in cone index; however, the descriptive power of the model was improved when soil size distribution was used with bulk density.

1197. Vimmerstedt, J. P., K. E. Jewell, and M. M. Larson. *Liriodendron* Seedling Growth on Calcareous and Acid Minesoils Developed Under Pine or Hardwood. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 74-78.

A greenhouse experiment was conducted to determine the effects of parent material, organisms, and topography (soil-forming factors) on the growth and mineral nutrition of tuliptree seedlings (*Liriodendron tulipifera* L.). Soil cores were taken from two parent materials, calcareous mine soil (consisting of acid shale, calcareous shale, and limestone) and acid mine soil (consisting of grayish-black shale), at two slope positions (top or bottom of ungraded, unfertilized spoil banks), and developed under four tree species. The soils developed under plantings established in 1946. The species planted were white ash (*Fraxinus americana* L.), white pine (*Pinus strobus* L.), black locust (*Robinia pseudoacacia* L.), and tuliptree. A total of 192 cores were obtained: 2 parent materials, 4 tree species, 2 slope positions, 3 trees per slope position, and 4 cores per tree. Two tuliptree seedlings were grown in each core for 17 weeks.

Tuliptree seedlings grown in black locust soils were taller, had greater root and shoot biomass, and had more leaves with high concentrations of nitrogen and phosphorus than the ones grown in soils developed under tuliptree, white ash, or white pine. Those seedlings grown in soil developed in white ash had less height growth and biomass than any of the others examined. The effects of slope position on seedling growth characteristics varied with parent material. On acid mine soils, soils from lower slope positions produced seedlings with the greatest height and biomass, however, on calcareous mine soils, soils from the upper slope positions produced seedlings with the greatest height and biomass development. Of the two parent materials, the acid mine soils (shales) produced bigger, more nutrient rich seedlings than the ones grown in calcareous (limestone) mine soils. Seedlings grown on acid mine soils had higher concentrations of nitrogen, phosphorus, potassium, magnesium, and manganese than seedlings grown on calcareous mine soils, which had higher tissue concentrations of calcium. Possible reasons for differences in seedling growth are given.

1198. Visser, S. Management of Microbial Processes in Surface Mined Land Reclamation in Western Canada. Ch. in Soil Reclamation Processes: Microbiological Analyses and Applications, ed. by R. L. Tate III and D. A. Klein. Marcel Dekker, 1985, pp. 203-241.

Three study sites located in different climatic and vegetational zones in Alberta, Canada, were chosen to illustrate effects of mining on selected soil characteristics. The main factors that require consideration to ensure successful plant establishment and growth on coal and oil sand spoils are (1) climate of the mined area, (2) soil nutrient status, (3) spoil texture, and (4) spoil organic matter content. Mine spoil chemical and physical properties are important for initial plant establishment and growth; however, biological factors must be considered for the successful maintenance of soil fertility and the evolution of a stable soil-plant system. Microbiological characterization of mine spoils on tailings in Alberta has involved three approaches: (1) qualitative and quantitative determination of bacteria, actinomycetes, and fungi, (2) measurement of soil biological activity, and (3) assessment of the leaf litter decay process and rates at which essential plant nutrients are mineralized.

The author recommends a holistic approach to describing microbial status and processes in mine wastes. The parameters that should be evaluated include (1) numbers of bacteria and actinomycetes, (2) nature of colonizing bacteria, (3) mycelial lengths of fungi, (4) types of fungi, (5) soil respiration, (6) microbial biomass carbon, and (7) ATP estimates. Methods of restoring biological activity to soils disturbed by mining are presented. The reestablishment of mineral activity is considered essential to the successful reclamation of mine wastes. The most important aspect in any reclamation program is the presence of organic matter. Organic matter content can be improved on mine spoils by (1) establishing a vegetative cover that will result in the accumulation of stable organic matter through plant decomposition and (2) ameliorating the waste with an organic amendment followed by revegetation. Soil chemical characteristics and microbial populations, activity, and biomass were decreased after amendments of fertilizer, sewage sludge, and peat to a subalpine coal mine spoil and oil sands tailings. To raise the microbial activity in mine spoils it may be necessary to increase the level and input rates of soil organic matter.

1199. Visser, S., C. L. Griffiths, and D. Parkinson. Topsoil Storage Effects on Primary Production and Rates of Vesicular-Arbuscular Mycorrhizal Development in Agropyron Trachycaulum. Plant and Soil, v. 82, No. 1, 1984, pp. 51-60.

A greenhouse study was conducted to determine the effects of stockpiling prairie soil for 3 years on the root and shoot production of slender wheatgrass (*Agropyron trachycaulum* (Link) Malte) and the rate of mycorrhizal fungi involved in the symbiosis. The stockpile samples were compared with undisturbed prairie samples. The soil parameters were measured in the undisturbed prairie soil. Shoot and root weights and root lengths of the seedlings increased between 1, 3, and 5 days with no difference between plants in undisturbed and stockpile soil. Vesicular-arbuscular mycorrhizal infection was first observed on roots of 3-day-old seedlings grown in undisturbed topsoil, while grasses in the stockpiled topsoil remained uninfected after 5 days. Root production was not affected by stockpiling. Eight weeks after planting, the root-to-shoot ratio of the stockpiled soil was higher than that of undisturbed soil.

One week after planting, the total length of roots infected with VA mycorrhizae was significantly less for grasses grown in stockpiled soil than for grasses in the undisturbed soil. After 3 weeks, however, the amount of root infected with VA mycorrhizae was the same for both soil types, with no significant difference in mycorrhizal root length detected after 8 weeks. The percentage of VA mycorrhizal infection was significantly less in the stockpiled topsoil at 1 week, but at 3 and 8 weeks no significant differences were detected between the soil types. Spores found on plots grown in undisturbed soil were mainly produced by *Glomus fasciculatum*, while spores produced on grasses in the stockpiled soil were primarily *Glomus mosseae*. Stockpiling did not have a significant effect on VA mycorrhizal spore production, but it did alter the proportion of spores produced. The delay in initial VA mycorrhizal infection and shift in VA mycorrhizae species did not affect plant productivity, which was greatest in the stockpiled soil. The data indicated that topsoil storage would delay initial VA mycorrhizal development and that a shift in VA mycorrhizae dominating the root system would occur; however, these changes would not alter plant productivity or the decomposition potential of the stockpiled topsoil.

1200. Visser, S., J. C. Zak, and D. Parkinson. Effects of Surface Mining on Soil Microbial Communities and Processes. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 643-651.

This article provides a unique view of the effects of mining and reclamation on an often-overlooked area of reclamation, soil microbiology. The authors relate the results of a study conducted in a subalpine spruce-fir forest area near Luscar, AB, Canada. They investigated the effects of mining disturbances on soil microbial communities, the development of microbial communities, and activities in mine spoils following treatment with various organic and inorganic amendments.

1201. Vogel, W. G. A Guide for Revegetating Coal Minesoils in the Eastern United States. U.S. For. Serv., Gen. Tech. Rep. NE-68, 1981, 198 pp.

This report contains information, recommendations, and guidelines for the revegetation of land in the Eastern United States disturbed by coal mining. Included are brief descriptions of Eastern Coal Mining Regions along with their respective mine-soil properties and procedures for sampling, testing, and amending these soils. Plant species suitable for revegetating surface-mined lands are identified and described in tabular form. Selection procedures for plant species are described, and methods and requirements for seeding and planting are explained. Reforestation methods and results are described from recent data on 30-year-old plantings in the Eastern States. This report is a good treatment of the revegetation procedures and considerations necessary for coal mined lands of the eastern coalfields. It contains extensive bibliographic listings and a glossary of terms.

1202. Vogel, W. G. A Manual for Training Reclamation Inspectors in the Fundamentals of Soils and Revegetation. (Prepared for Off. Surf. Min. Reclam. and Enforcement by U.S. Dep. Agric., For. Serv.) Soil and Water Conserv. Soc. Am., Sept. 1987, 178 pp.

This handbook was developed to give surface mining and reclamation inspectors a basic understanding of soils and vegetation as they relate to the reclamation of surface-mined lands. It is a guide to understanding soil and plant science principles appropriate to overburden and soil removal, replacement, testing, and treatment; species selection for various land uses; and evaluating revegetation success. The manual is divided into nine main sections. The first section, the permit application package, discusses the information that an inspector should have about the mined site prior to an inspection, how to prepare for an inspection, what equipment should be carried in the field, and what to look for when making an inspection.

Important overburden characteristics are discussed. Soil chemical, physical, and biological properties determine the suitability of a soil as a medium for plant growth. Other characteristics discussed include soil profile descriptions, geologic strata, and sampling and testing mine soils. The handling of plant growth media is discussed in terms of removal (methods and timing), storage and protection, and replacement. A section on the special considerations associated with soil removal, stockpiling, replacement,

reconstruction, and proof of productivity for prime farmland soils, remined areas, and refuse areas is included.

The section on vegetation establishment and cultural practices contains information on soil amendments, irrigation, water harvesting, seeding practices, planting woody species, and mulching. Amendments discussed include fertilizers, liming materials, organic materials, microbiologic materials, and mulches. Techniques for application and, in some cases, rates are given. Mulching is discussed separately and is not considered an amendment by the author because mulch is not incorporated into the soil. Considerable information is given on the reasons for mulching, mulch selection, and material mulches grown in place, as well as soil stabilizers and application rates.

Various postmining land uses are given, along with methods of evaluating revegetation success. Sections are devoted to the revegetation of coal surface-mined lands in the eastern and western coal regions, divided by the 100th meridian. Each section briefly describes each geographic coal region, plant species suitable for revegetating surface-mined lands in each region, criteria for selecting these species, and species and species mixtures for different land uses in each region. This manual contains much useful information on soils and revegetation of coal surface-mined lands in the United States.

1203. Vogel, W. G. Revegetation Research on Surface-Mined Land in Eastern Kentucky. Paper in Proceedings Fourth KY Coal Refuse Disposal and Utilization Seminar (Pineville, KY, June 6-7, 1978). Inst. Min. and Miner. Res., Univ. KY, Lexington, KY, 1978, pp. 5-15.

The author discusses some of the U.S. Forest Service's revegetation research and its application to mined land reclamation in eastern Kentucky. Research has been conducted on the suitability of woody and herbaceous species; effects of spoil properties on plants; requirements for fertilizer, lime, mulch, and seedbed preparation; feasibility of all-season seeding; compatibility of trees with herbaceous cover; and microbial associations. Research studies initiated by other Federal and State agencies are also discussed. The author feels that one of the current problems associated with reclamation is how to devise revegetation strategies for specific land uses.

1204. Vogel, W. G. Revegetating Surface Mined Lands With Herbaceous and Woody Species Together. Paper in Trees for Reclamation (Lexington, KY, Oct. 27-29, 1980). U.S. For. Serv., Gen. Tech. Rep. NE-61, 1980, pp. 117-126.

The author reviews the literature that deals with the use of seeded grasses and legumes, fertilizers, and herbicides to increase the survival and growth rates of planted and direct-seeded hardwoods and conifers on surface-mined lands in the Eastern United States. The importance of establishing a herbaceous cover, excluding grass species, to provide adequate erosion control is demonstrated. Climatic factors and the tree species used are important variables to consider when reclaiming mine spoils. The survival and growth rate of planted trees can be significantly affected by the yearly precipitation and how resistant to competition and drought the tree species is. When tree species and herbaceous species are planted in combination, the best method of planting is to use alternate strips of seeded herbaceous and tree species. This paper provides the reader with a clear understanding of all the factors affecting the establishment of trees on surface-mined lands.

1205. Vogel, W. G., and B. Gray. Will Trees Survive on Topsoiled Surface Mines? Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 304-305.

The results of a greenhouse study and a field study comparing herbaceous and tree growth on nontopsoiled spoil and topsoiled spoil are presented. The field study documents the survival of pine trees planted on spoil and replaced topsoil, while the greenhouse pot study compares vegetative growth on spoil and topsoil samples from the site. Both lime and fertilizer were used on the replaced topsoil and spoil treatments in the field and greenhouse studies.

In the field study, the spoil was seeded to tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.), alfalfa (*Medicago sativa* L.), white clover (*Trifolium repens* L.), and sericea lespedeza (*Lespedeza cuneata* (Dum.) G. Don) and then planted with 1-0 seedlings of Virginia pine (*Pinus virginiana* Mill.), loblolly pine (*Pinus taeda* L.), white pine (*Pinus strobus* L.), and autumn olive (*Elaeagnus umbellata* Thunb.). The replaced topsoil was seeded to sorghum (*Sorghum* spp.), red fescue (*Festuca rubra* L.), and Korean lespedeza (*Lespedeza stipulacea* Maxim.) and then planted with 1-0 seedlings of shortleaf pine (*Pinus enchinata* Mill) and loblolly pine. After the first growing season, pine survival was 89 pct on the topsoiled area and 48 pct on the spoil area; however, at the end of the second growing season, pine survival was 4 pct on the topsoiled area and 36 pct on the spoil. Although there was a late summer drought during the second growing season, root evaluations on the topsoiled areas showed that pine roots were not able to penetrate into the compacted soil. The topsoiled area limited infiltration and deep rooting by the pine species while the spoil, which was porous, allowed deeper infiltration and deeper penetration by tree roots.

In the greenhouse pot study, tall fescue and red clover (*Trifolium pratense* L.) were both seeded into each pot,

which contained one of the two growth mediums, and treated with lime and fertilizer, dolomite and fertilizer, or fertilizer only. Yields of both species in the amended spoil exceeded the yields in amended topsoil. These results indicate that the amended spoils used can be as productive as the amended topsoil material. The field study shows that there is no advantage, nor is it necessary, to topsoil for acceptable tree survival and growth on most mine spoils.

1206. Vogel, W. G., and F. M. Rothwell. Bark Mulch Aids Establishment of Black Walnut on Western Kentucky Mine Spoils. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 104-110.

In this study four methods of planting black walnut (*Juglans nigra* L.) were compared, and the effects of hardwood bark mulch on the survival of the planted trees was evaluated on a western Kentucky coal surface minesite. The treatments consisted of planting bar, planting bar and mulch, mattock, mattock and mulch, augered hole backfilled with spoil, augered hole backfilled with spoil and mulch, augered hole backfilled with topsoil, and augered hole backfilled with topsoil and mulch. Mulch was spread around the tree so that a patch 30 in. in diameter and 3 to 4 in deep resulted.

The most significant result of the study was that the survival of mulched trees was greater than that of unmulched trees. After 7 years, survival was 58 pct for mulched trees and 17 pct for unmulched trees. Where mulch was not used, the auger method produced slightly better survival than the mattock or planting bar. Augering may have resulted in better survival, but not enough to justify the additional cost. The same results could be achieved at less cost by planting a greater number of seedlings using the mattock or planting bar method. There were no relationships between tree height and planting method or mulch treatment, owing to the dieback and resprouting that occurred on many of the trees. Vesicular-arbuscular mycorrhizae (*Glomus* spp.) were associated with the root tissues of trees that had dieback and no dieback, indicating that factors other than the lack of VA mycorrhizal associations were responsible for the dieback.

1207. Vogel, W. G., and F. M. Rothwell. Mushroom Compost and Papermill Sludge Influence Development of Vegetation and Endomycorrhizae on Acid Coal-Mine Spoils. Paper in Mine Drainage and Surface Mine Reclamation, Volume II. Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 206-213.

A greenhouse pot study and field studies were conducted to evaluate the effectiveness of amending acid mine spoils with papermill sludge and spent mushroom compost, compared with lime plus fertilizer, on promoting yields of perennial ryegrass (*Lolium perenne* L.) and red clover (*Trifolium pratense* L.). In addition, the influence of these amendments on the formation of endomycorrhizae by VA mycorrhizal fungi was also evaluated.

In the greenhouse study 11 treatments were used: none (control), lime plus fertilizer, papermill sludge at three rates (25, 50, and 75 g per 1,000 g soil), mushroom compost at three rates (same as papermill sludge), and a 1:1 mix of papermill sludge and mushroom compost at three rates (one-half the rate of each material alone). These rates were equivalent to 56, 112, and 168 mt ha^{-1}. Sixty days after seeding, the vegetation was harvested. Four succeeding harvests were made periodically during the next 10 months.

In the field, treatments consisted of agricultural lime (16 mt ha^{-1}) plus fertilizer (560 kg ha^{-1} 10-10-10), papermill sludge and mushroom compost at 76 and 112 mt ha^{-1}, and 1:1 mix of sludge and mushroom compost at 38 and 56 mt ha^{-1} of each material. Herbage yields were determined at the end of the growing season. Chemical characteristics of the acid mine spoil and organic amendments used are presented.

Herbage yields in the greenhouse study were progressively higher with each increment of papermill sludge, mushroom compost, and mix added. The highest yields were obtained from the high rate of the 1:1 mix. Yields from the low-compost amendment were similar to yields from the lime plus fertilizer treatment. The low rate of sludge and 1:1 mix resulted in yields that were lower than those from treatments with lime plus fertilizer.

Field results supported the results obtained in the greenhouse study. Sludge and compost amendments produced higher yields than did the lime plus fertilizer amendment. In both the greenhouse and field studies, endomycorrhizal formation was enhanced by papermill sludge and a 1:1 mixture of sludge and compost compared with the lime fertilizer treatment. Mushroom compost alone, however, inhibited mycorrhizal formation at all treatment levels because of the high levels of phosphorus in the composted material.

The results of these studies show that both papermill sludge and spent mushroom compost can be effective in amending acid mine spoils in southeastern Ohio and can promote the growth of herbaceous vegetation. Comparative costs of each amendment are also given. Compared with the cost of liming, fertilizing, and mulching, the cost of applying papermill sludge and mushroom compost was about 2.5 times higher, but the yields were 2 to 3 times greater than with the lime-fertilizer treatments.

1208. Voorhees, L. D., M. J. Sale, J. W. Webb, and P. J. Mulholland. Guidance for Disposal of Uranium Mill Tailings: Long-Term Stabilization of Earthen Cover Materials (U.S. Nucl. Regul. Comm. contract BO279). Oak Ridge Natl. Lab., ORNL/TM-8685, Oct. 1983, 101 pp.

The purpose of this document is to provide the technical information necessary for NRC to evaluate plans for stabilizing uranium mill tailings over a wide range of site and environmental conditions. It specifically addresses means to minimize long-term erosion, disturbance, and dispersal of uranium mill tailings by natural forces. This document provides excellent literature reviews of the physical and biological factors and processes of soil surface stabilization. The variations of the environmental characteristics at existing and potential uranium mill sites are discussed. The concept of an optimal plan is addressed, and the information necessary to judge whether a proposed plan constitutes an optimal design for long-term tailings disposal with respect to site-specific conditions is outlined. While this manual was designed to provide guidance in assessing plans for the stabilization of uranium mill tailings, it provides an excellent reference to soil surface stabilization in general. Consequently, it is applicable to reclamation planning for surface coal mine lands.

1209. Voorhees, M. E. Infiltration Rate of Bentonite Mine Spoil as Affected by Amendments of Gypsum, Sawdust and Inorganic Fertilizer. Reclam. & Reveg. Res., v. 5, No. 4, 1986, pp. 483-490.

This laboratory study was conducted to characterize changes in the infiltration rate of bentonite mine spoil as affected by gypsum, inorganic fertilizer, and sawdust and to use the characterizations to make recommendations on the types and amounts of amendments to be used in revegetation efforts. Each amendment was applied alone and in combination in a 23-factorial arrangement. Gypsum was applied at a rate of 3.1 kg m^{-3} of spoil; fertilizer (N-P-K) was applied at 11.3 g N, 1.8 g P, and 50 g K per cubic meter of spoil; and sawdust was applied at rates equivalent to 144 Mg ha^{-1}. All amendments were thoroughly mixed with spoil. Infiltration rates were highest on spoil material amended with sawdust or combinations of sawdust and other amendments during the first 24 h. Gypsum or fertilizer amendments had no significant effect on infiltration. Water penetrated sawdust-amended spoils at rates 92, 259, and 300 pct greater than the rates of penetration for spoil not amended during 0- to 1-, 1- to 2-, and 2- to 24-h time periods after wetting, respectively. Sawdust amendments had no effect on infiltration after 24 h. Sawdust amendments, alone or in combination, also significantly affected cumulative infiltration. Results show that sawdust amendments have the potential for improving bentonite mine spoil as a plant growth substrate.

1210. Voorhees, M. E., M. J. Trlica, and D. W. Uresk. Growth of Rillscale on Bentonite Mine Spoil as Influenced by Amendments. J. Environ. Qual., v. 16, No. 4, 1987, pp. 411-416.

This study evaluated the response of rillscale (*Atriplex suckleyi* (Torrey) Rydb.) to three soil amendments (gypsum, fertilizer, and sawdust with nitrogen) when seeded on unreclaimed bentonite mine spoil in northeastern Wyoming. Each amendment was used alone and in all possible combinations and applied in the fall prior to seeding and again (on separate plots) at the time of seeding. Standing crop, height, and cover of rillscale were sampled at the end of the first two growing seasons. The unamended spoil was low in nitrogen, but levels of iron, soluble salts, sulfates, SAR, CEC, and saturation percentages were high.

After the first growing season, spoil treated with all three amendments during the previous fall had the greatest amount of standing crop biomass. Fall applications of gypsum (alone or in combination) increased standing crop, plant height, and canopy cover by 90, 46, and 70 pct over nongypsum treatments, respectively. Spring applications of gypsum had little effect on plant growth. Sawdust amendments (alone or in combination) in the fall increased standing crop, plant height, and canopy cover by 129, 69, and 90 pct, respectively, over nonsawdust treatments. Spring applications of fertilizer resulted in less plant height than fall applications. After two growing seasons, the peak stand crop of control plants averaged 600 kg ha^{-1}, while plots treated with all three amendments (fall application prior to original seeding) resulted in an average peak standing crop of 3,500 kg ha^{-1}. Sawdust amendments (alone or in combination) in the fall had a greater positive effect on second-year peak standing crop than did the spring-applied sawdust. Gypsum, sawdust, and fertilizer amendments increased cover by 85, 226, and 56 pct, respectively, over that of plots not receiving these amendments. The influences of gypsum and fertilizer additions on rillscale growth declined during the second growing season. The sawdust amendment (alone or in combination with gypsum or N-P-K fertilizer) had the greatest effect on all vegetative parameters during the growing seasons studied, with the fall application having a greater effect than the spring application of amendments.

1211. Voos, G., and B. R. Sabey. Nitrogen Mineralization in Sewage-Sludge-Amended Coal Mine Spoil and Topsoils. J. Environ. Qual., v. 16, No. 3, 1987, pp. 231-237.

A laboratory incubation study was conducted to measure the amount of inorganic nitrogen that would accumulate in sewage-sludge-amended coal mine spoils, two topsoils, 1:1 mixtures of the spoil with each topsoil, and

a quartz sand. Ammonification and nitrification rates were determined, and the amount of net mineralization of organic nitrogen added with the sewage sludge was calculated. The amount of inorganic nitrogen that accumulated in each material over a 16-week period was compared with the value derived from a previously developed first-order kinetic equation using nonlinear least squares analysis. All topsoil and spoil used in this study was collected from an active mine located near Steamboat Springs, CO. Topsoils were collected from an undisturbed site adjacent to the open pit and from a topsoil stockpile (approximately 9 months old). The undisturbed topsoil (UTS), stockpiled topsoil (STS), spoil, 1:1 (weight-to-weight) mixtures of UTS-spoil and STS-spoil, and sand were combined with 0, 1.78, 3.57, and 5.35 g of aerobically digested sewage sludge and incubated for 0, 1, 2, 4, 6, 8, 11, and 16 weeks at 25° C. The rates of sludge were equivalent to 0, 40, 80, and 120 Mg ha^{-1} of dried sewage sludge.

Among the materials tested, there were significant differences in the amount of native organic nitrogen that was mineralized. Accumulation of inorganic nitrogen in each material after 16 weeks was 636 Mg kg^{-1} UTS, 392 Mg kg^{-1} STS, plus 274 Mg kg^{-1} spoil, 359 Mg kg^{-1} UTS plus spoil, 319 Mg kg^{-1} STS plus spoil, and 40 Mg kg^{-1} soil at the 0-Mg-ha^{-1} sludge rate. Sludge rate significantly affected the amount of inorganic nitrogen accumulated in each material over the 16-week incubation period. The greatest amount of inorganic nitrogen accumulated was in the UTS with 1,023, 935, 730, and 636 Mg N per kilogram soil at the 120-, 80-, 40-, and 0-Mg-ha^{-1} sludge rates, respectively. The amount of NO_3-N accumulated remained constant throughout the incubation period among the sludge rates for the same material tested. Possible reasons are given. The amount of NO_3-N produced in the spoil at all sludge rates was less than that produced in the other materials tested, with the exception of the soil where little or no NO_3-N production was detected. The amount of NH_4-N that accumulated increased significantly as the rate of sludge addition increased. Except for the UTS and spoil treatment, the rate of ammonification had stabilized after 8 weeks. The percentages of sludge organic nitrogen that was mineralized in 16 weeks for each soil-spoil material ranged from 9.7 pct in the soil to 32.7 pct in STS. The nonlinear least squares regression equation for nitrogen mineralization slightly overestimated nitrogen mineralization over the 16-week period.

1212. Vories, K. C. Proof of Vegetative Productivity: Research Needs. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 145-149.

Areas where research is needed to provide a basis for bond release of cropland are identified. Three problem areas must be addressed if cropland reclamation is to be achieved: reclamation technology, measurement of crop yield, and soil description and mapping. Research is needed in the areas of (1) evaluation of existing methods for stabilizing crop productivity standards, (2) evaluation of soils and physical plant growth, media information to determine potential crop productivity, and (3) evaluation of methods of reclamation planning necessary to predictably project the effects of given mining and reclamation methods on crop yield potential.

1213. Vrabec, S. H. Physiochemical Characterization of Vegetated Iron Ore Mine Spoils in Central Wisconsin. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 255-260.

The formation of a mine soil in a revegetated iron ore spoil pile in central Wisconsin was investigated after 12 years had passed since the initial excavations of the ore pit. The spoil pile was graded and revegetated, but no topsoil, fertilizer, or other soil amendments were used. Particle size, water-holding capacity, plant nutrient levels, and organic matter content were determined. Particle size analysis revealed that the surface 20 cm had a sandy loam texture, which is indicative of parent materials that have been weathered rapidly. The percentage of clay increased from the 0- to 5- cm to 5- to 10-cm depth, indicating that clay illuviation has occurred. Clay migration depicts rapid soil formation. Average levels of phosphorus, potassium, calcium, and magnesium in the surface 20 cm of soil are compared with the recommended levels of nutrients for agricultural production. There is a significant decrease in organic matter content with depth, but this is within the range for sandy loam agricultural soils. The effects of soil-forming processes on revegetated mine spoils are exhibited in the 12-year-old mine soil studied.

1214. Vroon, H. R. J., L. W. Dekker, and J. M. H. Hendrickx. A Method for Measuring Hydraulic Properties of Brittle Soil Horizons. Soil Sci. Soc. Am. J., v. 52, No. 1, 1988, pp. 292-295.

A method is described for taking undisturbed samples of brittle sandy soil horizons that are suitable for use in determining hydraulic properties. An undisturbed soil pedestal is carved out in situ by removing soil along its sides with a knife, with the pedestal left connected with the underlying soil. The soil pedestal is then covered with a mixture of nitrocellulose lacquer and thinner and allowed

to dry (1 h) before detaching. The saturated hydraulic conductivity is measured by infiltrating water into the exposed upper surface (by peeling off a lacquer layer) and collecting it below the exposed lower surface (by peeling off the lacquer layer) of the pedestal.

In this study the saturated hydraulic conductivity of a sandy hardpan was determined by three methods: steel cylinders, lacquer-covered blocks, or gypsum-covered blocks. Soil water retention capacity of a sandy humus hardpan was determined with steel-core cylinders or lacquer-covered blocks. Finally, horizontal and vertical saturated hydraulic conductivity was measured on lacquer-covered samples.

When compared, the lacquer-covered samples yielded the lowest conductivity values. The conductivities of the steel-core samples exceeded those of the lacquer-covered samples by a factor of 4, while gypsum-covered samples yielded excessively high conductivity values because of the lack of good contact between the sample and its gypsum casting. The lacquer-covered samples yielded more representative saturated hydraulic conductivity values for the brittle soil horizons studied.

Significant differences in water-retention capacity were found between the steel-core samples and lacquer-covered samples. The steel core caused horizontal cracking between the layers in the brittle horizon and some vertical cracking, resulting in more macropore space than found in lacquer-covered samples. At 0 and 4 kPa the steel-core samples contained 6.5 and 1.5 pct more water, respectively, than the lacquer-covered samples. The increase in macropore space in steel-core samples also helps to explain the increased saturated hydraulic conductivity of these samples compared with lacquer-covered samples.

The vertical and horizontal saturated conductivities of the sandy humus hardpan, measured on the same lacquer-covered samples, were significantly different. This difference was caused by horizontal layering of the pan. This type of measurement, using the same sample, could not be carried out using the other methods described. The authors state that the lacquer-cover sampling method is well adapted to the study of hydraulic properties of brittle horizons.

1215. Waaland, M. E., and E. B. Allen. Relationship Between VA Mycorrhizal Fungi and Plant Cover Following Surface Mining in Wyoming. J. Range Manage., v. 40, No. 3, 1987, pp. 271-276.

The relationships between plant cover, mycorrhizal root infection, and mycorrhizal spore density in orphan (abandoned) and reclaimed minesites of different ages and native undisturbed sites were examined in southwestern Wyoming. The sites studied were reclaimed topsoil (6 years old), reclaimed spoil (5 years old), abandoned mine spoil (10, 18, 24, and 31 years old), and two native sites. At each site, plant cover was estimated and soil samples were taken for mycorrhizal spore and edaphic analyses. No apparent trends due to increased age were found for any of the edaphic factors on the reclaimed or abandoned sites. Species and groups of species showed different trends in abundance among the sites. Annuals were most abundant in recently reclaimed spoil and decreased with age. No apparent trends with time for reclaimed topsoil or abandoned sites were evident. Percent total cover of perennial grasses and shrubs generally increased with time. There were no apparent trends in mycorrhizal root infection with site age for dominant perennial grasses. Percent vesicular-arbuscular mycorrhizal root infection of shrubs was lower on younger reclaimed sites than on the older abandoned and native sites. Density of mycorrhizal spores was related to substrate. Spore density was lower in spoil, reclaimed or abandoned, than in topsoil, reclaimed or native. Other factors besides time may be important in determining root infection and spore numbers. The authors made two general conclusions: first, substrate appeared to be more important than time in determining conditions for spore inoculation, and second, low spore numbers in spoil did not result in lower infection of the dominant perennial grasses than in topsoil.

1216. Wade, G. L., J. T. Crews, and W. G. Vogel. Development and Productivity of Forest Plantations on a Surface Mine in Southeastern Kentucky. Paper in Proceedings of the Fifth Better Reclamations With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 184-193.

The success of mixed hardwoods and pines established on a southeastern Kentucky surface mine in 1965 were evaluated in 1983-85. Site indices of the trees planted on the mined area compare favorably with those of an unmined area. Tree densities and basal areas of the established trees indicate that the mined site is productive, but overstocked. Spoil pH values have increased with time, while specific conductivity of the spoils has decreased over a 19-year period. Mean pH values for the mined site are similar to that for the unmined area. Phosphorus, potassium, and calcium concentrations are similar between sites, while magnesium concentrations are higher on the mined soils. Soil physical and chemical data indicate that the spoils have weathered rapidly in the 19 years since tree establishment. This study shows that areas in southeastern Kentucky that were once mined have medium to good potential for managed production of forest products.

1217. Wade, G. L., and H. G. Halverson. Soil Development Under 22-Year-Old Mixed Hardwood, Pine, and

Black Locust Plantations on a Surface Mine. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 54-62.

Mine soil development and the influence of vegetation on mine soil development were studied on three 22-year-old tree plantations located in southeastern Kentucky. After 22 years, soil development under three forest vegetation types showed development of O, A, and B horizons. Differences in forest floor O horizons due to forest vegetation type were significant. The pine plantation had the thickest (mean of 3.5 cm) horizon with the most litter weight, while the mixed hardwood plantation had a thinner (mean of 2.4 cm) O horizon with the least weight. Significant differences in concentrations of nitrogen, phosphorus, calcium, magnesium, copper, zinc, silicon, and nickel in the O horizon could be attributed to vegetation type. Differentiation of A and B horizons had occurred in less than 22 years, with the mean A horizon thickness being 2.3 cm. Soil chemical analyses showed that there were significant differences between the A and B horizons for organic matter content, conductivity, exchangeable acidity, and concentrations of available nitrogen, phosphorus, potassium, calcium, magnesium, manganese, copper, zinc, boron, sodium, lead, titanium, and chromium. Differences in soil pH, iron, silicon, aluminum, exchangeable aluminum, cobalt, and nickel were not significant for the A and B horizons. Vegetation type resulted in significant differences in the ratio of A to B horizon areas for pH, exchangeable acidity, conductivity, nitrogen, zinc, boron, sodium, and nickel.

1218. Wade, G. L., R. L. Thompson, and W. G. Vogel. Success of Trees and Shrubs in an 18-Year-Old Planting on Mine Spoil. U.S. For. Serv., Res. Paper NE-S67, 1985, 10 pp.

Plantings of 25 trees and 25 shrub species on a southeastern Kentucky surface mine were evaluated after 18 years. Tree survival, height of surviving trees and shrubs, and diameter at breast height of trees were determined. Soils were analyzed for pH, specific conductivity, and available phosphorus.

Soil pH increased from a mean of 3.90 to 4.46 during the 18-year period. Soluble salts dropped from 0.31 to 0.15 mmho cm^{-1}, and available phosphorus dropped from 6.83 to 4.02 ppm. These changes were statistically significant. Soil pH was related to the species that occupied the test plot, while specific conductivity and phosphorus were not related to the species occupying the plot. After 18 years, pin oak (*Quercus palustris* Muenchh.), sweet birch (*Betula lenta* L.), European white birch (*Betula pendula* Roth), Austrian pine (*Pinus nigra* Arnold), and bur oak (*Quercus macrocarpa* Michx.) showed potential value for wood products on this site. Several tree species of little or no commercial timber value showed potential usefulness as soil builders and site stabilizers. These species included mimosa (*Albizzia julibrissin* Durazz), thornless honeylocust (*Gleditisia triacanthos* L. f. *inermis* (Pursh.) Schneid.), tree-of-heaven (*Ailanthus altissima* Swingle), and Siberian elm (*Ulmus pumila* L.). Several shrub species showed promise for ground cover, erosion control, soil building, and sources of wildlife habitat and food.

1219. Walker, R. F. The Growth, Nutrient Absorption, and Moisture Status of Selected Woody Species in Coal Mine Spoil in Response to an Induced Infection by the Ectomycorrhizal Fungus *Pisolithus Tinctorius*. Ph.D. Thesis, Univ. TN, Knoxville, TN, 1982, 106 pp.

The growth, nutrient absorption, and internal moisture status of certain woody species inoculated with the mycorrhizal fungus *Pisolithus tinctorius* and planted on coal mine spoil are examined in this report. Nursery-grown loblolly pine (*Pinus taeda* L.) and Virginia pine (*Pinus virginiana* Mill.) seedlings infected with *Pisolithus* were outplanted on coal mine spoil in Tennessee that had been previously hydroseeded with a mixture of herbaceous species. Fertilizer was then applied. Sweet birch (*Betula lenta* L.) and European black alder (*Alnus glutinosa* (L.) Gaertn.) were grown under high-, intermediate-, and low-fertility regimes in sand culture containing *Pisolithus* for 5 months prior to transplanting onto spoil in the greenhouse. This article contains an excellent background discussion concerning mycorrhizae on coal spoil in the Eastern United States, as well as an excellent reporting of the study itself. Significant differences in the effects of inoculating with *Pisolithus* on the four species were found, as well as fertilizer effects. However, the loblolly pine and sweet birch that were inoculated with *Pisolithus* showed considerable potential for use in revegetating coal mine wastes.

1220. Walker, R. F., D. C. West, and S. B. McLaughlin. *Pisolithus tinctorius* Ectomycorrhizae Enhance the Survival and Growth of *Pinus taeda* on a Southern Appalachian Coal Spoil. Paper in Proceedings of the First Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 6-7, 1980). U.S. For. Serv., South. For. Exp. Stn., Gen. Tech. Rep. 50-34, 1981, pp. 29-33.

The effects of *Pisolithus tinctorius* ectomycorrhizae on the establishment and growth of loblolly pine (*Pinus taeda* L.) on surface-mined sites were evaluated in a study conducted on coal spoil in Campbell County, TN. *P. tinctorius* significantly improved the survival and growth of loblolly pine seedlings on coal spoils where a grass cover had been

previously established. Fertilization improved seedling growth but substantially reduced seedling survival. Unfertilized seedlings inoculated with *P. tinctorius* produced the best survival and growth.

1221. Walker, R. F., D. C. West, and S. B. McLaughlin. *Pisolithus tinctorius* Ectomycorrhizae Reduce Moisture Stress of Virginia Pine on a Southern Appalachian Coal Spoil. Pres. at the North American Forest Biology Workshop (Lexington, KY, July 25, 1982). Oak Ridge Natl. Lab., KY, CONF-820793-1, 1982, 10 pp.

This study examined the effect of *Pisolithus tinctorius* ectomycorrhizae on the internal moisture status of Virginia pine (*Pinus virginiana* Mill.) outplanted on sites disturbed by surface mining in Campbell County, TN. The study incorporated nursery-grown seedlings with three levels of infection with this fungal symbiont and control seedlings without symbiont. A split-plot design was used so that each ectomycorrhizae treatment contained seedlings fertilized at a rate of 336 kg ha^{-1} N-P-K and nonfertilized seedlings. All seedlings had additional minor infections with another ectomycorrhizal species, *Thelephora terrestris*. A pressure chamber technique was used to determine the internal water status of the seedlings during a period of high moisture stress. During this period, xylem pressure potential was measured at dawn, when internal water stress was least, and again at midnight, when it was greatest. The seedlings infected with *Pisolithus* exhibited lower moisture stress than seedlings not infected or infected at the lowest rate. The effect of fertilizer was not significant.

1222. Walker, R. F., D. C. West, S. B. McLaughlin, and C. C. Amundsen. The Performance of Loblolly, Virginia, and Shortleaf Pine on a Reclaimed Surface Mine as Affected by *Pisolithus Tinctorius* Ectomycorrhizae and Fertilization. Paper in Proceedings of the Third Biennial Southern Silvicultural Research Conference (Atlanta, GA, Nov. 7-8, 1984). U.S. For. Serv., Gen. Tech. Rep. 50-54, 1985, pp. 410-416.

This study assessed the effects of an induced mycorrhizal infection by *Pisolithus tinctorius* and broadcast fertilization on the growth of loblolly pine (*Pinus taeda* L.), Virginia pine (*Pinus virginiana* Mill.), and shortleaf pine (*Pinus echinata* Mill.) outplanted on an east Tennessee coal surface mine. Soil analyses showed that the site was typical of those found in east Tennessee; soils were deficient in phosphorus, and levels of iron and manganese were high. After 6 years, the survival and growth of loblolly pine were significantly affected by *P. tinctorius* and fertilization. Infection with *P. tinctorius* enhanced the survival and growth of loblolly pine, but fertilization reduced survival even when seedlings were infected with mycorrhizae fungi. Virginia pine survival was not affected by infection after 5 years; however, fertilization significantly reduced survival of Virginia pine when treated with mycorrhizae. Shortleaf pine survival also exhibited this same trend. The results indicate that the response of the tested pines to ectomycorrhizal infection by *P. tinctorius* is species dependent. When trees are planted into an established vegetative ground cover, broadcast application is not the desired option since broadcast fertilization in this study stimulated the growth of ground cover species and reduced the survival of the planted pines.

1223. Wallace, A., E. M. Romney, and R. B. Hunter. The Challenge of a Desert: Revegetation of Disturbed Desert Lands. Paper in Transuranics in Desert Ecosystems (NV Appl. Ecol. Group Prog. Rep. Meet., Las Vegas, NV, Mar. 2, 1977). U.S. Dep. Energy, NV Oper. Off., Las Vegas, NV, NVO-181, UC-11, Nov. 1977, pp. 17-40.

This report describes factors and natural processes that are of importance when revegetating areas in the northern Mojave and southern Great Basin Deserts. Aspects of desert ecosystems discussed include use of water by plants, amount of soil used by plants as a growing medium, soil characteristics, plant population dynamics, availability of plant nutrients, and plant population characteristics of disturbed sites. Measures to enhance vegetation success, such as transplanting clumps of shrubs and selecting seed from pioneering shrub species, are also discussed. While this report deals with very arid desert conditions, principles of desert ecosystems covered here may be applicable to other arid regions.

1224. Wallace, P. M., and G. R. Best. Enhancing Ecological Succession: 6. Succession of Vegetation, Soils, and Mycorrhizal Fungi Following Strip Mining for Phosphate. Paper in 1983 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Nov. 27-Dec. 2, 1983). Univ. KY, Lexington, KY 1983, pp. 385-394.

This study was conducted to investigate aboveground and belowground changes during succession following phosphate mining in southwestern Polk County, FL. Six different-aged nonreclaimed phosphate mined areas were studied. The sites ranged from an area presently being mined to one 60 years old. Four major variables were of interest in this study: (1) aboveground vegetation composition changes, (2) organic matter dynamics and soil nutrient parameters, (3) changes in root structure, and (4) mycorrhizal population density changes through time and the identification of indigenous mycorrhizae. Assessment of the aboveground structure indicated that within

60 years after mining a well-developed ecosystem was present. Data collected on root length and biomass indicated that belowground root structure increased with time. The majority of plant species invading phosphate mined areas exhibited extensive mycorrhizal infection within 3 years. This indicates the importance of endomycorrhizal fungi to the succession of native forest ecosystems on phosphate mined areas, warranting continued investigation into the potential use of mycorrhizal inoculation as a reclamation tool.

1225. Wallace, P. M., G. R. Best, and J. A. Feiertag. Mycorrhizae Enhance Growth of Sweetgum in Phosphate Mined Overburden Soils. Paper in Proceedings of the Fifth Better Reclamation With Trees Conference (Carbondale, IL, June 5-7, 1985). South. IL Univ., Carbondale, IL, 1985, pp. 41-52.

A growth experiment was conducted to evaluate mycorrhizae inoculation and increasing nitrogen and phosphorus additions on the growth of sweetgum (*Liquidambar styraciflua* L.) in phosphate mine overburden soils. A $5 \times 3 \times 3$ factorial experimental design was used with five levels of phosphorus (0, 12.5, 25, 75, 150 ppm), three levels of nitrogen (0, 50, 150 ppm), and three levels of endomycorrhizae additions (control, *Glomus macrocarpum*, and a composite sample of unidentified species isolated from a phosphatic clay setting area). Mycorrhizae inoculation was added directly below the seedling prior to planting, and fertilizer was added to each pot. Seedling height, leaf area, root length, and percent mycorrhizae colonization were defined for each experimental treatment. The composite mycorrhizal additions resulted in greater growth than either the control or *Glomus macrocarpum* treatments at all nutrient levels. Increasing amounts of nitrogen at each phosphorus level resulted in substantial growth enhancement. Leaf area measurements, a measure of photosynthetic area, showed that the composite endomycorrhizae treatment resulted in 30 times greater area than the control and 1.7 times greater area than *Glomus macrocarpum*. Multispecies inoculation allows the plants to select for the symbionts and allows for multiple symbiosis to occur.

1226. Walsh, J. P. Soil and Overburden Management in Western Surface Coal Mine Reclamation—Findings of a Study Conducted for the Congress of the United States—Office of Technology Assessment. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 257-264.

Soil and overburden management in the reclamation of western surface coal mines is discussed. The study is based on a review of the literature, permit applications, State and Federal acts, regulations and State guidelines, and interviews with regulatory authorities, environmental managers, staff scientists, researchers, and environmentalists. The purpose of this study was to describe the data and analytical techniques used in the baseline characterization of soil and overburden resources, evaluate the use of that information in reclamation planning, describe the methods used by the regulatory authorities in evaluating reclamation plans, determine if the baseline data accurately predict the conditions formed during mining, describe reclamation monitoring and the criteria for reclamation success, evaluate the effectiveness of the regulatory programs, and suggest alternatives for resolving uncertainties and improving the process. Thirteen case study mines from North Dakota, Montana, Wyoming, Colorado, and New Mexico were selected.

1227. Warburton, D. B., J. R. Nawrot, and W. D. Klimstra. Coarse Refuse: Alkaline Enhancement and Reduced Soil Cover—An Effective Reclamation Alternative. Paper in Proceedings, 1987 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 91-98.

The Surface Mining Control and Reclamation Act (SMCRA) requires that toxic coarse refuse material be covered with 4 ft of nontoxic material to prevent the oxidation of acid-forming materials and to allow for effective vegetation stabilization. This study evaluated the relative effectiveness of liming rates and soil cover depths of coarse refuse in order to address the long-term and base equilibrium in the oxidizing refuse surface zone beneath the soil cover. Soil cover depths of 0, 1, 2, 3, and 4 ft were established over limestone-amended coarse refuse. Limestone application rates were 0, 15, 50, and 150 mt acre^{-1}. The 15 mt-acre^{-1} rate was based on maximum potential acidity values. After soil cover was completed, 2 mt acre^{-1} was applied to all soil cover depth plots. Regardless of soil cover depth, the 150-mt-acre^{-1} treatment prevented the upward diffusion of acid and the acidification of the overlying soil. Soil cover depth had no effect on soil acidity above the treated refuse. Refuse amended with limestone at 150 mt acre^{-1} maintained near neutral conditions at 0 - to 6-in depth over a 5-year period. Principles of alkaline enhancement and current reclamation projects in southern Illinois are given.

1228. Ward, A. D., L. G. Wells, and R. E. Phillips. Infiltration Through Reconstructed Surface Mine Spoils

and Soils. Pres. at the 1981 Winter Meet., Am. Soc. Agric. Eng. (Chicago, IL, Dec. 15-18, 1981). Am. Soc. Agric. Eng., Paper 81-2508, 1981, 28 pp.

Reconstructed profiles consisting of spoil and soil material from a surface mine location in western Kentucky were prepared in large laboratory bins and subjected to simulated rainfall. The profiles consisted of spoil material alone and topsoil over spoil material. The profiles were instrumented to measure infiltration rate, soil-spoil density, water content, soil water potential, and surface runoff. Infiltration through the reconstructed spoil profiles was very low despite the coarse texture of the material, which may have been due to the well-graded nature of the material. Infiltration through the topsoil horizons was similar to that of many agricultural soils of this area. Surface sealing eventually dominated as the tests progressed, greatly reducing infiltration rates. Initial moisture content and the density of the material significantly influenced the infiltration measured for both the spoil and the topsoil. The results of this study are relevant to establishing a favorable planting medium for revegetating surface-mined lands.

1229. Ward, R. T., W. L. Slauson, and C. W. Weldon. Ecogenic Variability in Native Shrubs Related to the Establishment of Vegetation on Disturbed Arid Shrub-Lands. Ch. in Revegetation Studies on Oil Shale Related Disturbances in Colorado (U.S. DOE contract DE-AS02-76EV04018, Dep. Range Sci., CO State Univ.), U.S. Dep. Energy, DOE/EV04018-6, June 1982, pp. 57-65.

This study is part of a larger project evaluating the impact and potential for reclamation following oil shale mining and retorting processes. This paper reports the sixth-year results of this study. The objectives of the study were to (1) evaluate the natural variation within species (especially shrubs) native to the Piceance Basin, CO, (2) recommend source materials expected to provide long-term, natural succession on selected sites, and (3) evaluate the responses of shrub species already growing in an edaphic environment containing retorted shale. The populations of true mahogany (*Cercocarpus montanus* Raf.), antelope bitterbrush (*Purshia tridentata* (Pursh.) DC.), and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) studied did not exhibit strong evidence of ecotypic differentiation. Ecotypic differentiation with respect to competitive ability, moisture, and short growing season stress are documented for mountain snowberry (*Symphoricarpos oreophilus* Gray), Utah serviceberry (*Amelanchier utahensis* Kochne), and winterfat (*Ceratoides lanata* (L.) C.A. Mey.). This paper is an excellent reference for choosing plant materials for revegetation activities.

1230. Warman, P. R. Effects of Fertilizer, Pig Manure, and Sewage Sludge on Timothy and Soils. J. Environ. Qual., v. 15, No. 2, 1986, pp. 95-100.

The effects of inorganic fertilizer, pig manure, and sewage sludge amendments on the yield and elemental composition of timothy (*Phleum pratense* L.), and soil chemical properties were compared on two soils. Field plots were amended annually with two rates each of inorganic N-P_2O_5-K_2O fertilizer (110-50-85 and 220-50-85 kg ha^{-1}), liquid pig manure (75 and 150 wet Mg ha^{-1}), and aerobically digested sewage sludge (150 and 300 wet Mg ha^{-1}), and compared with a control (no amendment). All amendments resulted in dry matter yields that were significantly greater than those of the control during the first 2 years of this 3-year study. Dry matter yields from waste-treated plots equaled or exceeded yields from fertilized plots. Amendments applied at the high rates resulted in average yield advantages over the lower rates of 1.2, 0.9, and 1.0 Mg ha^{-1} yr^{-1} for fertilizer, pig manure, and sewage sludge, respectively. Plant tissue concentrations of nitrogen, phosphorus, potassium, calcium, magnesium, zinc, copper, manganese, and molybdenum are presented. Soil and plant tissue analyses indicate that there is no metal contamination as a result of manure or sewage sludge amendments. At the high rate of pig manure addition, soil analyses indicated that soil nitrogen, phosphorus, and potassium were significantly increased over other treatments, and at the high rate of sludge addition only soil phosphorus and copper were significantly increased over other treatments. The author recommends that any of these amendments can be applied to timothy at either rate, without any adverse effect on yield, nutrient concentrations, or soil fertility.

1231. Watkin, E. M. Factors Affecting Vegetation Establishment on Acidic Tailings and Rock Wastes. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, supplement.

This paper reviews and discusses some of the unresolved factors affecting vegetation establishment on tailings and waste rock dumps in the metal mining industry. Site factors that should be assessed prior to devising a revegetation plan are given; these factors include general environmental factors, physical and chemical characteristics of the tailings, side slope characteristics, and the required end point of the revegetation program. The author warns that reclamation knowledge applicable to acidic coal spoils cannot necessarily be extrapolated to acid metal mining tailings. The status of acid metal mining tailings and rock waste revegetation is also presented.

1232. Watzlaf, G. R., and P. M. Erickson. Topical Amendments of Coal Refuse: Effect on Pore Gas Composition and Water Quality. Paper in Proceedings 1986 National Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 8-11, 1986). Univ. KY, Lexington, KY, pp. 255-261.

Three alternative cover treatments to reduce acid production from coal refuse by limiting oxygen availability in the refuse were investigated. Refuse piles were constructed and treated with four amendments: (1) barren control, (2) topsoil (30 cm seeded with a grass mixture), (3) coal refuse fines (23 cm of filter-cake refuse fines covered with 7 cm of topsoil and seeded with a grass mixture), and (4) spent mushroom compost (30 cm). The topsoil-amended and refuse-fines-amended piles were fertilized. In each pile, gas probes were placed at 0.25, 0.5, and 1.0 m to collect pore gas samples (0_2, CO_2, and N_2) and one monitoring well was installed to collect water samples for temperature, pH, SO_4, acidity, iron, and manganese analysis.

The amendments delayed water quality deterioration by 2 to 6 weeks compared with the control piles. There were seasonal differences in water quality due to the type of soil amendment used. Gas composition also varied as a function of the cover material used; oxygen depletion was greater on amended refuse than on unamended refuse. Oxygen content at the 0.25- and 0.5-m depths recovered to levels found in the barren refuse in the order of topsoils > fines > compost. Topsoil was the most effective material to use to delay the onset of acid production (11 weeks). Acidity, SO_4, iron, and manganese concentrations were below control levels for 10 months; however, topsoil did not effectively limit oxygen. Compost delayed acid production for 11 weeks and kept acid levels below those of control piles for 11 weeks. Compost was the most effective at limiting oxygen by keeping the oxygen content 5 pct below the control for 4 months. Refuse-fines amendment was the least effective material and only delayed acid production for 3 weeks.

1233. Webber, M. D., and S. Lesage. Organic Contaminants in Canadian Municipal Sludges. Am. Soc. Agron., Agron. Abstr., 1986, p. 38.

Abstract of a paper presented at the 1986 Annual Meetings of ASA, CSSA, and SSSA. Organic contaminants were analyzed in several Canadian municipal sludges. Generally, organic contaminants were low, with 15 of the 77 contaminants tested not being detected.

1234. Webber, M. D., and A. Shamess. Heavy Metal Concentrations in Halton Region Soils: An Assessment for Future Municipal Sludge Utilization. Can. J. Soil Sci., v. 67, No. 4, 1987, pp. 893-903.

Maximum permissible heavy-metal concentrations in Ontario, Canada, agricultural soils have been defined. This study evaluated the heavy-metal concentrations in sludge- and no-sludge-amended agricultural soils in the Halton Region of Ontario and determined if an estimate of at least 39 years for land application of sludge in the Halton Region was valid. In general, heavy-metal concentrates for no-sludge- and sludge-treated soils fell within the permissible values. Exceptions occurred where very large sludge applications were used and where native soils had high lead and zinc concentrations, which were derived from lead and zinc sulfides in the soil parent material. As a result, sludge application is an acceptable practice on a large portion of these agricultural lands. The authors state that the 39-year estimate for continuing sludge applications was conservative.

1235. Weetman, G. F. Nutrition and Fertilization of Lodgepole Pine. Paper in Future Forests of the Mountain West: A Stand Culture Symposium (Missoula, MT, Sept. 29-Oct. 3, 1986). U.S. For. Serv., Gen. Tech. Rep. INT-243, 1988, pp. 231-239.

This article reviews recent fertilization trials with lodgepole pine (*Pinus contorta* Dougl.). Two phases in lodgepole pine stand development are recognized: phase I, prior to canopy closure, and phase II, after canopy closure. During phase I, lodgepole pine is very dependent on soil nutrients and almost any nutrient may be limiting, especially on nutritionally poor sites. Several examples of increased growth rates with fertilization during this phase are presented. After canopy closure, nutrient cycling may provide the nutrients necessary for tree growth, according to the author, decreasing the need for supplemental nutrients. Additional nitrogen fertilization, however, may be necessary during this phase since several studies have shown up to a 50-pct increase in stand volume increment over a period of 10 years with nitrogen applications. This article was included in the review process because of lodgepole pine's ability to tolerate and grow successfully on nutrient-poor sites and its wide ecological range.

1236. Wehner, R. R., and G. B. Coltharp. Effects of Sample Collection, Preparation, and Lab Testing Procedures on Spoil Analyses. Paper in Proceedings 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 9-13, 1985). Univ. KY, Lexington, KY, 1985, pp. 269-272.

This study describes the differences in soil data reported by two soil testing laboratories when soil from a southeastern Kentucky coal mine spoil was analyzed for particle size distribution and texture class, pH, buffer pH, potential acidity, and concentrations of phosphorus, calcium, and magnesium. Standard soil-testing procedures were used by both laboratories. Apparently, the method of sample preparation used by each laboratory affected the results of the soil test analyses.

1237. Weiler, G., and W. L. Gould. Establishment of Blue Grama and Fourwing Saltbush on Coal Mine Spoils Using Saline Ground Water. J. Range Manage., v. 36, No. 6, Nov. 1983, pp. 712-717.

This article reports the results of a greenhouse study conducted in New Mexico that examined the effect of limited irrigation of topsoiled sodic shaley spoil with water of various salinities on the emergence and growth of blue grama grass (*Bouteloua gracilis* (H.B.K.) Lag.) and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.). Four levels of salinity for the irrigation water were used, ranging from 750 to 12,890 μmho cm^{-1}. The sodium adsorption ratio of the irrigation water ranged from 2 to 68.

The emergence and growth of blue grama were reduced with increased irrigation water salinity. The blue grama did not survive the highest salinity treatment. The highest saline water treatment reduced four-wing saltbush emergence but not growth following the seedling stage. The infiltration rate of the simulated topsoiled spoil decreased as the sodicity of the irrigation water increased. The electrical conductivity of the soil increased as the amount and salinity of the water increased. The results indicate that moderately saline water (EC < 4,230 μmho) may be suitable for revegetating mine spoils with blue grama and four-wing saltbush.

1238. Weisenfluh, G. A., J. C. Ferm, A. Bailey, T. L. Despard, and W. G. Vogel. A Study of Geologic Factors Influencing Reclamation of Federal Coal Bearing Lands in Northern Alabama. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 151-156.

This study was done to determine the geochemical attributes of potential overburden materials from Federal lands in northern Alabama and how these materials may affect plant growth. A second objective was to determine whether rock material could be identified as being favorable or unfavorable for reclamation purposes. The study was divided into three phases: (1) description of the geologic setting of the area, (2) analyses to determine the geochemical and mineralogical properties of the material, along with a greenhouse study to determine the ability of the material to support plant growth and respond to fertilization, and (3) statistical analysis of the greenhouse and geochemical data.

The results of the study show that most of the rock material is not acid producing, but slightly alkaline. The fine-grained, textured shales were found to be better suited for revegetation than the sandstones or pebbly sandstones. The best response was found when a nitrogen-phosphorus fertilizer was used. It would appear that little modification of overburden materials would be needed to enhance reclamation efforts in northern Alabama.

1239. Wetter, L. G., G. R. Webster, and J. Lickaze. Amelioration of a Solonetzic Soil by Subsoiling and Liming. Can. J. Soil Sci., v. 67, No. 4, 1987, pp. 919-930.

The effects of subsoiling and lime additions on physicochemical characteristics related to agronomic productivity, moisture status, and the aboveground and belowground crop yields of spring wheat (*Triticum aestivum* L.) were studied on a dark-brown solodized solonetz soil in Alberta, Canada. Treatments consisted of an unaltered control, subsoiling to a depth of 40 cm, liming (5.6 Mg ha^{-1}) followed by subsoiling, and liming only.

At the 0- to 13- and 13- to 26-cm depth sections, soil pH was significantly higher in the subsoil and subsoil and lime treatments than in the lime and control treatments. At the 0- to 13-cm depth section, soil pH of the lime treatment (7.0) was significantly higher than the control pH (5.7). Differences in SAR values in the 0- to 13-cm depth section were not significant; however, at the lower depth sections (13 to 26 and 26 to 32 cm), SAR values were significantly higher in nonsubsoiled treatments than in subsoiled treatments. The calcium-to-total-cation ratio in the upper 26 cm of soil was significantly higher in subsoiled treatments than in nonsubsoiled treatments, with the calcium-to-total-cation ratio being significantly higher in the 0- to 13-cm depth section of limed treatments than in the control. In the 0- to 13-cm depth section, the percent clay and moisture retention at -1,500 kPa were significantly higher in subsoiled treatments, while percent soil and silt were significantly higher in nonsubsoiled treatments. When differences occurred in available water, they were between the subsoiled and nonsubsoiled treatments.

The yields obtained on subsoiled treatments were significantly higher than on nonsubsoiled treatments. The main treatment differences observed were due to the effects of subsoiling. Subsoiling resulted in neutralization of surface acidity (elevated calcium salts) and improved subsurface soil structure, moisture status, root penetration, and crop yields.

1240. Whitby-Costescu, L., J. Shillabeer, and D. F. Coates. Environmental Planning. Ch. 10 in Pit Slope Manual. Can. Cent. Miner. and Energy Technol., CANMET Rep. 77-2, Feb. 1977, 93 pp.

This document is a chapter in a multivolume manual. Each chapter, as well as supplements to these chapters, has been published separately. The purpose of this chapter is to provide procedural guidelines for assessing and developing mineral exploration and mining plans, and for

postmining land use. Topics considered in this chapter include preproduction stage, water supply and disposal, reclamation of mineral wastes, time and budget guidelines, and legislation. This chapter provides an excellent reference for surface mine reclamation procedures, succinctly outlining major considerations and treatment options. While the manual was written for application in Canada, some of the information is relevant to reclamation activities in the Northern United States.

1241. White, J. A., and S. E. Williams. Symbiotic N2-Fixation by *Frankia*: Actinorhizae Establishment on Disturbed Lands. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min., and Reclam., 1985, pp. 289-297.

A literature review on the mutualistic symbioses between actinomycetes of the genus *Frankia* and woody angiosperms is presented. Information is presented on the physiology, ultrastructure, and growth of the *Frankia* endophyte. Edaphic factors that influence the symbioses (actinorhizae) between the actinomycete and plant include moisture availability, temperature, and soil pH. Reclamation practices that may affect the establishment of actinorhizal plants include soil amendments (particularly nitrogen fertilization), supplemental moisture such as irrigation, topsoiling (particularly storage of topsoil), and seedling establishment and inoculation. Low soil water and high soil nitrogen are potential edaphic factors that may limit the establishment of viable nodules with adequate nitrogen fixation.

1242. White, R. L. Land Reclamation in Texas—An Opportunity. Paper in Proceedings Gulf Coast Lignite Conference: Geology, Utilization, and Environmental Aspects (Austin, TX, June 2-4, 1976). Bur. Econ. Geol., Univ. TX, Austin, TX, 1978, pp. 199-208.

This paper gives a brief description of the land reclamation program used by Texas Utilities Generating Co. at its coal mines located near Fairfield, TX. Information is included on the characteristics of Texas lignite coal, location of the coal in east-central Texas, and natural vegetation of the area. By minimizing the environmental effects of surface mining and restoring the productivity of the land, the land reclamation program used by Texas Utilities Generating Co. has proven to be successful.

1243. Wiener, D. P. Reclaiming the West: The Coal Industry and Surface-Mined Lands. INFORM, 1980, 451 pp.

This book provides the results of a survey of 15 mines operated by 13 surface coal mining companies in North Dakota, Montana, Wyoming, Colorado, New Mexico, and Arizona. The land reclamation programs at each of the 15 minesites were evaluated against a set of 33 criteria. A synopsis of the results of the survey is provided, along with a case history for each mine. The author attempts to provide an unbiased view of the reclamation program for each revegetation effort. Considerable amounts of hard data are presented in each case history to substantiate the comments made by the author. In addition, the book contains sections defining the mining and reclamation techniques used in the survey. This book provides an excellent, unbiased, and uncompromising view of surface mine reclamation in the Western United States prior to 1980.

1244. Wilkey, M., and S. D. Zellmer. Land Reclamation at an Abandoned Deep Coal Mine. J. Environ. Eng. Div. (Am. Soc. Civ. Eng.), v. 105, No. EE5, Oct. 1979, pp. 843-853.

This article summarizes the reclamation of a 55-year-old coal gob pile near Staunton, IL. Erosion had cut deep gullies into the pile, and it was devoid of vegetation. Reclamation included recontouring, topsoiling, liming, and fertilizing prior to revegetation. Also, two revegetation studies were initiated to (1) assess overall revegetation success and (2) determine a cost-effective means of achieving long-term vegetation on highly acidic (pH <3) gob material. A very brief outline of these demonstration projects is given. The projects were still ongoing when this article was written.

1245. Williams, S. E., and R. S. Funston. Mercury. Ch. in Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures, ed. by R. D. Williams and G. E. Schuman. Soil Conserv. Soc. Am., 1987, pp. 313-323.

The contamination of water, soils, or air by mercury is not likely to occur in most mining operations unless mercury itself is being mined. The three most common naturally occurring mineral forms of mercury are cinnabar, metacinnabar, and livingstonite. Most total mercury concentrations are reported to be less than 10^{-9} g g^{-1}. Methods of sample collection and preparation, and analytical procedures for mercury analysis are presented. The bioavailability of mercury is determined by soil pH. In neutral or alkaline soils mercury is often precipitated and insoluble, but at low soil pH and high chloride concentrations, mercury exists as a chloride that is quite soluble in water. Movement of mercury in soils, however, is restricted.

1246. Wilm, B. W., and J. R. Nawrot. Metallic Ion Relationships of Aquatic Macrophytes Established on Slurry Wetland Substrates. Proceedings, 1987 National

Symposium on Mining, Hydrology, Sedimentology, and Reclamation (Springfield, IL, Dec. 7-11, 1987). Univ. KY, Lexington, KY, 1987, pp. 65-70.

The heavy-metal content in the dominant vegetation and substrates of four inactive slurry impoundments and two nonmine wetlands was compared. The metals examined in both the substrate and vegetation were iron, aluminum, manganese, boron, copper, zinc, cadmium, and nickel. Plant tissue analyses revealed that nonmined wetland vegetation contained greater levels of iron, manganese, and cadmium, while slurry vegetation had greater amounts of zinc. No extreme heavy-metal concentrations that would pose a threat to wildlife were found in slurry impoundment wetlands, and no toxicity problems were identified. The authors recommend that early slurry impoundment should be characterized prior to reclamation in order to identify the potential for the bioaccumulation of heavy-metal ions.

1247. Winterhalder, K. Trigger Factors Initiating Natural Revegetation Processes on Barren, Acid, Metal-Toxic Soils Near Sudbury, Ontario Smelters. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 118-124.

The factors responsible for the initiation of natural revegetation of barren, acid, metal-toxic soils near Sudbury, ON, Canada, are given. Without amendment treatments, but with improvements in air quality, several grass species, including tufted hairgrass (*Deschampsia cespitosa* (L.) Beauv.), ticklegrass (*Agrostis scabra* Willd.), and black bentgrass (*Agrostis gigantea* Roth), as well as several sedges (*Carex* sp.), and some woody species such as balsam willow (*Salix pyrifolia* Anderss.) and dwarf birch (*Betula pumila* L. var. *glandulifera* Regel) colonized the barren sites. With the application of dolomite limestone (1,400 kg ha^{-1}), fertilizer (350 kg ha^{-1} 7-7-7), and seeding of Canada bluegrass (*Poa compressa* L.), several changes in vegetative composition occurred within a year. Alsike clover (*Trifolium hybridum* L.) and woody species such as white birch (*Betula papyrifera* Marsh), trembling aspen (*Populus tremuloides* Michx.), and willows (*Salix* sp.) are some of the species that colonized the seeded area. The author determined that the triggering factor to the rapid colonization of the barren soil was the application of limestone.

1248. Wittwer, R. F., S. B. Carpenter, and D. H. Graves. Survival and Growth of Oaks and Virginia Pine Three Years After Direct Seeding on Mine Spoils. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 1-4.

Growth and survival of four tree species established by direct-seeding techniques on mountaintop removal spoils were evaluated after three growing seasons in Bell County in southeastern Kentucky. The species and seeding rates used were northern red oak (*Quercus rubra* L.), 2 seeds per spot; pin oak (*Quercus palustris* Muenchh.), 2 seeds per spot; chestnut oak (*Quercus prinus* L.), 1 seed per spot; and Virginia pine (*Pinus virginiana* Mill.), 6 to 10 seeds per spot. Treatments consisted of a control, fertilizer, bark mulch, and a fertilizer and bark mulch combination. Results indicate that stocking and height growth are improved by fertilizer and bark mulch amendments.

1249. Wittwer, R. F., D. H. Graves, and S. B. Carpenter. Establishing Oaks and Virginia Pine on Appalachian Surface Mine Spoils by Direct Seeding. Reclam. Rev., v. 2, No. 1, 1979, pp. 63-66.

This paper provides a brief review of a study assessing seeding of northern red oak (*Quercus rubra* L.), chestnut oak (*Quercus prinus* L.), pin oak (*Quercus palustris* Muenchh.), and Virginia pine (*Pinus virginiana* Mill.) on surface mine spoil in Bell County, KY. Seeds were planted and covered with spoil to a depth approximating their diameter. Treatments included 2.5 cm of bark mulch, fertilizer tablets, and a combination of mulch and fertilizer. Survival was increased 22 percentage points (31 versus 53 pct) by the combined treatment over the untreated control. The combined treatment increased first-year height growth 87 pct (6.0 versus 11.2 cm). The authors conclude that direct seeding of oaks and Virginia pine offers many advantages over bare-root seedlings for revegetating mine spoils in the Appalachian region.

1250. Wolf, C. H. Post Mining Land Use: Economic Comparison of Forestry and Pastureland Alternatives. Paper in Trees for Reclamation (Lexington, KY, Oct. 27-29, 1980). U.S. For. Serv. Gen. Tech. Rep. NE-61, 1980, pp. 127-135.

The author describes some of the factors that influence postmining land use and explores the economics of forest and pasture land use alternatives in southeastern Ohio. Most determinants to postmining land use can be categorized into one of three groups: (1) soil properties, (2) legal requirements and constraints, and (3) economic considerations. Climatic factors are important but are beyond human control. A comparison is made of the economic potential for cow-calf operations with hybrid poplar (*Populus* L. sp.) and black walnut (*Juglans nigra* L.) plantations. Results indicate that a combination of pastureland and black walnut plantations would achieve the highest rate of return on investment. The hybrid poplar plantation had a negative land value, indicating that from

a financial standpoint, it is not a desirable land use. The author concludes that during the planning process postmining land use alternatives must be thoroughly investigated. After evaluating the financial returns for several alternatives, it would be possible to select the most favorable postmining land use.

1251. Wolf, C. H., C. E. Cordell, and S. M. Keller. Fungus Speeds Mine Reclamation. Coal Age, v. 87, No. 9, 1982, pp. 62-64.

This article provides a general, nontechnical review of ectomycorrhizae, in particular, *Pisolithus tinctorius* (Pt). The authors review recent research conducted in the Eastern and Interior Coal Mining Regions involving ectomycorrhizal inoculation of pine seedlings during planting and its effect on growth and establishment. The cost of establishing Pt-inoculated pine seedlings on abandoned minesites at a 5- by 5-ft spacing is estimated at $300 per acre, a substantial saving over the usual practice of additional grading, resoiling, and grass planting. The information contained in this article may be of interest to individuals planting coniferous trees as part of a surface mine reclamation effort.

1252. Wolf, D. C., M. L. May, J. M. Phillips, and P. M. Gale. Ammonia Volatilization From Soil Amended With Hen Manure. Am. Soc. Agron., Agron. Abstr., 1987, p. 36.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. This field and laboratory study evaluated the NH_3 volatilized from hen manure when either surface applied or incorporated into a fine sandy loam soil. In the field, hen manure was applied at rates of 0, 3.4, and 6.8 Mg ha^{-1} using static chambers, while in the laboratory study, manure was added at a rate of 6.8 Mg ha^{-1} and evaluated using flow-through chambers. In the field and laboratory studies, 37 pct of the total nitrogen in the surface-applied manure was lost as NH_3 after 11 and 10 days, respectively, while NH_3 loss was less than 8 pct when the manure was incorporated, in both the field and laboratory studies. When hen manure is surface applied, a substantial amount of nitrogen will be lost by NH_3 volatilization.

1253. Wolf, D. D., R. E. Blaser, R. D. Morse, and J. L. Neal. Hydro-Application of Seed And Wood-Fiber Slurries To Bind Straw Mulch. Reclam. & Reveg. Res., v. 3, No. 2, 1984, pp. 101-107.

A series of field experiments were conducted to evaluate the effectiveness of wood-fiber slurry as a binder when applied over a straw mulch, compared with straw alone and the use of an asphalt binder. The potential phytotoxicity of the asphalt binder was also verified. Retention characteristics and percent plant ground cover were evaluated for wood-fiber and asphalt binders on straw cover.

Wood fiber applied as a binder was equivalent or superior to asphalt material for stabilizing straw. Application of wet wood-fiber slurries settled straw into a compact layer of wood-fiber particles, forming a blanketlike bonding. Vegetative cover of plantings where asphalt was used as the binding agent was lower than where straw was used alone or where wood fiber was used as the binding agent. Results show that asphalt may be toxic to seedlings when applied as a binder for straw. Other disadvantages of asphalt as a binder include (1) environmental pollution, (2) limitation to use during seasons with warm temperatures, and (3) high costs.

The authors recommend a three-step procedure where wood fiber is used as a straw binder, involving broadcasting the seed, spreading the straw mulch, and hydroapplying the wood fiber over the straw. This could be reduced to a two-step procedure involving straw application followed by hydroseeding the seed plus wood-fiber slurry over the straw.

1254. Wong, B. L., J. H. Melhuish, and C. McQuattie. The Role of Mycorrhizae in the Accumulation of Trace Metals Under Different pH Concentrations in Loblolly Pine. Paper in Forest Response Program Annual Meeting: Project Status Reports, Vol. 1 (Corpus Christi, TX, Feb. 22-26, 1988). NC State Univ., Raleigh, NC, 1988, pp. 70-78.

The role of the loblolly pine (*Pinus taeda* L.) mycorrhizal association in trace metal uptake, metal accumulation within the plant and fungus, and the resultant effects on seedling growth when exposed to a variety of metals at different concentrations and pH levels were evaluated and characterized. Four-month-old mycorrhizal and nonmycorrhizal loblolly pine seedlings grown in soil culture were treated with an unadjusted nutrient solution, a pH-adjusted treatment solution, or a metal plus pH-adjusted treatment solution. Each metal treatment consisted of zinc, aluminum, or lead at three concentrations and three pH levels (5, 4, or 3) for each metal concentration. The concentration used were: zinc 2.0, 20.0, and 75.0 $\mu g\ mL^{-1}$; aluminum, 2.0, 10.0, and 50.0 $\mu g\ mL^{-1}$; and lead, 1.0, 10.0, and 50 $\mu g\ mL^{-1}$.

Metal content in both the aboveground and belowground portions of mycorrhizal seedlings increased as the metal concentration in the treatment solution increased at constant pH levels. The acidity of the treatment solution affected the metal concentration in the mycorrhizal root and shoot at each metal concentration treatment. As the

acidity increased in the treatment solution, the metal content in the roots decreased. The percentage of the total metal content distributed in the aboveground and belowground portions of the seedlings depended on the metal. The metals were ranked, from most to least, in their translocation from root to shoot in both mycorrhizal and nonmycorrhizal seedlings: aluminum > zinc > lead. The translocation of metals was facilitated by the increased acidity of the treatment solution.

The concentration of metals in the roots was not significantly different between mycorrhizal and nonmycorrhizal roots as a result of exposure to different metal concentrations or acidity levels. There were no morphological changes in the mycorrhizal root structure as a result of the nutrient medium being adjusted to pH 4 or 5; however, mycorrhizal roots exposed to pH 3 exhibited an increase in electron-dense compounds in the endodermal cells. Exposure of mycorrhizal roots to different metal concentrations, in addition to pH treatment, resulted in varied alterations in mycorrhizal ultrastructure. Root exposure to 50 ppm Pb at pH 3 resulted in a breakdown in mycorrhizal symbiosis. Roots exposed to aluminum concentrations plus pH treatment became mycorrhizal at all treatment levels except at pH 3. The degree of root response is dependent on the level of metal and acidity in the treatment solution.

1255. Wood, C. W., D. G. Westfall, and J. F. Leemann. Evaluation of Spent Catalytic Polymerization Catalyst as a Phosphorus Fertilizer Source. Am. Soc. Agron., Agron. Abstr., 1988, p 50.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. Spent refinery catalyst was evaluated as a possible phosphorus source for winter wheat (*Triticum aestivum* L.). Other plant nutrients and metals were also analyzed to determine if they were taken up by wheat as a result of spent refiner catalyst additions. Spent refinery catalyst was applied at 0, 20, 40, 80, 160, and 320 kg ha^{-1} P. Equivalent rates of triple superphosphate fertilizer were also applied. Wheat grain, straw, and bootstage materials were evaluated for yield and ion uptake. Yield and phosphorus uptake of wheat grown on spent refinery catalyst equaled yield and phosphorus uptake of wheat grown on triple-superphosphate-amended soil. There were no differences in wheat tissue metal concentrations or surface soils between plots amended with spent refinery catalyst or triple superphosphate. No adverse effects of using spent refinery catalyst as a phosphorus fertilizer source for winter wheat were found.

1256. Wood, P. A. Characteristics, Comparisons, Classification, and Erodibility of Some Northern Alabama Coal Mine Spoils. Ph.D. Thesis, Auburn Univ., Auburn, AL, Aug. 1979, 221 pp.

Various coal mine spoils of northern Alabama are identified, characterized, and classified. The relative potential erodibility of these spoils is compared based on several erodibility indices. Recent spoils were compared on the basis of 14 physical and chemical properties. The older spoils were studied in a similar manner, with the additional study of carbon and nitrogen content and subsurface materials. A classification of northern Alabama mine spoils is proposed based on three properties: (1) percent of gravel-size particles (>2 mm), (2) color of the soil-size fraction, and (3) reaction of the soil-size fraction. Relationships between chemical and physical properties were developed for recently formed, dark-colored spoils. These relationships apply within a pH range of 2 to 8. The process of accumulation of gravel-size particles at the surface of spoils, termed "armoring," is discussed. Kaolinite and muscovite are the dominant clay minerals of the spoils examined. Chlorite and vermiculite were also generally present in the clay mineral assemblages.

1257. Wood, T. Commercial Microbial Inoculants and Inoculated Transplants for Reclamation. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 314-317.

This article discusses some guidelines for determining the need for inoculation with vesicular-arbuscular (VA) mycorrhizae, ectomycorrhizae, bacteria (*Rhizobium*), and actinomycetes (*Frankia*), specifies the microbial strains to be used, and gives information for purchasing and applying microbial inoculants and inoculated transplants for situations in which microbial inoculation may be needed or useful. Strains of mycorrhizal fungi and nitrogen-fixing bacteria selected for use should be adapted to specific hosts and site conditions. The availability of microbial inoculants is given. Microbial inoculants should be applied in conjunction with the plant materials when used in reclamation programs. *Frankia*, VA mycorrhizae, and ectomycorrhizae inoculations can be made in the nursery prior to outplanting, while *Rhizobium* inoculants are usually coated on seeds prior to sowing.

1258. Woods, F. W., R. L. Hay, and G. H. Irwin. Minesite Preparation for Reforestation of Strip-Mined Lands. Paper in Symposium on Surface Mining and Fish/Wildlife Needs in the Eastern United States (WV Univ., Dec. 1978). U.S. Fish and Wildl. Serv., FWS/OBS-78/81, 1978, pp. 306-310.

This study investigated the effects of minesite preparation on the establishment of two tree species on strip mine sites in the southeast. Virginia pine (*Pinus virginiana* Mill.) and pitch pine (*Pinus rigida* Mill.) seedlings were used on two different sites: (1) mulched and seeded to grass and (2) no revegetation treatment. Minesite preparation consisted of removing 50 cm^3 of spoil and mixing it at a rate of 12 parts soil to 4 parts pine bark and 1 part vermiculite. Lime and fertilizer were added, the amended spoil material was returned to the hole, and the seedlings were planted. Control seedlings were also planted without any type of site preparation. Results from the 9-month survival counts indicate that pine survival was better on prepared minesite areas than on controls for both bare and grass-covered sites. The authors believe that tree planting is feasible during the summer months if (1) the competitive effects of a dense grass cover are minimized, (2) erosion is minimized, (3) irrigation is used, and (4) soil amendments are used.

1259. Woods, L. E., and G. E. Schuman. Cultivation and Slope Position Effects on Soil Organic Matter. Soil Sci. Soc. Am. J., v. 52, No. 5, 1988, pp. 1371-1376.

Comparisons were made between land uses, (cultivated cropland and native grassland) and between erosional or depositional areas, as factors influencing soil organic matter and its biologically active fractions. Two soils with different A-horizon thicknesses and different cultivation histories were used. Two toposequences were selected for study. The top, mid, and bottom slope positions of each soil were selected to represent erosional, intermediate, and depositional sites. Each toposequence had contrasting land uses: grazed native shortgrass steppe and cultivated wheat-fallow cropland. Each cropland varied in years of cultivation: 25 years versus 1 year. Total organic matter (organic carbon and Kjeldahl nitrogen) and active organic matter (microbial biomass, and mineralized nitrogen and respired carbon in 20-day laboratory incubations) were measured for each soil, slope position, and land use. Concentrations of all measured soil variables were lower in cultivated soils than in comparable native grassland soils. The soil with the shallowest A horizon and longest cultivation history had the lowest concentrations of all measured properties. Slope position had the least effect on organic matter and did not affect the active organic matter concentrations.

1260. Wright, T. H., P. E. Speth, A. E. Peterson, and P. L. Schlecht. Utilization of Wastewater Solids for Growing Vegetables. Am. Soc. Agron., Agron. Abstr., 1988, p. 51.

Abstract of a paper presented at the 1988 Annual Meetings of ASA, CSSA, and SSSA. The effects of applying waste-water solids on the heavy-metal and nutrient content of several different vegetable crops were determined. Waste-water solids were applied at 11, 22, and 44 Mg ha^{-1}, with the 11 Mg ha^{-1} treatment repeated annually. Nitrogen and phosphorus tissue concentrations were improved through sludge additions. Heavy-metal tissue concentrations were elevated slightly or were not increased depending on the vegetable grown and sludge applications. Yields of five of the six vegetables tested were increased by sludge applications.

1261. Wyatt, J. W., D. J. Dollhopf, and W. M. Schafer. Root Distribution in 1- to 48-Year-Old Stripmine Spoils in Southeastern Montana. J. Range Manage., v. 33, No. 2, Mar. 1980, pp. 101-104.

The distribution of plant roots in strip mine soils ranging in age from 1 year to 48 years old, and in undisturbed soils, in the vicinity of Colstrip, MT, was determined using three methods: (1) soil profile description, (2) root biomass, and (3) radioactive tracer ^{32}P. The results indicate that the older spoils had substantially more roots below 100 cm than did the new spoils or the undisturbed soils. The authors attribute differences in root abundance and distribution among the various sites to differing species composition. Half-shrubs dominated the older spoils, while grasses were dominant on the new spoils and the undisturbed soils. In new spoils, root biomass was 44 pct less than in the undisturbed soils and 43 pct less than in the old spoils. The radioactive tracer method was used to determine maximum rooting depths of 15 important plant species. The information provided by the report has application for evaluating reclamation success and determining the necessary depth of burial for toxic overburden material.

1262. Wyngaard, G. A. Ethical and Ecological Concerns in Land Reclamation Policy: An Analysis of the Surface Mining Control and Reclamation Act of 1977. Paper in Wetlands and Water Management on Mined Lands, ed. by R. P. Brooks, D. E. Samuel, and J. B. Hill (Proc. Conf. PA State Univ., State College, PA, Oct. 23-24, 1985). PA State Univ., State College, PA, 1985, pp. 75-81.

The scientific, ethical, moral, and value concepts that underlie the Surface Mining Control and Reclamation Act of 1977 (SMCRA) were analyzed, and their application in controversies surrounding the reclamation of mined lands was evaluated. The regulations within SMCRA are among the most encompassing and detailed of any environmental regulations; however, the regulations rely on vague ecological, ethical, moral, and aesthetic notions. The concept of higher or better use is especially vague to the author. Three approaches to ethical aspects of mined land use regulations are discussed. The concepts discussed

are land as property, the public trust doctrine, and concerns with the biological character or integrity of the land. The author concludes that an ethical or political consensus concerning the use of land, rather than better scientific or economic analyses, underlies the appropriate implementation of the statute.

1263. Yamamoto, T. Mixing Overburden To Stimulate Soil Conditions: ARCO Black Thunder Mine. Paper in Ecology and Coal Resource Development, Volume 2 (based on Int. Congr. for Energy and the Ecosystem, Univ. ND, Grand Forks, ND, June 12-16, 1978). Pergamon, 1979, pp. 791-797.

This paper relates the results of a study conducted in northwestern Wyoming on the suitability of thoroughly mixed overburden for establishment of the Northern Great Plains short grass complex and associated woody vegetation. The paper is a good source of values for soil chemical and physical factors for mixed and natural soil that could be used for comparative purposes.

1264. Yamamoto, T. A Review of Uranium Spoil and Mill Tailings Revegetation in the Western United States. U.S. For. Serv., Gen. Tech. Rep. RM-92, Oct. 1982, 20 pp.

The author conducted an extensive review of the literature describing uranium spoil and mill tailing revegetation in the Western United States. Although the principles discussed are often applicable to coal operations in the same areas, the main emphasis was the control of radioactivity from uranium mining wastes. Site characterization, moisture considerations, erosion potential, and long-term effects are needs common to the reclamation of both uranium and coal wastes. The author concludes that the most simple and effective species selection method is to use species that have invaded the waste materials. Invading species are not adversely affected by the waste characteristics.

1265. Yee, A. R., and K. Broersma. The Bray, Mehlich and Kelowna Soil P Tests as Affected by Soil Carbonates. Can. J. Soil Sci., v. 67, No. 2, 1987, pp. 399-404.

The effects of carbonates on postextraction pH and on the correlation between soil and plant phosphorus concentrations were determined using five acid fluoride phosphorus test methods. The five soil phosphorus tests studied were (1) Bray P1 (soil-to-extractant ratio of 1:10), (2) Bray P1 (soil-to-extractant ratio of 1:50), (3) Mehlich II, (4) Kelowna I, and (5) Kelowna II. In a growth-chamber pot study, alfalfa (*Medicago sativa* L.) was grown on five calcareous and six noncalcareous soils fertilized at either 0 or 90 μg mL^{-1} P. The results suggest that when acid-fluoride methods are used it is important to maintain an extractant pH below 4.1 for significant correlations between soil test values and plant phosphorus concentrations. On calcareous soils, the Bray P1 (1:10) method gave the poorest results, owing to acid neutralization by excessive soil carbonates. The other methods were better than the Bray P1 (1:10) at resisting acid neutralization and are better correlated with plant phosphorus concentration. In situations where soils are high in carbonates, the Bray P1 (1:50), Mehlich II, Kelowna I, and Kelowna II methods will give better available phosphorus results.

1266. Yokell, M. D., and G. Sanders. The Economics of Reclamation. Paper in Conference on the Economics of Mined-Land Reclamation (cosponsored by Land Reclam. Prog., Argonne Natl. Lab., and U.S. Dep. Energy; Chicago, IL, Sept. 1-2, 1981). Argonne Natl. Lab., ANL/LRP-TM-20, Sept. 1981, pp. 3-36.

A conceptual approach to reclamation economics is presented, contrasting legal and economic approaches. The cost of reclamation is treated as another mining cost, with minimization of the total cost of mining as the objective. A mathematical model is presented to illustrate the concept. The costs inherent in reclamation are divided into premining costs, topsoiling costs, regrading and backfilling costs, and revegetation costs. Preliminary total reclamation cost data are presented by category (premining, topsoiling, revegetation, etc.), region, and mining method. The analysis, results, and discussion contained in this paper attempt to be national in scope.

1267. Young, S. A., and E. J. DePuit. Response of Seeded Species to Temporary Irrigation and Seeding Date. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 21-29.

This study was conducted to evaluate the effects of temporary irrigation on vegetation establishment on surface-mined land near Colstrip, MT. Two different types of vegetative establishment were used, spring (April) and early summer (June), along with four irrigation treatments: no irrigation, 1 month of irrigation, 2 months of irrigation, and 3 months of irrigation following establishment. The same species were used in both spring and summer plantings, followed by a fertilizer treatment once the seedlings emerged. The specific objectives of the study were to (1) evaluate the effects of temporary irrigation on establishment, productivity, structure, species composition, and diversity of seeded species during the initial year of irrigation and the subsequent years with no irrigation, (2) determine the effects of varied irrigation duration, and

(3) evaluate vegetation development and composition after summer seeding and temporary irrigation.

The results show that initial plant emergence was not affected by irrigation. After 2 years, however, there was greater species diversity on the spring-seeded plots with 1 month of temporary irrigation. After 2 years, following an initial period of slow development, the summer-seeded plots were dominated by cool-season perennial grasses. It appears that 2 months of irrigation are necessary for the development of successful vegetation on the summer-seeded plots. Irrigation seemed to favor the establishment of perennial grasses over seeded shrubs and forbs and reduced the production of weedy species on all plots. The authors conclude that temporary irrigation could be used as a management tool for successful reclamation in the Northern Great Plains.

1268. Younos, T. M., and M. D. Smolen. Simulation of Infiltration in a Sewage Sludge Amended Mine Soil. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 319-324.

The purpose of this study was to simulate the effect of sewage sludge incorporation on the water infiltration properties of mine soil in the laboratory. The mine soil used to construct the model was obtained from a mountaintop removal surface mine near Beckley, WV. The results of the simulation study indicate that sludge incorporation increases the hydraulic conductivity, promotes rapid filling of soil pores, and encourages rapid saturation of amended mine soils. All three contribute to an increase in the infiltration capacity of sludge-amended mine soil compared with unamended mine soil. The increased infiltration capacity results in a more rapid advance of the wetting front and more moisture available for plant growth.

1269. Zaburunov, S. A. Helping Nature Help Itself. Coal Min., v. 24, No. 5, 1987, pp. 42-43.

This article describes the bactericide system used in controlling the bacteria responsible for acid mine drainage. Costs and benefits of the system are presented.

1270. Zachmann, J. E., J. A. E. Molina, C. E. Clapp, N. A. Schumacher, and W. E. Larson. Toxicity and Stability of Municipal Waste Compost as Detected by the Earthworm *Eisenia Fetida*. Am. Soc. Agron., Agron. Abstr., 1987, p. 36.

Abstract of a paper presented at the 1987 Annual Meetings of ASA, CSSA, and SSSA. The earthworm *Eisenia fetida* was used as a bioassay in compost soil mixtures to assess the stability and toxicity of municipal solid waste compost. The compost was characterized based on three observed patterns of earthworm behavior.

1271. Zak, J. C. The Importance of Vesicular-Arbuscular Mycorrhizae in the Reclamation of Mine Spoils. Paper in Proceedings Second Annual Meeting American Society for Surface Mining and Reclamation (Denver, CO, Oct. 8-10, 1985). Am. Soc. Surf. Min. and Reclam., 1985, pp. 298-305.

A literature review is presented on the importance of vesicular-arbuscular (VA) mycorrhizae in the reclamation of mine spoils. General characteristics and the occurrence of VA mycorrhizae in mine spoils are discussed. Information is presented on the effects of various soil amendments on VA mycorrhizal development. Vesicular-arbuscular mycorrhizal associations are recognized as important components of most terrestrial habitats, and they have been shown to affect several key ecosystem processes and characteristics. Long- and short-term effects of any reclamation practice on the establishment and maintenance of VA mycorrhizae must be considered.

1272. Zell, L. M. Determining the Research Needs of Mining and Reclamation Council of America, the Surface Coal Mining Industry, Draft Report. (U.S. Dep. Energy grant DE-FG01-81FE00094). U.S. Dep. Energy, Off. Coal Min., May 1982, 122 pp.

This document is a synthesis of input from all sectors of the surface coal mining industry, academic researchers, and Government personnel. It reviews the status of present knowledge and technology pertaining to surface coal mining throughout the Nation and presents outlines for perceived research needs. These discussions are treated on a regional basis recognizing three coal mining regions nationally. The major subjects covered include hydrology, sedimentology, reclamation, air quality, and blasting.

1273. Zellmer, S. D. A Coal Refuse Reclamation Project. Proc. WV Acad. Sci., v. 51, No. 3, 1980, pp. 115-127.

This paper reports interim results of a project demonstrating methods that can be used to reclaim abandoned coal refuse sites. A 13.8-ha abandoned site in southwestern Illinois was reclaimed by recontouring the refuse material and covering it with a minimum of 30 cm of topsoil. A mixture of grasses and legumes was seeded on 8.9 ha of the site. A multidisciplinary approach was used to evaluate postconstruction environmental and economic effects of the reclamation effort. The author reports establishment of plant cover, development of soil microbial populations, and formation of wildlife habitats.

1274. Zellmer, S. D. Staunton 1 Reclamation Demonstration Project, Project Report for 1977. Argonne Natl. Lab., ANL/LRP-TM-14, Dec. 1978, 70 pp.

This progress report presents first-year research results for the many studies making up the Staunton 1 Project. The overall project objectives are to reclaim this abandoned minesite, and in the process, furnish necessary design data and develop and demonstrate economic methods for future reclamation efforts of this type. The project is located in Macoupin County in southwestern Illinois. Studies monitoring ground water, surface water quality, aquatic ecosystems, revegetation, soil characteristics, erosion and runoff, soil microbial and soil fauna populations, wildlife, and economic effects of the reclamation project are described.

1275. Zellmer, S. D. Staunton 1 Reclamation Demonstration Project—Progress Report II. Argonne Natl. Lab., ANL/ES-73, July 1979, 110 pp.

This document provides a status report for the Staunton 1 Reclamation Demonstration Project being conducted near Staunton, IL. The project involves an evaluation of the reclamation process on a 13.8-ha abandoned deep coal mine refuse site. Approximately 9.3 ha of refuse matter was recontoured, covered with a minimum of 30 cm of soil obtained on-site, and seeded with a mixture of grasses. The progress of a number of projects following 2 years of intensive monitoring and evaluation is reported. Studies being conducted at the site include monitoring of ground water quality, surface water quality, aquatic ecosystems, revegetation success, soil characteristics, slope angle and erosion rate, soil microbiology, wildlife, economic benefits, and site management and maintenance.

1276. Ziemkiewicz, P. F. Determination of Nutrient Recycling Capacity of Two Reclaimed Coal Mine Sites in British Columbia. Reclam. & Reveg. Res., v. 1, No. 1, 1982, pp. 51-62.

This paper is a brief summary of the author's Ph.D. thesis. Studies were conducted over a 14-month period to determine if fertilization is still necessary after 3 years of maintenance on two reclaimed coal mines near Sparwood in southeastern British Columbia, Canada. Two distinct phases of revegetated plant communities were identified, the immature and the mature. Immature vegetation is characterized by small root systems, with a major portion of the system's available nutrients being transferred from the shoots to the detritus in the autumn. Slow decomposition of the detritus causes nutrient deficiencies, particularly in cold and dry climates, and longer periods of maintenance fertilization are necessary. The mature phase is characterized by rapid detrital decomposition and a larger root system, both of which provide a readily mineralized pool of nutrients to the soil. Mature vegetation needs no maintenance fertilization; in fact, fertilization during a drought year may damage a mature reclaimed area. Immature plant communities do not necessarily become mature, particularly at subalpine and alpine locations where maturation may not occur until adapted native species become established.

1277. Ziemkiewicz, P. F., and S. M. Northway. A Species Selection Technique for Reclamation in British Columbia. Reclam. Rev., v. 1, No. 3/4, 1978, pp. 163-166.

This study determined which physiographic, soil chemical, or soil physical property had an influence on the establishment and productivity of 13 grass and legume species used to revegetate coal mined land near Sparwood, BC, Canada. The results indicate that species productivity is strongly correlated with elevation and aspect, with elevation being the most significant parameter. Along an elevational gradient two major plant groupings can be distinguished: (1) at 1,150 to 1,650 m, the plants are crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.), intermediate wheatgrass (*Agropyron intermedium* (Host.) Beauv.), smooth brome (*Bromus inermis* Leyss.), Canadian bluegrass (*Poa compressa* L.), and alfalfa (*Medicago sativa* L.) and (2) above 1,650 m, the plants are smooth brome, orchardgrass (*Dactylis glomerata* L.), timothy (*Phleum pratense* L.), meadow foxtail (*Alopecurus pratensis* L.), red fescue (*Festuca rubra* L.), Kentucky bluegrass (*Poa pratensis* L.), redtop (*Agrostis alba* L.), alfalfa, white clover (*Trifolium repens* L.), and red clover (*Trifolium pratense* L.).

1278. Zimmerman, L. J., and R. F. Wittwer. Use of Slow Release Fertilizers When Planting Sycamore, Yellow Poplar and Cottonwood Seedlings on Surface Mined Land. Paper in 1981 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation (Lexington, KY, Dec. 7-11, 1981). Univ. KY, Lexington, KY, 1981, pp. 477-480.

This study was conducted in Bell County, southeastern Kentucky, on a site that had recently been mined by the mountaintop removal method. The objectives of the study were (1) to compare the effects of two types of slow-release, tableted fertilizers at two application rates on the growth and survival of eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.), yellow-poplar (*Liriodendron tulipifera* L.), and American sycamore (*Platanus occidentalis* L.) and (2) to determine if the fertilizer tablet application is more effective than broadcast fertilizing for improving tree survival and growth. The fertilizer

treatments were (1) one 9-g slow-release tablet (18-8-3), (2) two 9-g tablets, (3) one 21-g slow release tablet (20-15-5), (4) two 21-g tablets, and (5) 280 kg ha^{-1} of diammonium phosphate (18-46-0) broadcast over the surface. The results show no significant effect of treatments on first-year survival, growth, and nutrient content of the trees. The authors speculate that this may be due to the age of the trees, the low fertilizer application rates, or the below-normal precipitation that occurred during the first growing season.

1279. Zipper, C. E. Economic Analysis and the Planting of Hardwood Trees on Surface Mined Lands. Paper in Third Annual Conference on Better Reclamation With Trees (cosponsored by AMAX Coal Co., Purdue Univ., South. IL Univ., and Madisonville Community Coll.; Terre Haute, IN, June 2-3, 1983). Purdue Univ., West Lafayette, IN, 1983, pp. 202-216.

The economics of establishing long-rotation hardwoods on mined lands are analyzed, assuming minimal establishment problems and yields approximating those achievable on natural soil sites. Given these assumptions, internal rates of return in the 2- to 4-pct range are indicated. Calculated rates close to 5 pct result from "best case" assumptions. The report offers a hypothetical economic analysis of long-rotation hardwood sawtimber production, which points out favorable potential yields if technical problems can be overcome.

1280. Zipper, C. E., and W. L. Daniels. Institutional Constraints to Production of Reclaimed Mine Lands Suitable for Development in Central Appalachia. Paper in Mine Drainage and Surface Mine Reclamation, Volume II: Mine Reclamation, Abandoned Mine Lands and Policy Issues. BuMines IC 9184, 1988, pp. 319-325.

The institutionalized context of mined land reclamation planning was examined in order to recommend actions with the potential to increase the rate at which flat lands are constructed in the central Appalachian region, which would improve postmining land use potentials. The discussion focuses on the goals, motivations, and influences of the three major interests to postmining landform and land use decisions: landowners, the mining industry, and regulatory agencies. Variances in the approximate original contour requirement are recommended; landform alteration mining activities and procedures are promoted in order to produce reclaimed sites with development potential in the central Appalachian region. Planning at the outset of mining is essential.

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