A mining research contract report
JUNE 1984

# A COMPARISON OF THE EFFECTS OF VARIOUS SOIL HANDLING EQUIPMENT ON THE DENSITY OF PRIME-FARMLAND SUBSOILS

Contract No. J0225007
Kenwill, Inc.

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

OFR
85-83

## DISCLAIMER

# A COMPARISON OF THE EFFECTS OF VARIOUS SOIL HANDLING EQUIPMENT ON THE DENSITY OF PRIME-FARMLAND SUBSOILS

Developed for:

BUREAU OF MINES
U.S. DEPARTMENT OF THE INTERIOR
Minerals Research Program

Prepared by:

**C. Steve Albrecht**
Kenwill, Inc.
Lexington Kentucky Regional Office

Authors Current Affiliation:

Land Resources, Inc.
Lexington Kentucky Office

Contract No. J0225007

Project Officer:

**David L. Veith**
U.S. Bureau of Mines
Minneapolis, Minnesota 55417

June, 1984

50272-101

| | | | |
|---|---|---|---|
| **REPORT DOCUMENTATION PAGE** | 1. REPORT NO. | 2. | 3. Recipient's Accession No. |

4. Title and Subtitle
A Comparison of the Effects of Various Soil
Handling Equipment on the Density of
Prime-Farmland Subsoils

5. Report Date
June 30, 1984

6.

7. Author(s)
C. Steve Albrecht

8. Performing Organization Rept. No.
K-LO-1001-82

9. Performing Organization Name and Address

Kenwill, Inc.
462 E. High Street
Lexington, KY 40508

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) J0225007
(G)

12. Sponsoring Organization Name and Address
U.S. Bureau of Mines
Twin Cities Research Center
5629 Minnehaha Ave., South
Minneapolis, MN 55417

13. Type of Report & Period Covered
Final Report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The primary objective of this study is to "evaluate the influences of different equipment systems on prime farmland subsoil compaction due to surface mining in the Midwest."

Basis for this research effort centers on four (4) major experiment designs:

- Comparison of soil bulk density values for three distinct equipment systems evaluated on the same general soil types (i.e. scrapers, bucket-wheel excavators and end-dump haulback);
- Evaluation of the effects of soil replacement in repeated lifts using scrapers;
- Presentation of bulk density values representing soil compaction for four (4) equipment systems (i.e. bucket-wheel excavators, draglines, scrapers and end-dump haulback) on four separate mine sites in the midwest;
- A prediction analysis model is developed for subsoil bulk density following reclamation based on equipment characteristics and a statistical evaluation of texture.

17. Document Analysis a. Descriptors

| | |
|---|---|
| Soil Compaction | Soils |
| Prime-Farmland Reclamation | Reclamation |
| Surface Mine Reclamation | Soil Modeling |

b. Identifiers/Open-Ended Terms

A Comparison of the Effects of Various Soil
Handling Equipment on the Density of
Prime-Farmland Subsoils

c. COSATI Field/Group

| | | |
|---|---|---|
| 18. Availability Statement<br>Release Unlimited | 19. Security Class (This Report)<br>Unclassified | 21. No. of Pages<br>269 |
| | 20. Security Class (This Page)<br>Unclassified | 22. Price |

(See ANSI–Z39.18)

OPTIONAL FORM 272 (4–77)
(Formerly NTIS–35)
Department of Commerce

# FORWARD

This report was prepared by Kenwill, Inc., in the Lexington, Kentucky Office under U.S. Bureau of Mines Contract No. J0225007. The contract was initiated under the Mining Research program. The project was administered under the technical direction of the U.S. Bureau of Mines with Gary Schroeher acting as Technical Project Officer. Mr. David L. Veith assumed Project Officer responsibilities for the completion of the project. Mr. Larry Anderson was the Contract Administrator for the Bureau of Mines. Micky LaChuga assumed Contract Administrator responsibilities for project completion. This report is a summary of work completed during the period September 31, 1982 through June 30, 1984. This report was submitted by the author on June 30, 1984.

Federal and state regulatory agencies are involved in the reclamation of mined lands and the return of prime land to original production. This report addresses one aspect of prime farmland reclamation, soil compaction. This report is intended to aid private industry and government agencies in the reclamation of prime land and to provide a basis for research in the future.

# ABSTRACT

The primary objective of this study is to "evaluate the influences of different equipment systems on prime farmland subsoil compaction due to surface mining in the Midwest." The study is centered on four mine sites each utilizing a different combination of equipment for soil removal and replacement.

Subsoil compaction is the primary focus of this research effort. Primarily owing to physical location, it is difficult to alleviate the increased compaction directly below the topsoil in reclaimed soils. Different equipment combinations cause varied effects when soils are replaced during surface mining activities. By collecting field data within a statistical framework, the effects of different equipment combinations on subsoil compaction can be evaluated and conclusions drawn.

This research effort evaluates a comparison of natural and replaced soils by moist bulk density data. This comparison centers on changes in bulk density and texture to a depth of 48 inches. For each study site a complete case study is provided for use in data correlation and interpretation.

Basis for this research effort centers on four (4) major experiment designs:

- **Comparison of soil bulk density values for three distinct equipment systems evaluated on the same general soil types (i.e. scrapers, bucket-wheel excavators and end-dump haulback);**

- **Evaluation of the effects of soil replacement in repeated lifts using scrapers;**

- **Presentation of bulk density values representing soil compaction for four (4) equipment systems (i.e. bucket-wheel excavators, draglines, scrapers and end-dump haulback) on four separate mine sites in the midwest;**

- **A prediction analysis model is developed for subsoil bulk density following reclamation based on equipment characteristics and a statistical evaluation of texture. The soil data base of information includes data from the 1982 Bureau of Mines study entitled, "Impact of Surface Mining on Soil Compaction in the Midwest" as well as data from this research project.**

The final report is synthesized through an analysis of field data, statistical analysis and literature review. The final report focuses on the interpretation of results for practical application by government and industry.

## TABLE OF CONTENTS

APPENDICES

# FIGURES

## TABLES

## ACKNOWLEDGEMENTS

This project was sponsored by the U.S. Bureau of Mines (BOM) and the work was conducted by KENWILL, INC. Several organizations contributed significantly to overall project success. These organizations include:

Arch Mineral Corporation
Southwestern Illinois Coal
Peabody Coal
Brazil Coal & Clay
AMAX Coal
Soil Conservation Service, (U.S.D.A.)
Caterpillar Equipment Company

Direct management, field data collection and authorship of the final report was provided by C. Steve Albrecht. Statistical analysis of the data was provided by Dr. Dennis Haack of Statistical Consultants, Inc. in Lexington, Kentucky. Dr. R.I. Barnhisel provided technical review support. The primary BOM project officer was Gary Schroeher of the Bureau of Mines Twin Cities Research Center, Minneapolis, Minnesota.

Other individuals who provided valuable assistance during the course of the project include: Bob Holloway--Southwestern Illinois Coal, Al Grandt and Steve King--Peabody Coal, Dave Ralston--AMAX Coal, Don Link--Brazil Coal and Clay, Dr. William Carter, Dr. Edgar Kuemmerle, Richard Marsh and Terry Carroll--KENWILL, and Cynthia P. Albrecht.

# INTRODUCTION

The coal regions of the United States are richly endowed with abundant mineral resources. Recovery of these resources through surface mining results in a major disturbance of the land and interrupts the natural balance between soils and geologic formations that has been established over many years. Nowhere is the impact of this disturbance more evident than in the prime farmland areas of the Midwest. When soil structures formed over many years of weathering are suddenly removed and replaced, there can be severe changes in naturally formed structures and consequential adverse impacts upon agricultural potential and production capabilities.

The post-mining productivity of prime farmland is one of the most important technical issues currently outlined in the surface mining permanent regulatory program. The new permanent regulatory program and Reclamation Act of 1977 is very specific when addressing prime farmland reclamation activities. These reclamation requirements for prime farmland are implicit in the Act; reconstruct the plant supporting soil profile and return the land to a productivity at least as great as that which existed prior to mining. How to return the mined prime farmland areas to original production capacities is the basis of this study that analyzes the effects of machine-induced soil compaction on basic soil characteristics.

Over the years, land disturbances created in the process of surface mining coal have depleted the amount of lands suitable for high levels of agricultural production. The geographic scope of the compaction related problem should not be underestimated. In the area referred to as the "Corn Belt" (Schmude, 1977), there are approximately 77 million acres of prime farmland. While all of these lands may not be considered prime farmlands under the criteria established by the Secretary of Agriculture, they would certainly be candidate areas. One area described by Schmude includes Iowa, Missouri, Indiana, Illinois and Ohio, and occupies much of what is considered to be the Midwestern U.S.A. Disruption of the land in the "Corn Belt" due to coal mining may involve as much as 450,000 acres by the year 2000, and of this 450,000 acres approximately 127,000 acres are prime farmland (Bernard, 1979).

Government and industry realize that continuing depletion of high quality land for agricultural production poses a long-term threat to our national food supply. This fact has brought about federal and state legislation and new mining industry practices which are designed to return mined land to original or better agricultural production capabilities. Environmental researchers evaluating surface mining methods and reclamation procedures have determined that a number of factors are important in achieving original production capacity through mined land reclamation. Special research emphasis is placed on the problem of soil compaction caused by the heavy equipment impact on soil density.

Evaluation of subsoil compaction caused by heavy equipment is the major objective of this study. This project is a companion project with a study completed in February, 1982 entitled, "Impact of Surface Mining on Soil Compaction in the Midwest." The 1982 study focused on four surface mining operations in the Midwest. Each of these operations used a different combination of soil removal, transport and replacement equipment (i.e. bucket-wheel, scraper, front shovel or dragline). The 1982 study documented the change in bulk density from natural to replaced prime farmland soils at specific depths to 48 inches. Conclusions documented that the topsoil densities were approximately the same in both natural and replaced soils owing mainly to tillage. The zone in the reclaimed soil profile found to contain the largest change in density from the natural soils was the subsoil directly below the topsoil/subsoil interface. The subsoil composition with respect to texture was found to have a significant influence on soil compactability. Sand content in particular was documented as contributing to high soil bulk density values.

The significant influence of soil texture on bulk density values gave rise to this research effort to isolate the machine impact on reclaimed subsoils. This project differs from the 1982 study in that different equipment systems were tested on the same soil type thus limiting the influence of changing soil types on the data. Scrapers were also evaluated to define soil density changes within the soil profile when soils were replaced in repeated lifts to a 4 foot depth.

The most important facet of this study is the development of a subsoil compaction prediction model based on bulk density and texture data. Given the texture of a subsoil mixture and the soil replacement method, the model predicts the resultant bulk density after mining. This model is a powerful tool for evaluation of prime farmland soil compaction and reclamation methods before compaction occurs.

This report is a comprehensive presentation of all project background material, methods and results. Background information on current soil compaction technology, site selection criteria, and project objections are presented in Section 2. Section 3 outlines the experiment design and project sampling program while Section 4 discusses case studies of each project site. The description of field study results are contained in Section 5 along with the statistical analysis summary. One unique portion of the final report is Section 6 which deals with the prediction of soil compaction by equipment based on soil characteristics. Sections 7 and 8 of the report provide a cost analysis and a summary of project conclusions. A conscious effort is made throughout the course of the study to gather data which pertains to actual field conditions.

# BACKGROUND

## Technical Discussion of Soil Compaction

Soil compaction in reclaimed areas following surface mining results from a complex interaction between reclamation machinery and the physical characteristics of the soil. This section of the report is provided only as a baseline of technical information leading into the portrayal and discussion of project background and results. Soil compaction by heavy equipment in effect interacts with every major soil characteristic and subsequently impacts ultimate plant growth. To achieve agricultural productivity, excessive soil compaction is controlled through proper environmental planning, management and design. Soil compaction control involves management of complex soil parameters and characteristics such as water content and texture.

The variability of overall soil characteristics introduces another interesting problem into the overall plan for prime farmland reclamation. Changes in soil type and texture greatly affect the overall compactability of the soil and hence subsequent plant growth success. Soil compaction involves diverse and complex relationships that interact naturally within undisturbed soil; and are made more complex by an external force, such as machine impact during the reclamation process. It is not within the scope of this study to summarize and discuss each interactive factor involved in the soil compaction process, however some technical discussion is needed to provide background information on the technical factors involved in soil compaction. For purposes of this discussion, the following subjects will be addressed:

o **Subsoil Compaction Process**
o **Applied Force and Soil Interaction**
o **Soil Components Involved in Soil Compaction**
o **Adverse Effects of Compaction on Plant Growth**

Interrelated in the evaluation of subsoil compaction are the internal and external factors that combine to produce the soil compaction that occurs on reclaimed mine land. Figure 1 displays the basic factors involved in the soil compaction process.

### Subsoil Compaction Process

As illustrated in Figure 1, soil compaction in surface mining operations can be divided into two distinct categories. These two categories are composed of both the internal and external factors which come to bear on the soil to produce soil compaction. As shown in Figure 1, external factors are composed of primarily

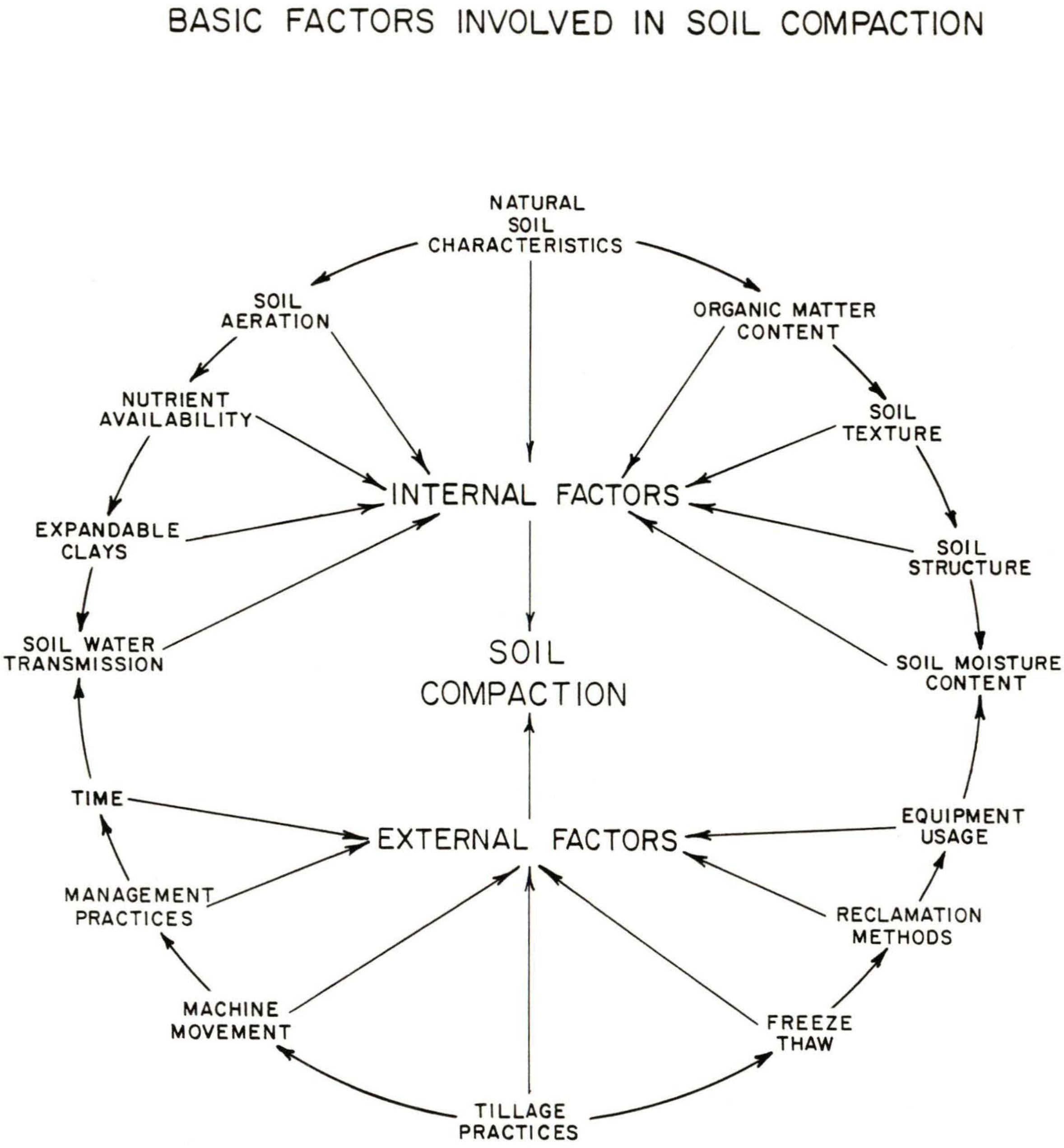

FIGURE 1. Internal and External Factors Involved in the Compaction Process

equipment impacts while internal factors are those found naturally within the soil. Management practices by an individual mining operation are external factors that can govern both the soils characteristics and machine interaction.

Machine impact and soil texture are the most important factors in the reclamation of prime farmland with respect to soil compaction. The machine impact is primarily caused by scraper tire interaction with the subsoil layers directly below the topsoil. Scraper activity that causes this compaction is shown in Figure 2. Heavy equipment, when fully loaded exert a tremendous force on the soil surface through the track or tire. This direct interaction between the vehicle tire and the soil surface initiates the subsoil compaction process. Constant control of ground traffic on the surface mine is needed to control the extent of the soil compaction process. In the course of surface mining, prime farmland soils are removed to a depth of 4 feet or more, transported and then replaced, regraded and reclaimed. During the course of this removal and replacement process, soil physical characteristics both natural and induced can change due to mixing and transport of the natural soil material. Soil texture in combination with water content is documented through previous research to have a significant effect on soil compactability.

The soil compaction process is evaluated through bulk density analysis and defined as a change in volume for a given mass of soil. Compaction can occur under the loading of soil material through heavy equipment traffic or by natural soil forces. Under natural conditions internal soil forces may result from alternate wetting and drying causing expansion of clays such as "montmorillonite", or from numerous freeze and thaw cycles in the surface regions. Soil compaction occurs even under the relatively small load of agricultural machinery in the natural course of row crop planting and harvesting. The words "small equipment" are to distinguish between agricultural machinery and that which is used in reclamation processes on large surface mines. Increases in soil compaction in the case of in-place natural soils are one problem, but when this problem is compounded by the physical removal, transport and replacement of natural soils, many different problems develop. All of the problems associated with increased soil compaction or bulk density directly relate to the overall productivity of the soil for crop growth.

The soil compaction process is a change in soil volume in response to an applied load and can usually be attributed to one of the following four factors:

- **Compression of solid particles**
- **Compression of liquids and gases contained within pore spaces**
- **Change in the amount of liquid and gas contained within pore spaces**
- **Rearrangement of soil particles (Harris, 1971)**

Due to the fact that most soils contain both clay and granular particles, the compaction process is a function of the individual particle deformation, particle rearrangement, and movement of soil particles, gases, and liquids (Harris, 1971). Figure 3 presents a graphic illustration of the liquid, gas and solid components of a typical silt/loam soil. The composition of the soil from the standpoint of its solid, liquid and gas components has a significant impact on soil strength properties. The compaction process depends on the type of loading as well as individual soil properties of the compacted soil.

FIGURE 2. Scraper Traffic (Rear View) Showing Compaction Track

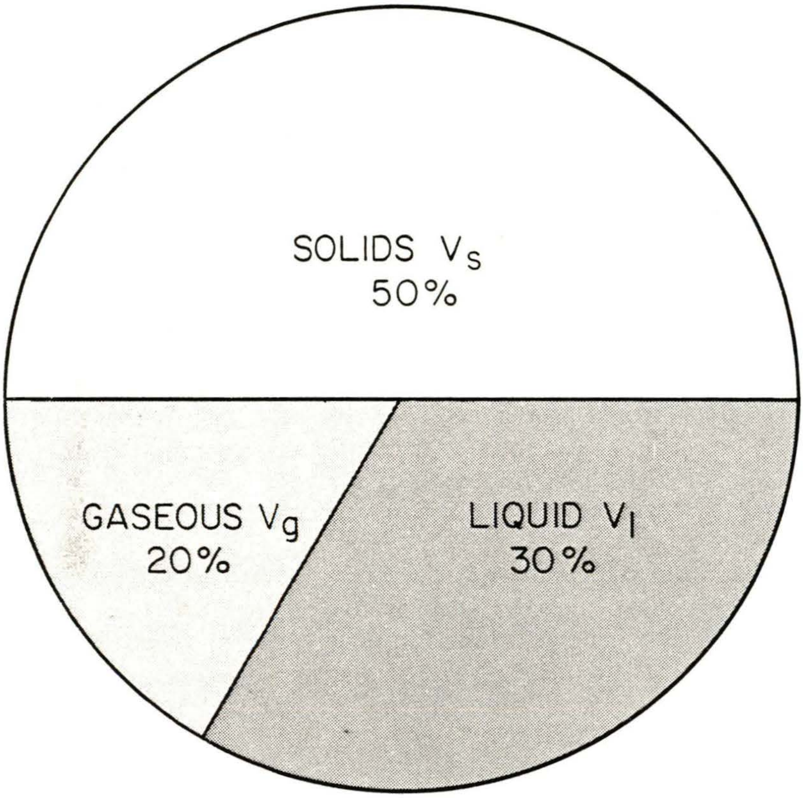

FIGURE 3. Volume Composition of a Typical Silt Loam Soil

The soil compaction process is difficult to explain from an analytical standpoint. The variability of the soil material is in part responsible for this lack of analytical description. Immense difficulties arise when attempting to accurately describe a change in bulk density due to a given soil characteristic. Later sections of this report will address the problem of predicting bulk densities on surface mining operations.

## Soil Components Involved in Soil Compaction

### Water Content and Movement

Soil compaction alters the void ratio within the soil and thus affects the content and transmission of water. Water content and transmission are affected most by changes in void characteristics (B.P. Warkentin, 1971). The arrangement of soil grains also exerts an effect to a smaller degree. Macropore space or the largest soil voids change the most under a compaction load. The large void spaces conduct most of the water and are closely related to water transmission. In the course of the reclamation process layers are formed in the soil profile which inhibit water movement. In reclaimed soils the general pattern in the layering process is a more permeable topsoil layer existing over a compacted subsoil layer. In general when the more permeable layer overlies the less permeable layer the following occurs: When the wetting front reaches the compacted zone, water moves into the zone with smaller void size and suction. This increase in suction temporarily increases the infiltration rate. In response to the increase in infiltration the top permeable layer fills with water and decreases the gradient. From that point the hydraulic conductivity is determined by the lower compacted zone (B.P. Warkentin, 1971).

The maximum content of water retained by the soil decreases at saturation after compaction. The important factor to consider is the amount of plant available water in the profile. Jamison (1953) has shown that compaction may increase storage and thus plant available water. Other factors such as root development may have more importance than water in analyzing crop response under compacted soil conditions.

### Air Movement in Compacted Soils

Transfer of gases within the soil occurs in air-filled pores. The major force involved in the transfer of air is a gradient of total pressure, the resulting change in air content is due to a mass transfer. Through the course of soil compaction, pore spaces can be decreased and consequently soil compaction may decrease the air composition in a biologically active soil (Albert R. Grable, 1966).

Field data indicates that soil compaction can be severe at times without greatly altering soil air composition. Blake and Page (1948) found at least 75 percent oxygen at 90 centimeter depths on all tillage plots on Brookstone silty clay loam. Phillips and Kirkham (1962) measured 10 percent or more oxygen at 60 centimeter depths in severely compacted Colo clay during the growing season. Overall air contents of soils depend primarily on macro pore spaces that drain quickly after rainfall or irrigation. The compaction or pulverizing of soil structure may destroy these large pores to restrict oxygen transfer to roots and microorganisms. Reducing the size of soil particles or increasing bulk density affects the intersoil gaseous transfer, which reduces air porosities and diffusivities.

## Heat Content

Soil heat content governs to an extent biophysical processes involved in plant growth, and soil compaction can have a great effect on the soil thermal diffusivity properties. Soils retain and transmit heat. The ability of soil to do this is influenced by the density, water content and transmissivity of the soil. Soil compaction can increase the soil density and in turn result in an increase in thermal conductivity. This alteration, while not well understood, changes the temperature equilibrium between the soil and plant root system, adversely affecting plant growth and crop yield.

The heat distribution in the soil is affected by tillage, structure, density, soil type, layering affects and water content. Gradwell (1963) demonstrated that soil density differences of .3 to .4 $g/cm^3$ between loose and dense soils caused the thermal conductivity in dense soil to be approximately double that for loose soil. General water management, which in effect is bulk density control affects soil temperatures through changes in heat capacity and conductivity as well as evaporation and ultimate plant growth (Willis and Raney,1971).

## Nutrient Availability

Soil compaction with respect to nutrient availability is both beneficial and destructive to crop growth. Soil compaction increases the rate at which nutrients move toward the roots by diffusion and mass flow (Kemper, Stewart, and Porter, 1971). In contrast, soil compaction results in a decrease in the amount of nutrients which are mineralized from soil organic matter. In a practical sense this loss of weathering of nutrients can be compensated for by adding fertilizer amendments. Infiltration reduction can decrease the diffusion of nutrients. If water entry into the soil profile remains at a competent level and fertility levels are maintained through fertilization, moderate compaction will not be detrimental to the plant nutrient status (Kemper, Stuart, and Porter, 1971).

The key to the above statements on the effect of soil compaction on nutrient movement and availability is based on a minimal amount of compaction. Minimal compaction levels are rarely found in surface mined reclaimed areas due to the extensive pressure exerted by heavy equipment. Bulk density values in the range of 1.7 to 2.0 $g/cm^3$ are not considered minimal compaction and thus would further limit nutrient movement through compacted zones.

## Soil Strength

The strength of a soil is associated with its physical resistance to deformation under stress. The major factor affecting specific relationships between soil strength and density is the soil moisture content (W.J. Chancellor,1971). Under general circumstances soils have less strength against deformation at high moisture contents; however, research under very high density levels on reclaimed surface mines indicates that a very high compaction can occur at both high and low moisture contents (Albrecht, 1982).

One important facet of soil strength is that of the overall particle size distribution within the soil. Soils containing a broad range of particle sizes generally offer less resistance to compaction, while soils having a narrow size range offer more resistance. Compaction is most easily achieved with soils consisting of different grain sizes, where smaller grains can roll into voids between larger ones. Soils with more than 40 percent silt-sized grains have a high bulk density (Diabold, 1954). Evidence of this fact will be illustrated later in this report under actual texture bulk density relationships on field data.

Another important aspect considered in the research of soil structure and bulk density is the change in soil structures due to machine impact. One example of this structural change is illustrated by conveyors which are used to transport materials into reclaimed areas. Belt transport of soil materials causes new soil structure formation, in essence an artificial soil. In the case of belt transfer of material, the vibrating action on the belt creates what is known as a "fritted structure". This change in structural identification from those structures found under natural field conditions alters the soils overall strength and compactability.

In many instances soil water content governs overall soil strength. This fact is important when considering equipment relationships and their effects on subsequent soil compaction. The moisture content at the time of movement of prime farmland soils can have a significant impact on the level of bulk densities following replacement. The prior arrangement of the internal soil structure can be altered at the time of wet soil movement. Soil structure after reclamation can be significantly different than that prior to mining. In the evaluation of the effect of water on soil compactability consideration should be given to water transmission and surface infiltration.

## Applied Force and Soil Interaction

The magnitude and distribution of forces applied to the soil by a rubber-tired vehicle have been studied extensively. Vandenberg and Gill (1962) imbedded transducers in the carcass of a smooth rubber tire in order to determine the stress pattern under a dynamic wheel load. Pressure patterns were obtained from the transducers in several types of soil. Data indicate that pressure patterns are influenced by the natural conditions of the soil as well as by the tire. In general, as the soil was softer and more compacted the magnitude of the pressure was less. Figure 4 shows the pressure distribution when the tire was operated on a firm sand and all of the deformation occurred in the tire. The data indicate that changes in the inflated tire pressure changed the pressure distribution pattern considerably. Please note that soils of increased sand content are compacted to a greater degree

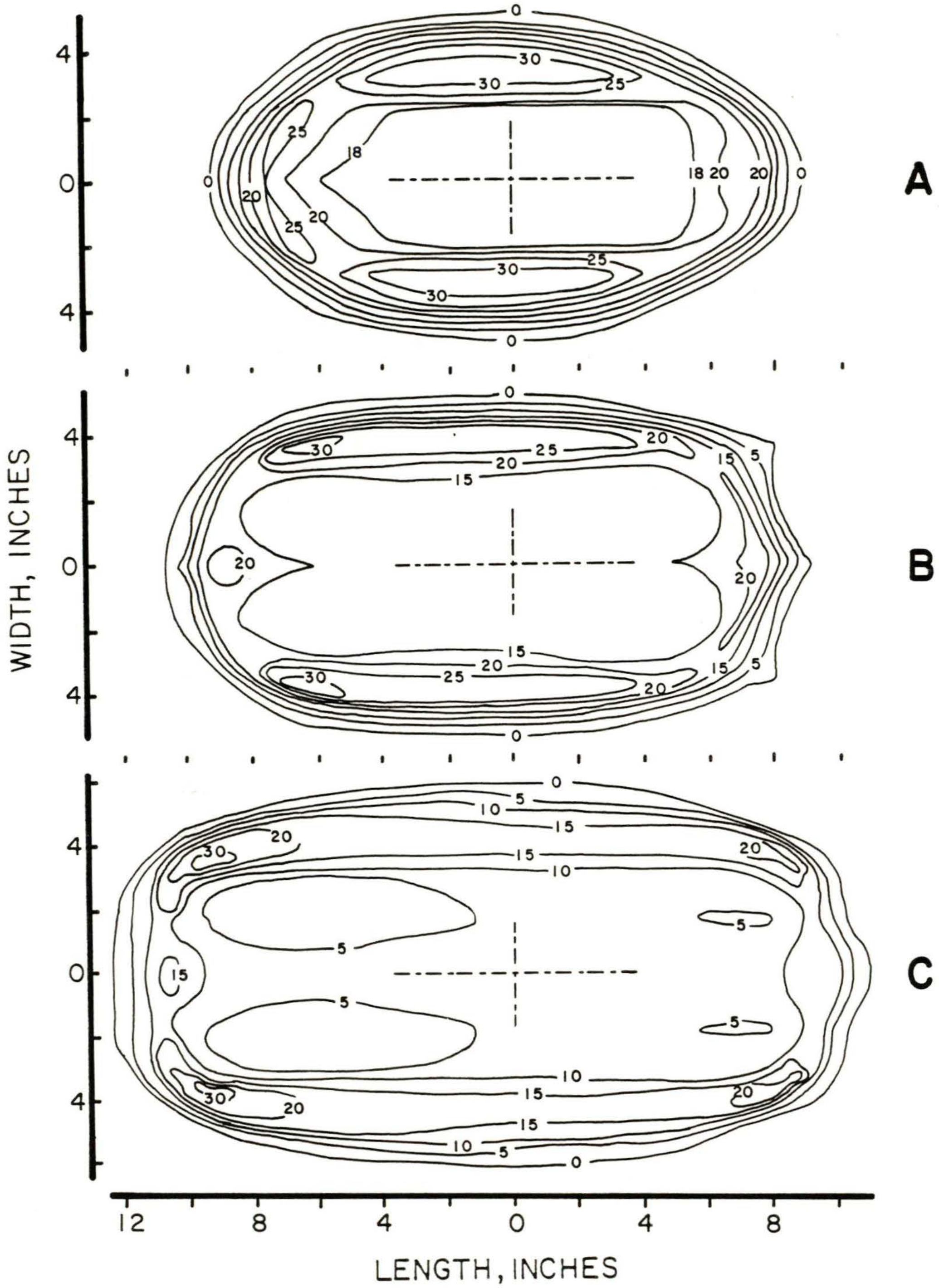

FIGURE 4. Pressure Distributions Under a Smooth Rubber Tire Moving Over Fine Sand When Inflated: A, to 14 psi; B, to 10 psi; C, to 6 psi. Direction of Travel was to the Left (Vandenberg and Gill, 1962)

than those containing higher silt and clay components. Loads such as those visualized in Figure 4 are common and often achieve pressures from 20 to 50 psi in agricultural tractors while scraper pans on reclaimed areas operate at psi values of over 100. This visual interpretation of the effect of an applied tire load on the soils sums up the problems associated with prime farmland reclamation. This externally applied force when replacing prime farmland soils causes a severe increase in overall soil compaction in both wet and dry soils.

The forces exhibited by heavy equipment in combination with the natural soil characteristics combine to govern the overall compactability of prime farmland soils. This study addresses the application of these technical factors to actual field conditions in reclaimed prime farmland areas and identifies the extent of overall subsoil compaction.

## Site Selection Criteria

Site selection in a project of this type is considered one of the most important factors to ensure the success of the field data collection phase of the study. In selecting study sites, a key criterion is the ability of an operation to provide a representative cross-section of equipment utilization and management practices currently used for soil handling. Company interest and cooperation are also of vital importance to overall field investigation success. Basic guidelines for site selection are shown in Table 1.

**TABLE 1 - Guidelines for Field Study Site Selection**

A. LOCATION
   1. Midwest prime farmland area
   2. Active surface coal mining region

B. COAL COMPANY COOPERATION
   1. Sincere interest in project objectives and results
   2. Willingness to participate in the project
      a. Site access to project personnel
      b. Site access to government personnel
   3. Post mining performance record
      a. Complies with applicable laws and regulations

C. METHODS AND EQUIPMENT EMPLOYED IN SOIL TRANSPORT
   1. Equipment type
   2. Combination of equipment on site
   3. Topsoil and subsoil handling techniques

D. SOIL SURVEY INFORMATION
   1. Availability of SCS soil survey data

E. MINING OPERATION CHARACTERISTICS
   1. Size of operation
   2. Stage of reclamation (concurrent)
   3. Tillage practices

The 1984 study required the mine site location have the support of several equipment systems. Since the report interacts with data in the 1982 and 1984 study, it is important to note that site selection criteria differ in research goals. These distinctions are:

- **The 1982 study was applied to different equipment combinations on different mine sites.**
- **The 1984 study was applied to different equipment combinations on the same mine site and in addition an analysis was applied to predict soil density following reclamation.**

The major site selection factors in both studies were equipment use, reclamation methods, basic soil characteristics and company cooperation.

## Study Site Locations and Descriptions

Data collected for use in this study was obtained from four study sites in the Midwest. These sites were each visited prior to field work to assess their suitability for data collection procedures. The final study sites were scattered throughout the Midwest and each displayed different types of soil movement methods (See Table 2). The 1984 study was performed totally on the Captain Mine in Southern Illinois. Study site locations are shown in Figure 5.

**TABLE 2. STUDY SITE PRELIMINARY DESCRIPTION**

| MINE NAME | MINE OWNERSHIP | LOCATION | SOIL MOVEMENT EQUIPMENT COMBINATIONS |
|---|---|---|---|
| Brazil Mine | Brazil Coal<br>and Clay | Indiana | Scrapers<br>Small Shovel<br>50 Ton End-Dump<br>Trucks<br>Bulldozer |
| Captain Mine | Arch ofIllinois<br>Illinois, Inc. | Scrapers<br>Bucket-Wheel | Excavators<br>Conveyors<br>Spreaders<br>Bulldozers |
| Delta Mine | AMAX | Illinois | Scrapers<br>Dragline<br>Small Dragline<br>Bulldozers |
| Power Mine | Peabody Coal | Missouri | Scrapers<br>Bulldozers |

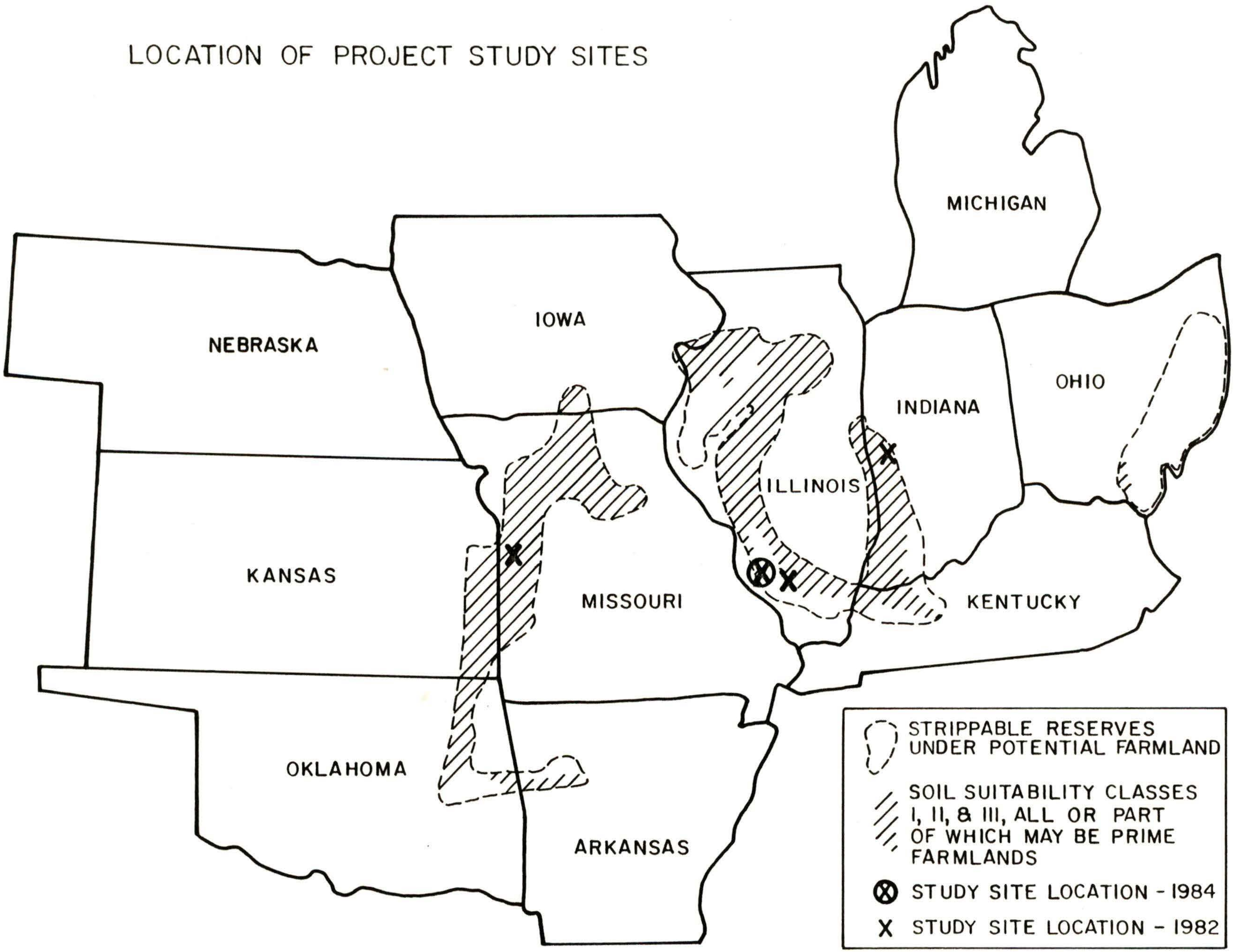

FIGURE 5. Location of Project Study Sites

## Project Objectives and Applications

This companion study focuses on the equipment impact on the subsoil horizons directly below where the topsoil is replaced primarily by scrapers. In reclaimed soils the previous research indicates that the topsoils can be returned to densities equal to natural soils through tillage. The major problem involving machine-induced compaction lies in the subsoil regions where remedial measures to relieve compaction are limited by physical location.

This study is designed to evaluate the effects of four (4) different equipment systems as they relate to the soil compaction problem. A unique portion of the study evaluates the effect of soil replacement by lift with scraper, focusing on a lift by lift analysis as well as an evaluation of lift by pass. In addition, a field evaluation was performed to evaluate changes in density over time due to natural factors (i.e. freeze/thaw). In summary the primary objectives of the study are:

- **Evaluate three soil replacement systems on the same soil types as they relate to the density of reclaimed subsoils.**
- **Evaluate subsoil replacement by lift using scrapers in a unique field study.**
- **Present and evaluate data collected in the 1982 Bureau of Mines study,"Impact of Surface Mining on Soil Compaction in the Midwest," for use in building a data base for predicting subsoil compaction.**
- **Formulate a model for predicting bulk density on reclaimed prime farmland subsoils.**
- **Perform a cost analysis of the three soil replacement systems and associated remedial measures.**
- **Present all findings in a useful, informative final report.**

This research study is designed to evaluate the subsoil compaction problem on a practical level with experiments performed in the course of actual mining activities. The conclusions and findings of this study are directly applicable to the management and reclamation of prime farmland soils in the Midwest. This report builds on current information and data on soil compaction and presents this information in a practical manner to help alleviate the problem. The total data base of information collected is combined to develop a predictive tool for evaluation of the impact of equipment traffic on the density of reclaimed prime farmland subsoils. This research effort adds to the current research base and creates a firm foundation for future research.

# EXPERIMENT DESIGN AND SOIL SAMPLING PROGRAM

## Overview

The design objective incorporates several research goals into one unique and comprehensive research experiment. The focus of the experimental design is to identify machine-induced compaction which occurs in the subsoil regions of reclaimed soils in prime farmland areas of the Midwest. Incorporated into the experimental design and soil sampling program are features of the experiment which indicate the effectiveness of current reclamation practices. These current reclamation practices are designed to reduce soil compaction either by equipment usage or by soil handling technique.

The interaction between the 1982 study and the 1984 study is important to overall project goals. The experiment design overlaps the 1982 Bureau of Mines study (Albrecht, 1982) to provide a large data base of soil compaction information. Use of the same sampling procedures for both studies allows for building this large data base of soil density data. This data base provides a foundation for study of compacted topsoil and subsoil regions and also for development of a method for predicting subsoil compaction. The soil compaction prediction analysis utilizes bulk density and texture data from both studies to develop a valid model.

Distinct differences between the experiment designs of the 1982 and 1984 studies require that separate discussions describe each study.

## Experiment Design - 1984 Study

### Design Rationale

The field study design is centered on the effect of heavy equipment operation on subsoil density in the reclamation process. The identification, in previous research, of topsoil as a material that is relieved of compaction problems through tillage eliminates it from this study. The focus is strictly on factors involved in the compaction of the subsoil region directly below the topsoil in an area approximately 12 to 48 inches from the surface. The current federal law states that the soils must be reclaimed to a depth of 48 inches to create a plant supporting medium for row crop production. For this reason the 48-inch soil depth is used in the current evaluation of subsoil compaction. During the preliminary phases of site selection as described in the previous section, a field study site was sought which would limit the amount of external factors involved in the experiment. By centering on the subsoil and eliminating many external factors which can greatly affect compaction, such as changes in soil type, the evaluation takes on more meaning and consistency within a statistical framework.

The primary design objective for the field study is to characterize the impact of three distinct equipment movement systems on the density of prime farmland subsoils. These systems are the bucket-wheel excavator, end-dump haulback, and scraper pan. This field study is designed to incorporate three equipment movement methods on the same basic soil material found on the Captain mine in Southern Illinois. Currently there are two major soil profile descriptions which result from the use of different prime farmland equipment systems. These systems are:

- **Replacement of the soil in lifts using scraper pans. These lifts are approximately 8 to 16 inches in depth and create a compacted zone at each soil interface in the profile.**
- **Replacement of soil in one deep lift utilizing end-dump haulback method or bucket-wheel excavator to create a thick lift of approximately 3 feet, and then the subsequent replacement of topsoil creating primarily one dense zone in the upper subsoil region.**

In addition to assessing the impact of different machine combinations on subsoil compaction included in the experiment design is the incorporation of certain equipment practices which can alleviate compaction. One such method is that of windrowing topsoil on the replaced subsoil and spreading that topsoil with a dozer rather than direct replacement with scraper. This limits the amount of traffic on each soil layer.

Included in the analysis of subsoil compaction is a study designed to evaluate the effect of soil replacement by lift using scrapers. This analysis is specifically designed to evaluate the effect of the first lift of soil replacement on the second then subsequently on the third and fourth lifts to a depth of approximately 4 feet. There is speculation concerning the effects of using scraper pans in soil replacement in 8-to 16-inch lifts compared to replacing one single lift of approximately 3 feet. The analysis of scraper compaction by lift will ultimately give insight into just how much affect the third and fourth lifts of soil replacement have on the first and second lifts. In contrast, does soil compaction occur to its total extent in each individual lift where there is no affect of lift by pass of equipment? The overall design rationale is to evaluate the subsoil compaction problem under actual field conditions. Goals and objectives are reflected in the following practical field application of the Experiment Design.

## Experiment Design

The total experiment is designed to provide the most comprehensive evaluation of the subsoil compaction problem under the constraints of the project objectives.

### Bucket-Wheel and Scraper Analysis

The basic premise in the design of this study is to evaluate the three equipment systems on one mine site under practical field conditions on homogeneous soil types. The three equipment systems for evaluation are the bucket-wheel excavator, end-dump haulback, and scraper pans. A field test site was sought through an extensive search of nine different mining operations in the Midwest evaluating soil characteristics and machine reclamation method for selecting the most suitable test area. After many discussions with mining personnel the Captain mine is selected as the study site due to the variety of equipment available for use in test plot development and plot construction.

The field evaluation centers on three major types of analysis. The first analysis involves the comparison of natural soils in the project area to reclaimed soils utilizing the three different equipment systems mentioned above. These equipment systems are tested based on bulk density values by core method and texture analysis. Since data had previously been collected on natural soil areas, the only testing to be completed was that of test plot layout for reclaimed soils. Natural soil data was used from the 1982 study collected on the same mine site.

In the course of the field study a problem arose which stopped testing of end-dump haulback plots on the Captain Mine. During plot construction several pieces of equipment are pulled off regular duties in actual reclamation. While constructing the end-dump haulback plots the actual reclamation activities on the mine fell behind schedule. This action resulted in a need for the equipment currently building test plots back on the active mining. The pre-winter reclamation activities on the mine required that the equipment be moved back into mine reclamation activities. Since it was not possible to reschedule the equipment for our use, haulback plot construction stopped.

Data which is collected on end-dump haulback plots is included in the the 1982 General Data section to represent the end-dump haulback method. The loss of the end-dump plots is not essential to overall study results because the major equipment soil movement techniques are tested with the scraper and bucket-wheel analysis.

The two natural soil test plots are located on the two dominant prime farmland series. These natural soil test plots are used as a baseline for comparison with reclaimed areas. The determination of the major prime farmland series and location is based on the intensive study of soil maps from the Soil Conservation Service (SCS) or private soil maps supplied by the mining companies. To identify all soil series that are included in reclaimed soil mixtures is an economically unfeasible task and entirely out of the scope of this study. This fact dictates that field testing is limited to the two major soil series. The two series selected for testing are excellent representations of the range of soil characteristics in the area between natural and replaced soils. Natural soil field data presented for comparison to reclaimed soil test plots is data collected in the 1982 study to provide a natural soil baseline.

On the two major natural soil series two plots are located, one on each natural soil series, and two plots are placed on the reclaimed soils (Plot layout shown in Figure 6). The dimensions of each plot are 25 feet by 100 feet and efforts are made to stay within the natural soil series boundaries. A soil map of soil boundary delineations is prepared utilizing SCS standard soil mapping procedures. The replaced soils are composed of a mixture of the two natural soil

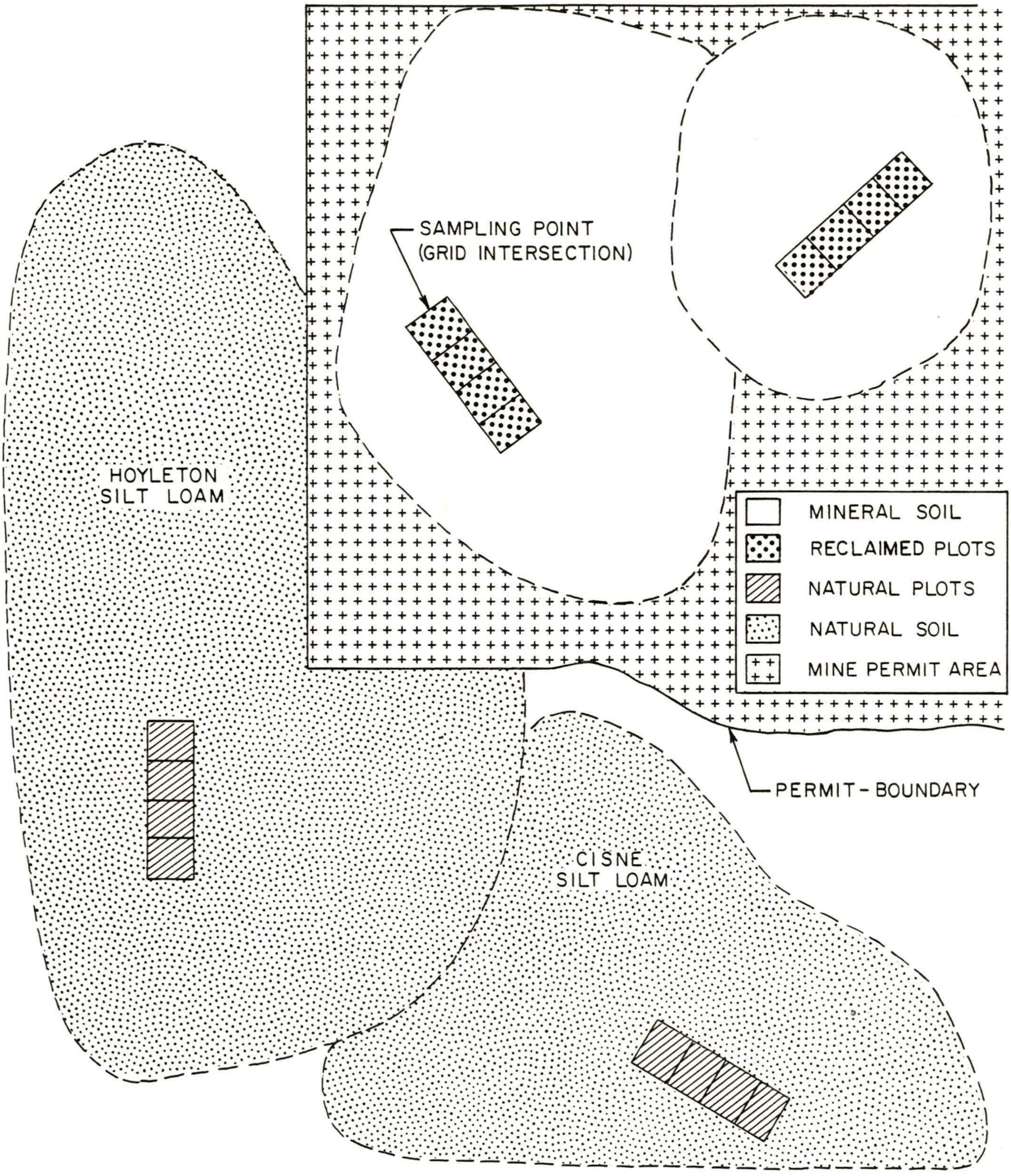

FIGURE 6. Example Plot Layout for Comparison of Natural and Replaced Soils for 1982 and 1984 Studies

series tested along with associated mapping units. Work is performed closely with the mining company to coordinate areas of replacement with areas of reclaimed plot location.

In each plot, 3-inch core samples are pulled to a depth of 48 inches every 10 feet around the plot perimeter. Each core provides three samples of approximate equal size for a bulk density analysis. This determination is needed to characterize density changes with depth in the natural and replaced soil material. Areas which are severely compacted within the profile are tested to determine the maximum compaction by heavy equipment.

Since compaction is created by scraper pan activity in the replacement of topsoil material, the location of samples within the soil core is determined by the amount of compaction visually evident in the core. Compacted zones within the soil profile are clearly evident in the core and create their own distinct separation between equipment soil placement interfaces. Three to four soil core samples were pulled from each location to accurately describe location of compacted zones in the profile. In addition to bulk density testing in each core sample, texture classification would be run on each individual soil core. This allows the direct analytical connection between soil compaction and soil texture through bulk density determination.

## Scraper Analysis by Lift

The second experiment design involves the construction of a test plot utilizing scraper pans replacing soil to a depth of 4 feet. To accomplish testing the impact of scrapers on a lift by lift basis, two windrows are constructed of homogeneous soil type. These windrows are tested with each lift of soil replaced. For example, two scraper pans removing rooting medium material from the same stockpile building one lift of soil in a 200-foot long windrow. Plot layout shown in Figure 7. Following the replacement of this 1-foot lift, 10 core samples are pulled at 20-foot intervals along the length of the windrow. After testing, the scraper pans replace a second lift over the previous lift. Following replacement of the second lift, the test crew came onto the site pulling ten cores from the same general positions not only from the second lift but also from the lift directly below to ascertain changes due to equipment and weight of lift. This procedure is continued until four lifts of soil are replaced to a depth of 4 feet. Each lift is tested before the next lift is replaced in both the top lift and the lifts directly below.

After field testing, a picture is portrayed of the affect of lift and pass on the scraper induced density. The construction of a windrow 200 feet long by approximately 30 feet wide is the most cost effective method to construct the scraper plot from an equipment utilization standpoint. This construction of a long plot rather than a square plot had no effect on the subsequent statistical analysis applied to the data. This experiment design duplicates direct replacement of subsoil material in the field during practical mine operations. Thus the resulting data reflects accurately the equipment compaction of scrapers by lift.

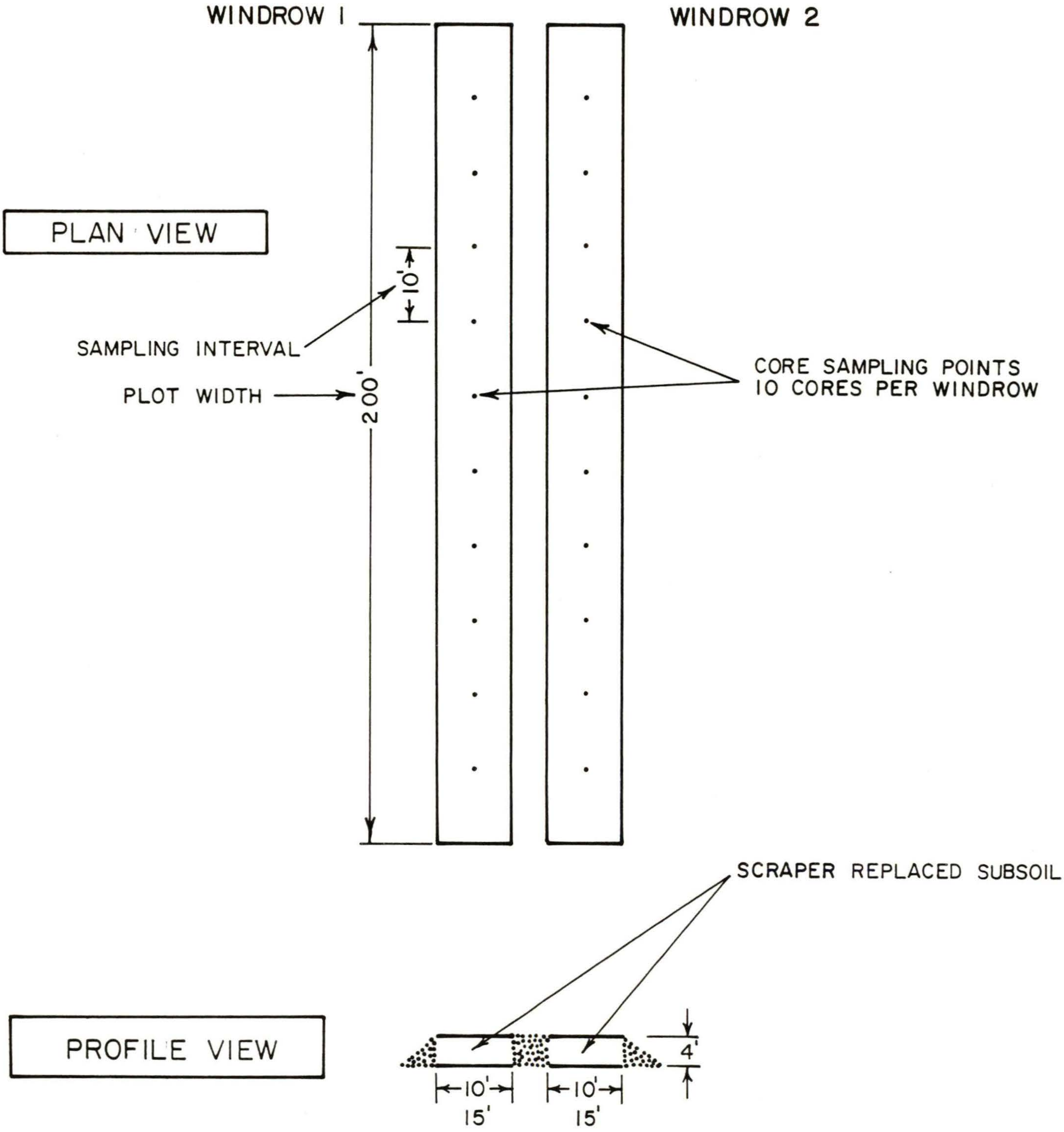

FIGURE 7. Plot Layout for Scraper Analysis of Soil Replacement by Lift

### Special Data Evaluation

A special data evaluation is provided to evaluate the changes in density over time. The changes in density over time is evaluated by testing a plot previously tested in the 1982 Bureau of Mines study and retested in 1983 to evaluate changes in density due to natural factors. This portion of the study gives indication of soil changes over time. In this special data evaluation an analysis is also made on "soil windrowing" through field data manipulation.

### Soil Compaction Prediction Analysis

The relationship between bulk density and texture as defined in the 1982 study has a significant influence on a soil's compactability. The relationship between texture and density is explored in the soil compaction prediction analysis. The prediction analysis is based on both 1982 and 1984 data and encompasses the cumulative soil data base on bulk density and texture from six individual field studies. From a research perspective the experiment design recognizes the difficulty in testing all factors which affect soil compaction, but the attempt is made to test the most influential factors as identified in the field studies as well as those identified by other researchers. The solid fraction of the soils composition or primarily texture is found to have a strong influence on density. The 1982 study data is presented solely to provide a complete data base of soil information for inclusion in the soil compaction prediction analysis.

### Design Summary

The overall design of the experiment is keyed to the very practical aspects of mining with no outside control given to sample location or plot selection due to technical bias. The reasoning behind this commitment to achieving actual soil conditions is to provide a clear analysis of actual field conditions on reclaimed prime farmland soils. With this base of information, conclusions are drawn on the causes and effects of machine-induced subsoil compaction.

The coupling of the 1982 study with the 1984 study allows an experiment design which is very cost effective yet provides a very large data base of information on which to evaluate soil compaction and to formulate relevant and practical solutions and design tools. The soil prediction analysis in Section 6 uses the large data base of texture and bulk density values to formulate a powerful tool for soil compaction prediction. The final project result combines all data summaries and case studies into a useful tool, the soil compaction prediction analysis.

## Experiment Design - 1982 Study

### Design Rationale

The primary design objective was to characterize the impact of soil compaction on a broad range of prime farmland soils. Although a limited amount of data has been collected on soil characteristics following reclamation, no real data base of information exists on a broad scale for soil characteristics. This experiment was designed to cover a broad base of soil material in the Midwest and to evaluate four different equipment systems with respect to soil density.

The inclusion of the 1982 data summaries and case studies in this study to evaluate subsoil compaction was to provide a larger base of soil information for use in the soil compaction prediction analysis. The inclusion of the 1982 data is solely for use in the prediction analysis.

## Experiment Design

In order to assess the impact of different types of machinery on soil characteristics, the types of machinery being utilized in surface mining in the Midwest had to be identified. This identification was made through personal contact with the mining companies and verification of the four major soil movement methods being utilized at the time. After many discussions with mining personnel, four different types of machinery were identified and locations for machinery application were selected. These four machine methods were: (1) bucket-wheel excavator, (2) end-dump haulback, (3) dragline and (4) scraper pan. The method of movement of the subsoil material or rooting medium was of primary concern. Scrapers are used exclusively in the Midwest for moving topsoil material due to their sensitivity to depth and their cost-effectiveness.

From a soil standpoint, the decision was made to locate the two major prime farmland series on each of the mine sites. This determination was based primarily on the study of soil maps obtained from the Soil Conservation Service or the mining companies. Identification of all series soils would have been an insurmountable task and entirely out of the scope of this study, so field testing was limited to the two major series. The two series were estimated to provide an excellent representation of changing soil characteristics between natural soil material and soils replaced after mining. On these two major soils series, two plots would be placed on the natural soils, one on each series, and two plots on the replaced soils (Figure 6). The dimensions of each plot were to be 100 feet by 400 feet and efforts would be made to stay within the soil series boundary in the natural soils. The replaced soils were to be composed primarily of a mixture of the two natural soils series tested. Three-inch core samples would be pulled to a depth of 48 inches every 100 feet around the perimeter of each plot. Each core would provide three samples of approximate equal size for a bulk density determination. This determination was needed to characterize density changes with depth in the natural and replaced soil material. Severely compacted areas within the profile of the replaced soil would also be tested to determine the maximum compaction created by the operation of heavy equipment on prime farmland. Since compaction was believed to be created by scraper pan activity in the replacement of the topsoil material, the second sample in each core would be placed in the layer directly affected by this pan compaction.

The scope of the testing program was extended from the initial bulk density testing to include texture determinations with depth within each plot. The texture information would be concerned with the changes which may occur in actual soil texture percentages between the natural and replaced soils.

Overall, the program design recognized that it would be impossible to test for all of the factors which affect soil compaction, but sought to test the most influential factors.

The plot layout design was tested on the first study site for variation within a plot. Duplicate samples were to be taken at each point to determine variability within a testing zone on the 100-foot parameter. The entire experiment was set up on a ten-sample-per-plot basis so that a statistical analysis of multiple regression and Duncan's multiple range could be applied to the data upon completion of the field study. The intent of this project, however, was the determination of major factors such as moisture content, texture and bulk density.

The overall design of the experiment was keyed to the practical aspects of mining, with no outside control being given to sample location or plot selection due to technical bias. The basic reasoning behind this commitment to condition was to actually achieve a clear picture of what is happening in the field on reclaimed prime farmland soils. With this base of information, further studies could be directed toward the solving of other complex problems within the mine reclamation research programs, and results should be more easily achieved.

## Plot Layout

### 1984 Field Study Plot Design

Completion of the field study required that the study plots be laid out according to the design plan. As discussed in the experiment design, two plots were placed on natural soil areas and two plots on reclaimed soils for the comparison of bucket-wheel and scraper. In the scraper by lift analysis emphasis was placed on reclaimed soils for the impact of scrapers on a lift by lift basis. In the evaluation over time study, the same plots that were tested in 1982 were retested in 1984 to illustrate density changes due to natural factors.

Selection of the study sites required careful study of aerial photographs and maps of the natural soils in the mine area. Visual reconnaissance and the use of soil maps was followed by field exploration of soil boundaries in the undisturbed areas and the gathering of all information available on replacement of soils in the reclaimed areas. Particular attention was given to the detection of any problem areas within the reclaimed site that might be unrepresentative of the total reclamation program. For example, some areas were reclaimed in an unusually wet condition but were very site specific and therefore not a widespread problem. These areas were ruled out for sample sites because of their inconsistency and difficulty in evaluation of results.

Soil maps of the areas in which the testing was accomplished were generally accurate. However in order to determine the exact soil boundaries, cores were taken to confirm that the plot was within the series boundaries. Plots on natural soil areas were located on the major soil series of the area. This was accomplished to give the best possible overall picture of soil changes between natural and replaced soils.

Following the determination of the accurate soil series boundaries, a 25-by 100-foot plot was established within each natural soil series. In the soil test plots at 10-foot intervals around the perimeter of the plot, ten stakes were placed to mark individual core sampling points. A sample plot layout is illustrated in Figure 6. This procedure was followed in the establishment of all plots on the Captain mine.

The change in the plot size between the 1982 and 1984 studies caused no statistical problem in the evaluation of the data. Any plot over 25 feet in length could be used owing to individual soil plot variation over wide areas. Smaller plot sizes were tested because less soil movement was required by the mining company. Plots were placed on major natural soil series to give the best representation of soil characteristics.

The plot layout for the scraper analysis by lift was totally different from the previous plot layout concepts. An Example Plot layout is shown in Figure 7. The plot layout for the evaluation of scraper effect on each lift of soil replaced was designed for efficient use of equipment. To achieve speed of plot construction two windrows were constructed 200 feet in length rather than building a standard rectangular plot. Sampling locations were detailed in the design plan.

### 1982 Field Study Plot Design

Preliminary procedures for location of plot sites were the same for both 1982 and 1984 studies. After the location of plot sites and soil series boundaries, 400-by 100-foot plots were established on both natural and replaced soils. Example plot layout is shown in Figure 7. At 100-foot intervals around the perimeter of the plot stakes were placed to mark individual sampling points. Two plots were placed on natural soils and two on replaced just as stated in the design plan. This plot layout procedure was followed on all four of the mine sites tested.

## Sampling Procedures

Sampling equipment used for all core removal was by Giddings Soil Probe. This piece of equipment is specifically designed for soil sample collection whether for rotary drilling or core removal. The drill is mounted on the rear of a 3/4-ton pickup for optimum on-site maneuverability and ease of access to remote areas (Figure 8).

For the purposes of this study, the soil drill was used to remove 3-inch diameter core to depths up to 80 inches. Primarily the core tube was pressed to a depth of 48 inches as specified by the prime farmland soil reconstruction regulations. Before beginning the sampling program, cores were pulled from the reclaimed soils to determine the position of the compacted zones. Depth of sampling in both natural and reclaimed soils was governed by their initial sampling. Depth of compacted zones determined sample location in the core. The goal of sample location was to sample zones of the maximum compaction in reclaimed soils and correlate this to the sample depth in natural soils. Before each

FIGURE 8. Giddings Soil Probe Sampling Natural Soils on the Captain Mine

sample was removed from the 3-inch core, its depth from the surface was recorded for future use in data analysis.

From each 3-inch core, up to four samples were cut approximately 4.5 inches in length. Pieces of PVC pipe were cut to length and split up the side so that cores could be trimmed to length without disturbing the soil structure and soil core dimensions. Placing the core into the pipe more evenly distributed the force of the hand grip on the core surface area and thus provided an easier cut for the sampling team. Examples of cores are shown in Figure 9.

Core samples were cut to size and measured in the field with a vernier caliper. Three measurements were recorded for both the length and diameter of each core to determine volume and later calculate bulk density. Core lengths were determined by averaging three measurements taken at 120 degree intervals around the core circumference. Three random measurements were also made from the core diameter. After all core measurements were made, the samples were bagged, labeled and transported to the Kenwill laboratory for testing.

One of the major problems associated with core sampling is sample compression. To limit the amount of compression, slotted sample tubes were used to allow careful observation of each core during sampling. If the soil surface within the tube was lower than the actual soil surface, compression was occurring and another core was removed. Soil moisture contents were low during the sampling period, as a result very little problem arose with sample compression within the sample tube.

## Sample Analysis

All sample analyses were performed by the Kenwill laboratory in Maryville, Tennessee. Detailed outlines of sample analysis procedures are found in Appendix D. In each study plot ten cores were pulled and analyzed for bulk density and texture.

A bulk density determination was made for each sample collected. A fourth sample was collected below the 48-inch depth in several natural soil plots for the determination of soil density increase with depth in natural soils. A total of over 800 bulk density determinations were made from the field samples collected in both the 1982 and 1984 study.

Texture determinations were made on odd numbered cores in the study plots for the subsoil samples. Bulk density and texture analyses were performed on the same core sample. All of the topsoil samples were evaluated for texture in the 1982 study. The total texture determinations required over 350 individual tests each correlated exactly to a different bulk density. Correlation of bulk density and texture infers that the core sample is split and analyzed, thus matching a bulk density and texture value. Soil variability requires that this split core analysis and correlation be performed in the lab.

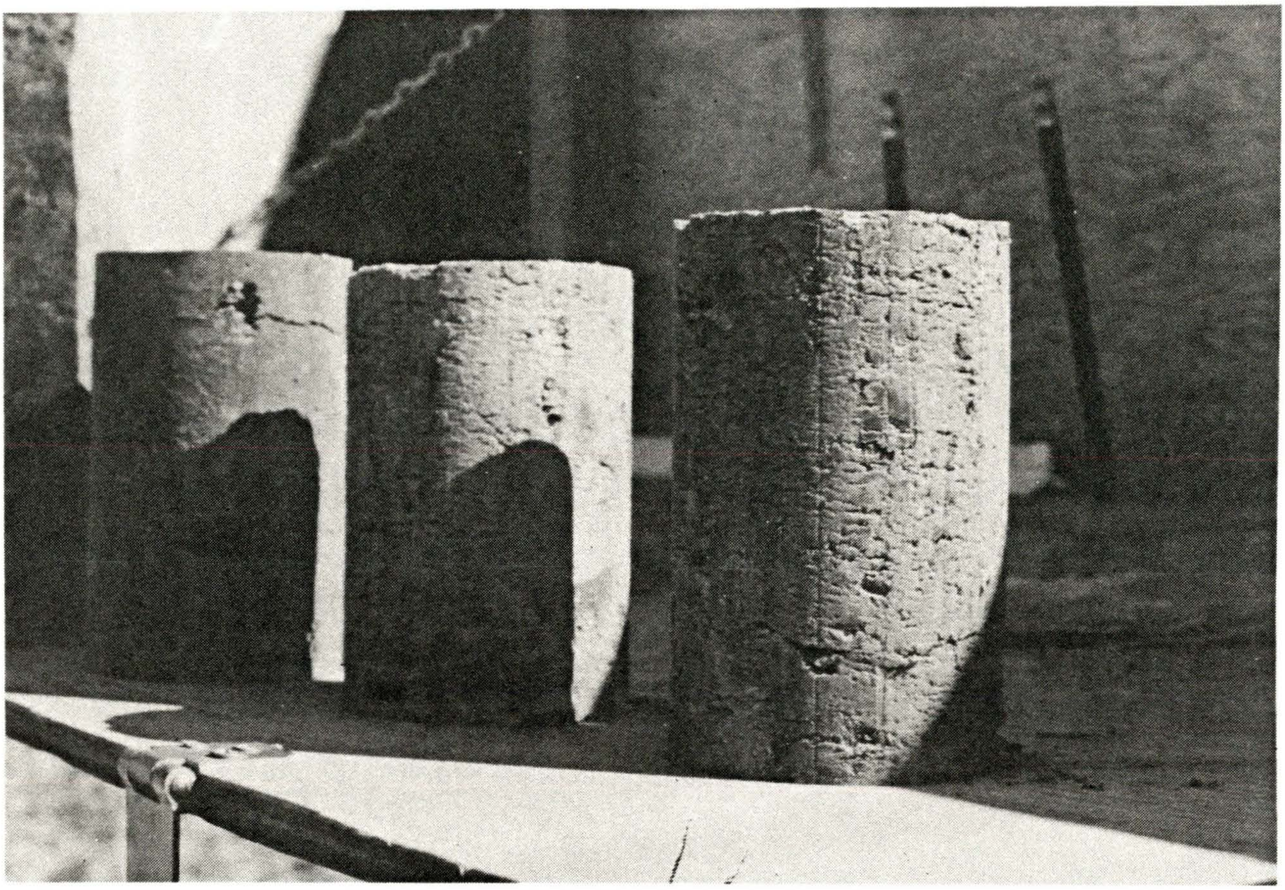

FIGURE 9. Cut Core Samples for Topsoil (right) and Upper and Lower Subsoil (center and left)

# CASE STUDIES OF PROJECT SITES

## Case Study Content

In order to provide a complete summary of individual mine case studies, all mining operations utilized in both the 1984 and 1982 study sites are summarized in the case studies section. The major reason for the inclusion of all mine study sites is the incorporation of data from each mine site into the bulk density prediction analysis discussed in Section 6. The 1982 field study was designed to evaluate soil compaction in a broad spectrum, and the mine study sites utilized were the Brazil Coal and Clay, Captain Mine, Delta Mine and Power Mine. These case studies will correlate later in this report with the 1982 General Data Summaries analysis.

The 1984 research study concentrated on the Captain mine in Southern Illinois, and although the case studies of the 1982 and 1984 studies are similar in some respects, a special case study is provided for each analysis. All mine sites are included in the case study format to provide a clear picture of the overall data base used for data analysis and conclusions.

## Case Study Format

A case study is provided for each of the four surface mines involved to provide necessary background material for a research base. For each of the four study sites in the 1982 and the 1984 studies, the following information is provided:

- **General Mine Description,**
- **Soil Series Descriptions and Maps,**
- **Equipment Combinations for Plot Development or On-site Soil Movement,**
- **Reclamation Program and**
- **Soil Study Plot Location and Aerial Site Maps.**

From on-site field reconnaissance, information was compiled from mining company data, SCS soil survey data and aerial photography of the project sites to provide a base of information on which to design and analyze study results. Review of this section should provide a clear understanding of soil factors and how they relate to individual mining characteristics, such as equipment and reclamation practices.

The Soil Conservation Service was helpful in collecting soil series information and soil maps of the permit areas. Information supplied by the mining company was also helpful in correlating soil characteristics from soil surveys to information provided for permit applications from private consultants.

Complete aerial photography of the project sites was also provided by the mining companies.

While on the individual mine sites, a complete set of information was collected on equipment utilization for soil removal and replacement. Observations were made on equipment efficiency and characteristics of changes in soils from an equipment standpoint. Data reported in this study on depth of soil removal and replacement, equipment usage and time motion studies were collected by the field team during the data collection portion of the study.

As much information as possible was collected on reclamation methods used in replacement of soils and remedial measures implemented following soil replacement. This included data relative to tillage practices, fertilization rates and crop yields where available. The following information has been presented to provide a baseline when correlating actual data collected to the individual mine site characteristics.

## Case Studies - 1984 Field Studies

The 1984 field study was conducted entirely on the Captain mine in Southern Illinois. This mine was selected due to its use in the previous field study as outlined in a case study earlier in this section. This field study was performed on reclaimed soil plots with natural soil data established during the 1982 study used as a baseline for purposes of comparison.

### General Mine Description

The permit area consists of 18 square miles of two to five percent slopes, much of which is prime farmland. The topography of the recently reclaimed land closely resembles that of the natural landscape, with the exception of the final cut lake remaining near the sampled area.

### Soil Series Descriptions and Maps

The soil survey report provided by the Southwestern Illinois Coal Company indicates the series on the Captain mine to be: Alford, Ava-Hickory, Ava, Banlic, Bluford, Belknap, Blair, Bonnie, Cisne, Damstadt, Hickory, Hosmer, Hoyleton, Huey, Racoon, Richview, Stoy, Tamalco, Weir, Wynoose, and Wakeland. Many of these series are considered to be prime farmland soils. The Cisne and Hoyleton are the dominant series and are chosen for sampling because of their proximity to the soil removal area. Location of natural soil test plots C-3 and C-4 are shown in Figure 10.

#### Hoyleton Series

The Hoyleton series consists of somewhat poorly drained soils that have 0 to 5 percent slopes on uplands. They have a very dark grayish-brown silt loam surface layer and a yellowish-brown silt loam subsurface layer. The subsoil is

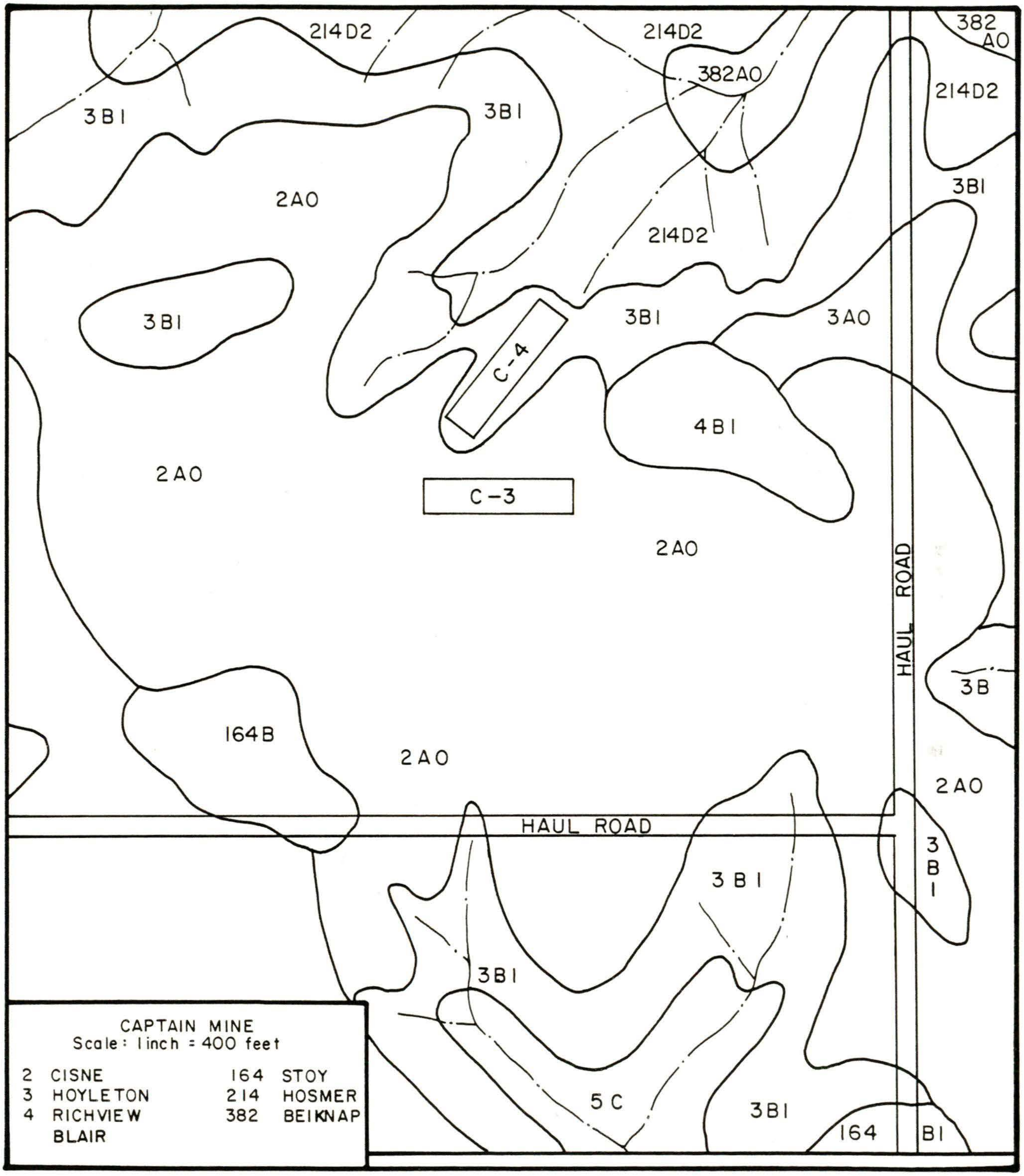

FIGURE 10. Natural Soil Map Illustrating Positions of Natural Soil Test Plots on the Captain Mine

brown to pale brown silty clay loam mottled with red, grayish-brown, and yellowish-brown in the upper part. The lower part is light yellowish-brown and brownish-gray silty clay loam and clay loam.

The underlying material is loam to clay loam. Hoyleton soils have a low organic matter content, slow to moderately slow permeability in the subsoil, and a high available water capacity. Surface runoff is slow to medium.

The Hoyleton series is a fine, montmorillonitic, mesic Aquollic Hapludalf. Hoyleton soils typically have very dark grayish-brown silt loam Ap horizons, yellowish-brown silt loam A2 horizons, brown and yellowish-brown mottled heavy silty clay loam upper B horizons and light brownish-gray and pale brown mottled clay loam or loam lower IIB horizons.

## Cisne Series

The Cisne series consists of poorly drained soils that have less than 2 percent slopes on uplands. They have a very dark grayish-brown silty clay loam surface layer. The subsurface is grayish-brown silty clay loam mottled with brown and yellowish-brown. The underlying material is dark grayish-brown silt loam, loam, or clay loam mottled with gray. Cisne soils have a moderate organic matter content in the surface layer, very slow to slow permeability in the subsoil, with high available water capacity. Surface runoff is slow.

The Cisne series is a fine, montmorillonitic, mesic Mollic Albaqualf. Cisne soils have a very dark grayish-brown silt loam Ap horizons, grayish-brown and light gray silty A2 horizons, mottled grayish-brown heavy silty clay loam B2 horizons, mottled light brownish-gray silty clay loam B3 horizons and dark grayish-brown silt loam C horizons at depths of about 60 inches.

## Soil Profile Descriptions

### Hoyleton Series

Ap--0 to 7 inches, very dark grayish-brown (10YR 3/2) silt loam; weak fine granular structure; friable; very strongly acid; abrupt smooth boundary. (6 to 9 inches thick)

A2--7 to 12 inches, yellowish-brown (10YR 5/4) silt loam; weak fine platy structure; friable; very strongly acid; clear smooth boundary. (4 to 12 inches thick)

B21t--12 to 18 inches, brown (10YR 5/3) heavy silty clay loam; common medium prominent red (2.5YR 4/6), common medium distinct yellowish-brown (10YR 5/8), and few fine faint grayish-brown (10YR 5/2) mottles; moderate medium prismatic structure parting to moderate medium angular blocky; firm, some thin discontinuous dark grayish-brown (10YR 4/2) clay films and when dry some light brownish-gray (10YR 6/2) silt coatings; few small very dark brown (10YR 2/2) concretions (Fe-Mn oxides); very strongly acid; clear smooth boundary. (5 to 12 thick)

B22--18 to 25 inches, pale brown (10YR 6/3) heavy silty clay loam; few medium prominent red (2.5YR 4/6), few fine faint grayish-brown (10YR 5/2), and many medium distinct yellowish-brown (10YR 5/8) mottles; moderate medium prismatic structure parting to moderate medium angular blocky; firm; moderately thick continuous grayish-brown (10YR 5/2) clay films; few small very dark brown (10YR 2/2) concretions (Fe-Mn oxides); very strongly acid; clear smooth boundary. (4 to 12 inches thick)

B23t--25 to 31 inches, light yellowish-brown (10YR 6/4) heavy silty clay loam; many medium distinct yellowish-brown (10YR 5/8) and common medium distinct light brownish-gray (10YR 6/2) mottles; moderate medium and coarse angular blocky structure; firm; moderately thick continuous grayish-brown (10YR 5/2) clay films; few small very dark brown (10YR 2/2) concretions (Fe-Mn oxides); strongly acid; clear smooth boundary (5 to 10 inches thick)

B31t--31 to 38 inches, light yellowish-brown (10YR 6/4) light silty clay loam; many medium faint light brownish-gray (10YR 6/2) and many coarse distinct yellowish-brown (10YR 5/8) mottles; moderate medium and coarse angular blocky structure; firm; thin discontinuous grayish-brown (10YR 5/2) clay films; few small very dark brown (10YR 2/2) concretions (Fe-Mn oxides); medium acid; clear smooth boundary. (0 to 15 inches thick)

IIB32t--38 to 45 inches, light brownish-gray (10YR 6/2) light clay loam; many coarse distinct dark yellowish-brown (10YR 4/4) and few coarse blocky structures: firm, few small very dark brown (10YR 2/2) concretions (Fe-Mn oxides); few pebbles; slightly acid; gradual smooth boundary. (6 to 25 inches thick)

IIB33--45 to 60 inches, pale brown (10YR 6/3) loam; common medium faint light brownish-gray (10YR 6/2) and few coarse distinct yellowish-brown (10YR 5/8) mottles; weak coarse angular blocky structure; firm; few pebbles; slightly acid. (0 to 30 inches thick)

Type Location: Shelby County, Illinois; about 4 miles southwest of Stewardson, Illinois, 2162 feet west and 578 feet south of N.E. corner of Sec. 18, T. 9 N., R. 9 E.

Range in Characteristics: Sola range from 40 to over 60 inches in thickness. The solum formed in less than 45 inches of Peoria loess and the underlying sediment at the surface of the Illinoian till. The A2 and B2 horizons range from strongly to extremely acid and the B3 horizons from slightly to strongly acid. The Ap or A1 horizon has 10YR hue, value of 2 or 3, and chroma of 1 or 2. It has weak or moderate, very fine to medium granular structure. The A2 horizon has 10YR hue, value of 4 to 6 and chroma of 3 or 4. It has weak or moderate, very fine to medium platy or granular structure. The B horizon has hue of 10YR or 7.5YR, value of 4 to 6, and chroma of 2 to 6. Mottles in the B horizon commonly have hues of 10YR, values of 4 to 6, and chromas of 1 to 8 and in the upper part of some pedons, the hues are 5YR. The upper part of the B horizon has colors in the matrix, mottle, or coatings on surfaces of peds with chromas of 2 or less. The B2 horizons are silty clay loam or silty clay. The control sections average between

35 and 45 percent clay. The B horizons formed in loess or silty material have weak to strong, fine to coarse, prismatic, angular blocky, or subangular blocky structure. The IIB horizon is silt loam, loam, or clay loam formed in a sediment which consists of the reworked material of the A horizon and locally the upper B horizon of the Sangamon soils, along with pebbles, concentrated by erosion of the Illinoian till and an admixed amount of earliest Wisconsinian loess. This material contains more sand, gravel,and clay and is considerably more weathered than the overlying loess.

**Cisne Series**

Ap--0 to 8 inches, very dark grayish-brown (10YR 3/2) and some gray (10YR 3/1) silt loam; moderate, fine granular structure; friable; medium acid; abrupt smooth boundary. (6 to 9 inches thick)

A21--8 to 13 inches, grayish-brown (10YR 5/2) silt loam; common fine distinct yellowish-brown (10YR 5/8) mottles; weak, medium platy structure; friable; strongly acid; clear smooth boundary. (4 to 6 inches thick)

A22--13 to 17 inches, light gray (10YR 7/2) and some light brownish-gray (10YR 6/2) silt loam; weak, medium platy structure; friable; strongly acid; abrupt smooth boundary. (3 to 6 inches thick)

B1t--17 to 19 inches, gray (10YR 6/1) heavy silt loam common, medium, prominent strong brown (5YR 4/6) mottles; moderate, fine and medium angular blocky structure; friable; thick light gray (10YR 7/1) silt coatings; strongly acid; clear smooth boundary. (1 to 3 inches thick)

B21t--19 to 28 inches, grayish-brown (10YR 5/2) heavy silty clay loam; common medium prominent strong brown (5YR 4/6) mottles; strong, fine prismatic structure parting readily to strong, fine and medium blocky structure; firm; gray (10YR 5/1) clay films; strongly acid; clear smooth boundary. (8 to 12 inches thick)

B22t--28 to 37 inches, grayish-brown (10YR 5/2) heavy silty clay loam; common, medium distinct dark yellowish-brown (10YR 4/4) mottles; moderate, medium blocky structure; firm, few gray (10YR 5/1) clay films; strongly acid; clear smooth boundary. (8 to 12 inches thick)

IIB31t0--37 to 43 inches, light brownish-gray (2.5YR 6/2) heavy silty clay loam; contains some sand; common medium and coarse prominent dark yellowish-brown (10YR 4/4) mottles; weak, coarse blocky structure; firm; few gray (10YR 5/1) clay films; strongly acid; gradual smooth boundary. (4 to 8 inches thick)

IIB32t--43 to 60 inches, light brownish-gray (2.5YR 6/2) silty clay loam; common, coarse prominent dark yellowish-brown (10YR 4/4) mottles; weak coarse blocky structure; firm, some sand in upper part and considerable sand in lower part; medium acid; gradual smooth boundary. (6 to 9 inches thick)

IIC--60 to 70 inches, dark grayish-brown (10YR 4/2) heavy silt loam, many coarse prominent gray mottles; massive; firm; some pebbles; few iron concretions; slightly acid.

Type Location: Jasper County, Illinois; at .2 miles west of Newton at the Newton Experiment Station; 9 feet north and 25 feet east of S.W. corner of plot 309, N.W. 1/4 of N.E. 1/4, Sec. 3, 9. 16 N.R. S.E.

Range in Characteristics: Sola range from 40 to 65 inches in thickness. The lower A2 and upper B horizons are very strongly or strongly acid and the lower B horizons are medium acid. The A1 or Ap horizons have hue of 10YR, value of less than 4, and chromas of 1 or 2. The A2 horizon has value of 5 or 6 in the upper part and 6 or 7 in the lower part and has chroma of 1 or 2.

The matrix of the B horizon has hue of 10YR or 2.5YR, value of 5 or 6, and chroma of 1 or 2. Mottles of strong brown, yellowish-brown, and dark yellowish-brown are common. The upper B horizon is commonly heavy silty clay loam but ranges to light silty clay. The IIB horizon is commonly silty clay loam that contains a noticeable amount of sand but ranges to clay loam. It is formed in reworked material of pebbles concentrated by erosion of the Illinoian till and an admixed amount of earliest Wisconsinian loess. This material contains more sand, gravel, and clay and is considerably more weathered than the Peoria loess. The finest part of the B horizon averages between 35 to 45 percent clay.

The IIC horizon is clay loam, loam, or heavy silt loam, with a noticeable amount of sand and is medium acid or slightly acid.

### Equipment Combinations for Plot Development

The field study sites were selected on the Captain mine to demonstrate the movement of soils using only scrapers to a depth of four feet and to evaluate the bucket-wheel excavator used for rooting medium replacement and scrapers for topsoil replacement to a depth of four feet. In addition, scraper pans were evaluated in a unique experiment to test the effect of repeated lifts in the characteristic practice of soil replacement utilizing scrapers.

Tables 3 and 4 describe equipment combinations and their application in field studies. Table 5 displays equipment involved in the bulk density prediction analysis.

TABLE 3. EQUIPMENT SYSTEM COMPARISONS 1984 STUDY

| EQUIPMENT TYPE | SOIL MOVEMENT APPLICATION | EQUIPMENT MANUFACTURER |
|---|---|---|
| | SCRAPER ANALYSIS | |
| Scraper 651 | Topsoil | Caterpillar |
| Bulldozer | Regrading | Caterpillar |
| Scraper 651 | Subsoil | Caterpillar |
| | BUCKET-WHEEL ANALYSIS | |
| Bucket-Wheel | Subsoil | O & K |
| Beltwagon | Topsoil & Subsoil | O & K |
| Conveyors | Topsoil & Subsoil | Weserhutte |
| Spreaders | Topsoil & Subsoil | Mitsubishi |
| D-7 Bulldozers | Regrading | Caterpillar |
| Scraper 651 | Topsoil | Caterpillar |
| | END-DUMP HAULBACK ANALYSIS | |
| Loader | Subsoil | P & H |
| 50-Ton Truck | Subsoil | Webco or Euclid |
| Scraper | Topsoil | 210 HB Clark |
| Bulldozer | Regrading | D-9 Caterpillar |

Equipment system comparisons for scraper and bucket-wheel plots tested on the same soil types are summarized as follows:

- **On scraper plots topsoil and rooting medium were removed and replaced utilizing scraper pans with all materials used stockpiled for a period of one year.**

- **In the case study of the bucket-wheel excavator plots, the topsoils were removed directly with scrapers and stockpiled on the wheel bench on the production side of the pit. Following stockpiling with scrapers the bucket-wheel excavator was used to transport the topsoil material some four miles with conveyors around the pit and restockpile on the reclamation side of the pit. From that point scrapers were utilized again to move the topsoil to the desired location. Bucket-wheel excavator on wheel bench with subsoil working face in the background is shown in Figure 11.**

TABLE 4. EQUIPMENT UTILIZATION - SCRAPERS BY LIFT

| EQUIPMENT TYPE | SOIL MOVEMENT APPLICATION | EQUIPMENT MANUFACTURER |
|---|---|---|
| Scraper | Topsoil | Terex |
| Scraper | Subsoil | Terex |

TABLE 5. EQUIPMENT INVOLVED IN PREDICTION ANALYSIS

| MINE EQUIPMENT SYSTEM | EQUIPMENT PERCENTAGE |
|---|---|
| Bucket-Wheel System | 100% |
| End-Dump Haulback System | 100% |
| Dragline System | 100% |
| Scraper System | 100% - Except Power Subsoils |

In contrast to direct placement of topsoil with scrapers, the Captain mine employed the windrowing technique in topsoil replacement. This technique utilizes scrapers to build a windrow of topsoil across the rooting medium in rows approximately 200 to 300 feet long and 1.5 times the scrapers' width. Following replacement of this topsoil in windrows a low ground pressure tractor is used to spread the topsoil, thus limiting scraper traffic. Rooting medium below the topsoil was replaced directly using the Mitsubishi spreader. In a concurrent reclamation

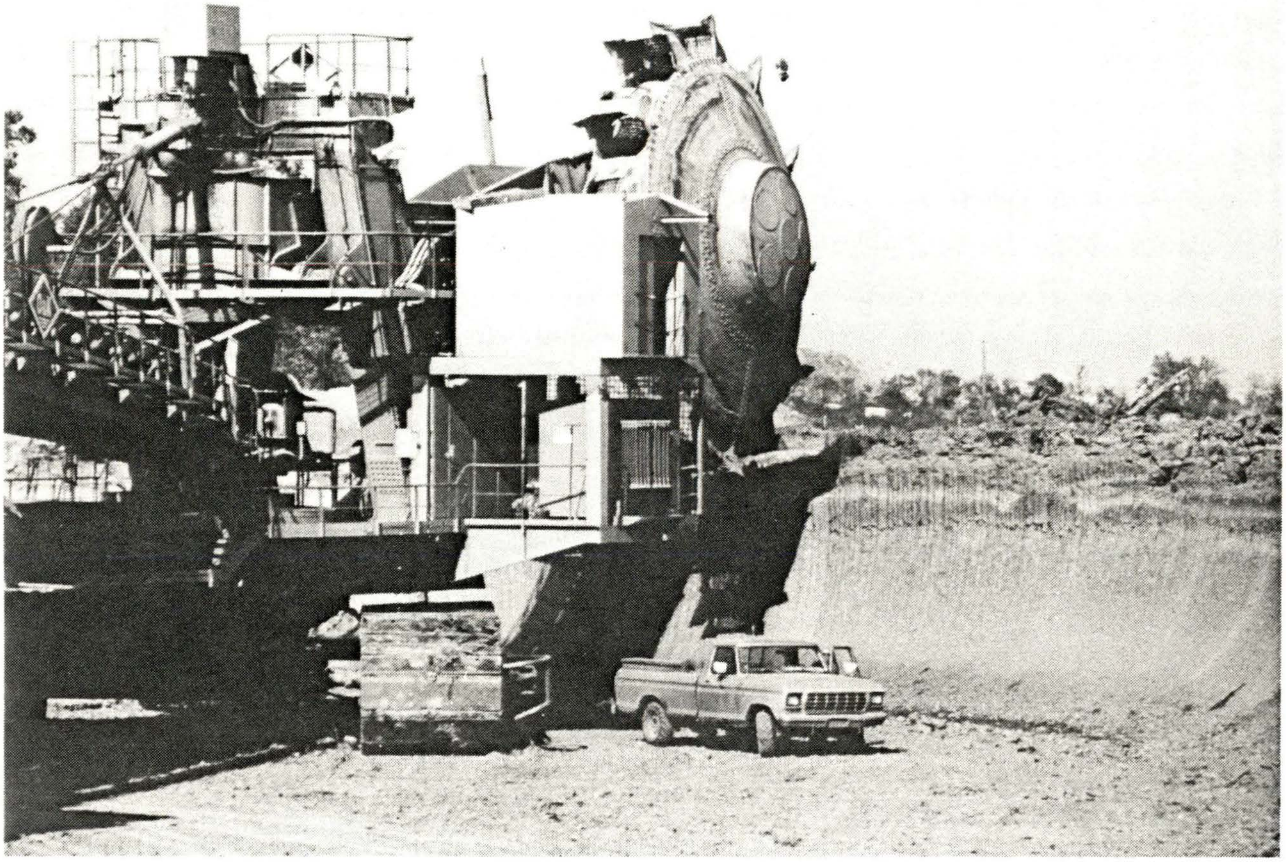

FIGURE 11. Bucket-Wheel Excavator Shown Near Working Face (Subsoil) on the Captain Mine

system the spreader retrieved material from the conveyor system after subsoil removal by the bucket-wheel excavator.

In the scrapers by lift analysis, scraper pans were utilized to construct windrows much as they would under normal soil replacement conditions. The purpose of creating a long windrow was to evaluate the impact of scrapers by soil lift. Scraper pans were used to deposit lifts of material into a study plot which was 4 feet in depth, approximately 35 to 40 feet in width and 200 feet long. Plot construction activities with 12 inches of soil in the windrow is shown in Figure 12. The compaction prediction analysis will be discussed in more detail in Section 6.

### Reclamation Program

No actual reclamation practices were used to alleviate subsoil compaction in the plot areas tested. The only reclamation practices occurred in the topsoil areas and consisted of general tillage for seedbed preparation. All topsoil and subsoil plot material, except for direct replacement of rooting medium in the bucket-wheel excavator plots was stockpiled for a period of approximately one year.

### Soil Study Plot Location

Identification of study plot locations on subsequent maps will carry the same delineation throughout the report to provide clarity in overall data evaluation. On this mine site in the 1984 study only reclaimed areas were utilized for plot construction and testing. Natural soil test plots sampled in the 1982 study were used as a baseline for comparisons of equipment systems in 1984. These natural soil test plot locations are presented in line drawings of aerial photographs in Figure 13. The plot identification numbers as well as soil area identification and equipment type are presented in Table 6.

**TABLE 6. STUDY PLOT IDENTIFICATION - 1984 STUDY**

| PLOT NO. | SOIL AREA IDENTIFICATION | EQUIPMENT TYPE |
|---|---|---|
| W-1 | Reclaimed | Bucket-Wheel |
| W-2 | Reclaimed | Bucket-Wheel |
| S-1 | Reclaimed | Scraper |
| S-2 | Reclaimed | Scraper |
| O-1 | Reclaimed | Bucket-Wheel |
| C-3 | Natural | Agricultural |
| C-4 | Natural | Agricultural |

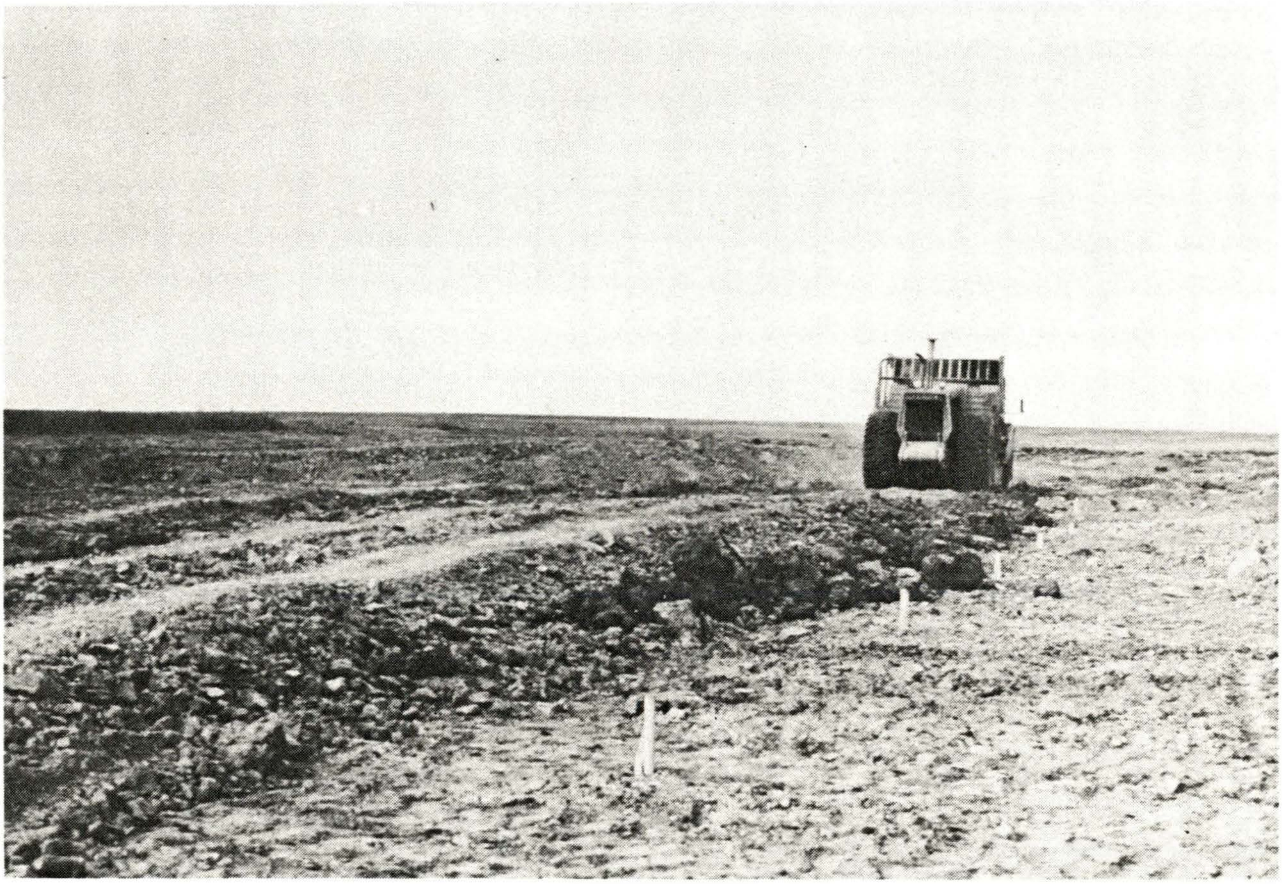

**FIGURE 12. Construction of Windrow Test Plot with the First Lift Replaced**

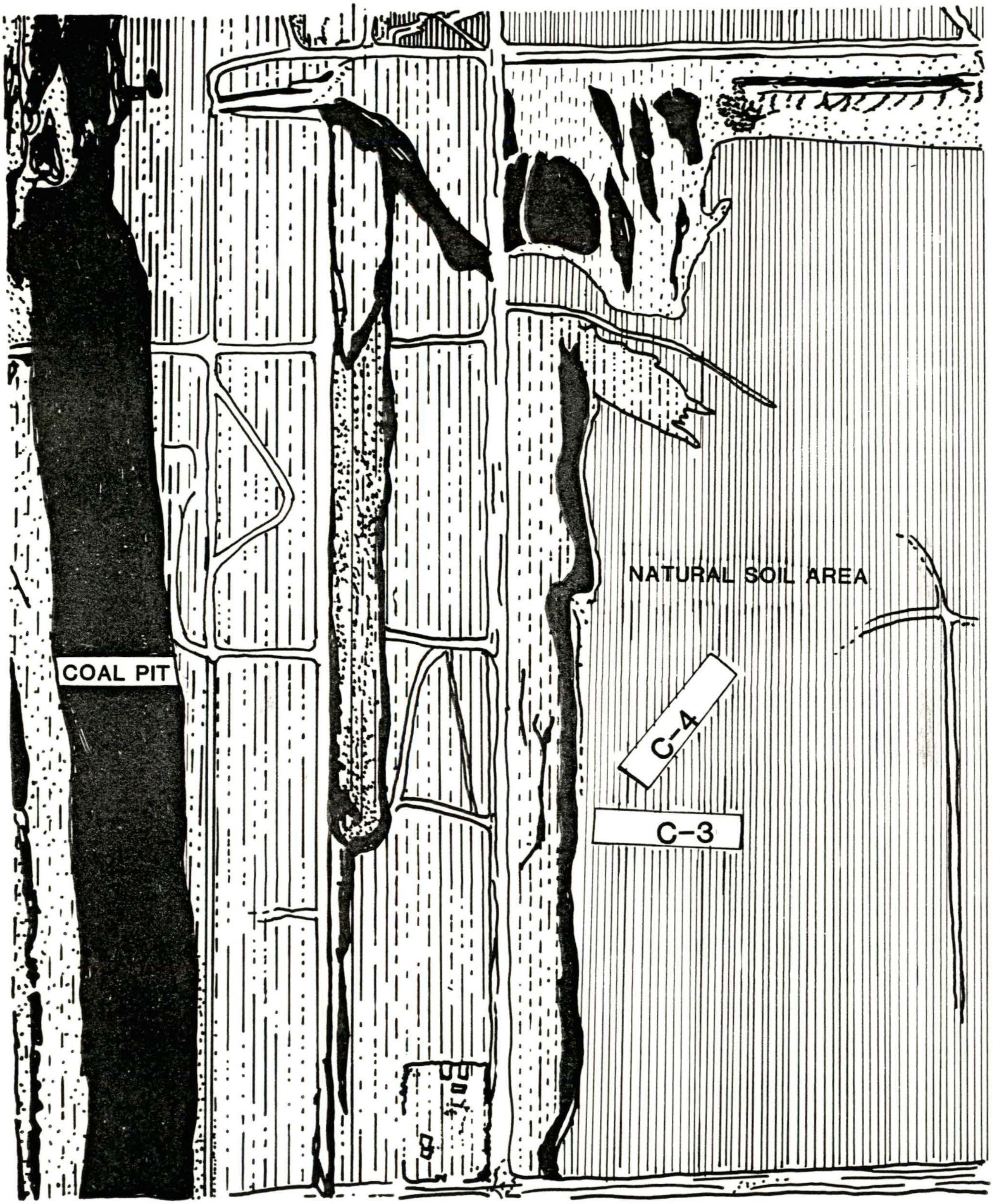

FIGURE 13. Line Drawing of an Aerial Photograph Showing Natural Soil Test Plot Location on the Captain Mine

Soil test plots shown as reclaimed in Table 6 are all located on the reclaimed side of the coal removal pit. Bucket-wheel reclaimed test plots ( W-1 and W-2) locations are shown in Figure 14. As shown these plots are located close to the pit area across from the mine office on soils reclaimed as prime farmland. Figure 15 shows the position of scraper plot S-1 and location of soil stockpile used for plot construction. Scraper plot S-2 and general layout of surrounding area is shown in Figure 16.

## Case Studies - 1982 Field Study

### Brazil Mine

### General Mine Description

The Brazil Coal and Clay Company is near Brazil, Indiana, approximately 20 miles east of Terra Haute. The permit area covers approximately 166 acres and the mining of the permit area is almost complete. The topography of the permit area is gently rolling with 0 to 2 percent slopes on areas well suited for and with a history of crop production. The mined area is surrounded by lands which were mined under the regulations prior to 1977 and therefore in an unreclaimed condition. The following section summarizes natural soil baseline conditions for purposes of comparison.

### Soil Series Descriptions and Maps

From the information given by Day Associates, the soil series in the mine area are Shouls, Cincinnati, Hickory, Ava, and Iva silt loams. The Iva and Ava series are classified by the USDA (SCS) as prime farmland. These two dominant, companion series were the only series tested. Locations of natural and reclaimed soil test plots on these two series are shown in Figure 17.

#### Iva Series

The Iva series consists of deep, somewhat poorly drained, nearly level to gently sloping soils on uplands. These soils formed in more than 6 feet of loess under a native vegetative cover of mixed hardwood trees.

In a representative profile, the surface layer is about eleven inches of silt loam. The upper 8 inches is grayish-brown, and the lower part is light brownish-gray and has yellowish-brown mottles. The subsoil is about 44 inches thick. It is mottled, dark grayish-brown and yellowish-brown, firm light silty clay loam in the upper part, and grades to mottled yellowish-brown and light brownish-gray, friable heavy silt loam in the lower part. The upper part is strongly acid, and the lower part is slightly acid. The underlying material is mottled yellowish-brown and light brownish-gray silt loam that grades from slightly acid to neutral below a depth of 6 feet. This material below 6 feet is primarily glacial till.

Iva soils have high available water capacity and slow permeability.

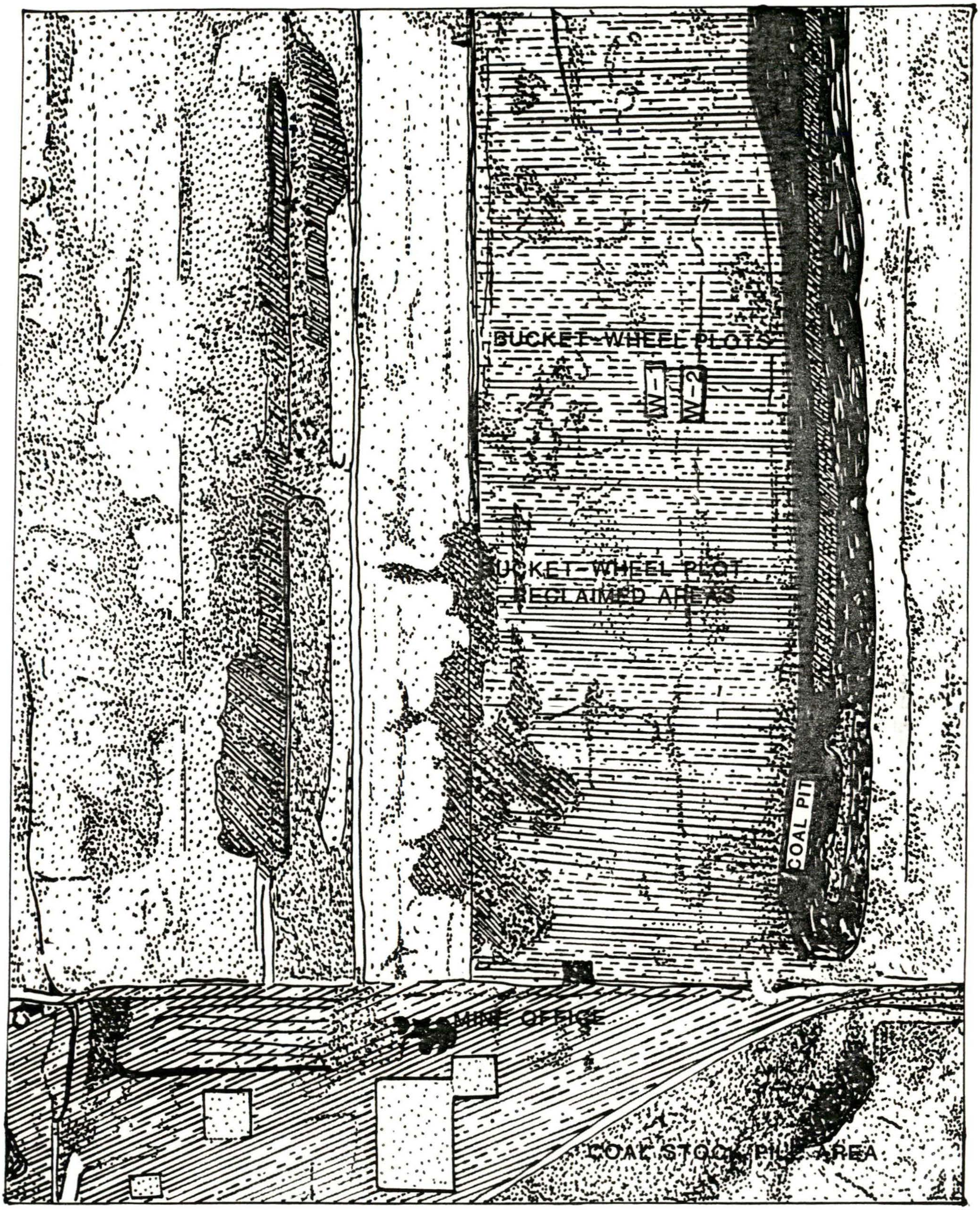

FIGURE 14. Line Drawing of an Aerial Photograph Showing Reclaimed Soil Test Plot Location for the Bucket-Wheel Plots (W-1 and W-2)

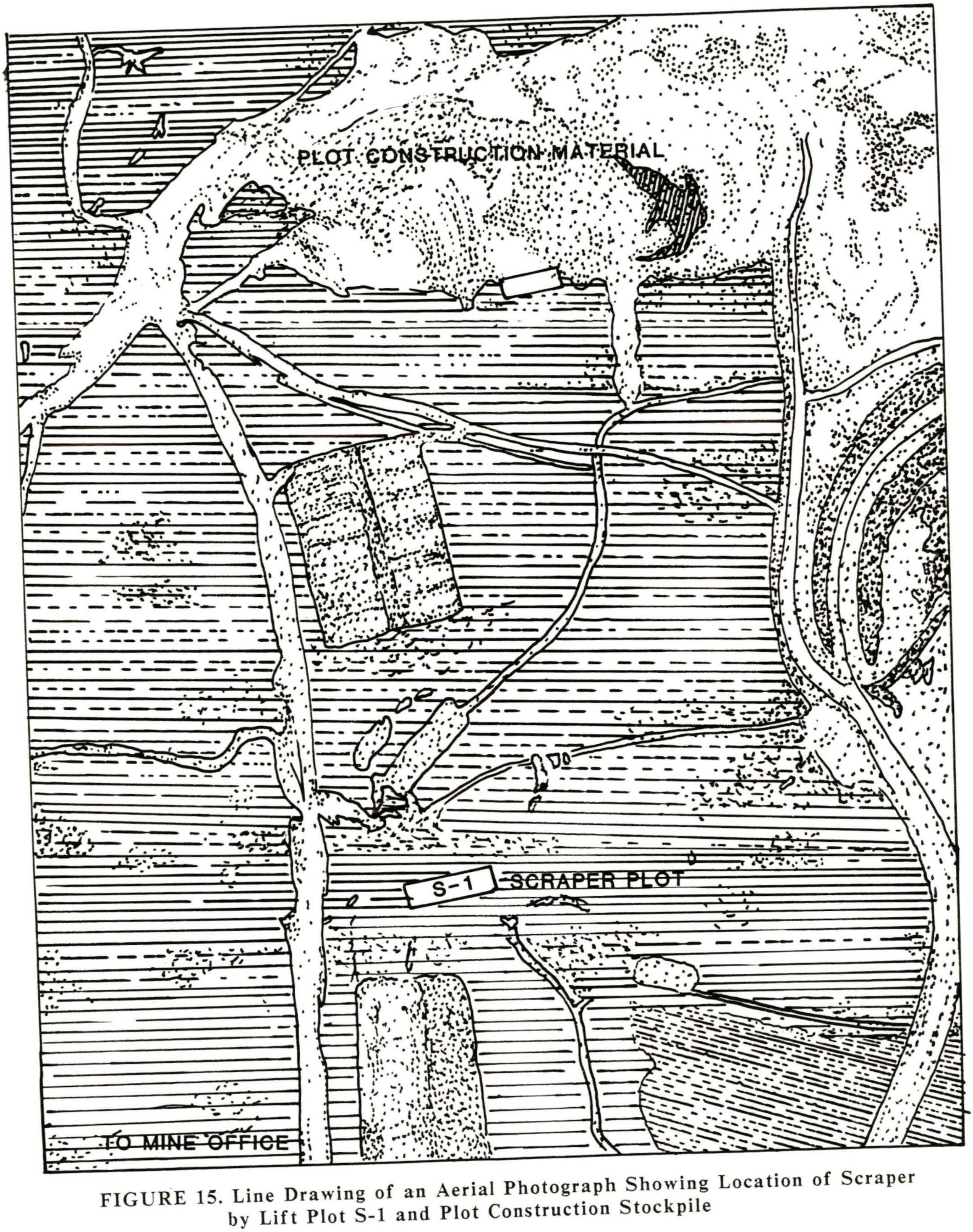

FIGURE 15. Line Drawing of an Aerial Photograph Showing Location of Scraper by Lift Plot S-1 and Plot Construction Stockpile

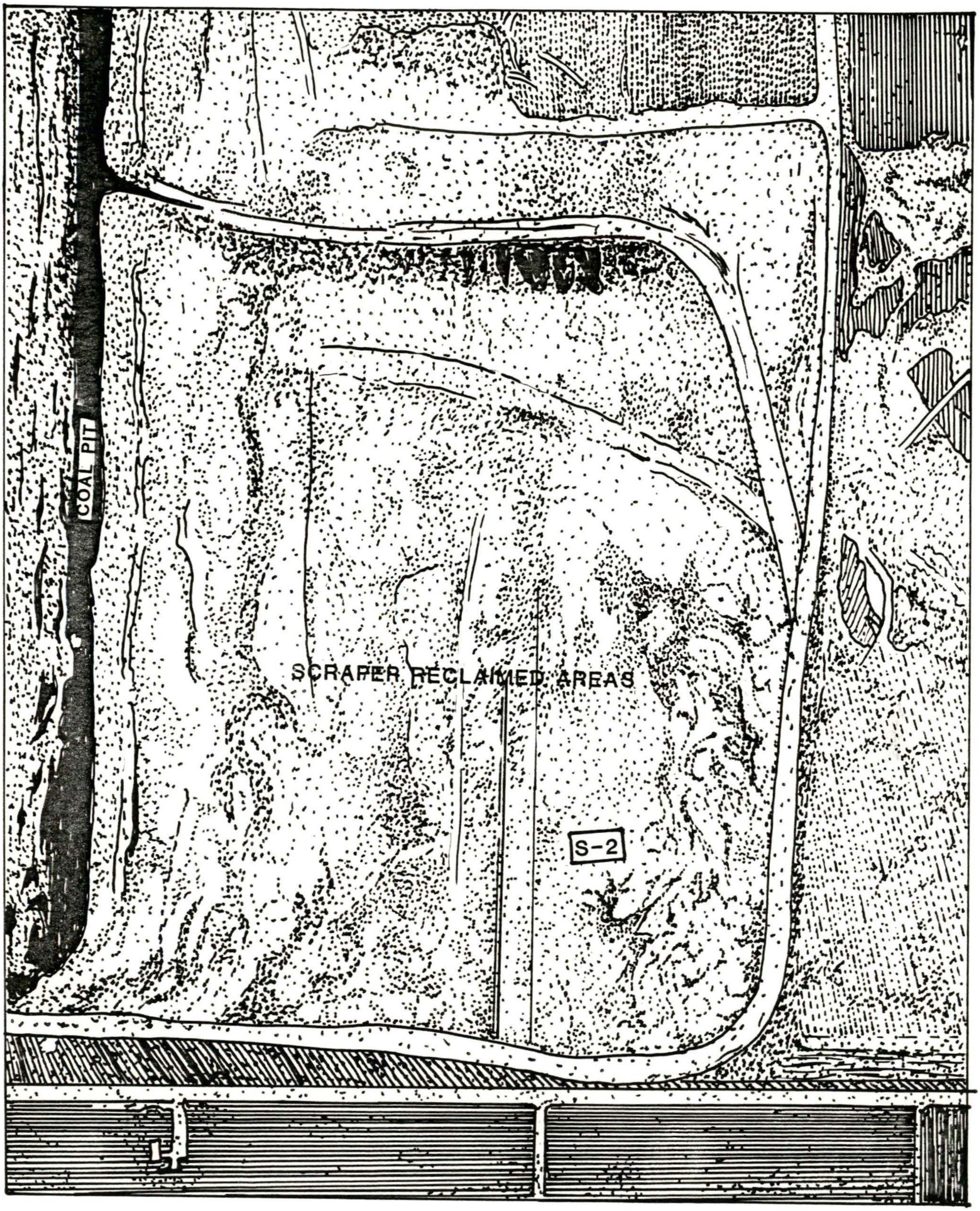

FIGURE 16. Line Drawing of an Aerial Photograph Showing Location of Scraper Plot S-2

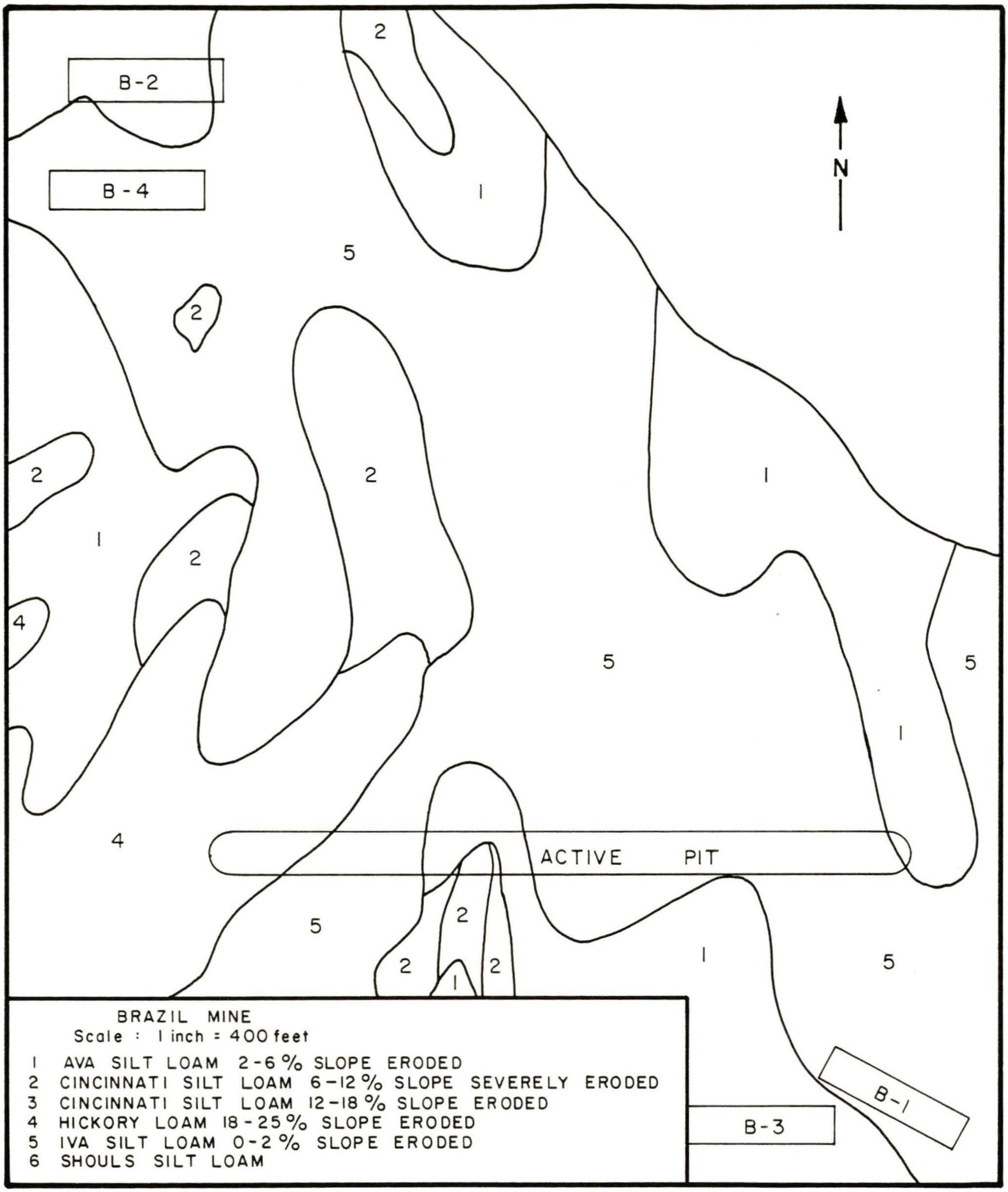

FIGURE 17. Area Soil Map Showing Natural and Replaced Soil Test Plots on the Brazil Mine

## Ava Series

The Ava series consists of deep, moderately well drained, gently sloping soils on uplands. These soils formed in 2 to 4 feet of loess and the underlying glacial till and are leached free of carbonates to a depth of 10 feet or more. They have a very firm and brittle fragipan at a depth of about 2.5 feet. The native vegetation was mainly mixed hardwood trees.

In a representative profile, the surface layer is dark grayish-brown silt loam about 6 inches thick. The subsoil is thicker than 60 inches. In sequence from the top, the upper 14 inches of the subsoil is yellowish-brown, firm light silty clay loam; the next 9 inches is yellowish-brown, firm light silty clay loam that is mottled with light brownish-gray; and the next 29 inches is a very firm and brittle fragipan. The fragipan is mottled yellowish-brown and light brownish-gray and is heavy silt loam in the upper part and light silty clay loam in the lower part. The next layer of the subsoil, which extends to a depth of more than 108 inches, is mottled yellowish-brown and light brownish-gray silty clay loam that grades to light clay loam as depth increases.

Ava soils have moderate available water capacity and very slow permeability.

## Soil Profile Descriptions

### Iva Silt Loam

Ap--01 to 8 inches, grayish-brown (10YR 5/2) silt loam; moderate, fine and medium, granular structure; friable; neutral; abrupt, smooth boundary.

A2--8 to 11 inches, light brownish-gray (10YR 6/2) silt loam; common, fine, distinct, yellowish-brown (10YR 5/4) mottles; weak to moderate, thick, platy structure; friable; few, thin, light gray (10YR 7/2) silt coatings on faces of peds; neutral; clear, wavy boundary.

B1g--11 to 14 inches, dark grayish-brown (10YR 4/2) light silty clay loam; common, medium, distinct, yellowish-brown (10YR 5/4) and light brownish-gray (10YR 6/2) mottles; moderate, medium and fine, subangular blocky structure; firm; few, thin, light gray (10YR 7/2) silt coatings on faces of peds; few, small, very dusky red (25YR 2/2) iron and manganese concretions; medium acid; clear, wavy boundary.

B215g--14 to 28 inches, yellowish-brown (10YR 5/4, 40YR 5/6) light silty clay loam; many, medium, distinct, light brownish-gray (10YR 6/2) mottles; moderate, medium, subangular blocky structure becoming coarser with depth; firm; few, thin, light gray (10YR 7/2) silt coatings that tend to disappear on wetting; thin, discontinuous, light brownish-gray (10YR 6/2) clay films on faces of peds and in root channels; strongly acid; gradual wavy boundary.

B22tg--28 to 38 inches, yellowish-brown (10YR 5/4, 10YR 5/6) light silty clay loam; many, medium, distinct, light brownish-gray (10YR 6/2) mottles; weak, coarse, subangular blocky structure; firm; thin discontinuous, light brownish-gray (10YR 6/2) clay films on faces of peds and in root channels; few, thin, light gray (10YR 7/2) silt coatings that tend to disappear on wetting; few, small, very dusky red (2.5YR 2/2) iron and manganese oxide concretions; medium acid; gradual, wavy boundary.

B3--38 to 55 inches, mottled yellowish-brown (10YR 5/4) and light brownish-gray (10YR 6/2) heavy silt loam; weak; coarse; subangular blocky structure; friable; few, medium, very dusky red (2.5YR 2/2) iron and manganese oxide concretions; slightly acid; gradual, wavy boundary.

C--55 to 80 inches, mottled light brownish-gray (10YR 6/2) and yellowish-brown (10YR 5/4) silt loam; massive; friable; few, medium, very husky red (2.5YR 2/2) iron andmanganese oxide concretions; slightly acid in upper part, becoming neutral as depth increases.

Thickness of the solum ranges from 36 to 60 inches. The Ap horizon ranges from dark grayish-brown to grayish-brown. The A2 horizon ranges from light brownish-gray to grayish-brown. Depth to mottling ranges from six to 15 inches. The B2 horizon is silt loam to light silty clay loam and is strongly acid to medium acid. The underlying material is silt loam or silt and is medium acid to slightly acid. In some places the C horizon is mildly alkaline below a depth of 6 feet.

Iva soils have drainage similar to that of Cory and Reesville soils. They have a lighter colored surface layer that is lower in organic matter content than Cory soils. Iva soils are more acid, lower in bases, and leached to a greater depth than Reesville soils. Also, their solum generally is thicker than that of Reesville soils.

### Ava Silt Loam

Ap--0 to 6 inches, dark grayish-brown (10YR 4/2) silt loam, brown (10YR 4/3) when crushed; moderate, medium, granular structure; friable; neutral; abrupt, smooth boundary.

B1--6 to 9 inches, yellowish-brown (10YR 5/4) light, silty clay loam; weak, fine, subangular blocky structure; firm; medium acid; clear, wavy boundary.

B21t--9 to 20 inches, yellowish-brown (10YR 5/6) light, silty clay loam to silty clay loam; moderate, medium, subangular blocky structure; firm; thin, discontinuous, yellowish-brown (10YR 5/4) clay films on faces of some peds; few, small, black (10YR 2/1) iron and manganese oxide concretions in lower 2 inches of horizon; strongly acid; clear, wavy boundary.

B22t--20 to 29 inches, yellowish-brown (10YR 5/6) light silty clay loam; few, fine, distinct, light brownish-gray (10YR 6/2) mottles; moderate, medium and coarse,subangular blocky structure; firm; thin, discontinuous yellowish-brown (10YR 5/4) and dark yellowish-brown (10YR 4/4) clay films on faces of peds; many, medium, very dark brown (10YR 2/2) iron and manganese oxide concretions; strongly acid; clear, irregular boundary.

Bx1--29 to 41 inches, yellowish-brown (10YR 5/6) heavy silt loam; common, medium, distinct, light brownish-gray (10YR 6/2) mottles; moderate, medium and coarse, prismatic structure; very firm and brittle; thin, discontinuous, light brownish-gray (10YR 6/2) clay films on most peds and linings of voids; thin to thick, light gray (10YR 7/2) silt coatings on faces of some prisms and occurring as cappings on the tops of prisms and as vertical crack fillings; many, medium, very dark brown (10YR 2/2) iron and manganese oxide concretions; strongly acid; gradual, wavy boundary.

11Bx2--41 to 58 inches, mottled yellowish-brown (10YR 5/6) and light brownish-gray (10YR 6/2) light silty clay loam; moderate, very coarse, prismatic structure parting to moderate, thick, platy structure; very firm and brittle; thin, discontinuous, light brownish-gray (10YR 6/2) clay films on faces of prisms and in lining of some voids; thin light-gray (10YR 7/2) silt coatings on some peds; thin light-gray (10YR 7/2) silt fills in vertical cracks; small pebbles throughout horizon; few, small, soft, very dark brown (10YR 2/2) iron and manganese oxide segregations; strongly acid; gradual, wavy boundary.

11B31--58 to 72 inches, yellowish-brown (10YR 5/6) light silty clay loam; many, medium, distinct, light brownish-gray (10YR 6/2) mottles; weak, very coarse, prismatic structure parting to weak, coarse, subangular blocky structure; firm; few medium, soft, very dark brown (10YR 2/2) iron and manganese oxide segregations; several small pebbles; medium acid; gradual, wavy boundary.

11B32--72 to 108 inches, mottled yellowish-brown (10YR 5/6), light brownish-gray (10YR 6/2), and light gray (10YR 7/2) light clay loam; weak, many pebbles of varying sizes; thin to thick, discontinuous clay films on faces of prisms; few iron and manganese segregations; slightly acid in the upper part, becoming neutral as depth increases.

The Ap horizon ranges from dark grayish-brown to brown or grayish brown. An A2 horizon is present in some areas that are not eroded. Depth to the fragipan ranges from 18 to 36 inches. Texture ranges from light silty clay loam to silt loam in the upper part and grades to light clay loam in the lower part in places. The lower part of the pan generally contains small pebbles. The material underlying the fragipan ranges from loam or silt loam to light silty clay loam or light clay loam. In places the silt loam and silty clay loam contain enough sand to have a gritty feel. The underlying material ranges from strongly acid in the upper part to mildly alkaline in the deeper, unleached glacial till. Thickness of the loess cap ranges from 24 to 48 inches.

Ava soils are associated with Cincinnati and Iva soils, but are less well-drained than Cincinnati soils. They are formed in a thinner deposit of loess and are naturally better drained than Iva soils. In addition, Ava soils have a fragipan that is lacking in Iva soils.

## On-Site Soil Movement

The Brazil mine employs an equipment combination for soil movement that is unique in the Midwest. The combination of equipment used consists of a 4-cubic yard coal loader, a 50-ton end-dump truck, scraper pans and bulldozer. Table 7 lists the equipment combination and its application to the soil transport and replacement process.

TABLE 7. EQUIPMENT UTILIZATION - BRAZIL MINE

| EQUIPMENT TYPE | SOIL MOVEMENT APPLICATION | EQUIPMENT MANUFACTURER |
|---|---|---|
| Loader | Rooting Medium | P & H |
| 50-Ton Truck | Rooting Medium | Webco or Euclid |
| Scraper | Topsoil | 210 HB Clark |
| Bulldozer | Regrading | D9-Caterpillar |

The scraper pans were used to remove the topsoil material to a depth of approximately 12 inches and to replace it directly on the reclamation side of the pit with no stockpiling in the areas we tested. Following topsoil removal, the loader was used to remove subsoil to a depth of approximately 10 to 14 feet. This subsoil material was mixed as the scoop came up the working face and then deposited into 50-ton end-dump trucks for transport around the pit (Figure 18). The end-dump haulback truck traveled around the pit and dumped the material in a pattern that allowed the truck to avoid tracking the subsoil material. Following dumping a bulldozer worked the top 24 to 36 inches of the rooting medium material deposited by the truck down into a level surface. Both soil series tested on the Brazil mine had topsoils replaced in the spring of 1979 and subsoils replaced in the fall of 1978.

The unique aspect of the Brazil operation is the replacement of the topsoil in a "windrow" before final regrading. Normally topsoil is respread over the entire soil replacement area. In the windrow method, topsoil is placed in a long row approximately 1.5 times the scraper's width and to a depth of 5 to 7 feet (Figure 19). Following windrowing a D-9 Caterpillar is used to spread the topsoil to the correct depth, thus limiting scraper traffic on the rooting medium.

## Reclamation Program

After soil replacement, the reclaimed areas were tilled with a chisel plow and then disced. A fertilization program was implemented at a rate of 300 pounds of 17-17-17 fertilizer per acre. The area was harvested of one crop of wheat in mid summer of 1980. Since that time the area was seeded in sunflowers, and

FIGURE 18. Rooting Medium Removal and Loading by Front Shovel/Truck System on the Brazil Mine

FIGURE 19. Topsoil Windrow Construction on the Brazil Mine

contained regrowth of orchardgrass, fescue, perennial ryegrass, alfalfa, lespedeza, and alsike clover which were sown initially with the wheat.

Wheat yields harvested on the reclaimed soils compared favorably with yields which were obtained in natural soils. The natural soil area produced 31 bushels per acre while the replaced Iva and Ava series produced 29.6 and 33.5 bushels per acre.

### Soil Study Plot Location and Aerial site Map

At the Brazil mine the soil series were segregated in removal and replacement. Plot identification numbers as well as soil type and series name are shown in Table 8.

**TABLE 8. STUDY PLOT IDENTIFICATION - BRAZIL MINE**

| PLOT NO. | SOIL AREA IDENTIFICATION | SOIL TYPE |
|---|---|---|
| B-1 | Natural | Iva Series |
| B-2 | Reclaimed | Ava Series |
| B-3 | Natural | Ava Series |
| B-4 | Reclaimed | Iva Series |

A line drawing from an aerial photograph of the site and study plot locations, as outlined in Table 8, is shown in Figure 20.

## Captain Mine

### General Mine Description

The permit area consists of 18 square miles of two to five percent slopes, much of which is prime farmland. The topography of the recently reclaimed land closely resembles that of the natural landscape, with the exception of the final cut lake remaining near the sampled area.

### Soil Series Descriptions and Maps

The soil survey report provided by the Southwestern Illinois Coal Company indicates the series on the Captain mine to be:

> Alford, Ava-Hickory, Ava, Banlic, Bluford, Belknap, Blair, Bonnie, Cisne, Damstadt, Hickory, Hosmer, Hoyleton, Huey, Racoon, Richview, Stoy, Tamalco, Weir, Wynoose, and Wakeland

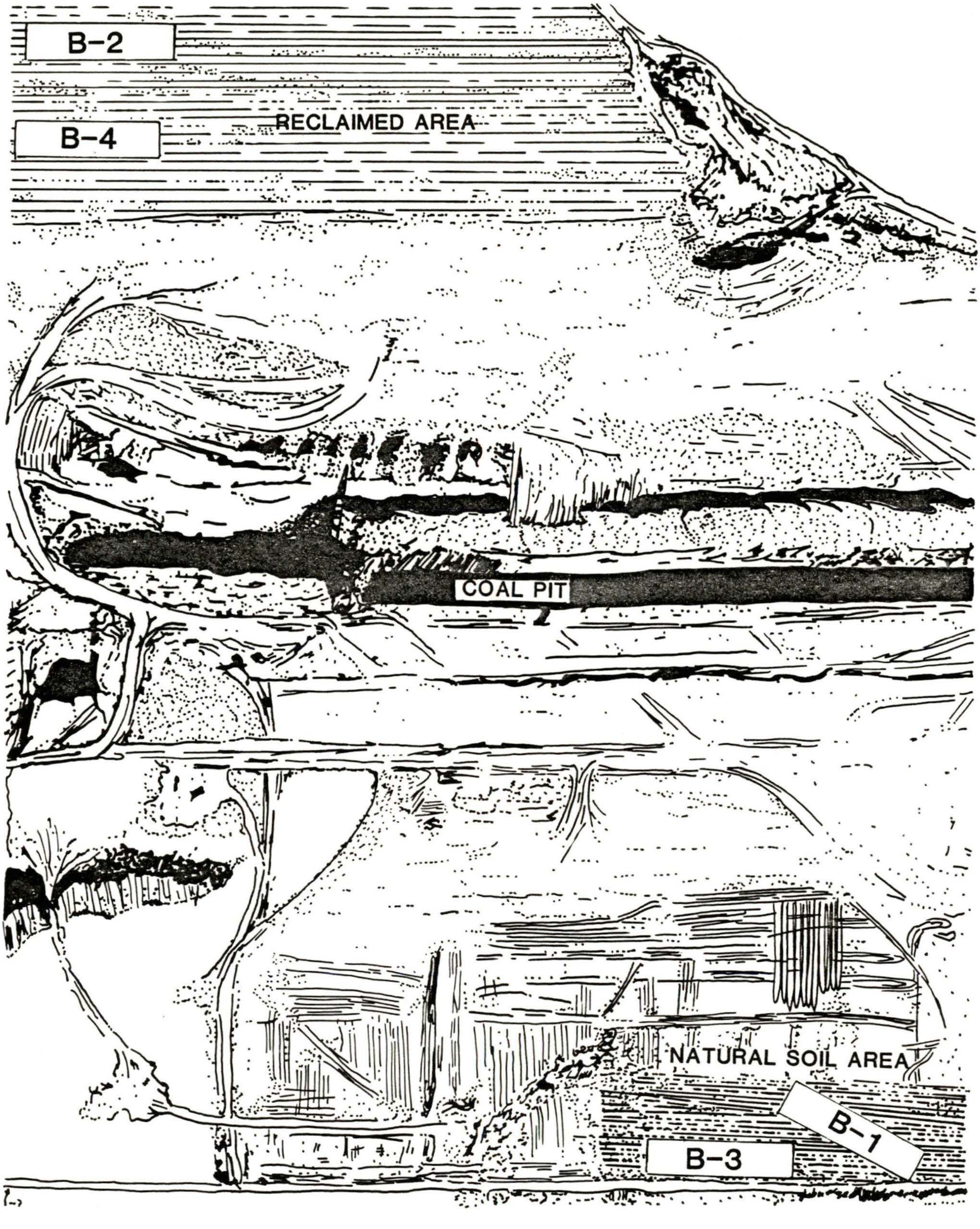

FIGURE 20. Line Drawing of an Aerial Photograph of the Brazil Mine Showing Both Natural and Reclaimed Test Plots

Many of these series are considered to be prime farmland soils. The Cisne and Hoyleton are the dominate series and were chosen for sampling because of their proximity to the soil removal area. Detailed soil series information is provided in the 1984 case studies section. Plot locations are shown in Figure 13.

### On-Site Soil Movement

The Captain mine employs a state-of-the-art primary soil movement method, the bucket-wheel excavator system (Figure 21). The combination of equipment used in soil movement is illustrated in Table 9.

TABLE 9. EQUIPMENT UTILIZATION - CAPTAIN MINE

| EQUIPMENT TYPE | SOIL MOVEMENT APPLICATION | EQUIPMENT MANUFACTURER |
|---|---|---|
| Bucket-Wheel Excavator | Rooting Medium | O & K |
| Beltwagon | Topsoil & Rooting Medium | O & K |
| Conveyors | Topsoil & Rooting Medium | Weserhutte |
| Spreader | Topsoil & Rooting Medium | Mitsubishi |
| Scraper 651 | Topsoil | Caterpillar |
| D-7 Bulldozers | Regrading | Caterpillar |

The following summarizes procedures and equipment utilized in the removal, transport and replacement of soil material involved in this system. The topsoil was removed with scraper pans to a depth from 8 to 12 inches and stockpiled on the natural soil or wheel side of the pit. The bucket-wheel excavator was used to load the stockpiled topsoil into a beltwagon which in turn loaded it on a conveyor system for transport approximately 4 miles around the pit for stockpiling a second time (Figure 22). Scrapers were then used to spread the topsoil over the leveled subsoil.

The subsoil material was removed following topsoil removal with scrapers, with the laser-controlled 26-foot wheel and transported by conveyor around the pit where it was respread with a Mitsubishi spreader. D-7 and D-9 bulldozers were utilized for final soil regrading. Although subsoil material was removed from a depth from 15 to 20 feet, the rooting medium, as defined by law, the top 4 feet of subsoil material, was deposited in a 4-foot lift on the reclamation side of the pit.

### Reclamation Program

Final reconstruction of the reclaimed soils was completed by early 1980. After reconstruction, the areas were disced and seeded in alfalfa. Test plots were

FIGURE 21. Bucket-Wheel Excavator Shown on Working Bench (Subsoil) on the Captain Mine

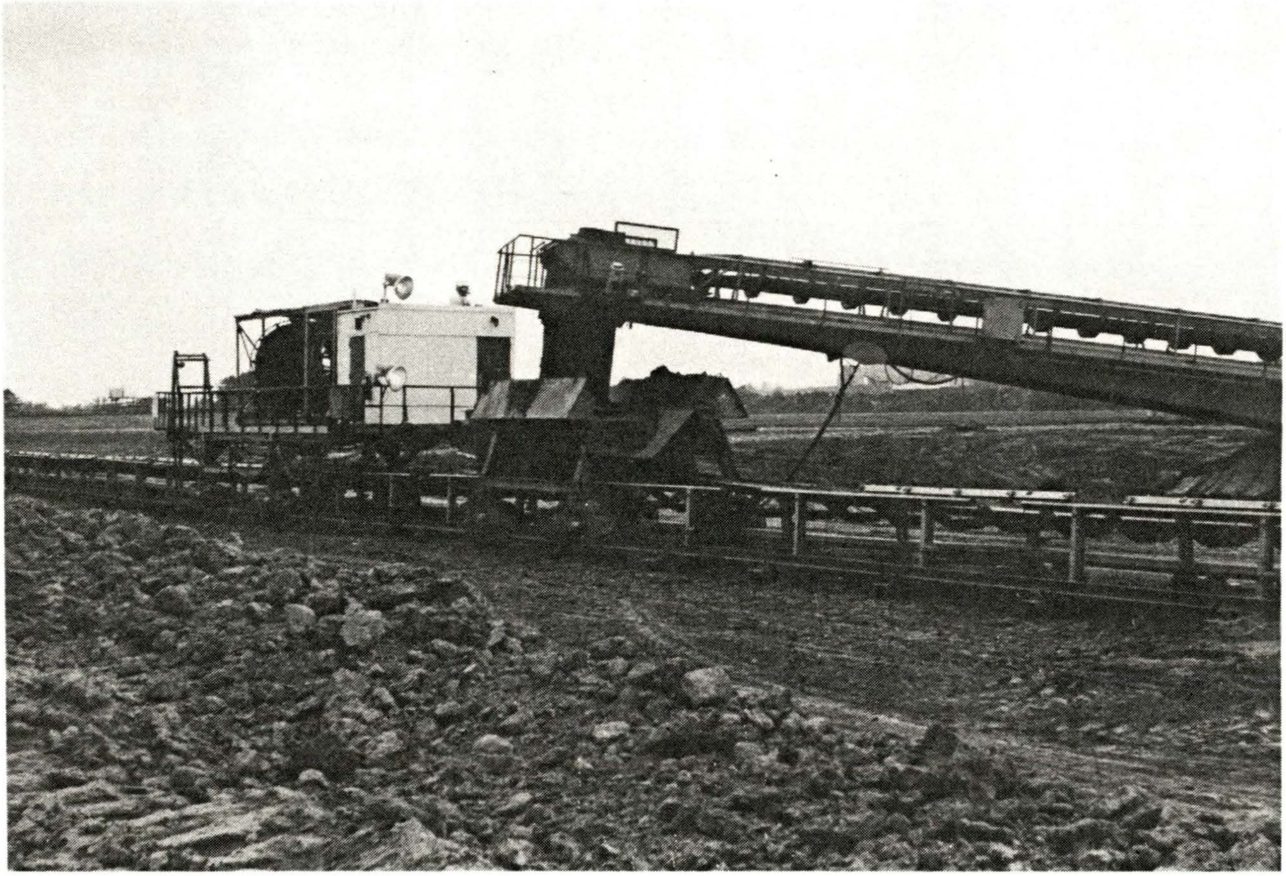

FIGURE 22. Beltwagon Loading Conveyor System on the Captain Mine

located in the reclaimed area and yields were found to be acceptable only if irrigated. These test plots were established by the mining company to document post-reclamation yields for bond release.

### Soil Study Plot Location and Aerial Site Maps

Soils on the reclaimed areas of the Captain mine were a mixture of the series on the permit area and were not segregated in their transport and replacement. Plot identification numbers are illustrated in Table 10.

TABLE 10. STUDY PLOT IDENTIFICATION - CAPTAIN MINE

| PLOT NO. | SOIL AREA IDENTIFICATION | SOIL TYPE |
|---|---|---|
| C-1 | Reclaimed | Series Mixture |
| C-2 | Reclaimed | Series Mixture |
| C-3 | Natural | Cisne Series |
| C-4 | Natural | Hoyleton Series |

Aerial site maps of reclaimed soil test plot locations are shown in Figure 23.

## Delta Mine

### General Mine Description

The Delta mine is between Crab Orchard and the Saline County border in Southern Illinois.

The topography of the area is extremely rolling, in some areas up to 12 percent slopes are found. Consequently, much of the reclaimed land is used as pasture for livestock. Most of the older reclaimed areas are not suitable for row crops due to existing final cut lakes, steep slopes and rocky soils. Land recently reclaimed on this mine is visibly different from the undisturbed soils by having less topsoil, rocks visible on the surface, and poor drainage resulting in retention of rainwater on the surface. The exact area coverage of this permit area is not known but is estimated to encompass approximately 3 square miles.

### Soil Series Descriptions and Maps

According to the soils map supplied by the Amax Coal Company, the series found on the Delta mine are: Ava, Belknap, Bluford, Hickory, and Wynoose. The most commonly found prime farmland series in the path of the mining pit were the

FIGURE 23. Line Drawings of an Aerial Photograph Showing Replaced Soil Test Plots (C-1 and C-2) on the Captain Mine

Ava and the Bluford silt loam. Natural soil plots are shown within series boundaries in Figure 24.

## Ava Series

The Ava series consists of moderately well-drained soil formed in 24 inches of loess over glacial till on uplands. Typically, the surface layer is dark grayish-brown silt loam, 4 inches thick. The surface layer is yellowish-brown silt, loam 5 inches thick. The upper topsoil is strong-brown silt loam, 14 inches thick. The next layer is brown silty clay loam with silt coatings. The loess subsoil is yellowish-brown, pale brown. Brown and light brownish-gray silt loam extend to 60 inches. Slopes range from 2 to 12 percent. Most areas are cultivated and seeded with either row crop or pasture.

The Ava series is fine-silty, mixed, mesic Typic Fragiudalf. Ava soils typically have a silt loam upper sequence of horizons with a dark grayish-brown A1 horizon, yellowish-brown A2 horizon and strong brown B2 horizon, and a lower sequence of horizons with brown and light gray silty clay loam B and A horizon and a fragipan at depths of about 28 inches.

## Bluford Series

The Bluford series consists of somewhat poorly drained soils formed in loess over glacial till on uplands. The surface layer is dark grayish-brown silt loam 9 inches thick. The subsurface layer is mixed brown and pale-brown silty clay loam in the upper 3 inches, mottled brown grayish-brown, light brownish-gray and dark yellowish-brown silty clay and silty clay loam in next 17 inches, and mixed brownish-brittle silt loam in the lower part. Slopes range from 1 to 7 percent. Most areas are cultivated.

The Bluford series is a fine, montmorillonitic, mesic Aquic Hapludalf. These soils typically have dark grayish-brown silt loam Ap horizons, brown and pale brown silt loam A2 horizons, brown and grayish-brown mottled heavy silty clay loam and silty clay B2 horizons underlain by brown mottled silt loam dense layers at depths of about 36 inches.

## Soil Series Descriptions

### Ava Series

A1--0 to 4 inches, dark grayish-brown (10YR 4/2) light silt loam; weak fine granular structure; friable; very strongly acid; clear, smooth boundary. (3 to 6 inches thick)

A2--4 to 9 inches, yellowish-brown (10YR 5/4) silt loam; weak, fine, platy structure; friable; strongly acid; clear smooth boundary. (5 to 10 inches thick)

B1--9 to 14 inches, strong brown (7.5YR 5/6) silt loam; weak and moderate fine subangular blocky structure; firm; very strongly acid; clear, smooth boundary. (4 to 6 inches thick)

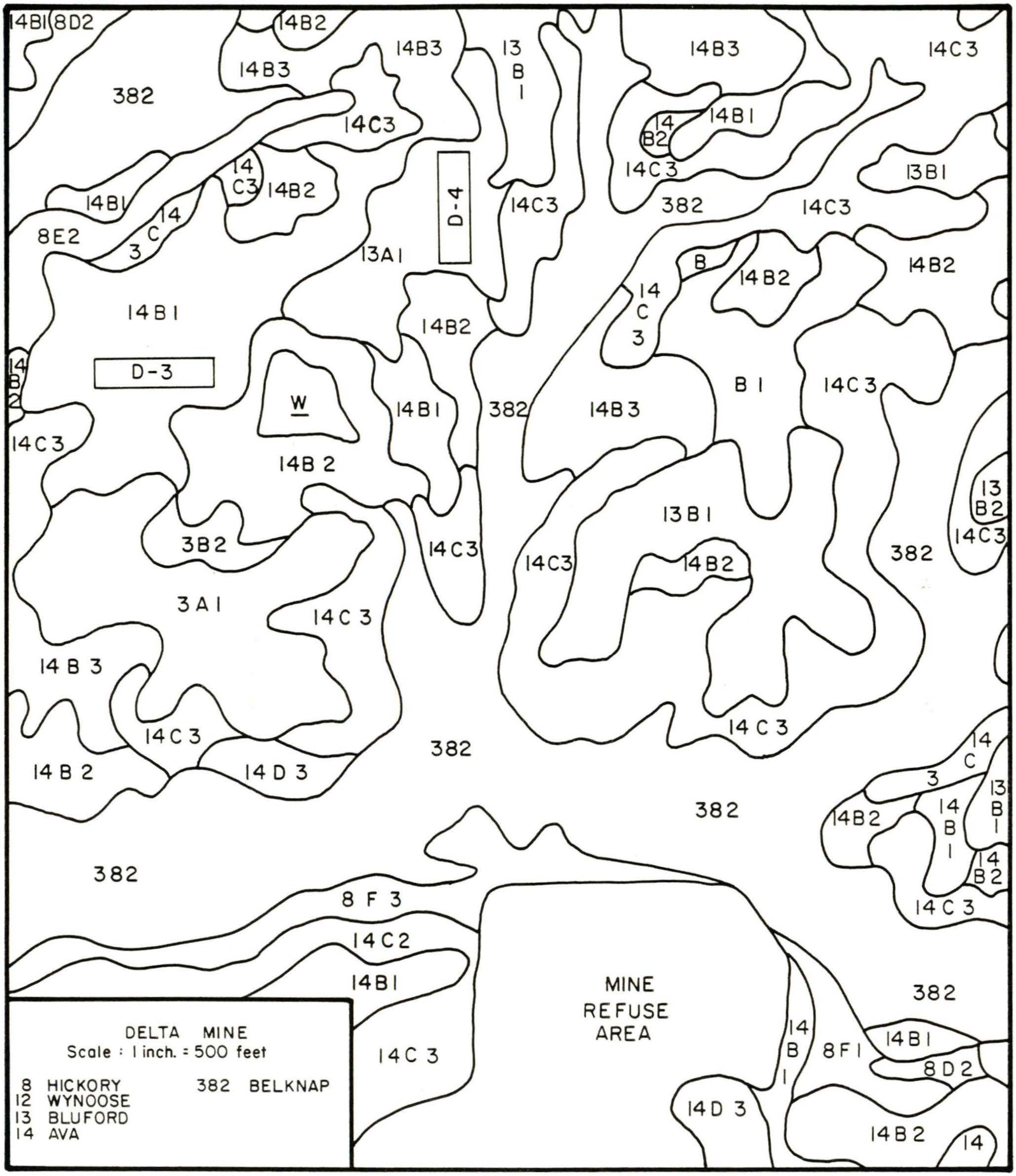

FIGURE 24. Natural Soil Map Showing Locations of Natural Soil Test Plots on the Delta Mine

B2t--14 to 23 inches, strong brown (7.5YR 5/6) heavy silt loam; moderate medium subangular blocky structure; firm; thin, patchy, dark brown (7.5YR 4/4) clay films; very strongly acid; clear smooth boundary. (8 to 10 inches thick)

B & A--23 to 28 inches, brown (10YR 5/2) (B2t) and light gray (10YR 7/2) (A2) silt coated ped exteriors, silty clay loam; moderate medium subangular blocky structure; firm, few thin discontinuous dark brown (7.5YR 4/4) clay films; very strongly acid; clear smooth boundary. (4 to 6 inches thick)

Bx1--28 to 36 inches, yellowish-brown (10YR 5/4) heavy silt loam; many medium, distinct, light brownish-gray (10YR 6/2) mottles; weak medium prismatic parting to moderate medium blocky structure; firm; somewhat fragile; thin, dark brown (7.5YR 4/4) silty material in polygonal cracks; very strongly acid; clear smooth boundary. (7 to 10 inches thick)

Bx2--36 to 41 inches, pale brown (10YR 6/3) silt loam; few fine prominent dark brown (7.5YR 4/4) mottles; weak coarse and very coarse blocky structure; firm; brittle; few thin, dark brown (7.5YR 4/4) clay films; light brownish-gray (10YR 6/2) silty material in polygonal cracks; very strongly acid; gradual smooth boundary. (4 to 7 inches thick)

IIBx3--41 to 48, brown (10YR 5/3) silt loam; few fine prominent gray (10YR 6/1) mottles; large prismatic blocks which part to weak very coarse blocky structure; firm; brittle; some noticeable sand; few thin, dark brown (7.5YR 4/4) clay films; light brownish-gray (10YR 6/2) silty material in polygonal cracks; very strongly acid; diffuse smooth boundary. ( 6 to 9 inches thick)

IIBx4--48 to 60 inches, light brownish-gray (10YR 6/2) silt loam; many medium distinct yellowish-brown (10YR 5/8) mottles; large prismatic blocks which part to very weak medium blocky structure; firm; somewhat brittle, but not as strong as above; few thin dark brown (7.5YR 4/4) clay films; some sand and pebbles; very strongly acid. (10 to 15 inches thick)

Type Location: Williamson County, Illinois; about 1 mile northeast of Pittsburg; 535 feet west and 30 feet south of N.E. corner, Section 35, T. 8 X. R. 3 E.

Range in Characteristics: The solum ranges from 40 to more than 70 inches in thickness and from strong to extreme acidity. The solum formed is less than 45 inches of Peoria loess and the underlying sediment. The A1 or Ap horizons are commonly dark grayish-brown (10YR 4/2) but ranges to brown (10YR 4/3). In undisturbed areas, the horizon is a very dark grayish-brown (10YR 3/2), dark brown (10YR 3/3), or brown (10YR 4/3). The A2 horizon is commonly yellowish-brown (10YR 5/4 or 6/4) but ranges to pale brown fine or medium, platy or granular structure. The B horizon is 32 to 54 or more inches thick; the lower part is formed in the underlying sediment. The B horizon matrix has hue of 10YR or 7.5YR, value of 4, 5, or 6, and chroma of 4 to 6 in the upper part to chroma of 2 and 3 in the lower part. Mottles range widely and are dark brown, yellowish-brown, gray, pale brown or light brownish-gray. The upper B horizon is silt loam or medium silty clay loam. Clay films are commonly patchy in the upper materials but difficult to recognize in some areas. The IIB horizon is silt loam, loam, or clay loam. The IIB horizon formed in reworked material of the A horizon and locally upper B horizon of the Sangamon soil contains more sand, gravel and clay and is considerably more weathered than the overlying loess. The Bx horizon ranges from weak to moderate very coarse prismatic structure parting to angular blocky.

**Bluford Series**

Ap--0 to 9 inches, dark grayish-brown (10YR 4/2) silt loam, light brownish-gray (10YR 6/2) dry; weak fine granular structure; friable; few fine dark concretions (Fe-Mn oxides); strongly acid; abrupt smooth boundary. (6 to 10 inches thick)

A2--9 to 16 inches; mixed brown (10YR 5/3) and pale brown (10YR 6/3) silty clay loam some splotches A2 material; few fine prominent reddish-brown (5YR 4/4) mottles; moderate medium subangular blocky structure; firm; thick continuous light gray (10YR 7/2) clay films; few fine dark concretions (Fe-Mn oxides); extremely acid; abrupt smooth boundary. (2 to 12 inches thick)

B21t--16 to 19 inches, mixed brown (10YR 5/3) and pale brown (10YR 6/3) heavy silty clay loam some splotches A2 material; few fine prominent reddish-brown (5YR 4/4) mottles; moderate medium subangular blocky structure; firm, thick continuous light gray (10YR 7/2) clay films; few fine dark concretions (Fe-Mn oxides); extremely acid; abrupt smooth boundary. (2 to 12 inches thick)

B22t--19 to 25 inches, brown (10YR 5/3) silty clay; common medium distinct light brownish-gray (10YR 6/2) and few fine faint yellowish-brown (10YR 5/6) mottles; moderate medium prismatic structure parting to moderate medium angular blocky, firm; moderately thick continuous light brownish-gray (10YR 6/2) clay films; few fine dark concretions (Fe-Mn oxides); extremely acid; clear smooth boundary. (5 to 12 inches thick)

B23t--25 to 31 inches, mixed grayish-brown (10YR 5/2) and brown (10YR 5/3) silty clay; common medium distinct strong brown (7.5YR 5/6) mottles; weak medium prismatic parting to moderate medium angular blocky structure; firm; moderately thick continuous light brownish-gray (10YR 6/2) clay films; common fine dark concretions (Fe-Mn oxides); extremely acid; gradual smooth boundary. (5 to 10 inches thick)

B31t--31 to 36 inches, mixed light brownish-gray (10YR 6/2) and dark yellowish-brown (10YR 4/4) silty clay loam; few medium distinct brown (7.5YR 4/4) mottles; moderate medium angular blocky structure; firm; moderately thick continuous grayish-brown (10YR 5/2) clay films; common fine dark concretions (Fe-Mn oxides); extremely acid; clear smooth boundary. (0 to 8 inches thick)

IIBx1--36 to 45 inches, mixed brown (7.5YR 5/4) and grayish brown (10YR 5/2) silt loam; weak fine and medium angular blocky structure; firm; thin continuous light brownish-gray (10YR 6/2) clay films, slightly brittle; extremely acid; gradual smooth boundary. (6 to 20 inches thick)

IIBx2--48 to 60 inches, mixed brown (7.5YR 4/4) and light brownish-gray (10YR 6/2) silt loam; weak medium angular blocky tending toward coarse platy structure; firm; thin discontinuous light brownish-gray (10YR 6/2)clay films; brittle; very strongly acid. (6 to 40 inches thick)

Type Location: Jefferson County, Illinois; three miles north and one mile east of Bonnie, Illinois; about 200 feet north and 2,600 feet west of S.E. corner of Sec. 21., T. 3 N., R. 3 E.

Range in Characteristics: Solum thickness ranges from 40 to 60 inches. The soil formed is less than 45 inches of Peoria loess and the underlying sediment at the surface of the Illinoian till. The upper boundary of the fragipan is within a depth of 40 inches. Soil ranges from medium to extremely acid. The A1 or Ap horizon is typically a dark grayish-brown (10YR 4/2) but some pedons have hue of 10YR, value of 4 or 5, and chroma of 2 or 3. Some pedons have a very dark grayish-brown (10YR 3/2) A1 horizon less than 6 inches thick. The B horizon has hue of 10YR or 7.5YR, value of 4 to 6, and chroma of 2 to 6. Typically the B2t and B3t horizons have 10YR hue, and the IIBx horizons have 7.5YR or 5YR hue. The Bt horizon is silty clay loam or silty clay averaging between 35 and 45 percent clay. The Bt horizon has moderate or strong fine or medium, prismatic or subangular blocky structure in the upper part and weak or moderate, fine to coarse, prismatic or subangular blocky structure in the lower part. The IIB horizon is silt loam, loam, silty clay loam, or clay loam. The IIB horizon formed in a sediment which consists of the reworked material of the A horizon and locally the upper B horizon of the Sangamon soils, along with pebbles concentrated by erosion of the Illinoian till and an admixed amount of earliest Wisconsinian loess. This material contains more sand, gravel, and clay and is considerably more weathered than the Peoria loess. The Bx horizon is firm when moist and fragile or brittle when dry.

### On-Site Soil Movement

The Delta mine utilizes a dragline for the primary method of rooting medium removal and replacement. The combination of equipment used for soil movement is shown in Table 11.

**TABLE 11. EQUIPMENT UTILIZATION - DELTA MINE**

| EQUIPMENT TYPE | SOIL MOVEMENT APPLICATION | EQUIPMENT MANUFACTURER |
|---|---|---|
| Dragline (60 cu.yd.) | Rooting medium | Bucyrus Erie |
| Dragline (6 cu.yd.) | Leveling rooting medium | Bucyrus Erie |
| Scraper | Topsoil | Caterpillar |
| Dozer | Regrading | Caterpillar,<br>Mitsubishi |

The topsoil was removed by scraper pan as on the other mines and stockpiled for a period of approximately one year before replacement. The topsoil removal depth ranged from 9 to 14 inches. There was no use of windrowing of topsoil to limit equipment traffic on this mine site.

Soil was moved by a small dragline to spread rooting medium which was then deposited by a large dragline. The rooting medium subsoil was removed to a depth of 70 feet with a 60-cubic yard dragline and transported across the pit and directly deposited on the reclamation side of the pit (Figure 25). A small 6-cubic yard dragline was then used to regrade the subsoil piles (Figure 26). Final regrading of the topsoil and rooting medium was accomplished with a D-9 dozer. The small dragline for spreading rooting medium was used to limit scraper activity on the subsoil.

### Reclamation Program

The reclaimed areas on the Delta mine were replaced 2 years prior to sampling in the summer of 1980. The older areas were sampled due to excessively wet conditions in newly reclaimed areas. The reclaimed area after soil replacement was sown in alfalfa, red clover and fescue, after a standard tillage program composed of discing for seedbed preparation. At time of sampling the area is still vegetated with the legume cover.

### Soil Study Plot Locations and Aerial Site Maps

The plot identification shown in Table 12 will be carried throughout the report to provide clarity in data analysis. The reclaimed soils were a mixture of soil types found on the permit area. The soil series were not segregated, stockpiled separately and replaced in the study sites involved on this mine. The primary series found were the Ava and Bluford.

TABLE 12. STUDY PLOT IDENTIFICATION - DELTA MINE

| PLOT NO. | SOIL AREA IDENTIFICATION | SOIL TYPE |
|---|---|---|
| D-1 | Reclaimed | Series Mixture |
| D-2 | Reclaimed | Series Mixture |
| D-3 | Natural | Ava Series |
| D-4 | Natural | Bluford Series |

FIGURE 25. Rooting Medium Removal by 60 cu. yd. Dragline on the Delta Mine

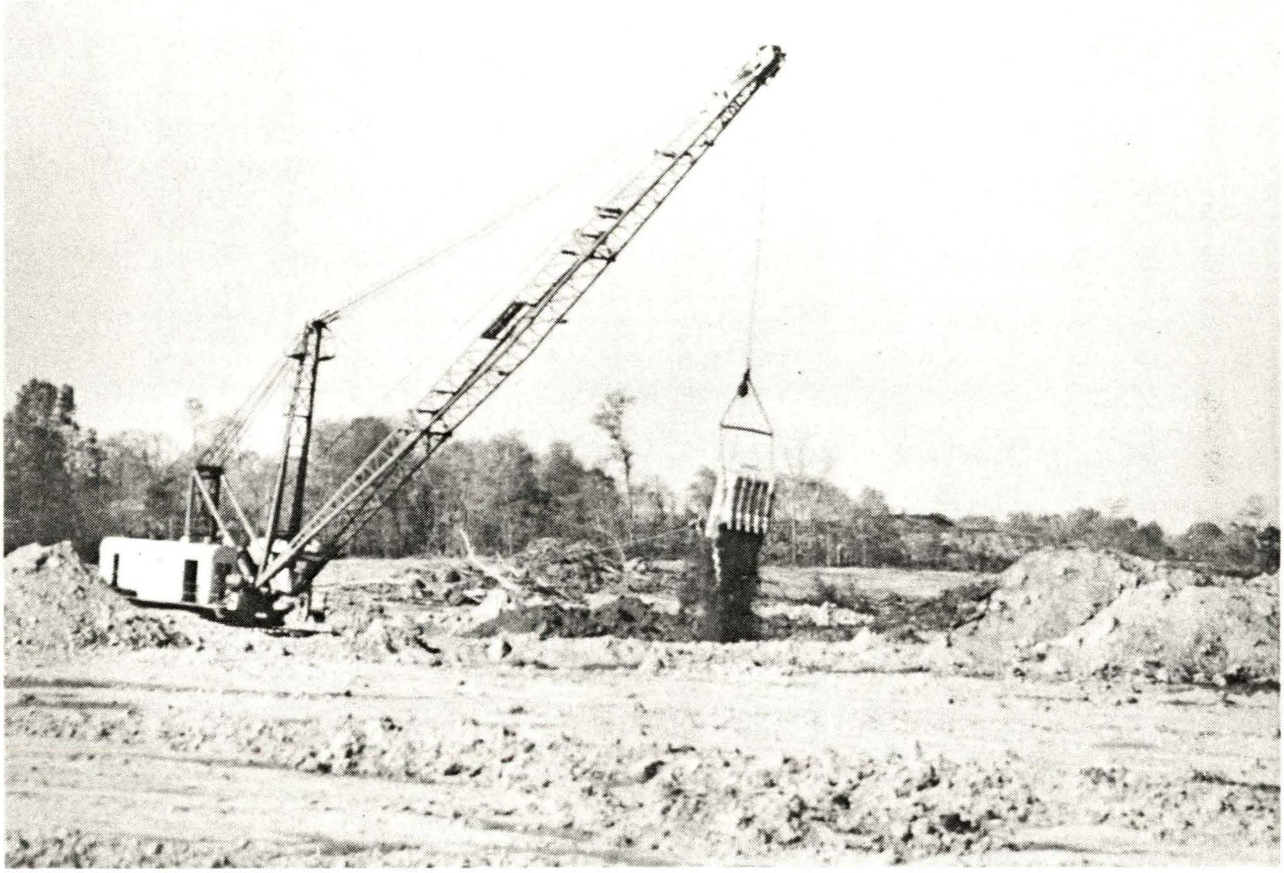

FIGURE 26. Spreading Subsoil with a 6 cu. yd. Dragline on the Delta Mine

Line drawings from aerial photographs of the mine site from an aerial photo depict natural and replaced soils and study plot locations (Figures 27 and 28).

## Power Mine

### General Mine Description

The Power mine is in Henry County, Missouri south of Montrose. The permitted area covers approximately 960 acres and is primarily on gently rolling slopes not to exceed 5 percent. A large portion of the permit area includes prime farmland, primarily of the Hartwell and Deepwater series. The topography of the reclaimed land is similar to the natural landscape which as previously mentioned is nearly level.

### Soil Series Descriptions and Maps

The soil survey report for Henry County lists the series on the mine to be: Barco, Deepwater, Hartwell, Quarles, Urich and Verdigris. The Hartwell and Deepwater series occur most frequently in front of the pit and are prime farmland. Natural soil plot location within series boundaries is shown in Figure 29.

During sampling, the soil series exhibited some distinct features. Among these were very granular structure, prominent red color, and gypsum crystals in the upper subsoil samples of the Hartwell.

#### Hartwell Series

The Hartwell series consists of deep, somewhat poorly drained and nearly level to generally sloping soils on broad upland divides. These soils formed in loess and silty and shaley materials. The native vegetation is tall prairie grasses.

In a representative profile, the surface layer is very dark grayish-brown silt loam about 10 inches thick. The subsurface layer is grayish-brown silt loam about 5 inches thick. The subsoil is about 27 inches thick. The upper part of the subsoil is very dark grayish-brown and pale brown, firm and very firm silty clay loam. The underlying material is very pale brown, brownish-yellow, and light brownish-gray silt loam.

Permeability is slow, available water capacity is moderate, and content of organic matter is moderate to high. Natural fertility is medium, and runoff is slow to medium. A perched water table is on top of the very firm clay subsoil in wet seasons. The major limitations to the use of these soils are wetness in spring, droughtiness in summer and susceptibility to erosion.

Many areas of these soils are used for row crops. A large acreage is used for hay and pasture.

FIGURE 27. Line Drawings of Aerial Photographs Showing Positions of Natural Soil Test Plots on the Delta Mine

FIGURE 28. Line Drawings of Aerial Photographs Showing Replaced Soil Test Plots on the Delta Mine

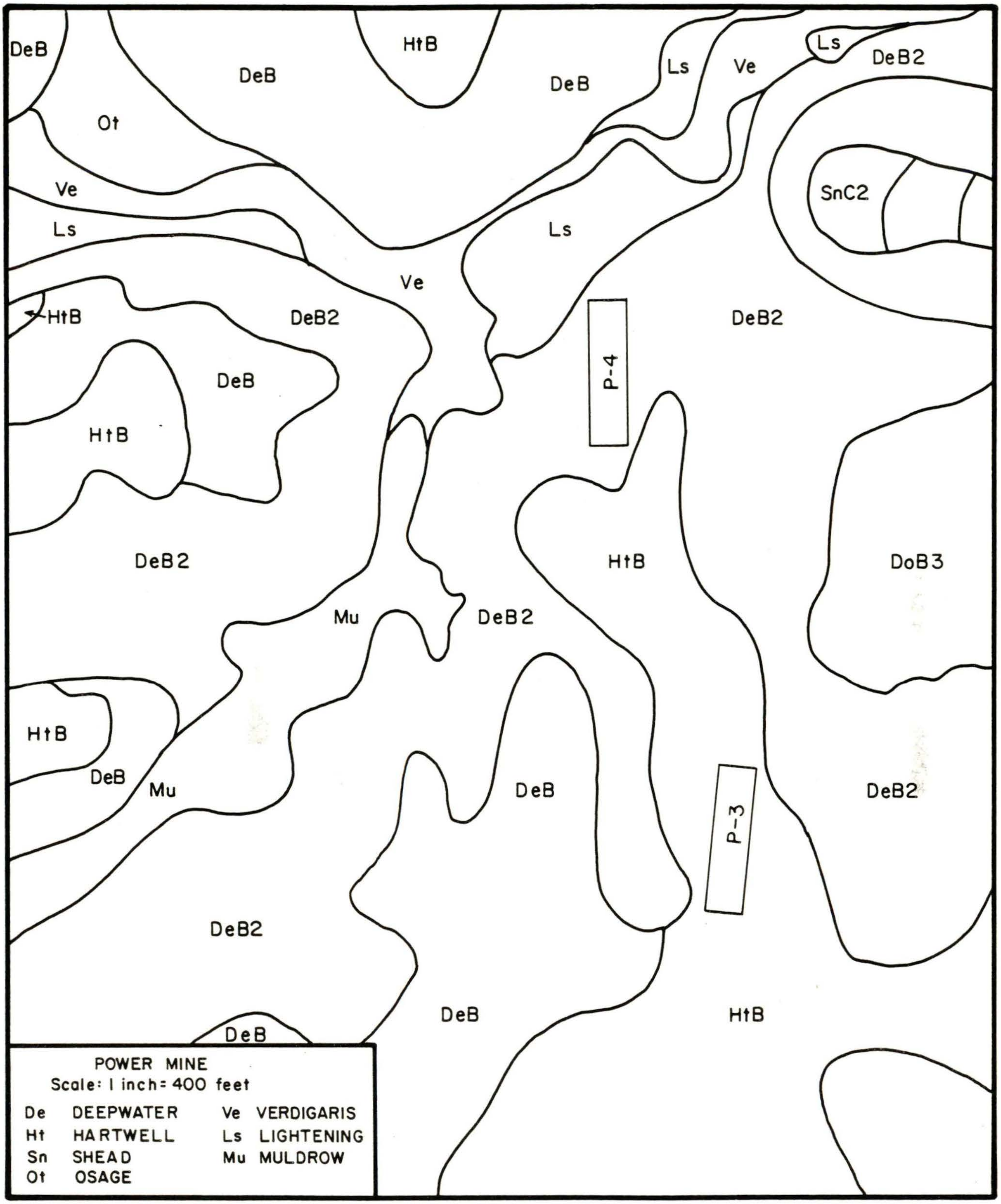

FIGURE 29. Natural Soil Map Illustrating Positions of Natural Soil Test Plots on the Power Mine

Hartwell silt loam was found on 0 to 2 percent slopes, 230 feet south and 430 feet west of the northeast corner of Sec. 32, T. 41 N., R. 26 W.

## Deepwater Series

The Deepwater series consists of deep, moderately well drained, gently sloping to moderately sloping soils on upland divides. These soils formed in residuum weathered from shale and covered with a thin loess mantle. The native vegetation is tall prairie grasses.

In a representative profile, the surface layer is silt loam about 18 inches thick. The upper part is very dark grayish-brown, and the lower part is dark brown. The subsoil is silty clay loam that extends to a depth of more than 60 inches. The upper part is brown and friable, the middle part is light gray and light yellowish-brown and firm, and the lower part is light brownish-gray and firm and has shale fragments.

Permeability is moderate, available water capacity is high to very high, and content of organic matter is medium to high. Most areas of these soils are used for cultivated crops and hay. Some areas are used for pasture.

A representative profile of Deepwater silt loam shows 2 to 5 percent slopes, in a bluegrass pasture 1,370 feet north and 30 feet west of the southeast corner of Sec. 33, T. 42 N., R. 26 W.

## Soil Series Descriptions

### Hartwell Series

A1--0 to 10 inches, very dark grayish-brown (10YR 3/2) silt loam; weak, fine, granular structure; very friable; common roots; medium acid, abrupt, smooth boundary.

A2--10 to 15 inches, grayish-brown (10YR 5/2) silt loam; weak, fine, granular structure; very friable; common roots; medium acid; abrupt, smooth boundary.

B21t--15 to 22 inches, very dark grayish-brown (10YR 3/2) clay; few, fine, prominent, red (2.5YR 4/6) mottles; moderate, fine subangular blocky structure; very firm; few roots; common small concretions; patchy clay films on ped surfaces; medium acid; clear, smooth boundary.

B22t--22 to 28 inches, grayish-brown (10YR 5/2) and yellowish-brown (10YR 5/6) clay; few, fine distinct, red (2.5YR 4/6) mottles; weak, medium, subangular blocky structure; very firm; many fine concretions; patchy dark gray (10YR 4/1) clay films on ped surfaces; medium acid; clear, smooth boundary.

B31t--28 to 33 inches, mottled grayish-brown (10YR 5/2), pale brown (10YR 6/3), and brownish-yellow (10YR 6/6) silty clay loam; weak, coarse, angular blocky structure; very firm; many small concretions; dark gray (10YR 4/1) clay coatings on cleavage faces; neutral; clear, smooth boundary.

B32t--33 to 42 inches, pale brown (10YR 6/2) silty clay loam; many, medium, distinct (30 percent by volume), very pale brown (10YR 7/4) mottles and (20 percent by volume) brownish-yellow (10YR 6/8) mottles; weak, coarse, blocky structure; firm; dark gray (10YR 4/1) clay coatings in root channels and on ped surfaces; many dark concretions; neutral; clear, smooth boundary.

C--42 to 60 inches, mottled very pale brown (10YR 7/4), brownish-yellow (10YR 6/8), and light brownish-gray (10YR 6/2) silt loam; weak, coarse, subangular blocky structure; firm; few shale fragments; neutral.

The A1 horizon ranges from black (10YR 2/1) to very dark grayish-brown (10YR 3/2) in color and from 8 to 13 inches in thickness. The A2 horizon ranges from dark gray (10YR 4/1) to grayish-brown (10YR 5/2). The A2 horizon is more prominent in nearly level soils. In some places the B22 horizon rests on partially decomposed shale, but a depth of 8 feet or more to the weathered shale is most common. A concentration of gravel appearing as an indistinct lag gravel line at the shale contact is present in some areas. This may indicate some water reworking of the shale materials. In some areas, chert fragments are in the B3 and C horizons.

Hartwell soils are near Deepwater soils. They differ from Deepwater soils in having an A2 horizon, and abrupt boundary between the A and B horizons, and a grayer B horizon.

**Deepwater Series**

A1--0 to 14 inches, very dark grayish-brown (10YR 3/2) silt loam; moderate, medium, granular structure; friable; many fine roots; neutral; clear; smooth boundary.

A3--14 to 18 inches, dark brown (10YR 4/3) silt loam; weak, fine, subangular blocky structure; friable; common fine roots; medium acid; clear, smooth boundary.

B21t--18 to 23 inches, brown (10YR 5/3) silty clay loam; moderate, fine subangular blocky structure; friable; few fine roots; patchy pale brown (10YR 6/3) silt coatings on ped surfaces; few dark concretions; strongly acid; clear, smooth boundary.

B22t--23 to 28 inches, brown (10YR 4/3) silty clay loam; moderate, medium, subangular blocky structure; firm; thin, continuous, dark grayish-brown (10YR 4/3) clay films on ped surfaces; few dark concretions; strongly acid; clear, smooth boundary.

B23t--28 to 46 inches, mottled light yellowish-brown (10YR 6/4) and light gray (10YR 7/2) silty clay loam; moderate, medium, subangular blocky structure; firm; discontinuous black (10YR 2/1) clay films, medium acid; gradual, smooth boundary.

B24t--46 to 62 inches, mottled light brownish-gray (10YR 6/2) and yellowish-brown (10YR 5/6) silty clay loam; moderate, medium, subangular blocky structure; firm; few fine shale fragments; slightly acid.

The A1 horizon ranges from 10 to 18 inches in thickness and from black (10YR 2/1) to very dark grayish- brown (10YR 3/2) in color. The A3 horizon ranges from three to six inches in thickness and from very dark grayish-brown (10YR 3/2) to dark brown (10YR 4/3) in color. The B2 horizon ranges from strongly acid to slightly acid and in most places, becomes less acid with depth.

Deepwater soils are near Barco, Hartwell, and Summitt soils. They have more clay in the B horizon than Barco soils and are underlain by shale, whereas Barco soils are underlain by sandstone. They lack an A2 horizon, which is typical for Hartwell soils. Deepwater soils are more acid and are not as dark colored as Summit soils.

### On-Site Soil Movement

The Power mine was the only study site which utilized scrapers as the primary soil movement method (Figure 30). The Power mine utilized scrapers not only for topsoil movement, but also for transport of 3 feet of rooting medium to compose the 4-foot prime farmland soil cover. Equipment utilization is shown in Table 13. Topsoil was removed with scrapers to a depth of 12 inches and stockpiled for approximately 1 year. The topsoil was also replaced by scrapers following stockpiling.

**TABLE 13. EQUIPMENT UTILIZATION - POWER MINE**

| EQUIPMENT TYPE | SOIL MOVEMENT APPLICATION | EQUIPMENT MANUFACTURER |
|---|---|---|
| Scrapers | Topsoil & Rooting Medium | Caterpillar |
| Bulldozers | Regrading | Caterpillar |

The subsoils were removed with scrapers by lift to a depth of 48 inches, stockpiled for 1 year and then replaced. Bulldozers were used for regrading of both topsoil and subsoil surfaces following soil replacement.

### Reclamation Program

The reclamation programs on the Power mine were analyzed by study plot location due to differences in soil management practices. Both reclaimed areas on the Power Mine were ripped in the study plot areas. Ripping was accomplished utilizing an agricultural ripper pulled by a 4-wheel drive tractor. No bulldozer ripping occurred on any study site.

FIGURE 30. Scrapers Used for Both Topsoil and Subsoil Removal and Transport on the Power Mine

Location of these study plots will be discussed in the next section. The soil was replaced 2 years prior to sampling on Plot 2 and 1 week before sampling on Plot 1. Plot 2 was originally disced and planted in wheat in the fall of 1979. Upon maturity, the wheat was plowed under and both plots were seeded in alfalfa during November, 1980.

### Soil Study Plot Location and Aerial Site Maps

The plot identification code will be carried throughout the report to provide clarity in data analysis. The primary series found were the Deepwater and Hartwell. Plot identification numbers are found in Table 14.

**TABLE 14. STUDY PLOT IDENTIFICATION - POWER MINE**

| PLOT NO. | SOIL AREA IDENTIFICATION | SOIL TYPE |
|---|---|---|
| P-1 | Reclaimed | Series Mixture |
| P-2 | Reclaimed | Series Mixture |
| P-3 | Natural | Hartwell |
| P-4 | Natural | Deepwater |

An aerial site map is provided for location of study plots in Figures 31 and 32.

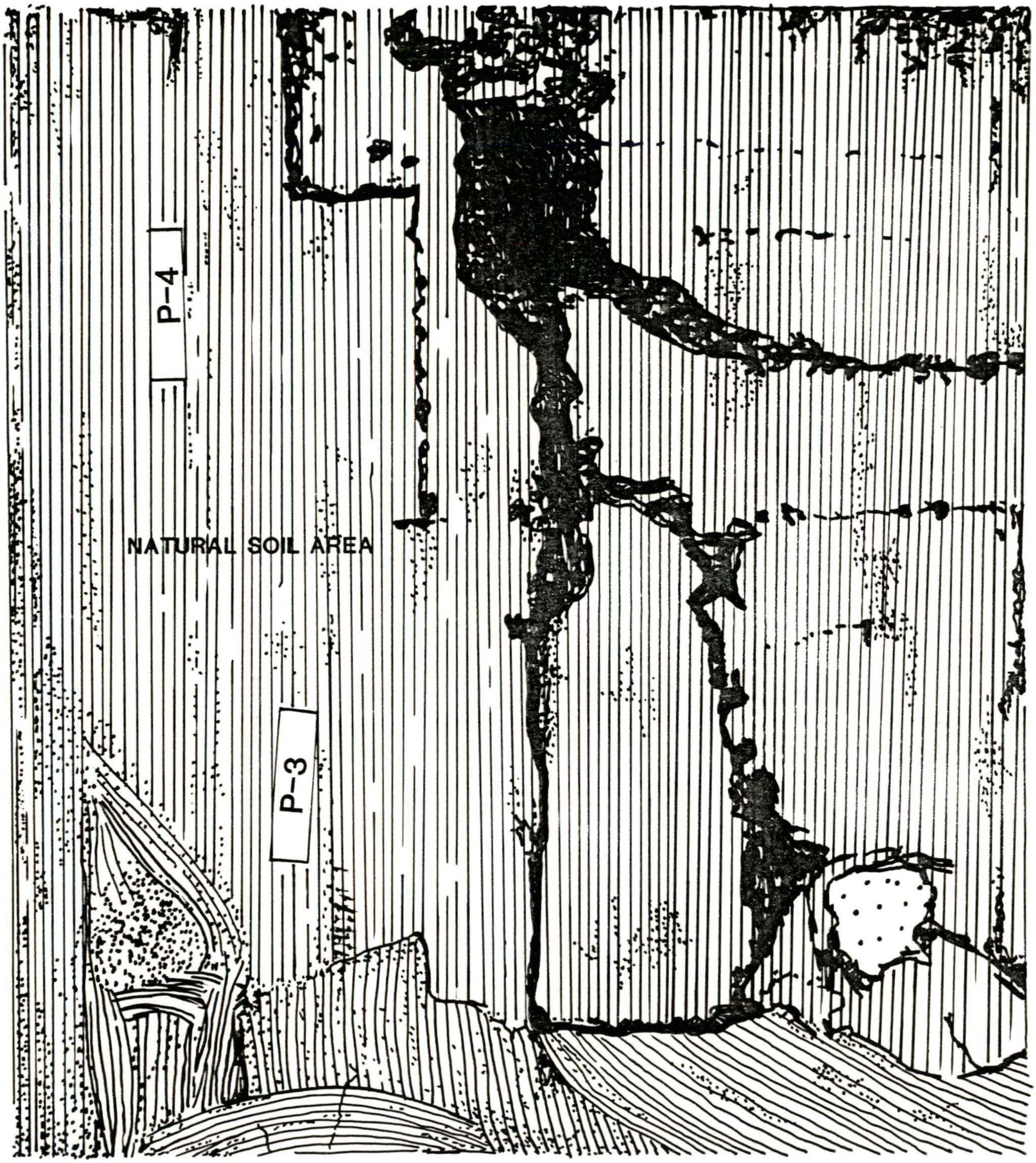

FIGURE 31. Line Drawing of an Aerial Photograph on the Power Mine Showing Natural Soil Test Plots (P-3 and P-4)

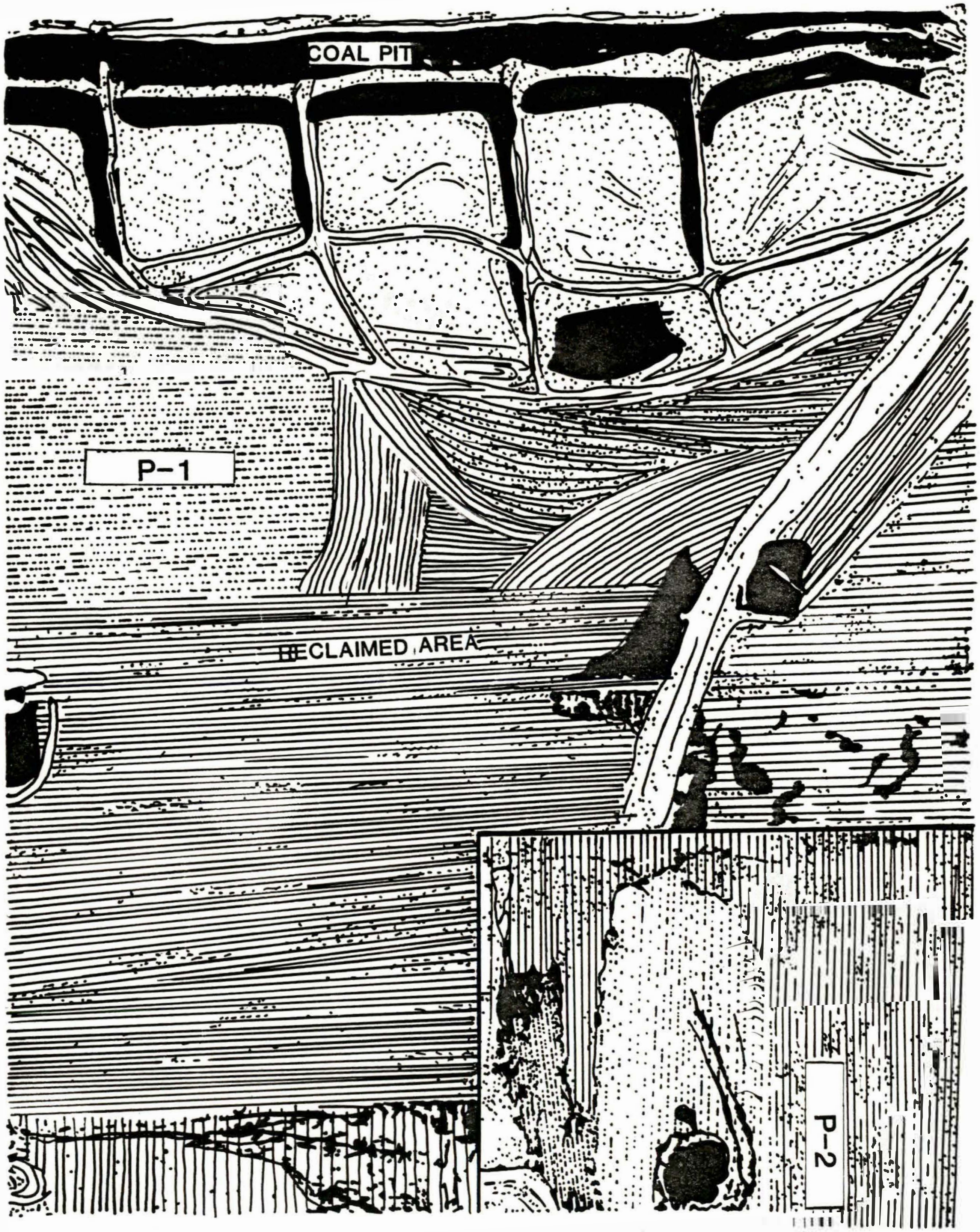

FIGURE 32. Line Drawing of an Aerial Photographs on the Power Mine Showing Replaced Soil Test Plots (P-1 and P-2)

# DESCRIPTION OF FIELD STUDY RESULTS

## Introduction

The Description of Field Study Results section of this report presents concise summaries of field data. Presentation of project field data is by individual study as described in the experiment design and sampling program section of this report. The format of data portrayal is conducive to individual evaluation by separate study and for a comprehensive data evaluation for correlation of results over the entire report. Results of the field study are reported and data evaluations performed under the following topics :

- **Bucket-Wheel and Scraper Data Summaries**
- **Scraper Analysis by Lift Data Summaries**
- **1982 General Field Data Summaries**
- **Statistical Analysis Summary**
- **Special Data Evaluations**
- **Comprehensive Data Evaluation**

Bucket-Wheel and Scraper Data Summaries present raw data in graphical form collected in the 1984 field study. This field study is conducted on one mining operation, on one general soil type comparing two separate equipment systems and the effectiveness of each in controlling bulk density. In addition to bucket-wheel and scraper systems data is also presented in the statistical summary from the Brazil mine representing the end-dump haulback method. As discussed in the case studies section the end-dump haulback plots were not constructed on the Captain mine. The equipment needed to build the Haulback plots was needed in reclamation activities before winter weather stopped work. The Brazil mine Haulback data is included in the "Statistical Analysis Summary" for comparison to the other systems. Inclusion of the haulback data also provides a representation of the influence of changing soil characteristics because data is presented from another mine site.

The Scraper Analysis by Lift Data Summaries illustrate the impact of scraper traffic on soil lift replacement to a depth of 4 feet. Data is presented for the unique windrow experiment analyzing the effect of lift and pass on replaced subsoil bulk densities. This section of data presentation illustrates the impact of repeated subsoil lifts and how the impact of replacing the soil in layers affects overall bulk density characteristics.

In the 1982 General Field Data Summaries data from field studies performed on four separate mine sites in the Midwest are presented in graphic portrayals. The graphic representation of the data illustrates the correlation between bulk density, equipment type and their relationship to soil texture. The presentation of these data correlates directly to equipment type and utilization practices illustrated in Section 4 - Case Studies of this report. The 1982 data is presented to combine with the 1984 data to provide a large base of soil density and texture information for the Soil Compaction Prediction Analysis (Section 6).

The Special data evaluations section displays data which is presented to analyze bulk density changes over time on one site-specific test plot. This analysis is not a statistically sound experiment that identifies soil changes over time, but rather an indication of the recovery time of soils reclaimed using the bucket-wheel excavator.

Before continuing into the presentation of project results a review of methodology of how the graphs are formulated and presented is important to understanding project results. Each individual experiment is represented by the following two types of graphs:

**o Bulk density graphed with depth, and**
**o Texture content graphed with bulk density**

The bulk density graphs contain data from the natural soil areas compared to data collected in areas where soils are replaced using different types of equipment. The zones of equipment influence are indicated across the top of the graphs to illustrate the extent to which an individual piece of equipment effects bulk density to a given depth. These zone delineations indicate the effects of individual equipment types on soil density within the scope of the entire equipment system.

Natural soil test plots are selected for their representation of major soil series in the areas of soil removal. The presentation of both natural soil data along with reclaimed data clearly indicates how bulk densities change with depth after soil replacement. Each point plotted on the density graphs is the result of averaging 10 density observations taken in the field at a given location and depth. Although data points are connected by lines to indicate trends, the data presented is not continuous. In theory the data values between data points follow the general trend of either increasing or decreasing in density. Testing of individual core samples collected every 6 inches throughout the profile indicate that viewing the data as continuous is valid in the majority of cases.

Soil texture graphs are composed only of subsoil analysis for the first, second or third samples in each core. For evaluation of changes in texture in the rooting medium zone below the topsoil, only subsoils were analyzed for texture class. In the texture graphs each point plotted consists of an average of five samples. In describing data results, the terms increasing and decreasing are used to denote data trends. Increasing and decreasing are used to describe reclaimed soils changes such as texture and density with respect to natural soil data found on the same graph.

The statistical analysis summary provides an indepth analysis of statistical interactions involved in the analysis of the previously described experiments. A complete list of analysis of variance models are contained in Appendix C.

The data evaluations section identifies major trends in the data as they pertain to the relationship of bulk density with depth and texture in both natural and reclaimed soil areas. Special data evaluations are noted that examine special handling practices, such as topsoil windrowing, in the total equipment management scheme for prime farmland reclamation.

Detailed summaries of all data presented in this section are presented in tabular form in Appendices A and B.

## 1984 Bucket-Wheel and Scraper Data Summaries

### Overview

In this study, the two distinct soil movement methods primarily used for soil removal, transport and replacement on surface mining operations are analyzed. The two equipment methods are of subsoil replacement in repeated single lifts, such as that utilized by scrapers or subsoil replaced in a single lift such as that found in the bucket-wheel excavator, end-dump haulback and dragline methods of soil replacement. The use of the term lift denotes the depth of soil replacement associated with a given equipment type. Similarities exist between the equipment systems that deposit soil in a single lift. For purposes of this analysis, the effect of scraper pans are compared to the single lift replacement effects of the bucket-wheel excavator on the same general soil type. Soil type, by definition in this analysis, is the new reclaimed soil constructed for subsoil replacement purposes by different equipment. Following review of these data, isolation of strictly the machine impact on soil compaction will be put in proper perspective with relationship to overall changing soil characteristics.

### Wheel Data Summaries

Plot development methods used for the wheel and scraper analyses are the same as those utilized in the previous section and described in the experiment design. Reclaimed soil test plots are located and sampled and then compared to natural soil test data which was collected in the 1982 study on the same mine. The results of this testing that compares natural and reclaimed soils with respect to soil density is illustrated in Figure 33.

#### Bulk Density

The natural soil test data follow a general trend, that is increasing density with depth. On these bucket-wheel test plots, topsoils are found, as indicated previously, to approximate natural soils in their overall densities due to tillage practices. The second sample shown at approximately the 15-inch depth indicates where the greatest amount of soil compaction occurs. This interface is caused by scraper/dozer traffic in topsoil replacement. The next sample at the 28-inch depth indicates that the bucket-wheel- removed material replaced with the spreader arm as shown in Figure 33 decreases the overall compaction by virtue of less traffic. The 44-inch depth sample further substantiates this compaction reduction when the spreader is used for subsoil replacement. Shown in Figure 33 at the top of the

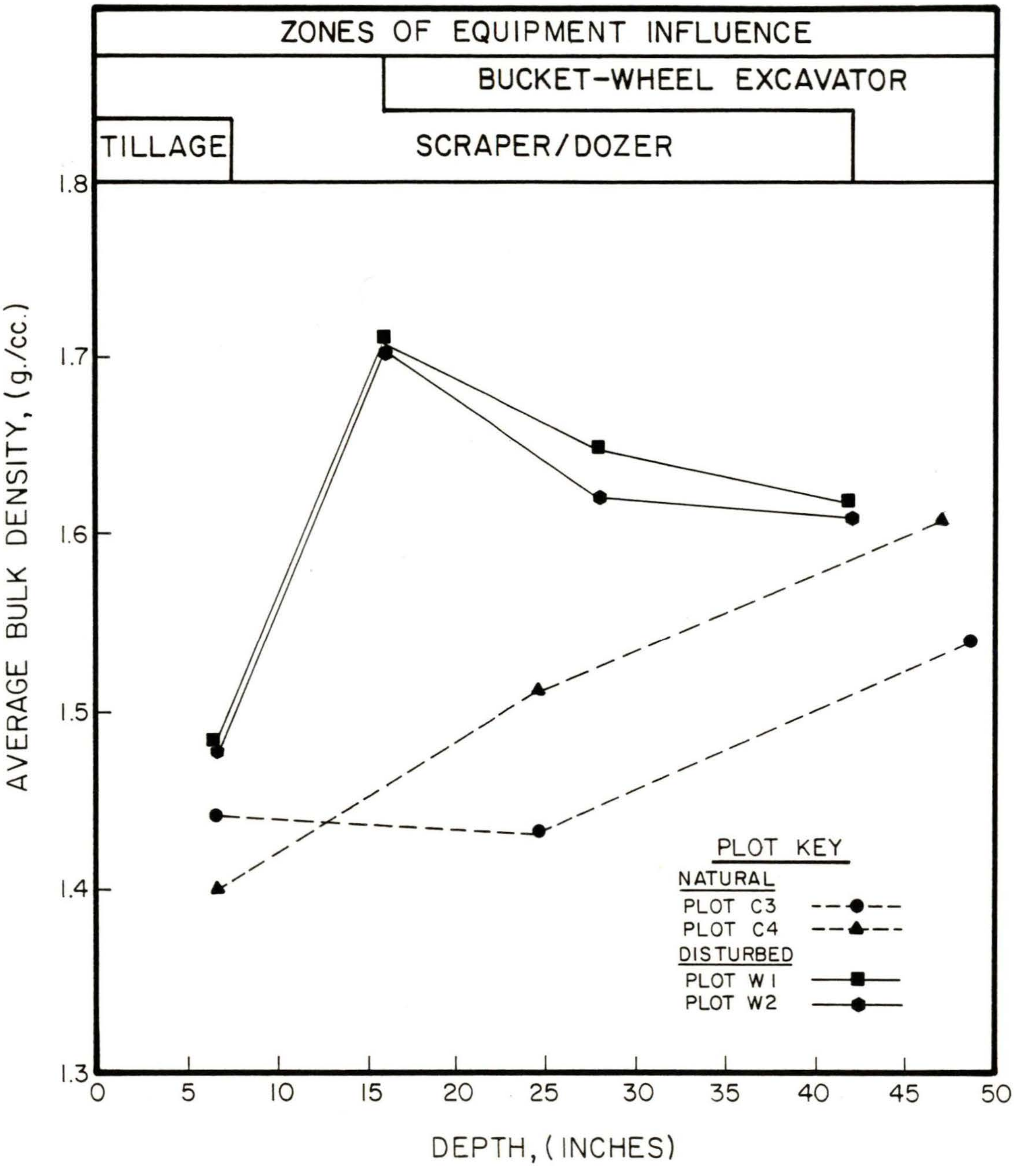

FIGURE 33. Bulk Density Changes with Depth on the Captain Mine Bucket-Wheel Plots (W-1, W-2, C-3 and C-4)

graph, the density range where the bucket-wheel system takes effect causes an overall decrease in soil density . The scraper traffic for topsoil replacement not only effects the 10- to 25-inch depth, but also the influence of scrapers extends into the lower subsoil zones to the 3-foot depth.

These data also include one other equipment utilization or method which is becoming more and more widely used in the Midwest. This method is that of topsoil windrowing. The windrowing effect results in an overall reduction in scraper traffic, and thereby a reduction in density values in the lower subsoil regions. The technique, briefly described, involves replacing soil in a long windrow approximately 1.5 times the width of the scraper pan and up to 10 feet in depth. Following windrowing a low ground pressure tractor is used to spread the topsoil material thereby keeping tractor traffic on the high organic topsoil material and reducing tractor subsoil contact. This data summary indicates a severe topsoil replacement problem with scrapers, but indicates density reduction in wheel spreader replaced soil.

## Soil Texture

Texture evaluations by percent versus bulk density follow general trends. For the wheel plots, average sand contents are illustrated in Figure 34. As presented, natural soils range in average sand percentage from 2 to approximately 10 percent, while reclaimed soils sand content increases to approximately 14 to 20 percent. Along with this increase in sand content comes the inevitable increase in density due to machine impact on a higher sand content soil. This increase in sand content is caused by mixing of the subsoils with glacial till when removed with the wheel.

Average silt percentages in relationship to bulk density are illustrated in Figure 35. As shown, the average silt percentage decreases from natural to reclaimed soil while the given bulk density value for the reclaimed soil is higher than for natural soils. This decrease in fine textured particles, as will be shown later, has a distinct impact on the compactability of a given soil. Silt contents for natural soils range from approximately 57 to 72 percent, while reclaimed soils range from 53 to 64 percent. A significant reduction in silt in reclaimed soils is clearly evident. Again the reduction in silt in the reclaimed soils is explained by the introduction of glacial till into the profile.

Average clay content illustrated in Figure 36, remains approximately the same for natural and replaced soils; both range from 20 to 40 percent. However, density values increase from 1.55 (natural) to 1.65 in reclaimed soils. This increase in density is due to the overall change in texture, and is not entirely governed by clay content.

In summary, the general trends from natural to replaced soils are:

- **Average sand contents are increasing**
- **Average silt contents are decreasing**
- **Clay contents remain approximately the same**

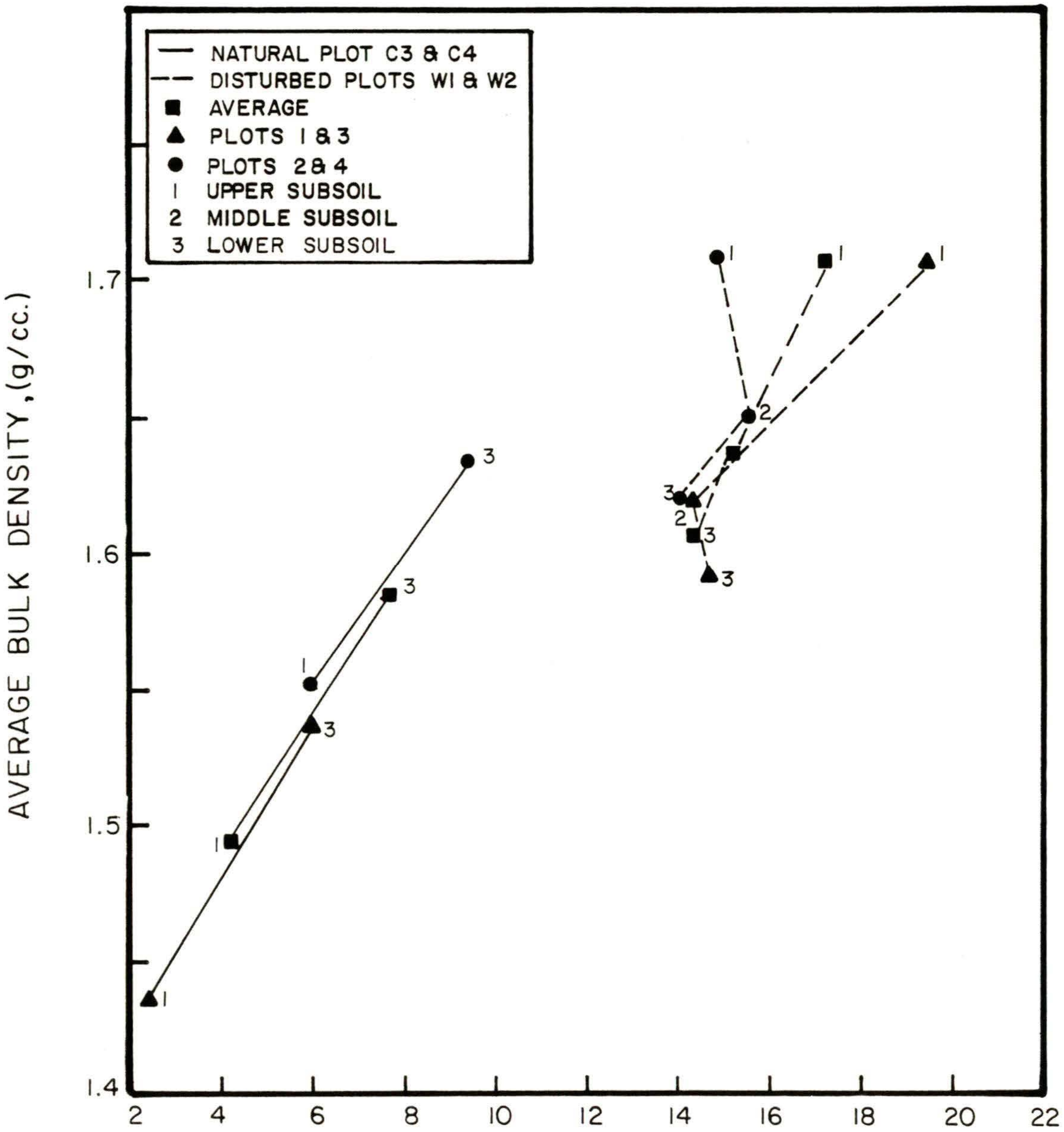

FIGURE 34. Change in Sand Content with Increasing Bulk Densities for Subsoils on the Captain Mine Bucket-Wheel Plots

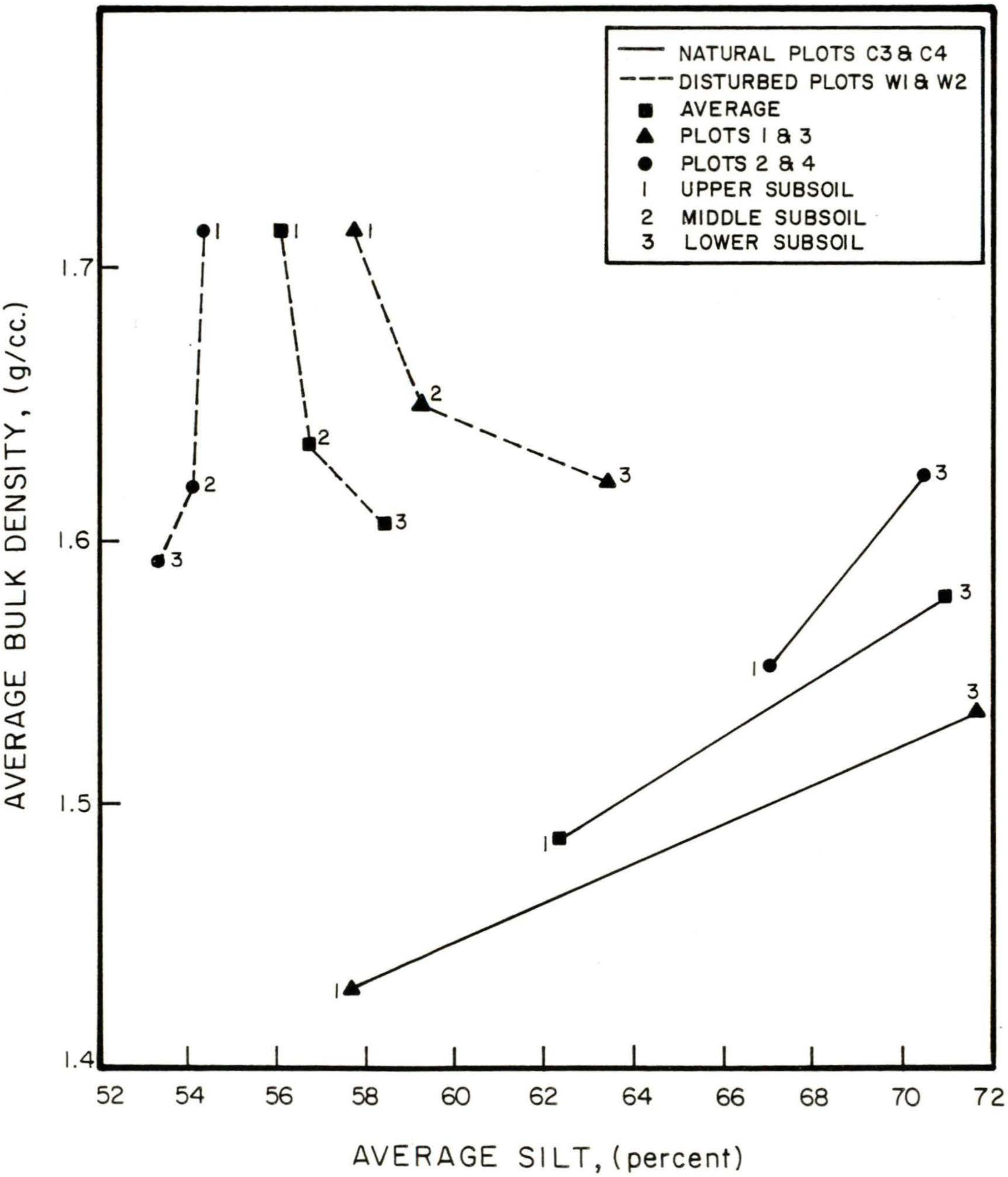

FIGURE 35. Change in Silt Content with Increasing Bulk Densities for Subsoils on the Captain Mine Bucket-Wheel Plots

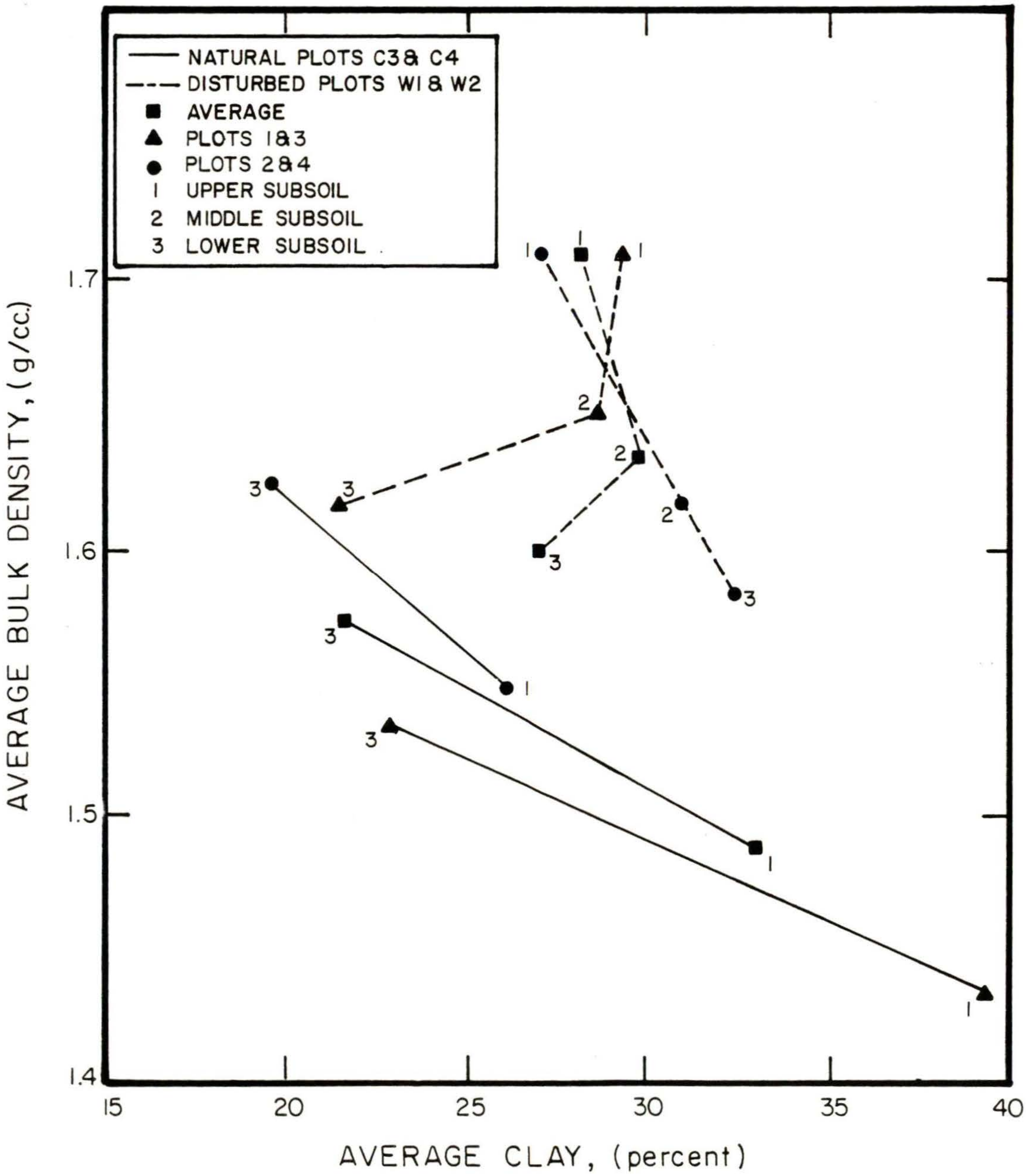

FIGURE 36. Change in Clay Content with Increasing Bulk Densities for Subsoils on the Captain Mine Bucket-Wheel Plots

These changes in texture content is caused by mixing of the subsoils with glacial till when removed with the bucket-wheel. Some change in textural content is probable when soils are mixed in the reclamation process.

## Scraper Data Summary

Scraper plots are located on the same general soil types and tested identically to the wheel plots. Natural soil data for plots C-3 and C-4 are illustrated with reclaimed plot S-2 in Figure 37. Test plot S-2 is actually two plots, but so little variation occurred between plots that they are illustrated as one plot location. The bulk density values of natural soils are the same as those illustrated under the wheel plot data summaries.

### Bulk Density

This graph illustrates bulk densities from topsoil through the lower subsoil region range from 1.4 g/cm$^3$ to a little less than 1.6 g/cm$^3$. In contrast, reclaimed soils although identical for topsoil in the 1.45 range show greater bulk density readings with depth. Notice that unlike the wheel plots previously described, increase in density for the scraper plot is more uniform with an increase in depth. Densities for the lower subsoil exibit values exceeding the 1.7 g/cm$^3$. Two-thirds of the densities reported for reclaimed soils on this plot are over the 1.6 g/cm$^3$. This 1.6 g/cm$^3$ is an arbitrary number for the value believed to inhibit plant growth or adequate root development depending on soil type.

### Texture

As indicated in the next three figures, the sand, silt and clay contents are quite similar to the ones found in the bucket-wheel plots. The general trend of the average sand content increases in the reclaimed soils as illustrated in Figure 38. The natural soils sand contents ranged from 2 to 10 percent while the reclaimed sand contents ranged from 13 to 20 percent.

Silt contents in Figure 39 are shown to decrease from natural to replaced soils. Natural soils range from 57 to 72 percent, while reclaimed plots range from 57 to 67 percent. Silt percentages indicated more homogeneous material in reclaimed soils than the natural soil condition.

Overall clay contents shown in Figure 40 decrease in the reclaimed soils. Natural soils range from 18 to 40 percent, while reclaimed soils occupy a very narrow range of 18 to 23 percent. A much more homogeneous clay content is found in the reclaimed soils. The experiment design goal was met through an analysis for texture values where sand, silt and clay contents on test plots in both bucket-wheel excavator and scraper plots were found to be approximately equal. This eliminated another factor which is involved in the soil compaction process and focussed the analysis more on the effect of the machines.

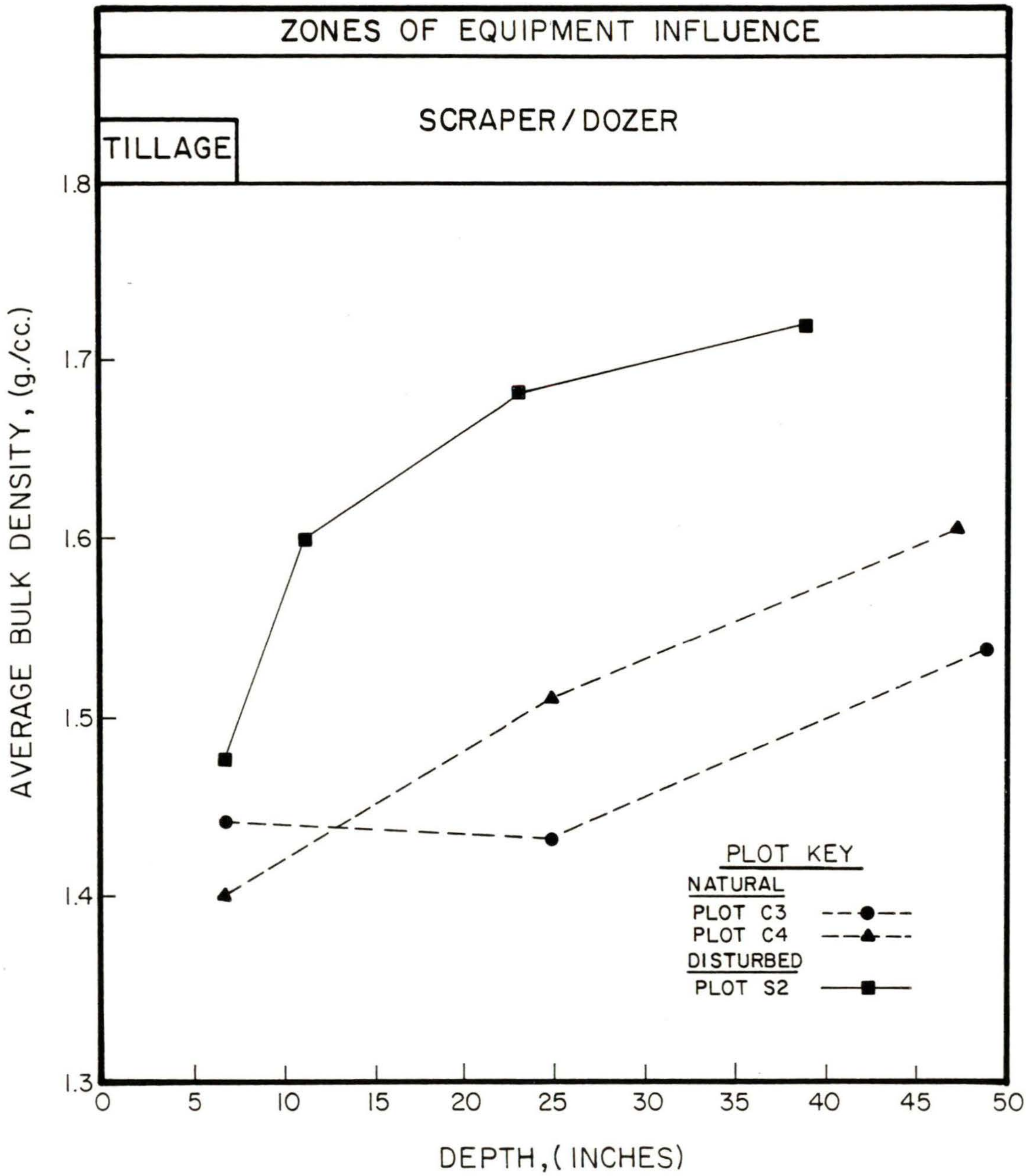

FIGURE 37. Bulk Density Changes with Depth for Scraper Plots (S-2, C-4 and C-3) on the Captain Mine

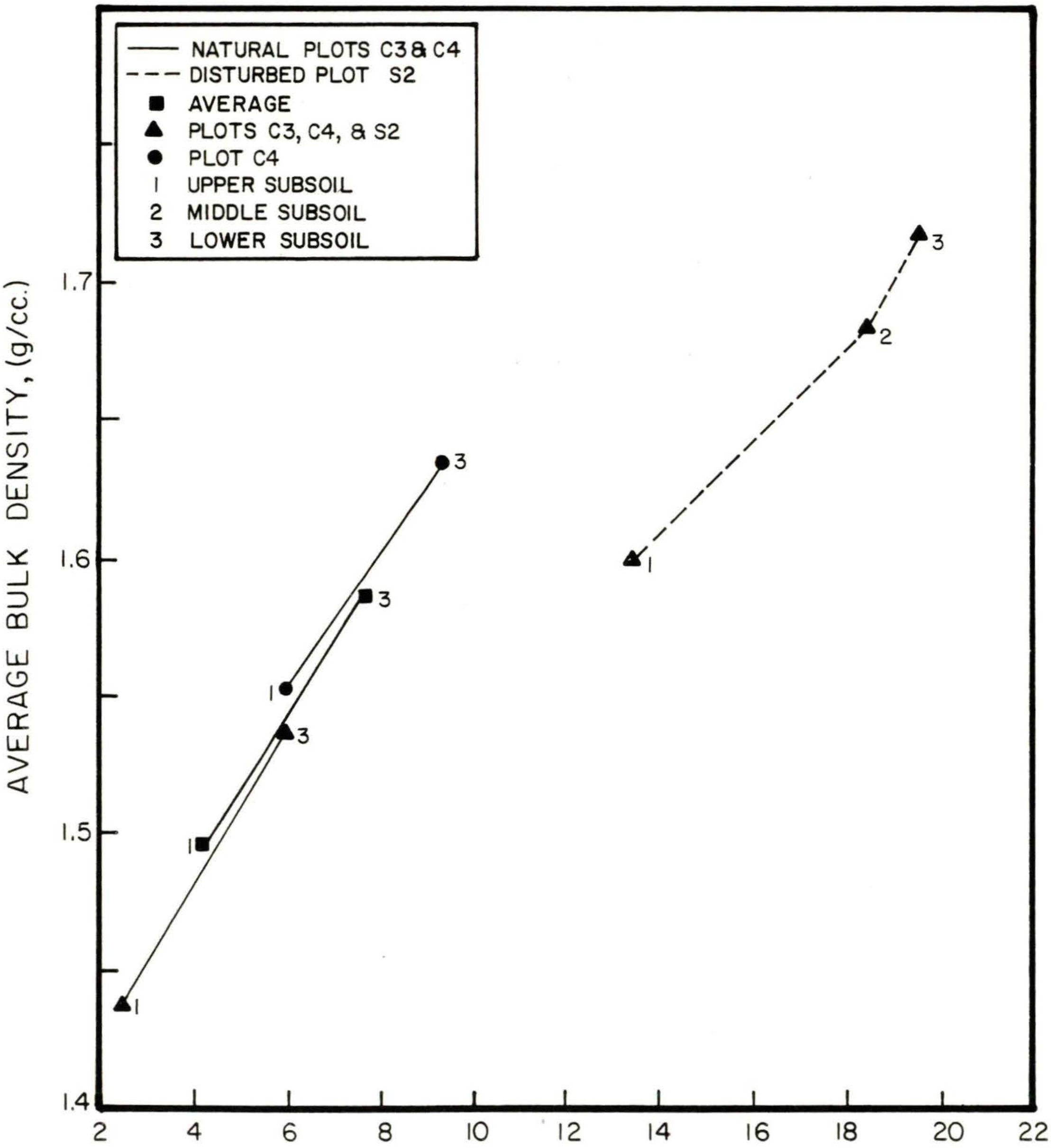

FIGURE 38. Change in Sand Content with Increasing Bulk Densities for Subsoils on the Captain Mine Scraper Plots

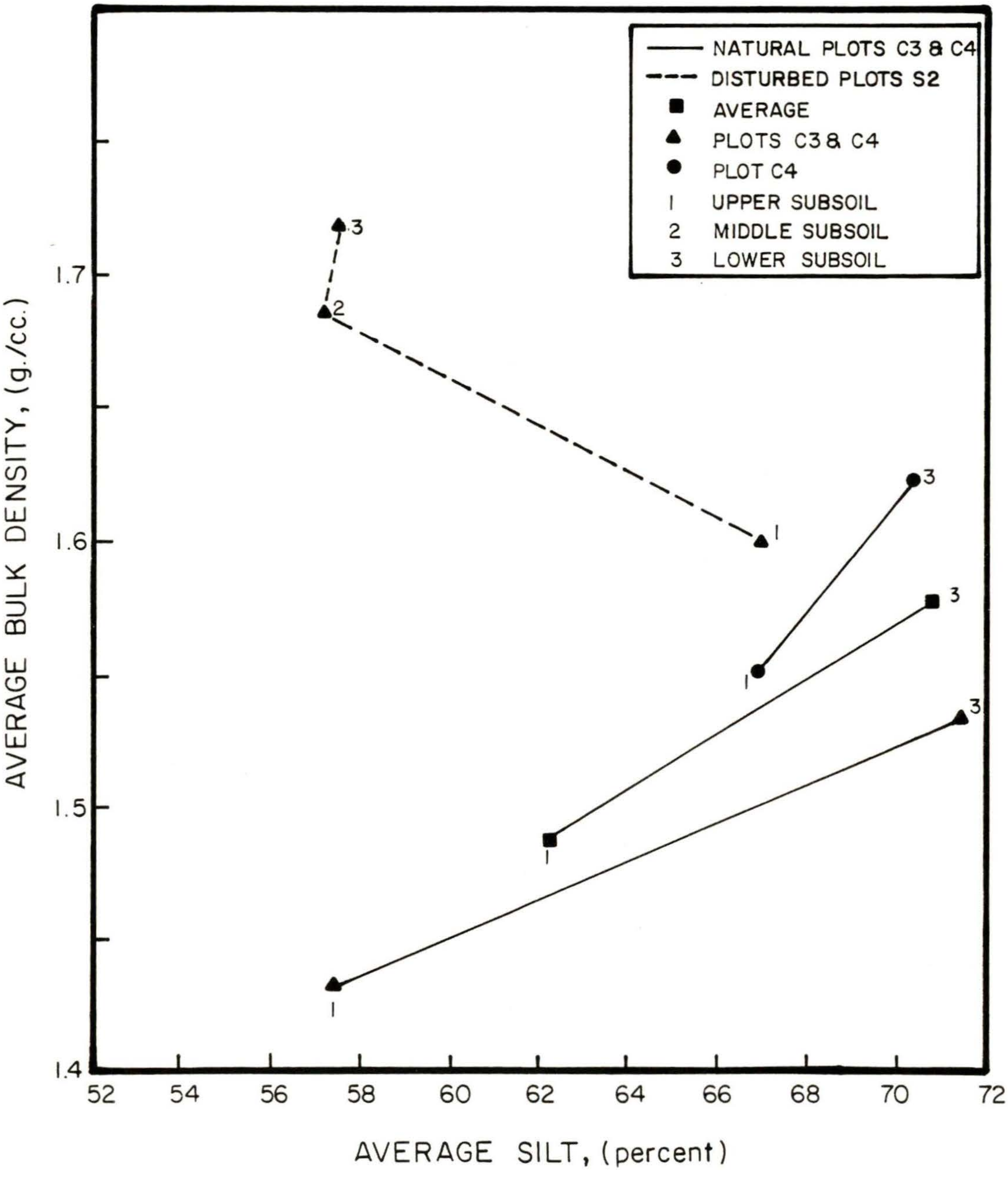

FIGURE 39. Change in Silt Content with Increasing Bulk Densities for Subsoils on the Captain Mine Scraper Plots

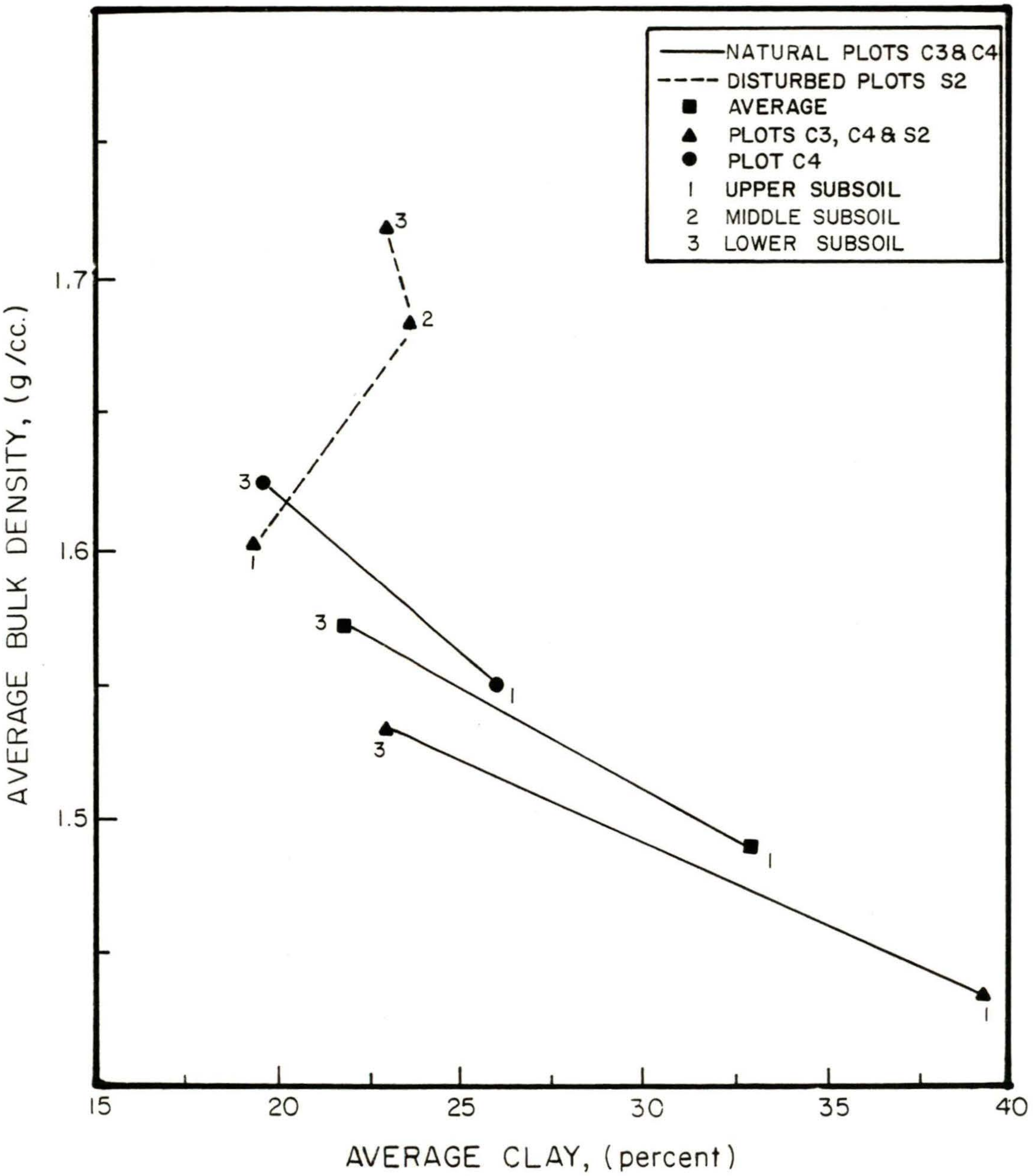

FIGURE 40. Change in Clay Content with Increasing Bulk Densities for Subsoils on the Captain Mine Scraper Plots

In summary, changes in texture from natural to reclaimed soils are:

- **The sand content is increasing**
- **The silt content is decreasing**
- **The clay content is decreasing**

### Data Evaluation

To summarize the effect of scrapers versus bucket-wheel excavators in soil compaction, the data indicates specific trends in equipment impact. Results for the end-dump haulback method and the dragline method would be similar to the bucket-wheel excavator if soil conditions were similar. This result is based on the soil density and texture changes involved in reclaiming the soil in a deep lift. The scraper compaction indicates a general increase in density values to a maximum at the 44-inch depth of over 1.7 g/cm$^3$. The bucket-wheel excavator with scraper for topsoil replacement indicates an area of greatly increased density directly below the topsoil region if scrapers are used for replacement. The bucket-wheel excavator with the spreader used for subsoil placement indicates high density values as compared to natural soils in the 25- to 35-inch depth while the 40- to 48-inch depth values are similar between natural and replaced soils.

The bucket-wheel and scraper equipment systems both produce bulk density values over the 1.6 g/cm$^3$ level which in theory inhibits plant growth and root development. The impact of scrapers versus bucket-wheel excavators indicates that scrapers cause high levels of soil compaction in the lower and upper subsoil, while the bucket-wheel system causes soil compaction in the upper subsoil at the topsoil/subsoil interface. The bucket-wheel excavator plots indicate that soil compaction occurs due to scraper traffic in the upper subsoil region, while scrapers cause a gradual increase in density with depth, the highest density occurring in the lower subsoil region.

## 1984 Scraper Analysis by Lift Data Summaries

### Design Summary

The objective of this study is to evaluate actual scraper-induced compaction and analyze this compaction by sample collection on a lift by lift replacement plot. Basic experiment design hinges on the development of a scraper- built soil test plot in which subsoil material is utilized to construct a 4-foot deep lift for soil compaction analysis. A photograph of scraper pan construction of the first 12-inch lift of the windrow test plot, is shown in Figure 41.

The experiment is designed to evaluate the effect of 12-inch soil lifts replaced to a depth of 4 feet by measuring the effect both within the lift itself, and on the preceding lift. Figures 42, 43 and 44 illustrate the construction of the four lifts to a depth of 4 feet. The study is developed by constructing a single lift of material with scrapers to a depth of 12 inches, subsequently coring that lift for bulk density samples and texture analysis, then replacing the second lift, sampling

**FIGURE 41. Construction of the First Lift of the Scraper Windrow Test Plot with 12 Inches of Subsoil**

FIGURE 42. Sampling of Second Lift of Windrow Test Plot Following Scraper Soil Replacement

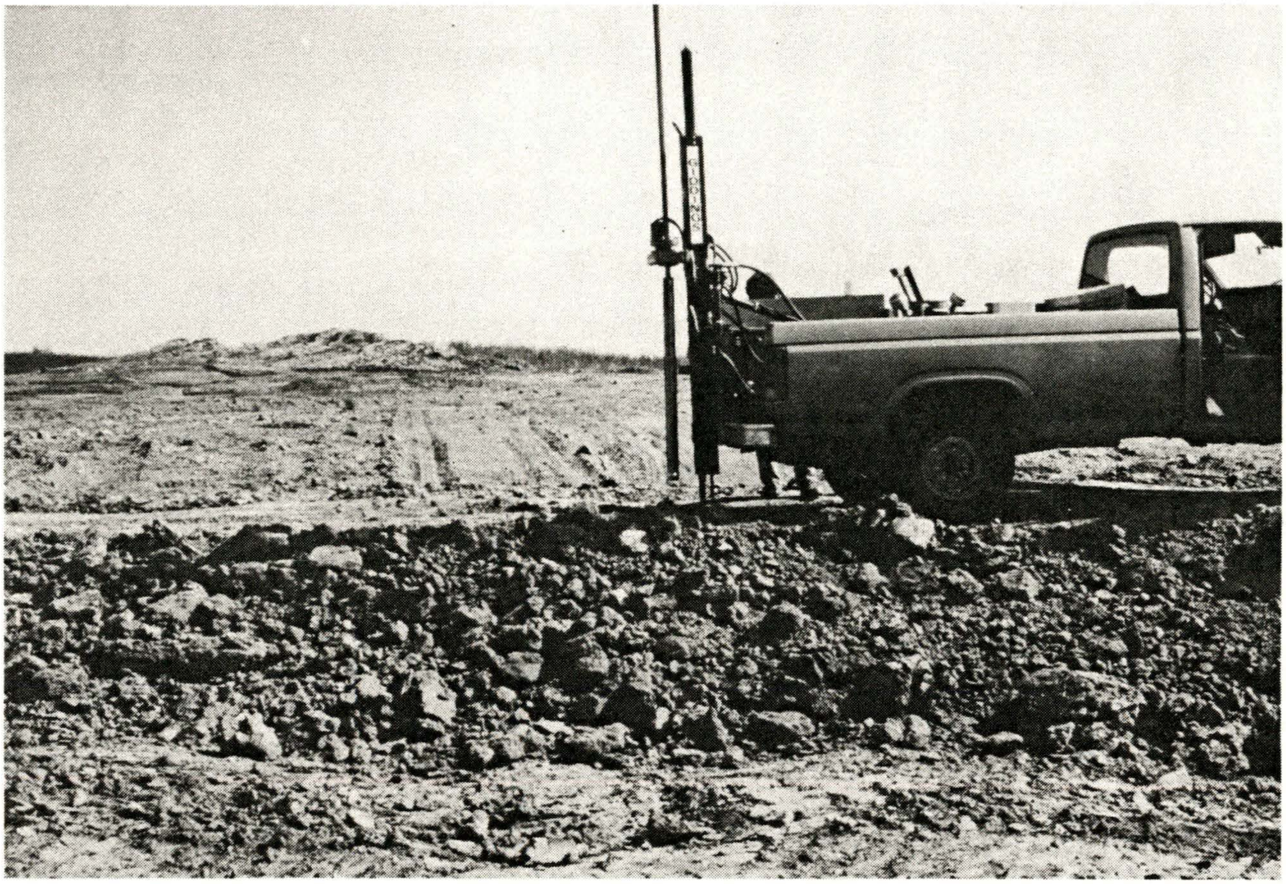

FIGURE 43. Side View of Sampling Third Lift of Windrow Test Plot Following Scraper Replacement

FIGURE 44. Sampling of Fourth Lift of Windrow Test Plot Following Scraper Replacement

that lift while in turn sampling the first lift. This sampling scheme was utilized to a depth of 4 feet.

In this field study one particular aspect is of great importance, overall plot moisture content. The moisture contents for the study plot were very low due to very dry conditions in the field during the summer of 1983. Moisture contents ranged from approximately 10 to 12 percent over the entire plot study area. These low moisture contents are not generally representative of actual field conditions in seasons of normal rainfall. There is an advantage to the low moisture contents with respect to bulk density analysis. Soil strength, which governs the overall compactability of the soil, is dependent to a large degree on soil moisture content. Where soil moisture content is at a very low level, the experiment interprets data in a "best case" situation with respect to bulk density. In other words, compactability of the soil is at its lowest point with respect to soil strength. This analysis therefore interprets what is possibly the best overall soil compaction that can be achieved under the constraints of the soil types utilized in plot development. All subsoil material for construction of the scraper plots is removed from the same area in the same stockpile to achieve uniformity of texture content in each lift replaced. Data collected from each individual core sampled is analyzed for bulk density and texture with each data value correlated directly within each core sample.

## Scrapers by Lift Data

This section evaluates changes in bulk density and texture on a lift by lift basis in a windrow test plot. Data for bulk density values recorded are illustrated in Figure 45. Each data point indicated on the chart represents an average of core samples pulled and analyzed for bulk density at that point. The graphic portrayal of the data is a computer generated data representation converted to a bar chart of bulk density values by lift and pass. Lift is defined as a 1- foot deep layer of soil. The overall analysis covers a 48- inch depth composed of four 12-inch soil layers or lifts. Pass is defined as the tracking of the soil as the scraper replaces another lift. As an example, Lift 1 would contain only one pass when it is replaced, while Lift 1 after the fourth lift replacement of soil is interpreted as the fourth pass by the scraper pan over the first lift. This analysis revolves around this lift by pass effect under low moisture contents in a windrow test plot shown earlier in this text.

A summary of changing bulk density characteristics by lift and pass indicates a marginally significant lift by pass interaction based on a 5 percent level of significance of 0.09. In order to evaluate the lift by pass bulk density values collected, an individual evaluation of changing bulk density will be discussed by lift. Shown graphically in Figure 45, Lift 1 values follow this pattern in bulk density for each of the four passes of the scraper on the first lift. Average bulk density values on the first pass are 1.67 g/cm$^3$, second pass equals 1.67 g/cm$^3$, third pass equals 1.69 g/cm$^3$, while the fourth pass drops back to 1.63 g/cm$^3$. As reported, the data cover a narrow range of bulk density values from 1.63 to 1.69 g/cm$^3$, with an overall change of .06.

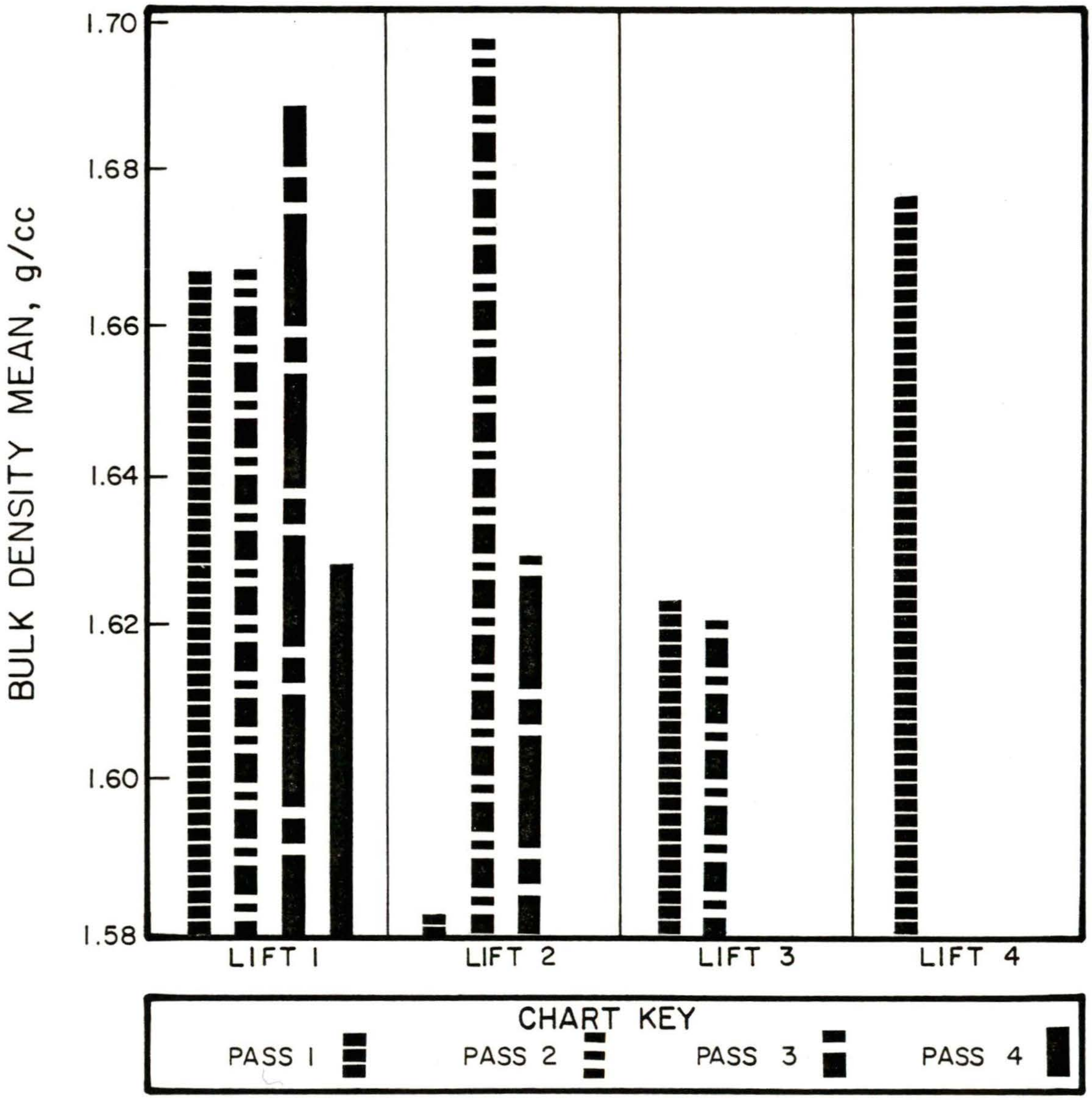

FIGURE 45. Windrow Scraper Test Plot Bulk Density Values Recorded by Lift and Pass

The theory of soil compaction with each pass of equipment is evaluated in this analysis to the extent of experiment design limitations. The accepted theory is that 90 percent of soil compaction is caused with the first scraper pass. This theory is proven to an extent in this first lift analysis by the very small change in bulk density on a pass by pass basis. The reduction in density on the fourth pass is not explained in the data and can only result from soil structure differences in replaced material at that particular depth. The first three passes increase, but not significantly in density with each pass, while the fourth pass on the first lift decreases in density. Even with this uncharacteristic fourth pass decrease the overall change in density in the first lift is still 0.06 g/cm$^3$.

As indicated for Lift 1, the only marginally significant change in bulk density in the lift by lift analysis is the pass 1 mean for Lift 2 which is 1.58 g/cm$^3$ and is a very small value for scraper reclamation bulk densities and marginally significant in the lift by pass interaction. In Lift 2 Pass 1 bulk density value is 1.58 g/cm$^3$, Pass 2 equals 1.69 g/cm$^3$ while Pass 3 equals 1.63 g/cm$^3$. Pass 1 and 2 show an increase in bulk density with increasing depth due to pass, while Pass 3 is less than Pass 2 which indicates natural soil factors such as moisture coming into play.

Lift 3 indicates no change in bulk density due to the pass effect in Pass 1 and 2. Lift 3 Pass 1 indicates a value of 1.62 g/cm$^3$, while Pass 2 stays at an identical value of 1.62 g/cm$^3$. This lack of density change based on repeated passes with the scraper indicates that the theory of 90 percent compaction with the first pass is valid in this case. The Lift 4 bulk density value with only one pass evaluated is at 1.68 g/cm$^3$. Lift 4 only evaluates the average for Pass 1 due to no additional lifts being replaced above the 4-foot depth. Further evaluations of this data presentation will be discussed in the Data Evaluation section.

### Texture Evaluation

As presented in Figure 46 the sand, silt and clay values when graphed on a lift by lift basis indicate very little change in texture over the entire 4-foot plot depth. Sand contents ranged from 18 to 22 percent with only the third lift sand content exceeding 19 percent. Sand contents are considered uniform with only a 4 percent variation between lifts. Silt contents range from 51 to 56 percent with the third lift decreasing in silt content below 52 percent. Clay contents remained very uniform, ranging from 26.5 to 28 percent over the entire plot depth. These uniform texture values indicate that the plot design and development successfully eliminated the changes in bulk density due to changes in texture content that normally occur over a wide range of soil types. Through this data analysis it is clear that the bulk density values focus on the machine impact and not on changing soil characteristics due to texture or moisture content.

### Data Evaluation

Bulk density changes by lift and pass cover a very narrow range of values in this controlled plot analysis. The only significant change in bulk density, as governed by a .05 level of significance, is in the second lift on the first pass where

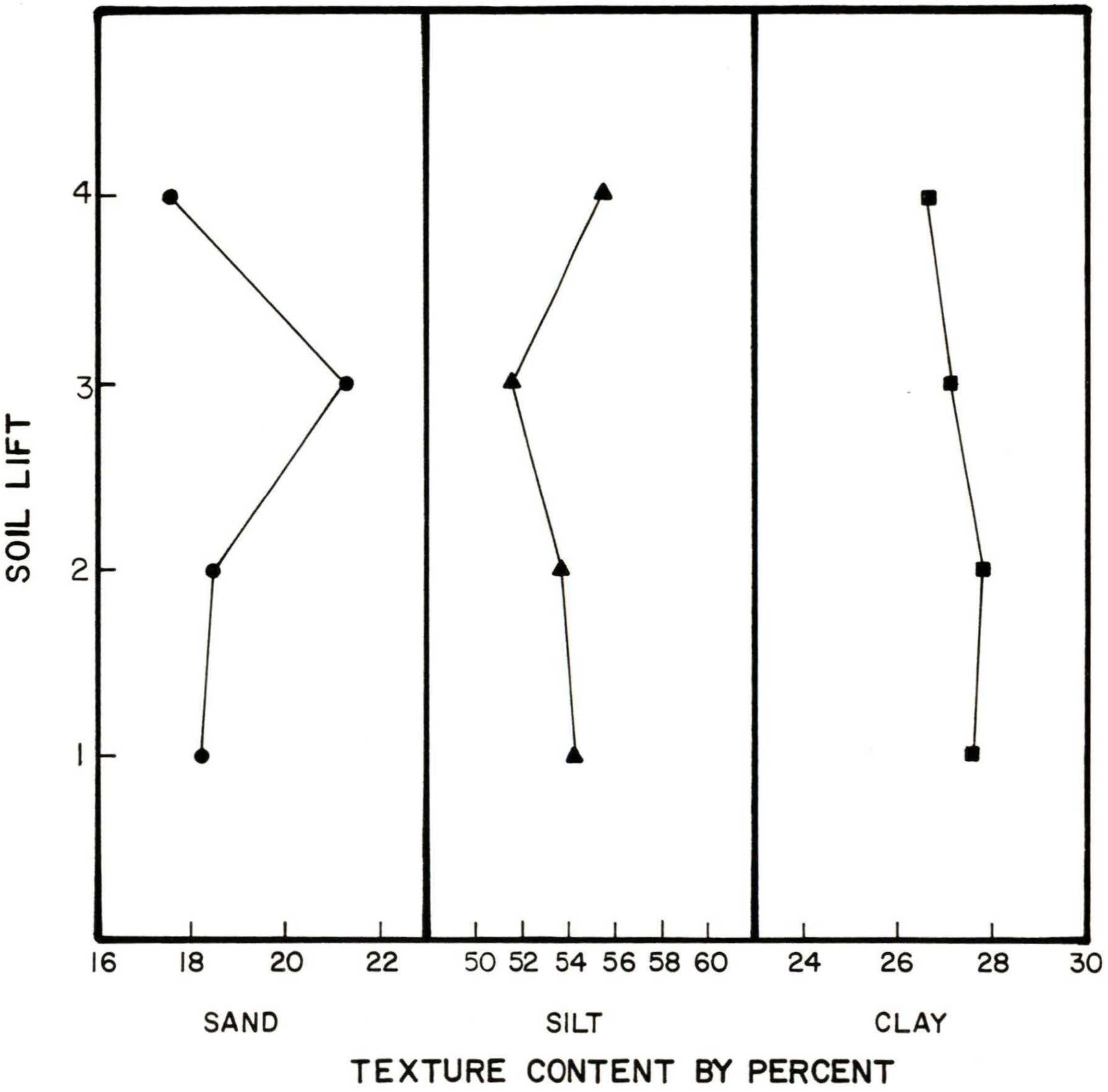

FIGURE 46. Soil Texture Content by Percent for Each Scraper Lift in Plot S-1

the density values between first and second pass are 1.58 and 1.69, respectively. The only explanation for this increase from pass 1 to pass 2 in the second lift is that of interplot relationships due to primary soil characteristics, or to not sampling exactly under the machine track in the area of the second lift. This change in density is not observed in the other lifts and may be due to soil parameter variability. Although the overall changes in density due to pass in a given lift are not statistically significant, a micro-analysis of the individual interlift changes warrants discussion. In Lift 1, Pass 1 and 2 are identical, while Lift 3 shows an increase. In Lift 2 there is a large increase between the first pass and the third pass. In Lift 3 bulk density values for Pass 1 and 2 are essentially equal. Within Lifts 1 and 2 a pass effect on a micro-basis does exist by virtue of increasing bulk densities from Pass 1 to Pass 2 and 3. While this circumstance is not evident studywide with each pass of the scraper over the same point in a soil profile, each pass contributes to higher densities in isolated lifts.

The increase of bulk density with each pass of the scraper is masked by scraper compaction of the soil on the first pass. These density values or changes in values depend on the bulk density value starting point within each lift at pass 1. When examining the data it is evident that in some portions the so called "sponge effect" has an impact on overall bulk density. The "sponge effect" is defined as the recovery of a given soil material following scraper traffic or soil compaction. If 1 foot of soil is replaced on overburden material that does not move under scraper traffic, the soil is squeezed between the scraper tire and the immovable overburden. When Lift 2 is replaced on Lift 1, Lift 2 has a cushion of Lift 1 between the scraper tire and the overburden. This cushion causes a recovery of bulk density due to expansion of the soil after scraper traffic. This sponge effect, while observed in the field during plot development, is not evident in the data as presented, but nonetheless exists.

One important conclusion is that soils can be compacted with scrapers to high densities above 1.68 g/cm$^3$ under very low moisture contents as defined by moistures usually found under field conditions. Further evaluation of these data will be summarized in the comprehensive data evaluation section and under project conclusions.

## Special Data Evaluation

In the crossover between the 1982 study and the 1984 study a significant compaction alleviation technique is viewed through data illustration. In 1982 the bucket-wheel excavator was evaluated for soil compaction characteristics utilizing conventional scraper replacement of topsoil. In 1984 the bucket-wheel excavator plots utilized the "windrow technique" for topsoil replacement. The use of windrowing decreases the amount of soil compaction that occurs in the subsoil regions due to topsoil replacement. This overall change in bulk density due to windrowing is illustrated by overlaying data graphs for wheel plots in 1982 over those collected in 1984. The results are illustrated in Figure 47.

As illustrated on the disturbed plots W-1 and W-2 decreased from the 1.7 g/cm$^3$ peak at the interface of topsoil and subsoil replacement. Following this topsoil/subsoil interface and proceeding down into the subsoil profile to the 44-

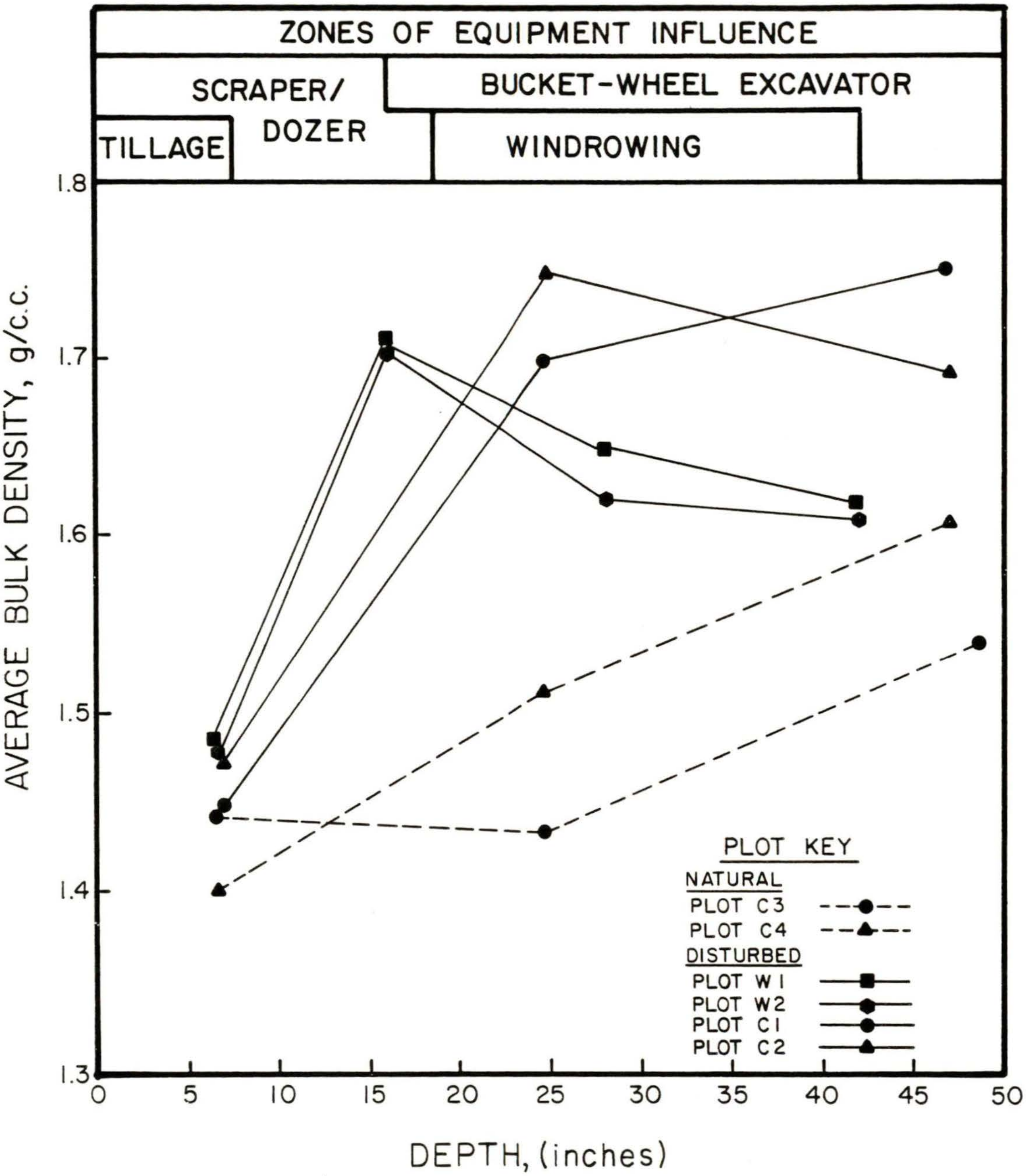

FIGURE 47. Bulk Density Changes with Depth on Windrowed Topsoil vs. Conventional Topsoil Plots

inch depth, densities decrease. In plot C-1 and C-2 densities increased to 1.72g/cm$^3$ and then remained constant in the subsoil to a depth of 48 inches. Plots W-1 and W-2 utilized windrowing to replace topsoil while C-1 and C-2 topsoil was replaced by conventional scraper techniques and traffic. As is clearly evident, a significant reduction in density is shown due to reduced scraper traffic.

Topsoil windrowing is an effective method by which traffic can be limited in the subsoil replaced areas and thus subsoil compaction is limited. Windrowed topsoil stockpile is shown in Figure 48.

## Bulk Density and Partical Size

Bucket-Wheel and Scraper Study and Scrapers by Lift analysis have interesting patterns and correlations between soil texture value and increasing or decreasing bulk densities. A review made of soil texture and its effect on bulk density given the data presented, shows patterns exist. For instance, bulk density increases with increasing sand contents, better defining the influence of soil texture on bulk density. Later in this report, one specific application for the texture bulk density relationship is addressed: that of the ability to predict soil compaction by different types of machinery based on texture class. The soil texture linked with the liquid and gaseous phases of the soil predominantly govern the degree a soil compacts. The Soil Prediction section of this report analyzes this possibility.

## Soil/Time Effects

On one plot area, tested in 1981 the same identical tests are performed to determine bulk density in 1983. This study is not performed under a statistical framework. The study indicates how natural factors, such as freeze thaw and root penetration, alleviate compaction. The bulk density values graphed with depth are presented in Figure 49 to illustrate natural soil data collected in the 1982 study. As shown, there was very little significant change between 1982 and 1984. Of the 10 cores pulled in each year at the 25-inch depth, there was less than .05 g/cm$^3$ change in density. In the deeper soil sample from 45 to 50 inches, an increase was actually shown in the 1984 data. This can be explained in theory by soil settling after replacement, but this single test plot in no way proves conclusively that soil settling will cause a density increase of .05 g/cm$^3$. This is the logical explanation for this particular test plot. Test plot area is shown in Figure 50.

Evidence of this slow soil recovery over time is in itself significant. The bond release periods now established for surface mining operations allow for return to original production in 10 years. If density values do not decrease at a faster rate than indicated, it is apparent that to bring the 25-inch sample to an acceptable density of less than 1.6 g/cm$^3$, more than 7 years would be required. It is also likely that soils would level out in their recovery and would stop at some point undetermined at this time, and not return to the natural soil density without a significantly longer period of time.

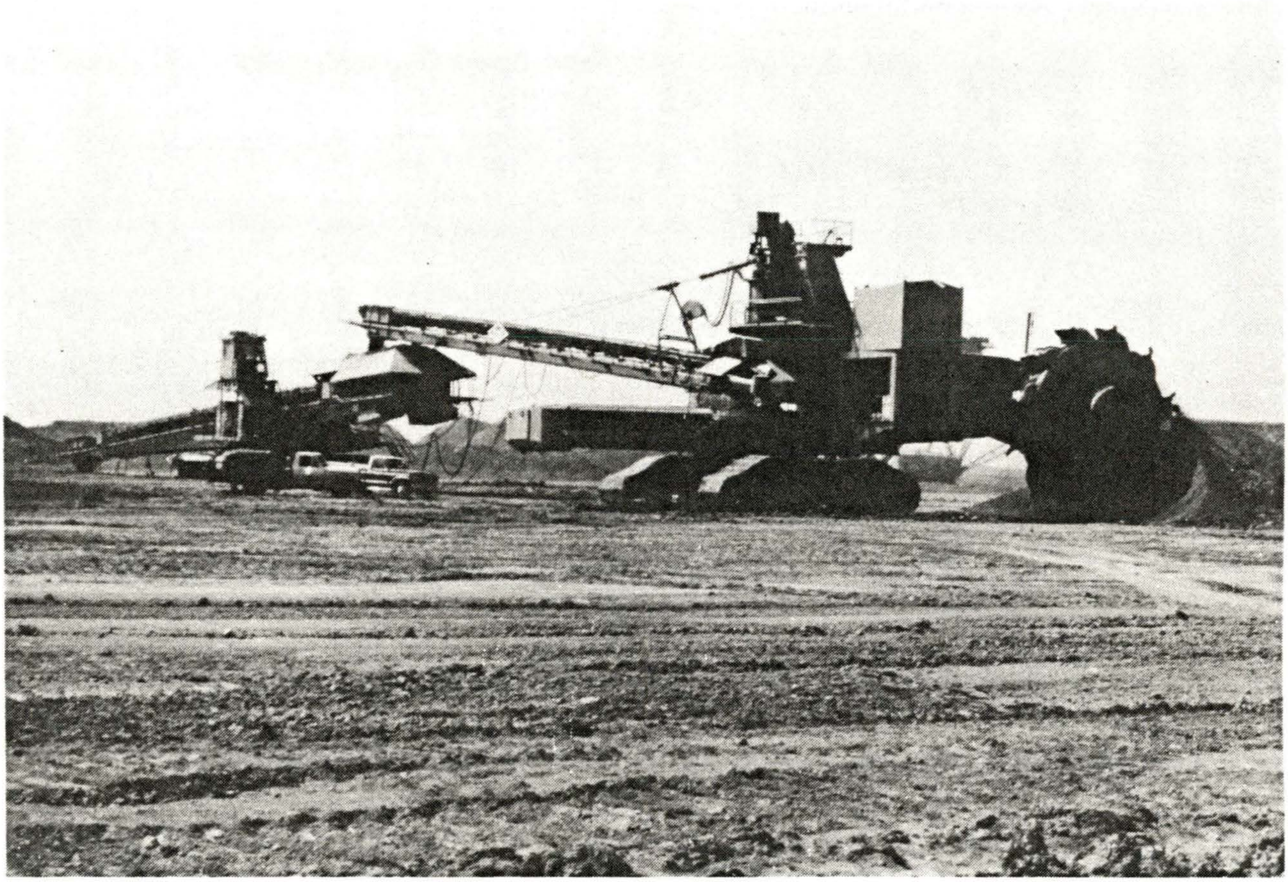

FIGURE 48. Windrowed Topsoil Stockpile Being Transported by Bucket-Wheel and Conveyor on the Captain Mine

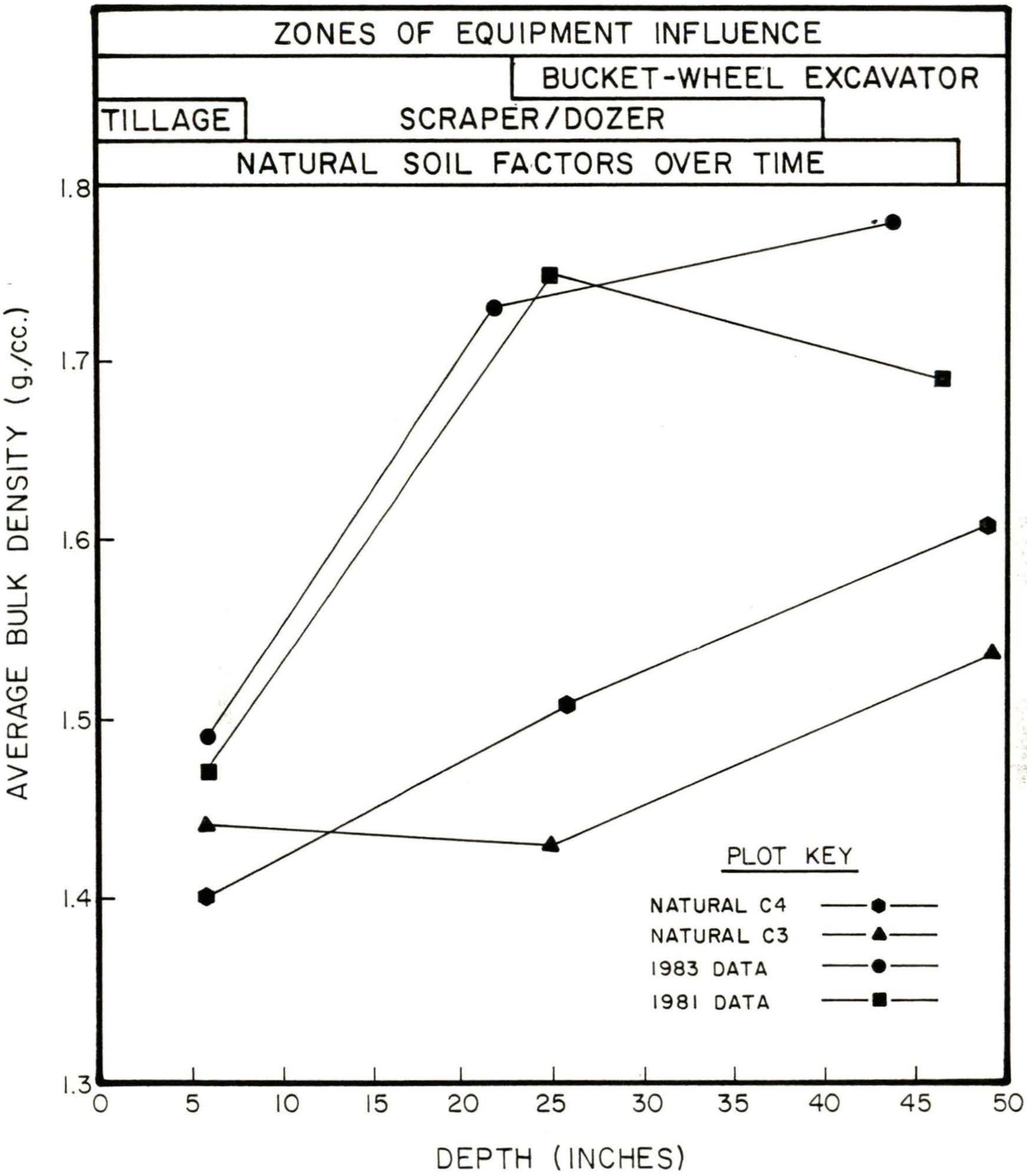

**FIGURE 49. Bulk Density Changes Over Time (Two Year Period) on Retested 1982 Plots on the Captain Mine**

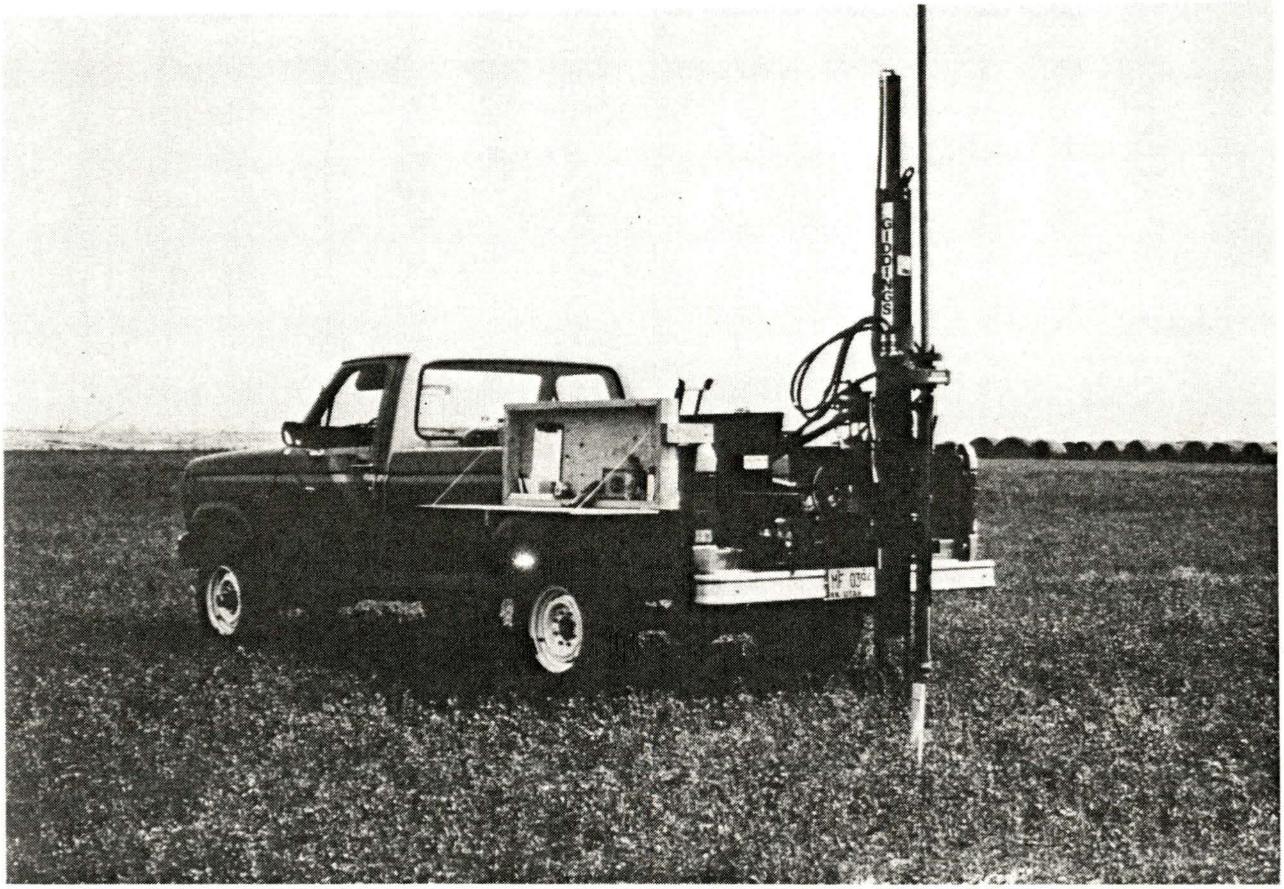

FIGURE 50. View of Resampled Test Plot on Captain Mine (O-1, O-2)

## 1982 - General Data Summaries

### Captain Mine Data

### Bulk Density

Basic changes in bulk density between the natural and replaced soils is characteristic of the equipment combination utilized for transport. The method of soil movement which replaces subsoil in a deep lift utilizing a bucket-wheel excavator, then topsoil replacement by scraper, results in characteristically higher density in the upper subsoil region. Figure 51 indicates that the topsoil region between the depths of 0 and 10 inches is very similar between natural and reclaimed soils. This is due primarily to extensive tillage in the topsoil during the seed bed preparation phase before seeding initial vegetative cover.

The second set of points shown on the graph at the 25-inch depth indicates a significant change in density between natural and replaced soils. This increased density is due to heavy equipment scraper traffic in replacement of topsoil materials. Even though bucket-wheel excavators are used to transport soil around the pit and replace them to a depth of 3 feet in the first lift, the damage with respect to soil density still occurs due to repeated scraper traffic for topsoil replacement. If the bucket-wheel excavator spreader on the reclamation side of the pit could be used for topsoil replacement, the density values would be considerably lower in the upper subsoil shown at the 25-inch depth. However, cost considerations must be taken into account when dealing with the efficiency of a particular type of equipment. The 30-foot bucket-wheel excavator is not an efficient tool for removing just 1 foot of topsoil material. The less dense subsoil material which was deposited with the spreader at depths from 12 to 48 inches is indicated as being more dense than the natural soils. As illustrated in Figure 51 the change in density between natural and replaced soils is not as great as that of the influence of scrapers at the 25-inch depth.

Note that the rooting medium or subsoil material on this mine site was removed to a depth of 15 to 20 feet with a bucket-wheel, and thus all the material in that depth is mixed as the machine passes up the working face. This replacement of rooting medium by material from a greater depth changes significantly the texture class as analyzed when comparing natural and replaced soils. Bulk densities in the natural soils at their densest point are less than 1.6 $g/cm^3$ but in the reclaimed soils these densities reach values of approximately 1.75 $g/cm^3$ which is more than enough to inhibit root growth and adequate crop development.

### Texture

Soil texture data at the Captain mine indicate a significant change between natural and replaced soils for sand, silt and clay content. Sand contents versus bulk density values are illustrated in Figure 52. In the soil removal process rooting medium was extracted to greater depths (15 to 20 feet). This removal to greater depths is reflected in the sand contents illustrated. The introduction of this primarily glacial till material from depths below 4 feet account for the drastic

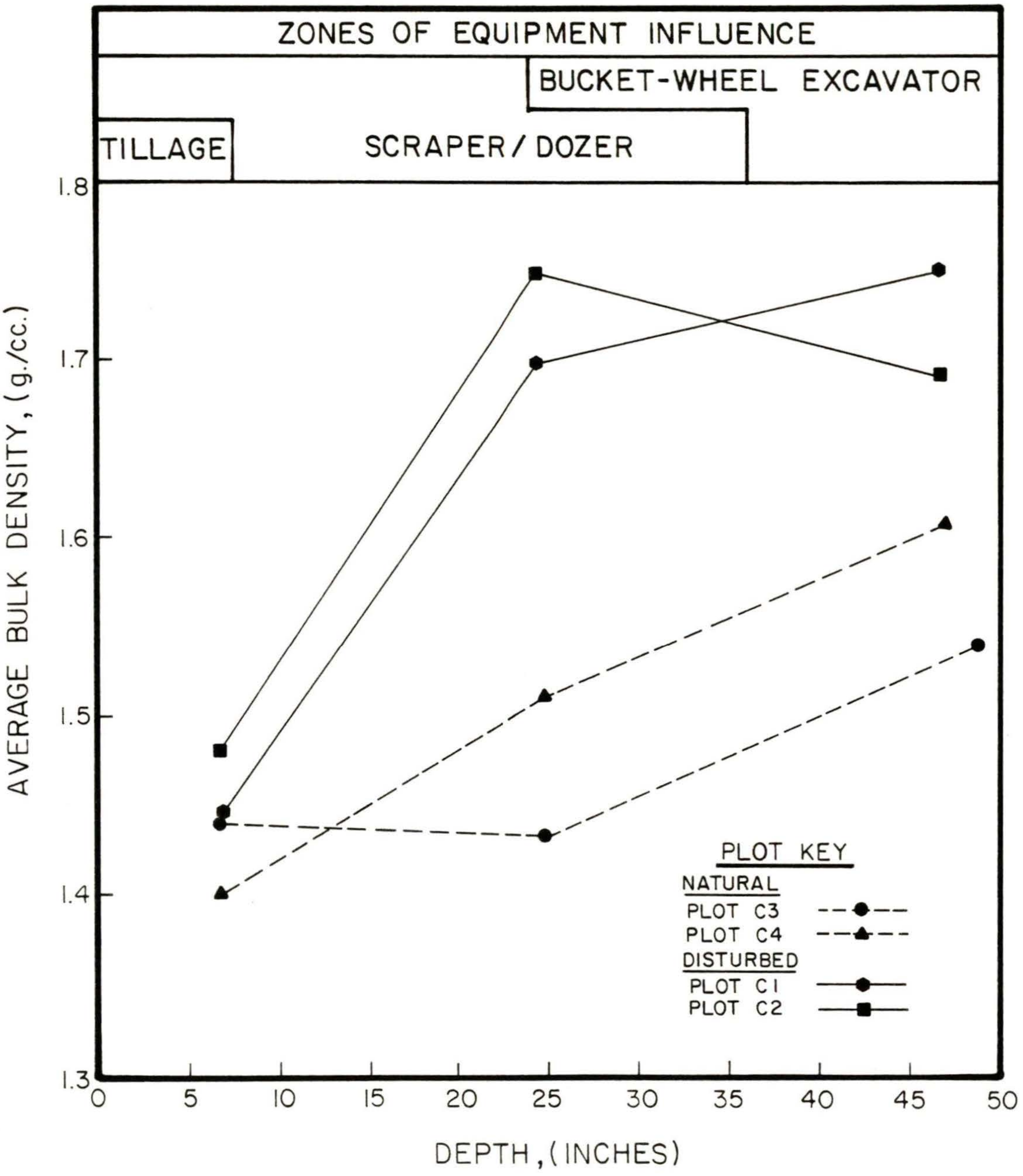

FIGURE 51. Bulk Density Changes with Depth on the Bucket-Wheel Excavator Plots on the Captain Mine

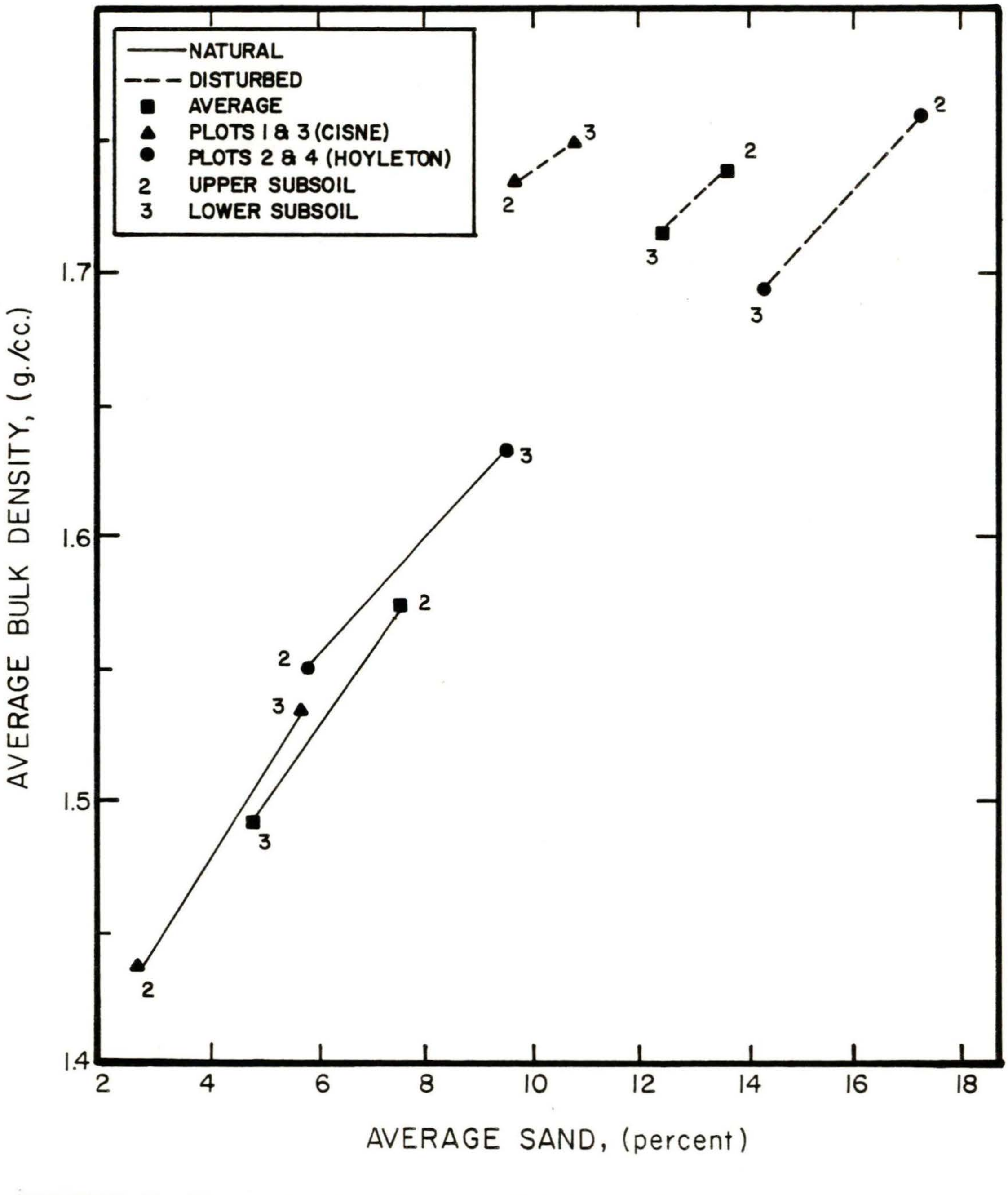

FIGURE 52. Change in Sand Content with Increasing Bulk Densities for Subsoils on the Captain Mine Bucket-Wheel Plots

change in soil texture. As indicated in Figure 52 the sand contents for disturbed soils cover a narrow range of values and also indicate an increase in sand content.

Changes in silt content in the subsoils sampled on the Captain mine are illustrated in Figure 53. Changes in silt content are significant in the overall change in bulk density due to their reduction from natural soil values. As indicated on the graph, silt contents in the natural soils range from approximately 58 to 72 percent, while in the reclaimed soils silt percentages cover a relatively narrow range from 59 to 64 percent. Bulk densities range from a maximum of 1.65 g/cm$^3$ in the natural soils for the deepest subsoil sample to over 1.75 g/cm$^3$ in the reclaimed soils. These changes in texture due to deeper removal of rooting medium materials have a dramatic effect on overall bulk density changes between natural and replaced soils. Please note the wide range of silt percentages in the natural soils while the range of silt content in replaced soils is more homogeneous over the study plot areas and covers a narrower range. This natural variability in virgin soils compared to those which are rebuilt after mining are significant in the overall density picture when relating texture to bulk density.

Dramatic changes also occurred in clay contents as indicated in Figure 54. Changes in clay content are not as great on a percentage basis as those found in sand and silt. Changes in reclaimed soils are significant from the standpoint of the more homogeneous narrow range of bulk density values found in reclaimed soils, while natural soils cover a broad range of clay percentages. As shown, the natural soil clay percentages range from approximately 20 to 40 percent over the entire range of data while reclaimed soils cover a very narrow range from approximately 23 to 27 percent.

In summary, the textural changes on the Captain mine using bucket-wheel excavators for rooting medium removal and replacement are as follows:

**o The sand contents were increased in reclaimed soils**
**o Silt percentages decreased in replaced soils**
**o Clay percentages decreased slightly in reclaimed soils**

Sand and silt percentages exhibited more significant changes in content than that of clay on this particular mine site.

## Brazil Mine Data

### Bulk Density

As shown in Figure 55, a severe and ultimately significant increase in soil bulk density values in the upper subsoil region is clearly evident on the Brazil mine. As discussed earlier in the Description of Case Studies, the Brazil mine utilizes loaders and trucks for subsoil removal transport and replacement, scrapers for topsoil removal and replacement and bulldozers for regrading. As is indicated graphically the natural soils increase in density with depth from topsoil through the 4 feet of subsoil. Natural soil densities range from 1.35 g/cm$^3$ in the topsoils to approximately 1.6 g/cm$^3$ in the lower subsoil sample. As indicated, the range of

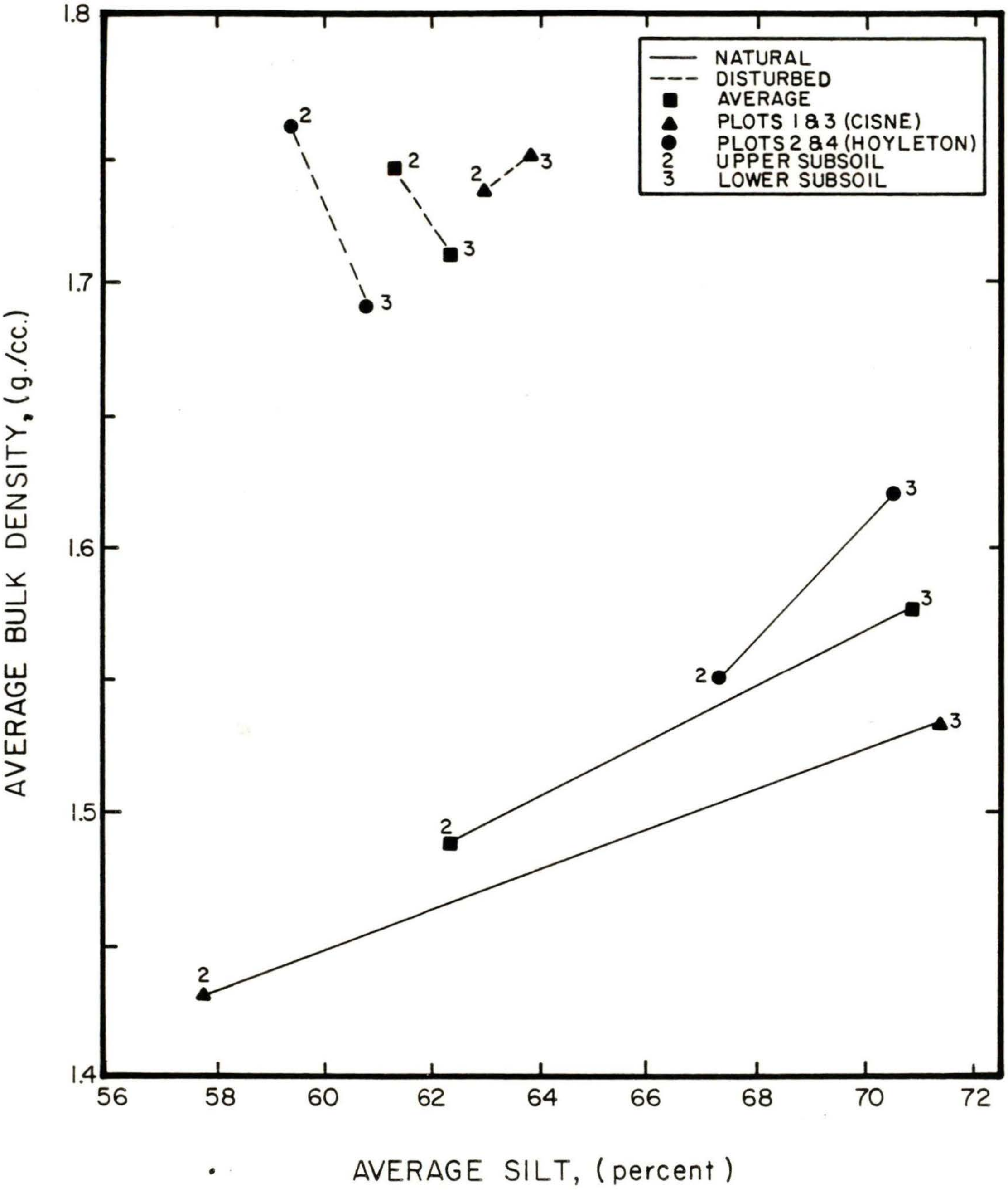

FIGURE 53. Change in Silt Content with Increasing Bulk Densities for Subsoils on the Captain Mine Bucket-Wheel Plots

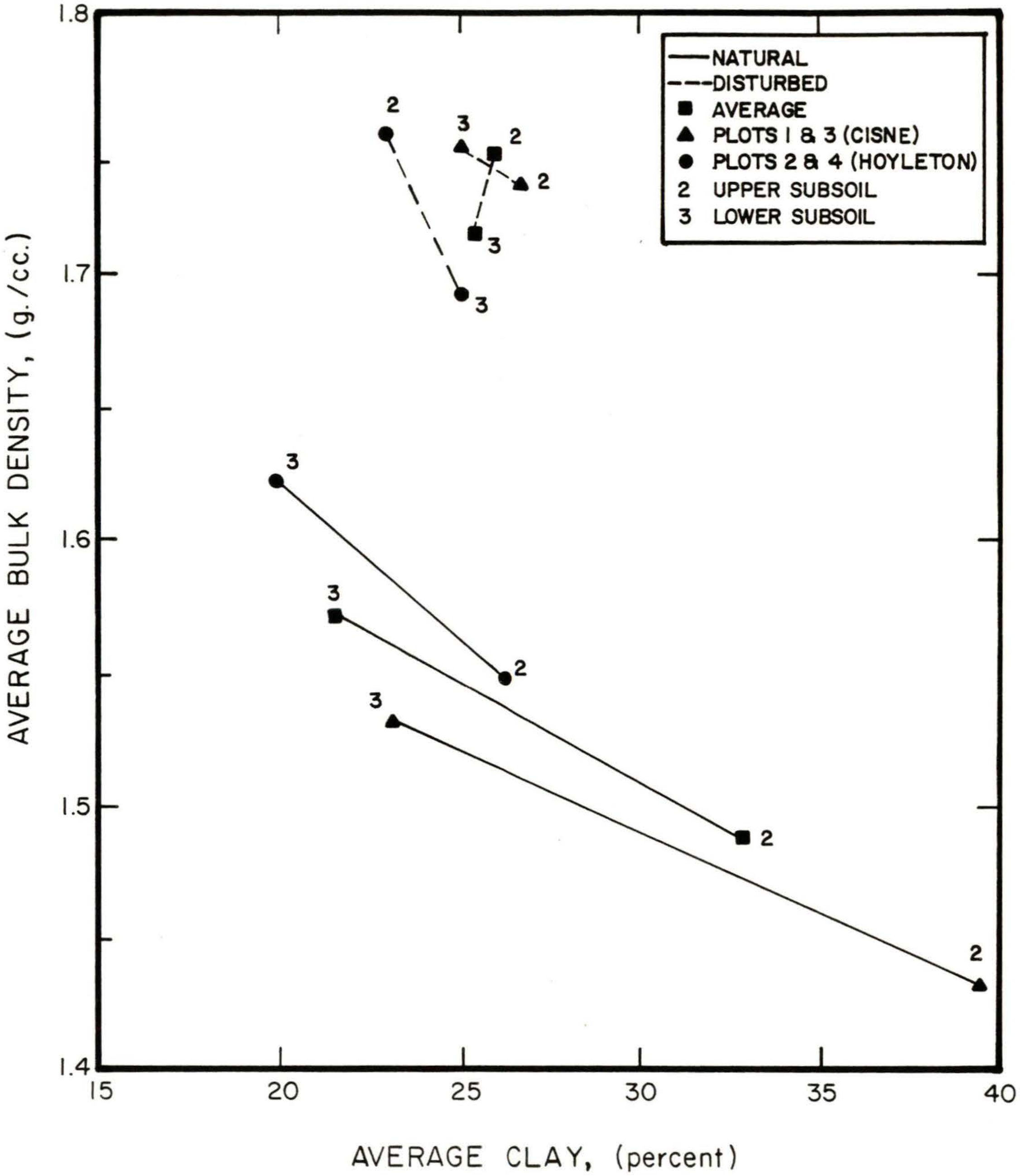

FIGURE 54. Change in Clay Content with Increasing Bulk Densities for Subsoils on the Captain Mine Bucket-Wheel Plots

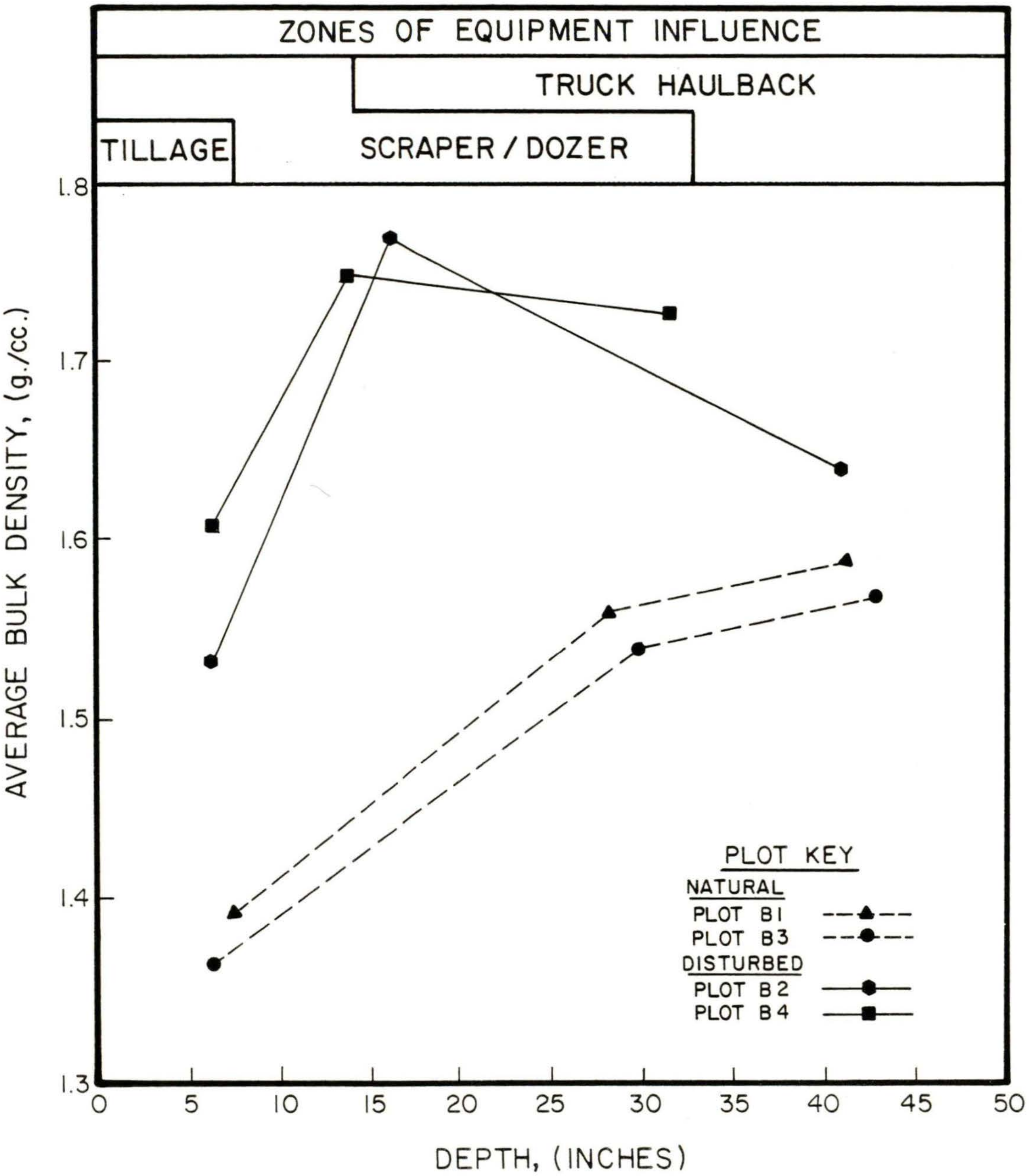

FIGURE 55. Bulk Density Change with Depth on the End-Dump Haulback Plots on the Brazil Mine

soil densities is increased significantly between natural and replaced soils are compared with respect to equipment impact. The upper subsoil compacted zone in the reclaimed soil plots as indicated at approximately the 15-inch depth is directly below the scraper interface which occurs with topsoil replacement. Bulk density values drop off when the end-dump truck haulback method of soil replacement takes effect in the 25- to 45-inch depth in the profile. Utilizing the truck haulback method causes a forced control of traffic on the subsoil material from a depth of 12 to 48 inches, thus the resulting drop in density from the upper subsoil to the lower subsoil. Although equipment impact has a great deal to do with a large increase in density shown in the upper subsoil region between natural and replaced plots, soil texture also plays an integral role.

## Soil Texture

Use of the front shovel facilitates more efficient removal of soil material from greater depths. The removal of rooting medium material from a depth of up to 15 feet changes the overall subsoil medium characteristics. When subsoil materials are removed from greater depth at the entire working face with the front shovel, the glacial till material becomes mixed with the original soil profile. Due to the increase in sand content in glacial till material, the sand content increases dramatically in the reclaimed test plots (Figure 56). Increases in sand content can, by engineering definition, contribute to greater increases in soil bulk density. This is due primarily to the fact that sand can be compacted to a greater extent than either a silt or a clay material. This is true especially through repeated loading such as occurs under heavy scraper traffic. As illustrated in the graph, the inversion of bulk density with depth is still visible and the second sample shows increased sand content which can greatly increase soil compaction values under machine movement pressure. Sand contents in natural soils as indicated cover a narrow range of approximately 7 to 12 percent while reclaimed soils range from 15 to 28 percent. This change in sand content in reclaimed soils is primarily due to the removal of glacial till material with a broader range of sand-size soil particulants.

As illustrated in Figure 57, the average silt content in the reclaimed soil is decreased in comparison to that found in natural soils. Natural soils cover a range from 65 to 70 percent, while reclaimed soils fall between 50 and 65 percent. This overall decrease in silt content and increase in sand content makes the soil more susceptible to repeated load soil compaction by scrapers.

Radical changes in average clay percent are not found in the subsoils of the test plots as indicated in Figure 58. Natural soils cover a range of textures from 21 to 26 percent while the reclaimed soils fall between 22 and 24 percent clay. These ranges of percentages suggest a more homogeneous material in the case of the reclaimed soil over the heterogeneous mixture found in the natural soils. This premise seems valid if the small changes due to natural weathering are taken into consideration. These small natural changes would facilitate a broader range of textures than would be found in a subsoil made up primarily of a glacial till mix.

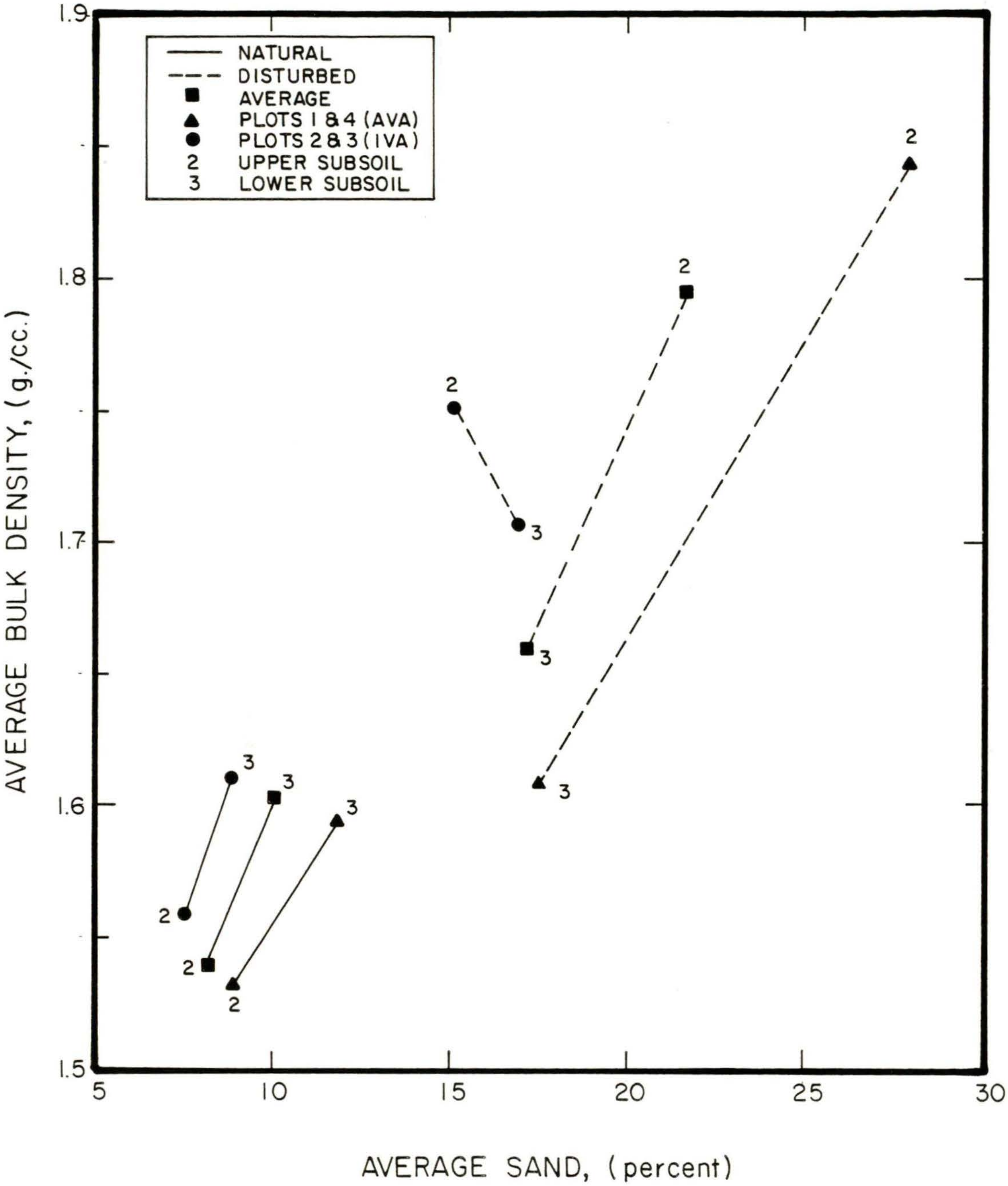

FIGURE 56. Change in Sand Content with Increasing Bulk Densities for Subsoils on End-Dump Haulback Plots on the Brazil Mine

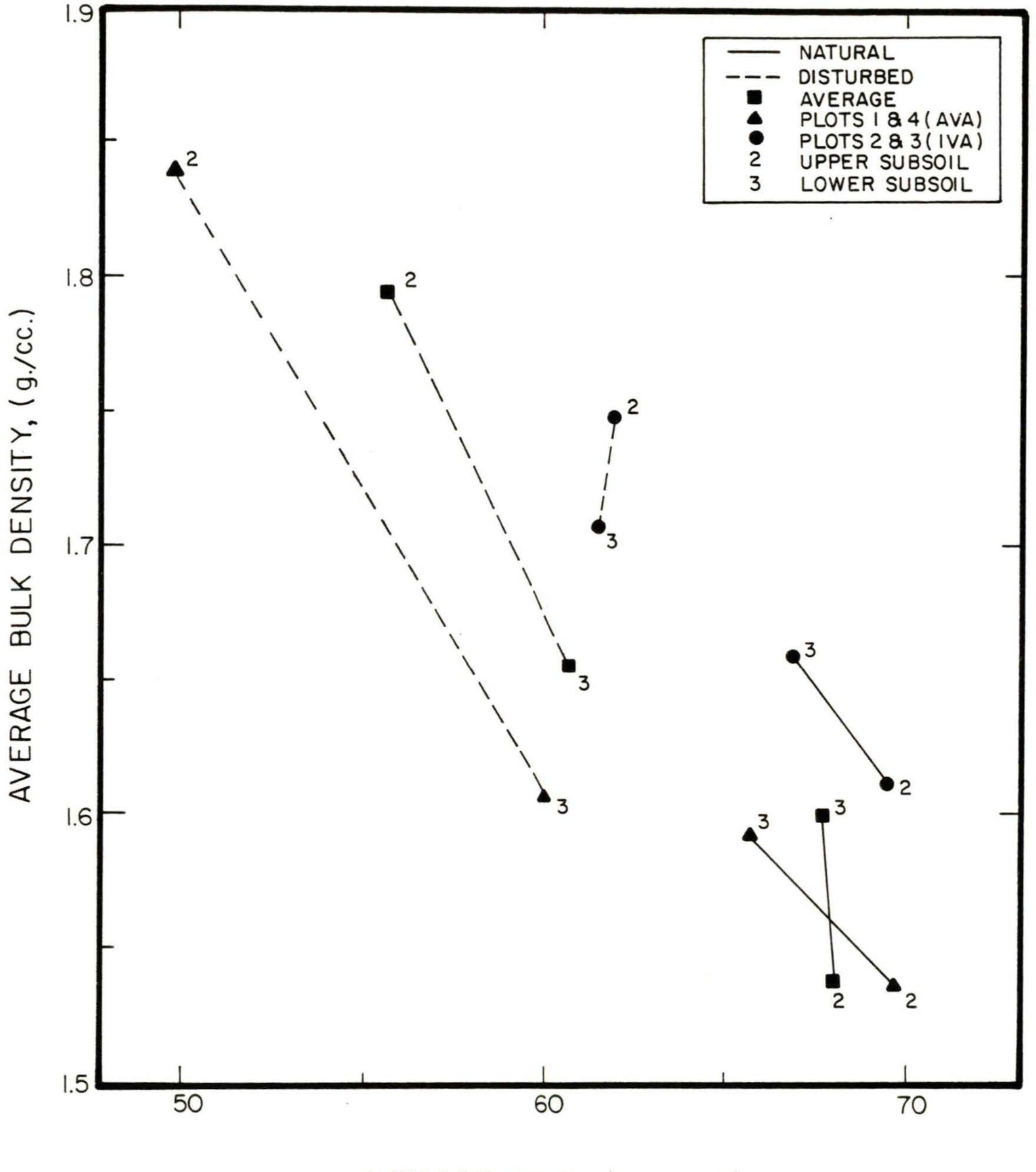

FIGURE 57. Change in Silt Content with Increasing Bulk Densities for Subsoils on End-Dump Haulback Plots on the Brazil Mine

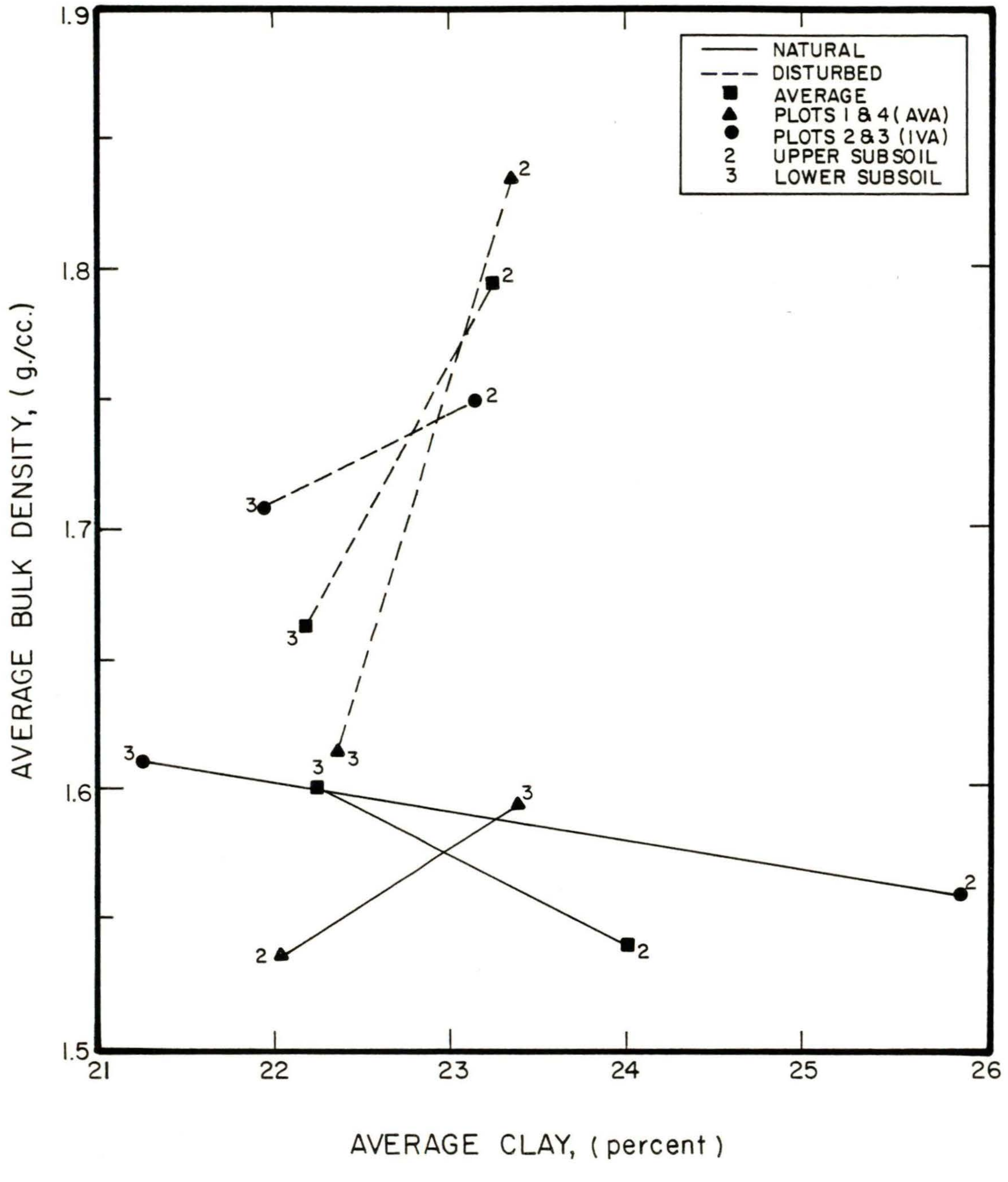

FIGURE 58. Change in Clay Content with Increasing Bulk Densities for Subsoils on the Brazil Mine End-Dump Haulback Plots

In summary, the general changes from natural soils to reclaimed soils are:

- **Average sand percentages are increasing**
- **Average silt percentages are decreasing**
- **Clay contents remain virtually the same**

These changes are primarily attributed to the variation in material from the 4-foot sampling zone in the natural soils to the 15-foot sampling zone in the material used in the reclaimed soils.

## Delta Mine

### Bulk Density

Soil characteristics at the Delta mine are notably different from any of those found on the other study sites. The major difference stems from the removal of rooting medium material from a depth of 70 feet. As will be indicated in the data graphs for the Delta mine, this deep material had a marked effect on overall soil characteristics and also on soil compaction levels caused primarily by heavy equipment traffic. As shown in Figure 59 a significant increase in density was found in upper and lower subsoil regions. The natural soil condition was virtually the same as that found on other mining operations; i.e. density increases with soil depth. The major density values found on the reclaimed test plots were the extremely high bulk density values approaching the 1.9 $g/cm^3$. Corresponding depths in the natural soils reach levels no higher than 1.5 $g/cm^3$. Density values in this extremely high range can have many adverse effects on plant growth and can inhibit water movement and content and influence almost every other factor associated with crop production.

### Texture

In Figure 60 the average sand content graphed with bulk density indicates a significant change between sand contents in natural soils and reclaimed soils. The range of average sand contents is from approximately 3 to 15 percent in the natural soils, while the reclaimed soils range from 24 to 32 percent. Subsoil materials are removed on the Delta mine by a dragline which mixes material from a 70-foot working face. The unusually high sand contents are due to the depth of material which is used for a rooting medium in the upper 4-foot soil profile. This increase in sand content also partially explains the very high bulk density values found in this test plot area. The upper subsoil samples, as indicated, are greater in density than the lower subsoil samples, but overall sand content to bulk density results in a very homogeneous material in the reclaimed areas. As shown in Figure 60, the natural soils cover a much wider range of sand content.

As indicated in Figure 61, average silt contents decreased approximately an average of 10 percent from natural to replaced soils. Silt contents in natural soils are distributed over a range from 59 percent to 68 percent while reclaimed soils cover a range of 52 to 58 percent. The overall silt content decreases while the densities increase significantly. This increase in bulk density is due to both changing textures and machine impact.

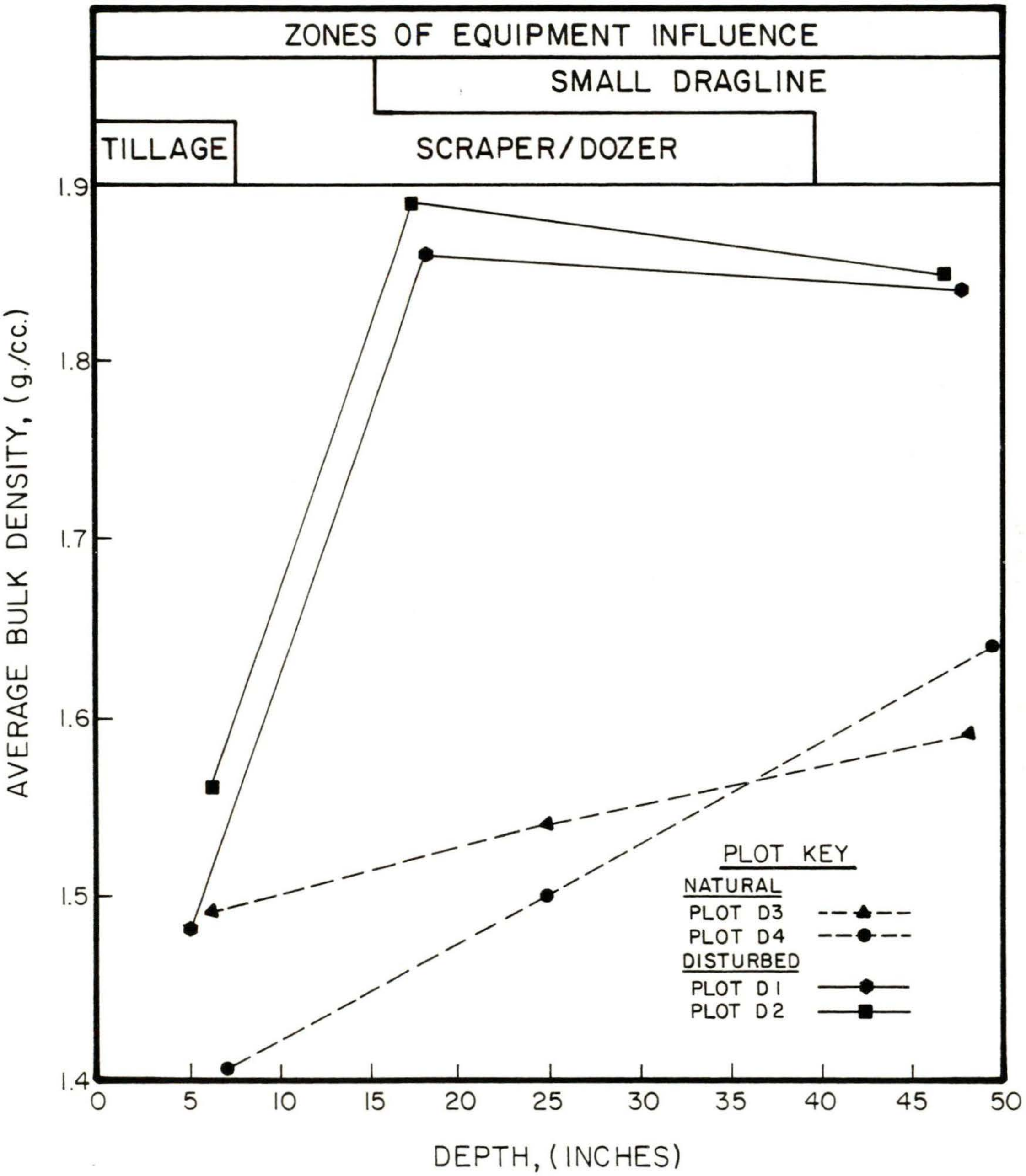

FIGURE 59. Bulk Density Changes with Depth on the Delta Mine Dragline Plots

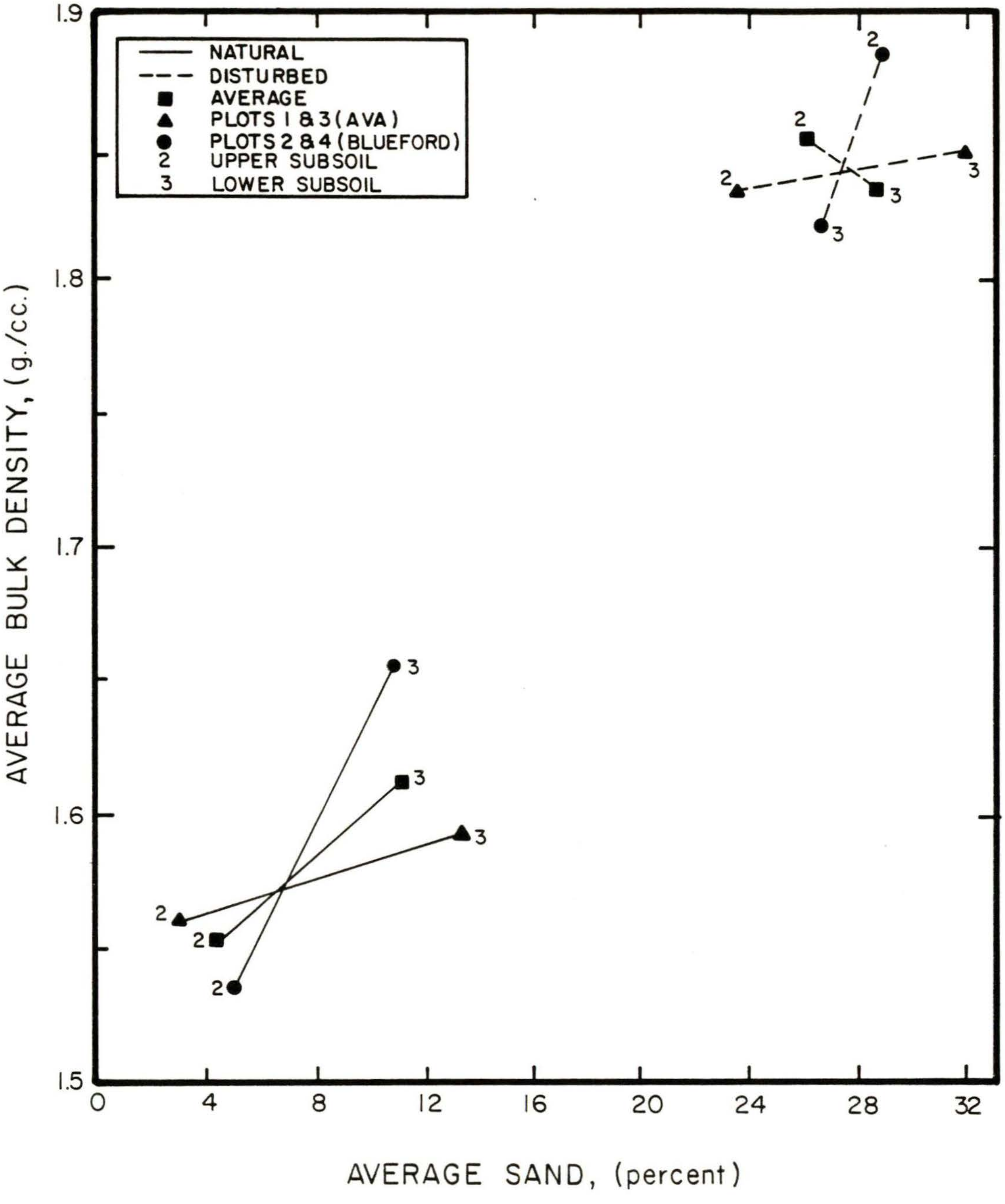

FIGURE 60. Change in Sand Content with Increasing Bulk Densities for Subsoils on the Delta Mine Dragline Plots

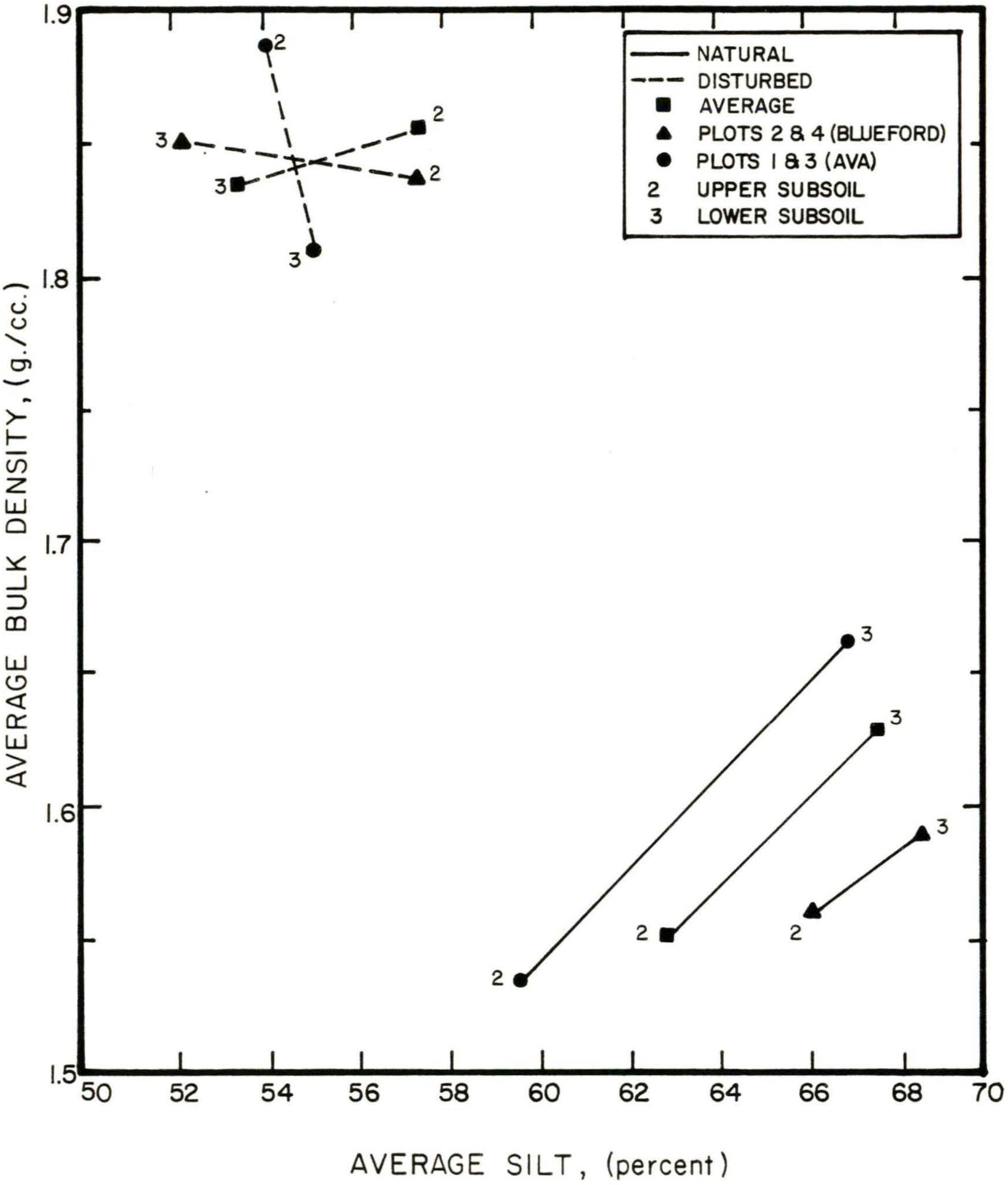

FIGURE 61. Change in Silt Content with Increasing Bulk Densities for Subsoils on the Delta Mine Dragline Plots

Changes in clay contents are illustrated in Figure 62. Clay contents range from 20 to 35 percent in the natural subsoils, while the range is from 16 to 20 percent in the reclaimed soils. Thus, the reclaimed soils are much more homogeneous over the subsoil region than are natural soils as illustrated in the graph.

These changing sand, silt and clay contents, as will be shown later in this report, have a significant impact on the extent to which soils can be compacted under different methods of machine movement. In summary, on this mine site the sand, silt and clay values were much more homogeneous in the reclaimed subsoils than in the natural soils. The average sand contents increased while the silt percentages decreased and the average clay contents also decreased slightly. Silt and clay percentages decreased when soil was moved from the natural to the replaced test plots.

## Power Mine Data

### Bulk Density

In this the last of four mine sites tested to obtain an overview of soil compaction due to surface mining, higher densities were expected for the replaced soils due to the use of scrapers, however as illustrated in Figure 63, the expected changes in density did not occur. As indicated in the previous mine studies, the topsoil samples are returned to equal to or better levels of density than that found in natural soils. At this particular mine, natural topsoils were in the 1.4 g/cm$^3$ density range, while the reclaimed soils decrease to 1.2 to 1.3 g/cm$^3$. This decrease in soil density in the topsoil below that found in natural soils is very unusual and generally indicates heavy equipment operation on the natural soils prior to sampling. However, at this mine site no indication of heavy equipment traffic on the natural soil plots was evident. The upper subsoil sample at the 15- to 20- inch depth in the reclaimed soils showed a significant increase in density over that found in the natural soils, but not as much as at the previous mine sites evaluated. Lower subsoil values around the 40- to 45- inch depth were approximately the same for natural and disturbed soils.

This mine site is a good example of how changes in natural soil characteristics can have a significant impact on overall subsoil compaction. Even under adverse conditions with the use of scraper pans with their heavy loads and repeated compaction the bulk density values were less at this mine than on any tested. These soil test plots were upon further consideration removed and replaced only to a 48-inch depth rather than removal from greater depths as was indicated on the previous three mine sites. This transport of soils to a 48-inch depth allowed for a more uniform transfer of soil characteristics from the natural to reclaimed soil plots. There is no doubt that the increases in sand contents by removal of material to a greater depth has an impact on overall soil compaction values. The analysis of data on this scraper equipment system indicates that the natural soil characteristics play a vital role in overall soil compaction for surface mining.

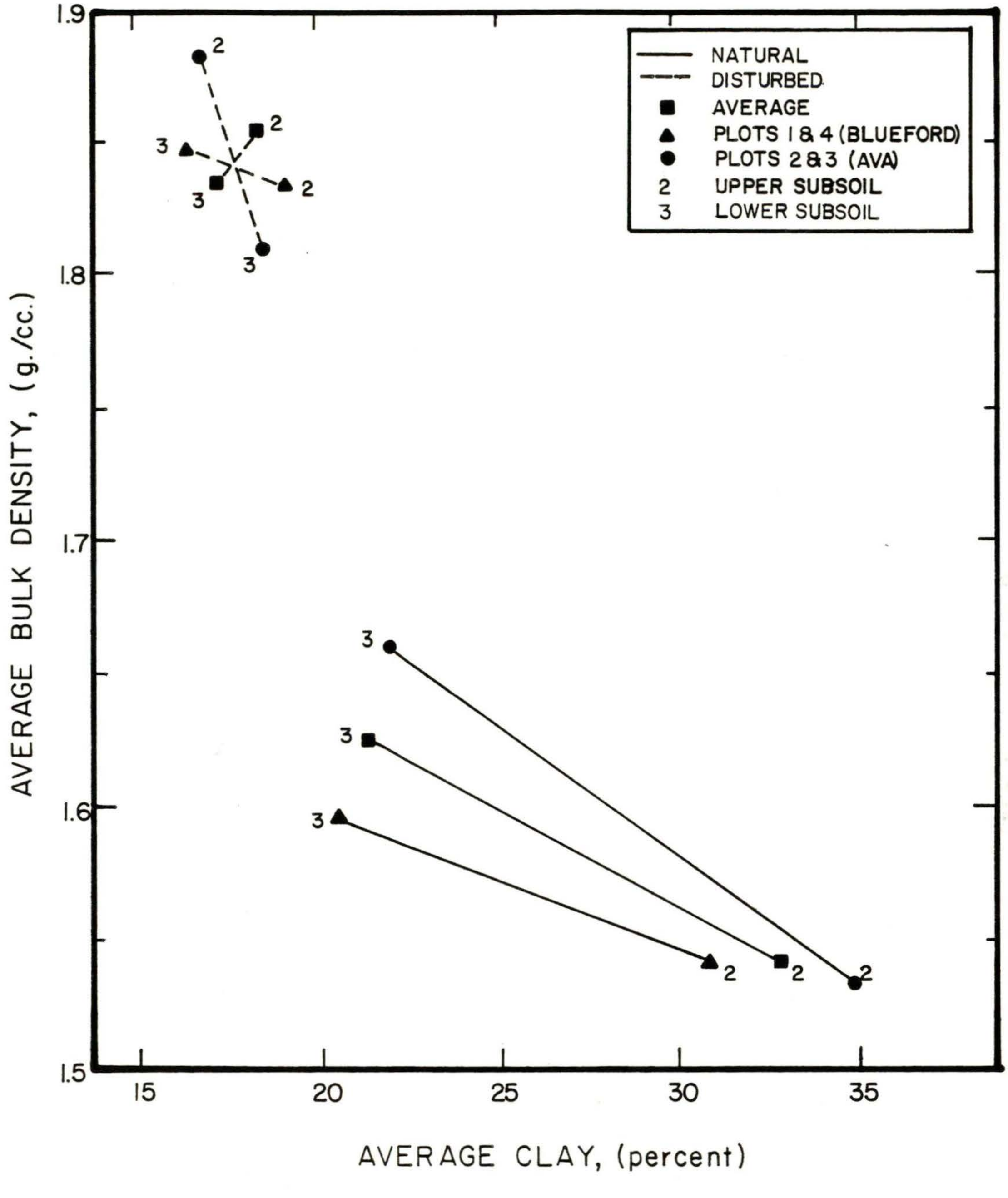

FIGURE 62. Change in Clay Content with Increasing Bulk Densities for Subsoils on the Delta Mine Dragline Plots

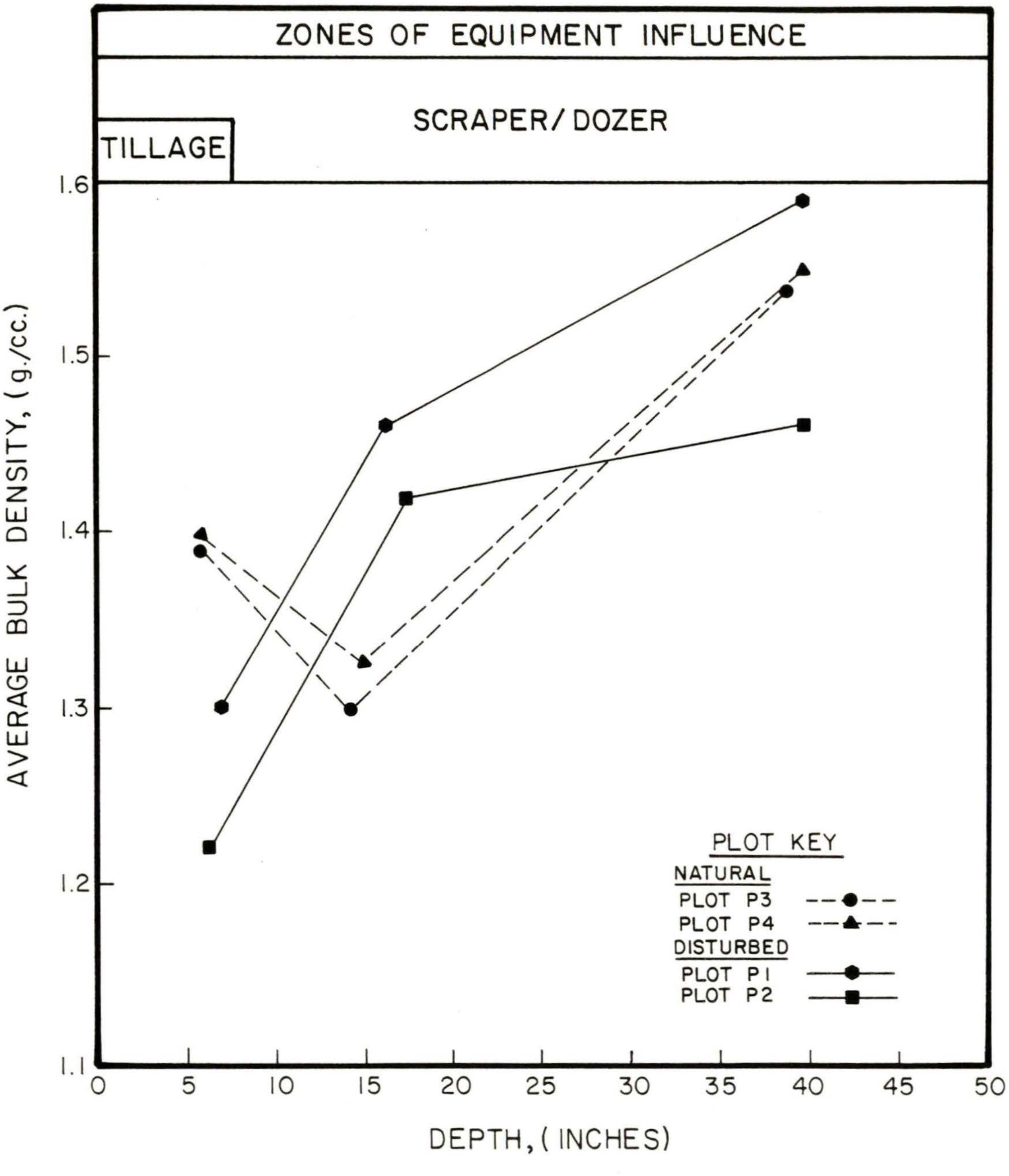

FIGURE 63. Bulk Density Changes with Depth on the Power Mine Scraper Plots

## Texture

The average sand contents are graphed in relation to bulk density in Figure 64. This graph is an excellent example of how texture content and in particular, sand content, can notably influence the extent of compaction by equipment traffic. Notice that the average sand content for disturbed soils covers a narrow percentage range and yet sand comprises a very small percentage of the total of this particular soil series. Low sand contents in turn increase the percentages of silt and clay found in the soil which make this reclaimed soil material more resistant to compaction by heavy equipment. As will be discussed in later sections of this report, this overall smaller change in density as compared to the other mine sites tested does not necessarily ensure this mine will be significantly better for crop development and yield than other study areas.

The average silt contents with respect to bulk density are presented in Figure 65. As indicated in this graph the overall silt content is high as compared to the other study sites. As indicated, there is a slight shift of silt percentages which increases from the natural soil plots to the reclaimed soil plots. This increase in silt content can also have positive effects on such factors as water holding capacity in reclaimed soils.

Clay content as graphed in Figure 66 indicates natural soils cover a very narrow range over the two plots tested in both the upper and lower subsoil. These values range from approximately 42 to 45 percent clay in the natural soils while the replaced soils range from 35 to 52 percent. This change in percentage of clays in the reclaimed soils is possibly due to the breaking down of silt-sized particles (structure change) in the equipment movement process, but this is as of now unproven through research.

In summary, the average sand contents were very low, in the range of 8 percent, while the silt percentages were high in the range of 50 to 60 percent and clay was also high in the range of 40 to 45 percent. A review of ranges of texture class in the three mines previously described compared to this mine shows a significant difference in the particle size distributions. This mine contains more finer-sized particles which, as will be seen later in this report, has a significant effect on overall bulk density and the impact of heavy equipment on soil characteristics.

## 1982 General Data Summaries Overview

The importance of the previous data summaries lies not in their direct comparison at depths between mines but in the change in density between natural and replaced soils compared between study sites. Table 15 summarizes density values by mine and plot showing averages and overall change between natural and replaced soils.

As indicated in Table 15 the change in bulk density between natural and

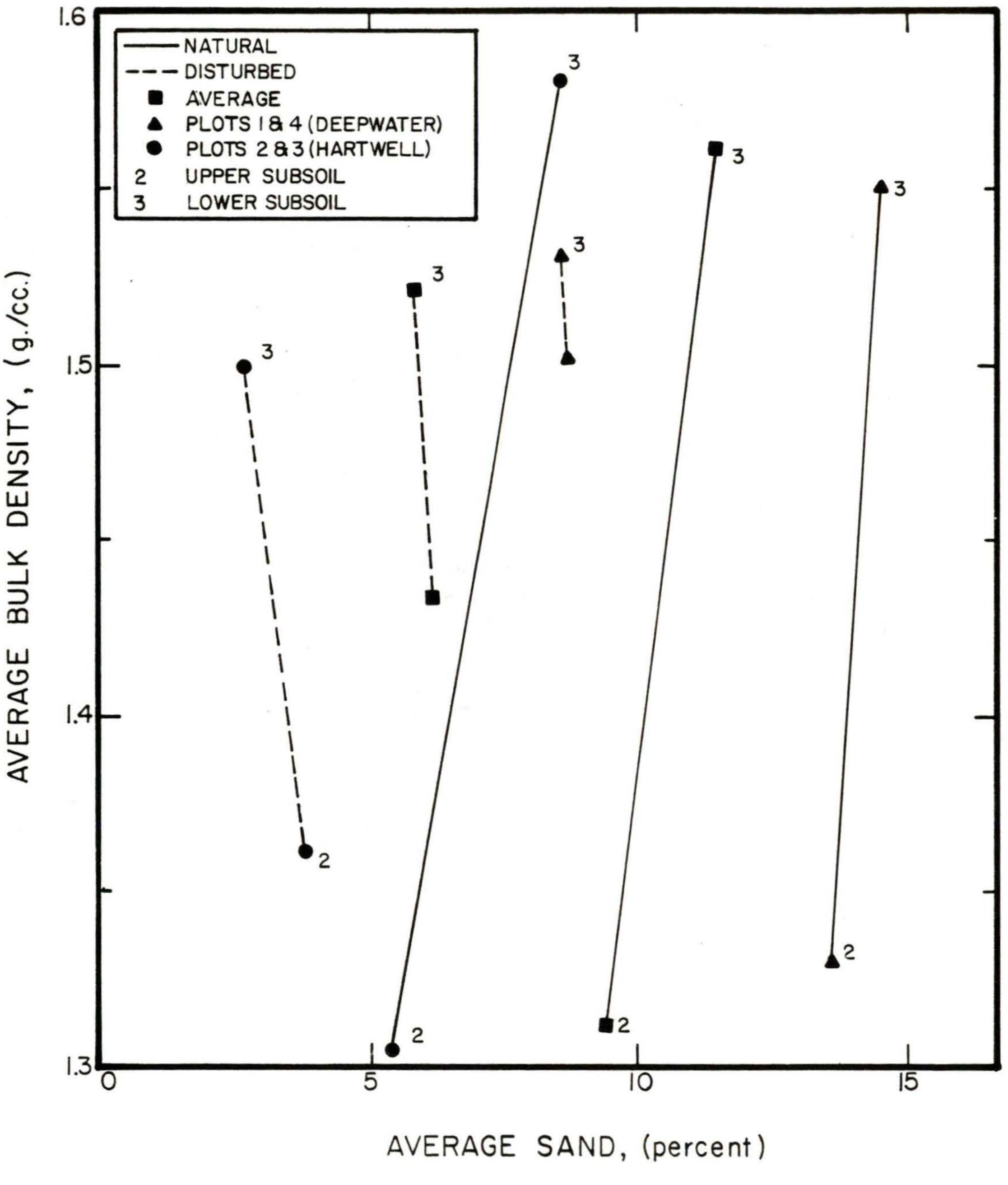

**FIGURE 64. Change in Sand Content with Increasing Bulk Densities for Subsoils on the Power Mine Scraper Plots**

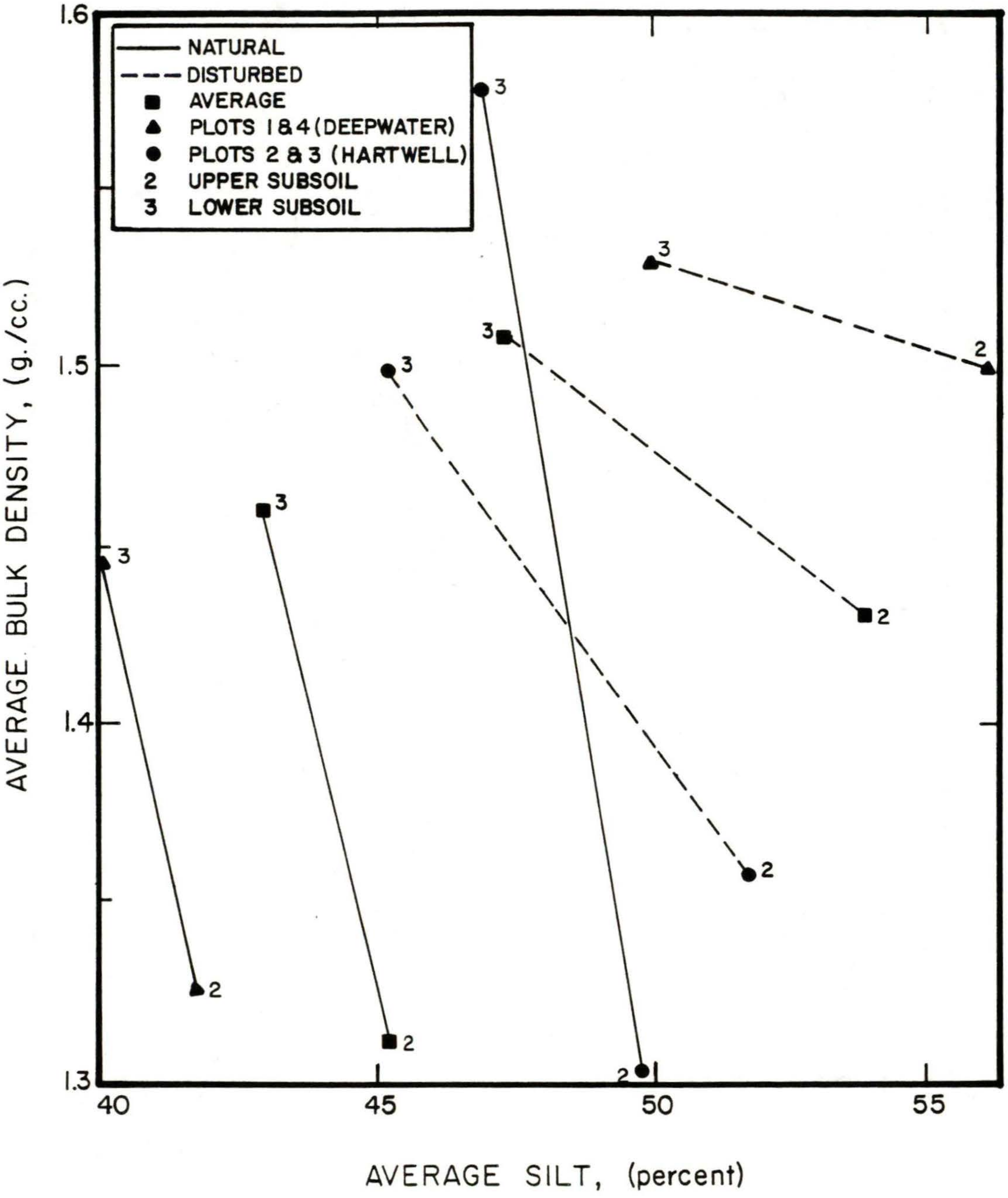

FIGURE 65. Change in Silt Content with Increasing Bulk Densities for Subsoils on the Power Mine Scraper Plots

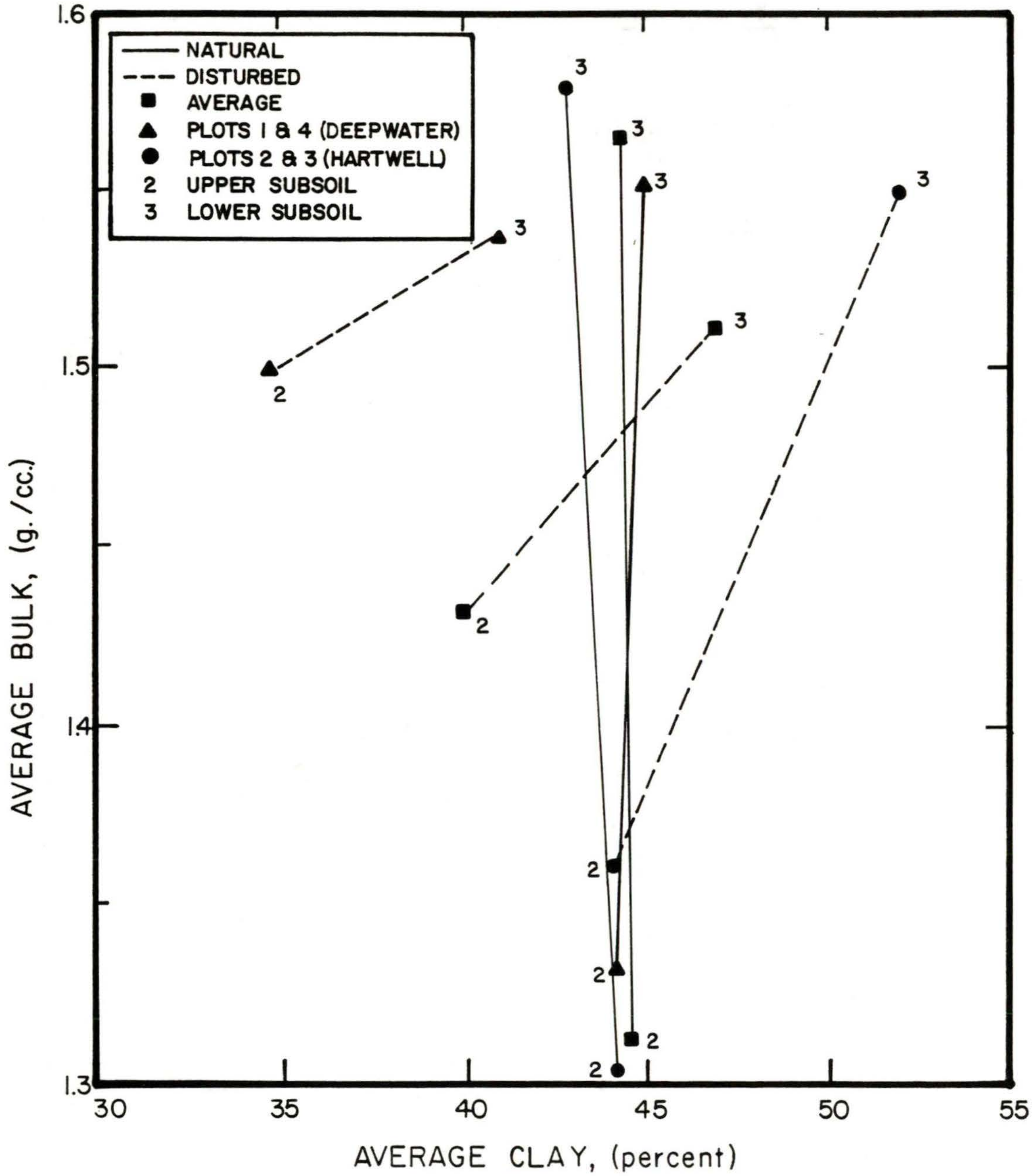

FIGURE 66. Change in Clay Content with Increasing Bulk Densities for Subsoils on the Power Mine Scraper Plots

replaced soils in the subsoil regions was 0.16 g/$cm^3$ at the Brazil mine and 0.19 g/$cm^3$ at the Captain mine, illustrating that these two methods of soil replacement yield approximately the same density increase. Although other factors come into play when evaluating overall change in density, the change which occurs between natural and replaced soils is more important than the starting point of, as example, a natural soil density.

The highest change between natural and replaced soils occurred on the Delta mine which yielded a 0.25 g/$cm^3$ increase from natural to reclaimed soils. This is due primarily to the high sand contents generated by soil removal from a depth of 70 feet and repeated loading by scrapers in topsoil replacement. Since these average data figures combine upper subsoil and lower subsoil samples, the actual density values for the upper subsoil where scraper traffic occurs would shift the bulk densities higher, but the general trends would be the same.

Contrary to early projections, the Power mine, where only scrapers are used, had an overall increase in density of 0.03 g/$cm^3$ which is excellent and an almost unobtainable result under normal soil conditions. This very low increase in density is due primarily to the fine textured soils which are found at the Power mine. The impact of the machine is masked by the resistance of this texture combination to compaction.

This analysis of four mining operations located in Illinois, Indiana and Missouri is intended to give a broad overview of soil compaction changes with texture and depth over a broad range of conditions. These data will be used later to develop a prediction analysis for bulk density based on texture.

**TABLE 15. SUMMARY OF BULK DENSITIES OF THE SUBSOIL HORIZONS**

| Location | Mean(1) Bulk Density $g/cm^3$ | Mean by Soil Type | Total Change(2) |
|---|---|---|---|
| **Brazil** | | | |
| B-1 | 1.56 | 1.57 | .16 |
| B-3 | 1.58 | | |
| B-4 | 1.73 | 1.73 | |
| B-2 | 1.73 | | |
| **Captain** | | | |
| C-3 | 1.48 | 1.54 | .19 |
| C-4 | 1.59 | | |
| C-1 | 1.74 | 1.73 | |
| C-2 | 1.72 | | |
| **Delta** | | | |
| D-3 | 1.58 | 1.59 | .25 |
| D-4 | 1.60 | | |
| D-1 | 1.84 | 1.84 | |
| D-2 | 1.85 | | |
| **Power** | | | |
| P-3 | 1.44 | 1.44 | .03 |
| P-4 | 1.44 | | |
| P-2 | 1.51 | 1.47 | |
| P-1 | 1.43 | | |

1) Bulk densities are averages of combined subsoil horizons, 10 entries at each location.

2) Overall change value is the difference between natural and replaced soils.

## Statistical Analysis Summary

### Statistical Methods

Software utilized in the analysis of these data is entitled STAN, an interactive statistical analysis system for microcomputers (a),. The linear models used for the various analyses are given in APPENDIX C along with the corresponding analyses of variance (ANOVA's).

Reported p-values are for two-sided alternative hypotheses. An argument can be made for the use of one-sided tests, especially when reclaimed and natural soils are being compared. P-values are reported to allow individual decisions regarding significance. P-values below .10 are discussed in this report.
(a) The p-System version of STAN for the IBM-PC was used for all analyses.

### Bucket-Wheel and Scraper Statistical Analysis

#### Scraper Analysis

Data were collected from three plots of land, one from reclaimed soils and two from natural soils. The total number of observations is 100 with the following breakdown:

**TABLE 16. SUMMARY OF STATISTICAL OBSERVATIONS / SCRAPERS**

| Sample Location | Natural Soil | Reclaimed Soil |
|---|---|---|
| **Lift 1 Total** | **20** | **20** |
| Plot C-3 | 10 | |
| Plot C-4 | 10 | |
| Plot S-2 | | 20 |
| **Lift 2 Total** | **20** | **40** |
| Plot C-3 | 10 | |
| Plot C-4 | 10 | |
| Plot S-2 | | 40 |
| **Totals Lift 1 & 2** | **40** | **60** |

The lift by soil group means are shown on a bar chart in Figure 67. There is a significant lift by soil type interaction (p=.06, TABLE C-2, APPENDIX C). For Lift 1 the mean bulk density of the reclaimed soil is .14 g/cm$^3$ larger

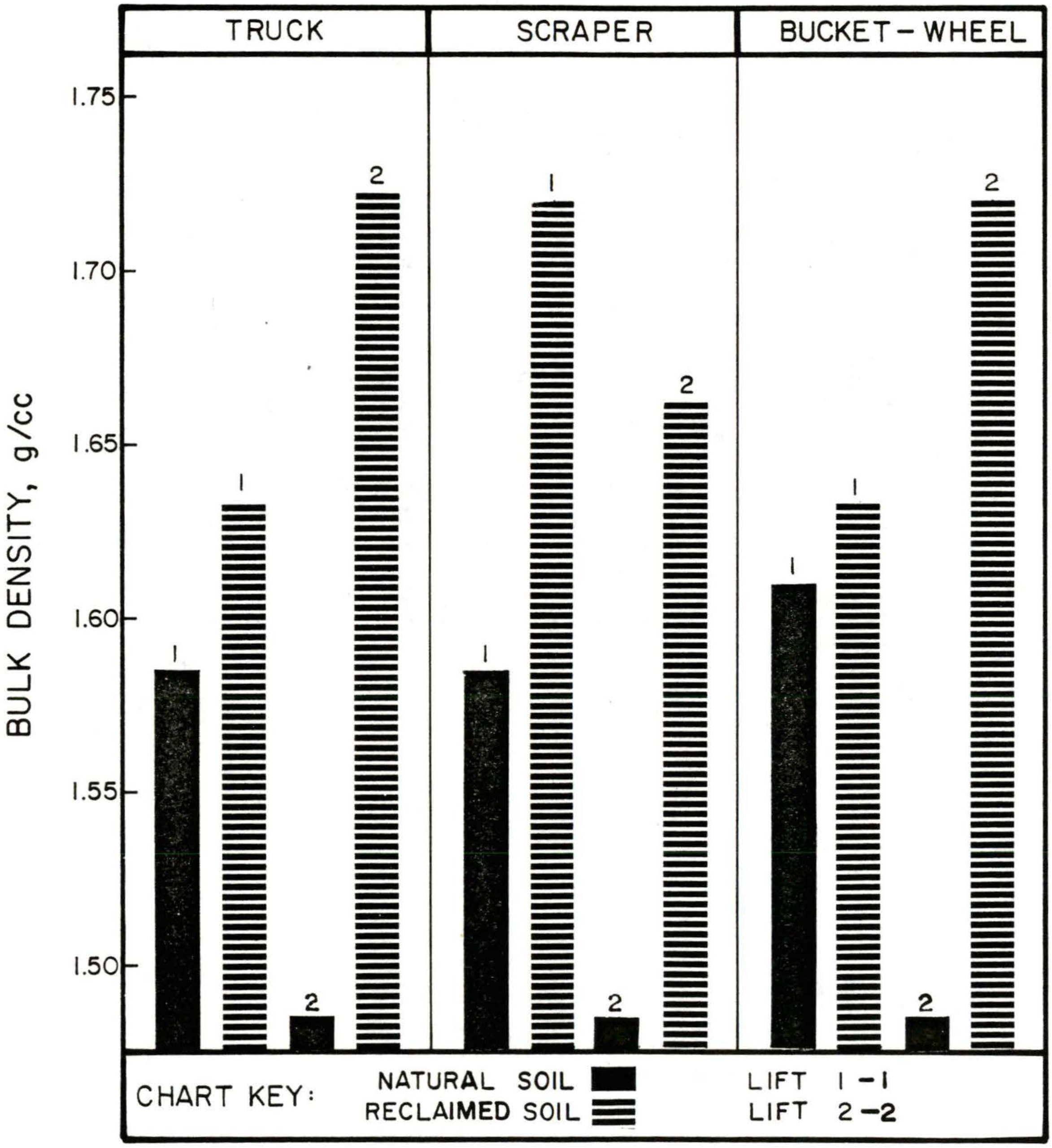

**FIGURE 67.** **Scraper, Bucket-Wheel and End-Dump Haulback Plot Means by Soil Type and Lift**

than the natural soil mean bulk density, while for Lift 2 the reclaimed soil mean is .19 g/cm$^3$ larger than the natural soil mean. That is, there is a greater difference between the natural and reclaimed soils for Lift 2, the top layer of soil.

Bulk density for the reclaimed soils was not significantly greater than the bulk density for the natural soil (p=.19, TABLE C-2, APPENDIX C), but the bulk density for Lift 1 was greater than for Lift 2 (1.65 and 1.57 g/cm$^3$ for Lift 1 and Lift 2, respectively; p<.0001, TABLE C-2, APPENDIX C). The lack of a significant effect of soil type likely reflects the lack of power for the statistical test being run. The proper error term for a test of a soil effect has only one degree of freedom as only three soil plots were studied.

## Bucket-Wheel Excavator Analysis

As shown in Table 17 data were collected from two plots each containing both reclaimed and natural soils (a total of 80 observations):

TABLE 17. SUMMARY OF STATISTICAL OBSERVATIONS / BUCKET-WHEEL

| Sample Location | Natural Soil | Reclaimed Soil |
|---|---|---|
| **Lift 1 Total** | **20** | **20** |
| Plot C-3 | 10 | |
| Plot C-4 | 10 | |
| Plot W-1 | | 10 |
| Plot W-2 | | 10 |
| **Lift 2 Total** | **20** | **20** |
| Plot C-3 | 10 | |
| Plot C-4 | 10 | |
| Plot W-1 | | 10 |
| Plot W-2 | | 10 |
| **Totals Lift 1 & 2** | **40** | **40** |

The means by lift and soil type are shown in Figure 67.

The lift by soil type interaction is highly significant (p<.0001, TABLE C-3, APPENDIX C). The reclaimed soil had a greater bulk density for both lifts with the difference between natural and reclaimed soils equaling .03 g/cm$^3$ for Lift 1 and .20 g/cm$^3$ for Lift 2. Overall, the reclaimed soil mean was greater (1.52 and 1.64 g/cm$^3$ for natural and reclaimed soil, respectively; p=.08, TABLE C-3, APPENDIX C).

## End-Dump Haulback Analysis

This data is included in the statistical analysis to provide a means of comparison between density values for another soil type. Haulback data presented is from the Brazil mine in Central Indiana. As shown in Table 18, ten observations were taken from each of two lifts and two plots of the natural and reclaimed soils for a total of 80 observations:

TABLE 18. SUMMARY OF STATISTICAL OBSERVATIONS / END-DUMP

| Sample Location | Natural Soil | Reclaimed Soil |
|---|---|---|
| **Lift 1 Total** | **20** | **20** |
| Plot B-1 | 10 | |
| Plot B-3 | 10 | |
| Plot B-2 | | 10 |
| Plot B-4 | | 10 |
| **Lift 2 Total** | **20** | **20** |
| Plot B-1 | 10 | |
| Plot B-3 | 10 | |
| Plot B-2 | | 10 |
| Plot B-4 | | 10 |
| **Totals Lift 1 & 2** | **40** | **40** |

The lift by soil type means are shown in Figure 67.

As with the previous soil reclamation method, a significant soil type by lift interaction exists (p=.004, TABLE C-4, APPENDIX C). The reclaimed soil had a mean bulk density which was .102 greater than observed with the natural soils for Lift 1. The difference between these means is .212 for Lift 2. Overall, the reclaimed soil mean was greater than the natural soil mean (1.56 and 1.72 g/cm$^3$ for the natural and reclaimed soils, respectively; p=.01, TABLE C-4, APPENDIX C).

## Scrapers by Lift Statistical Analysis

Data were collected at each of four passes and four lifts according to the schedule in Table 19.

TABLE 19. SUMMARY OF STATISTICAL OBSERVATIONS / SCRAPERS BY LIFT

| PASS | LIFT 1 | LIFT 2 | LIFT 3 | LIFT 4 |
|---|---|---|---|---|
| 4 | 10 | - | - | - |
| 3 | 10 | 10 | - | - |
| 2 | 10 | 10 | 10 | - |
| 1 | 10 | 10 | 10 | 10 |
| Total | 40 | 30 | 20 | 10 |

The following summarizes how data were supplied in relationship to soil lift: After the first lift of soil was replaced, 10 observations were taken. Following placement of the second lift, ten observations were taken on both the first and second lift. After placement of the third lift, ten observations were taken on each of the first three lifts. Finally, after placement of the fourth and final lift, ten measurements were taken at each of the four lifts.

The means by lift and pass are shown in Figure 45. The Pass 1 mean for Lift 2 (1.58 $g/cm^3$) is a relatively small value creating a marginally significant lift by pass interaction (p=.09, TABLE C-1, APPENDIX C). This interaction is most likely the result of "unusual" data rather than an indication of an effect of practical importance. These observations make it difficult to get a clear picture of the effect of lift; but, nonetheless, there is an indication of a lift effect.

The following section deals with the application of soil texture and bulk density values to a soil compaction prediction analysis.

# SOIL COMPACTION PREDICTION ANALYSIS

## Background Data

The synthesis of this analysis is based on the premise that soil texture explains a significant percentage of the interaction between reclamation equipment, texture, and bulk density. The analysis is composed of data from two years of field study in three states in the Midwest. The pooling of this data base of information provides a broad spectrum of soil characteristics on which to base a predictive analysis for bulk density. This model to predict bulk density is composed of a data base of information from both the 1982 and 1984 studies.

General analysis rationale is the need to evaluate under field conditions the impact of a particular machine system on resultant bulk density values of prime farmland subsoils. The topsoils in prime farmland reclamation can be reclaimed to approximately the same density levels as those that existed prior to mining through extensive tillage practices. This predictive analysis is directed toward the compaction effects on subsoil regions; major concern for the support of row crop growth. This predictive analysis is based entirely on bulk density values collected under these four equipment systems:

- **Scraper**
- **Bucket-Wheel Excavator**
- **End-Dump Haulback**
- **Dragline**

Evaluation of these four equipment systems by previous research has concluded that bucket-wheel excavators, end- dump haulbacks and draglines all deposit subsoil materials in a deep lift, while scraper pans compact soils in layers as each lift is replaced. This breakdown of soil replacement technique is the basis of data manipulation for this study. Lift 1 in the study is defined as a lift in the lower subsoil region where bucket-wheel excavator, end-dump haulback and draglines are the predominant equipment type with no scraper tracking. Lift 2 is defined as the upper subsoil region where topsoil replacement with scraper is the primary source of compactive effort.

Textural analysis measuring sand, silt and clay contents are compared with soil bulk density data derived from the same soil sample. This analysis identifies the "best predictor" by evaluating all data statistically. This section of the report evaluates the prediction analysis and presents the technical data content, statistical basis, correlation with crop response and summarizes prediction analysis and use. This analysis provides a foundation for evaluation of subsoil compaction on a practical level.

## Technical Data Content

The basic statistical analysis consists of measurements of soil texture (sand, silt and clay) and bulk density on 112 soil samples. All data contained in the analysis are from reclaimed soil areas. As indicated earlier, soil was replaced by scraper for Lift 2, while Lift 1 was by bucket-wheel excavator, end-dump haulback and dragline methods of deep lift soil replacement. All data presented and plot numbers cited correlate directly to information described in previous discussions, including plot locations and mining methods. A summary of plot observations included in this predictive analysis are cited in Table 20.

TABLE 20. SUMMARY OF PLOT OBSERVATIONS

| STUDY | PLOT | LIFT 1 | LIFT 2 |
|---|---|---|---|
| Brazil-82 | B-2 | 5 | 5 |
| Brazil-82 | B-4 | 6 | 5 |
| Captain-82 | C-1 | 5 | 5 |
| Captain-82 | C-2 | 5 | 5 |
| Delta-82 | D-1 | 5 | 5 |
| Delta-82 | D-2 | 5 | 6 |
| Power-82 | P-1 | - | 5 |
| Power-82 | P-2 | - | 5 |
| Captain-84 | S-2 | - | 10 |
| Captain-84 | W-1 | 5 | 10 |
| Captain-84 | W-2 | 10 | 5 |
| Totals: | 11 | 46 | 66 |

In Table 20 in the Lift 1 column the P-1, P-2 and S-2 plots are absent. This data is not included because all three plots involve scrapers for subsoil replacement which are not representative of machine types for Lift 1. These data are included in Lift 2 for the scraper predictive analysis. These data compise the total predictive analysis on sand, silt and clay and the relationship to clay. The following section summarizes the statistical analysis applied to evaluate the "best predictive" unit and to define all statistical data manipulation.

## Statistical Basis

The relationship between the three soil texture measurements and bulk density are studied. Statistical significance tests are expressed using the P-value shown in Appendix C. The P-value is defined as the probability of a result this much or more deviant from that which is expected under the null hypothesis given that the hypothesis tested is really true.

Sand and clay is significantly related to bulk density, while silt is not (TABLE's C-5--C-7, APPENDIX C). The best prediction equation for sand variation involves a single intercept for Lifts 1 and 2, while the slope varies by lift. For the variation in clay, the best prediction of bulk density does not depend on lift and is a simple linear regression, an overall model lift and pass is a simple linear regression. An overall model (TABLE's C-8 and C-9 for sand and clay, respectively, APPENDIX C) is tested to find the "best" prediction equation for sand and clay, each with lift in the model. For sand the slope appears to change with lift while the intercept is the same for both lifts. As can be seen in TABLE C-9, the prediction of bulk density from clay content does not depend on lift. The two models which appear to best predict bulk density from sand and clay are given in TABLES C-10 and C-11 of APPENDIX C, respectively. The prediction of bulk density from sand and clay have $R^2$=39.4 percent and 36.7 percent values, respectively; indicating that less than one-half of the variation in bulk density is explained by either sand or clay.

The graphs of the prediction equations and the 95 percent confidence intervals are given in Figure 68 for the prediction of bulk density using clay and in Figures 69 and 70 for the prediction of bulk density using sand for Lifts 1 and 2, respectively. For determining a general texture class for each density prediction refer to the SCS textural triangle presented in Figure 71.

Because of the functional relationship that exists between the soil texture variables (sand+clay+silt=100 percent), the prediction of bulk density is equally accurate if any two of the variables are used. That is, that the $R^2$ is the same when any two of the three soil texture variables are used to predict bulk density. Since sand and clay are individually related to bulk density, the ability of these two variables to predict bulk density is studied further. TABLE's C-12 and C-13 in APPENDIX C give an overview of analysis of variance's (ANOVA) that test how these two variables predict bulk density and a model which seems to "best" predict bulk density using a LIFT indicator. As can be seen in TABLE C-12 a common intercept for the two lifts and a common coefficient for clay for both lifts are indicated. The "best" model for using sand, clay and lift to predict bulk density is given in TABLE C-13. A listing of the predicted bulk densities with a 95% confidence interval for certain values of sand and clay is found for Lift 1 in Table 21 and Lift 2 in Table 22.

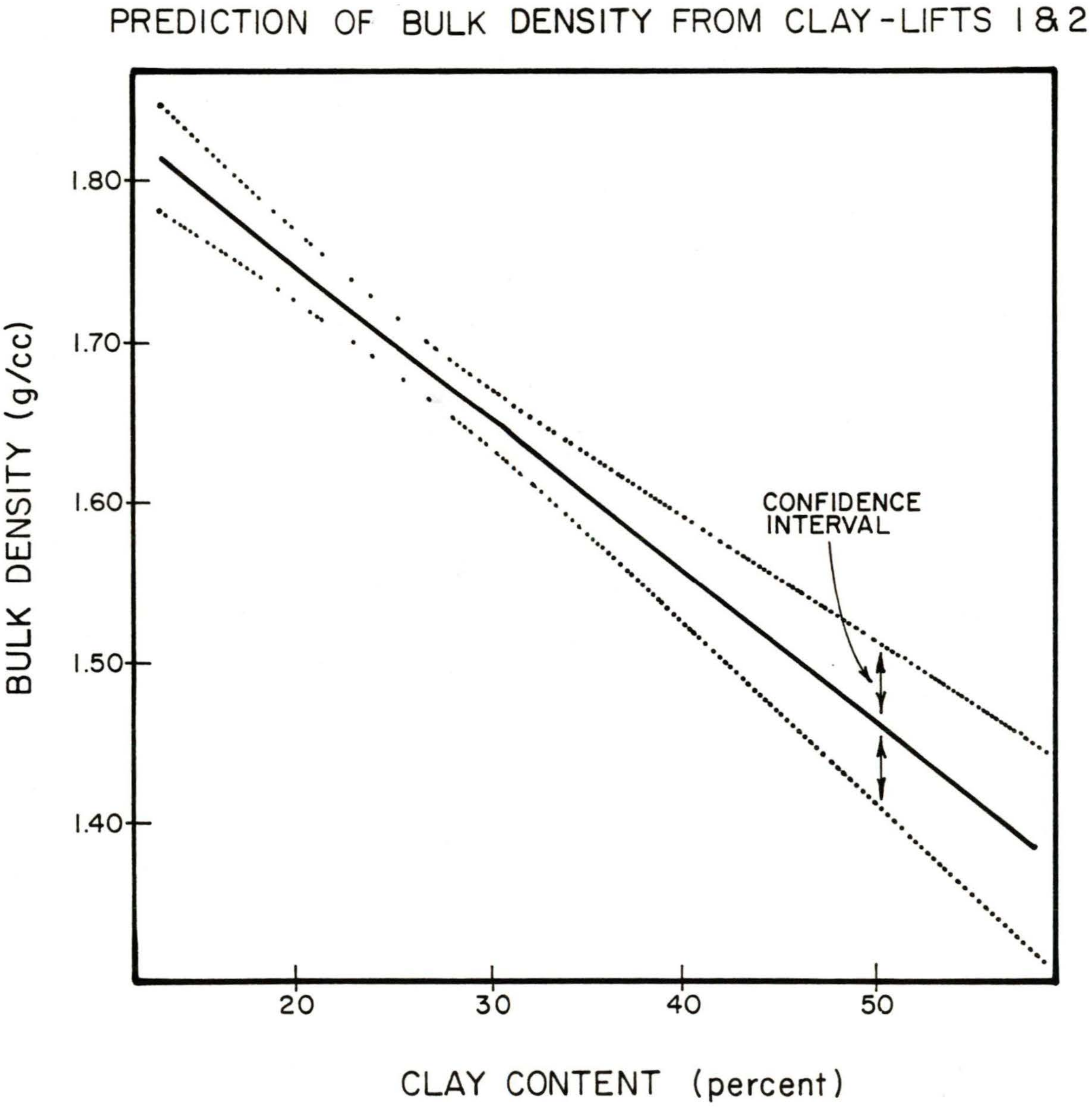

**FIGURE 68.** Prediction Curves for Bulk Density from Clay Content for Lifts 1 and 2

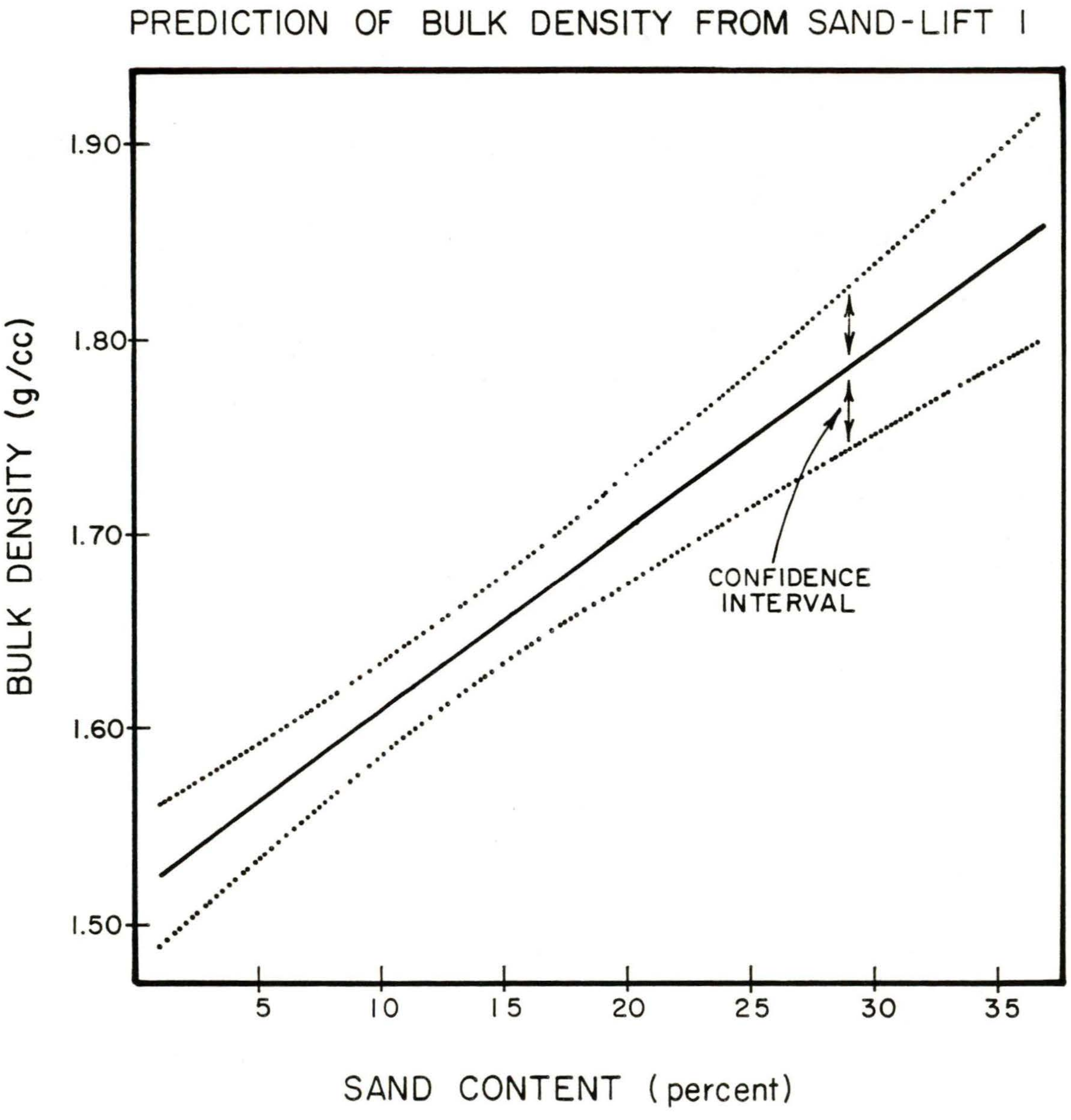

**FIGURE 69. Prediction Curves for Bulk Density from Sand Content for Lift 1**

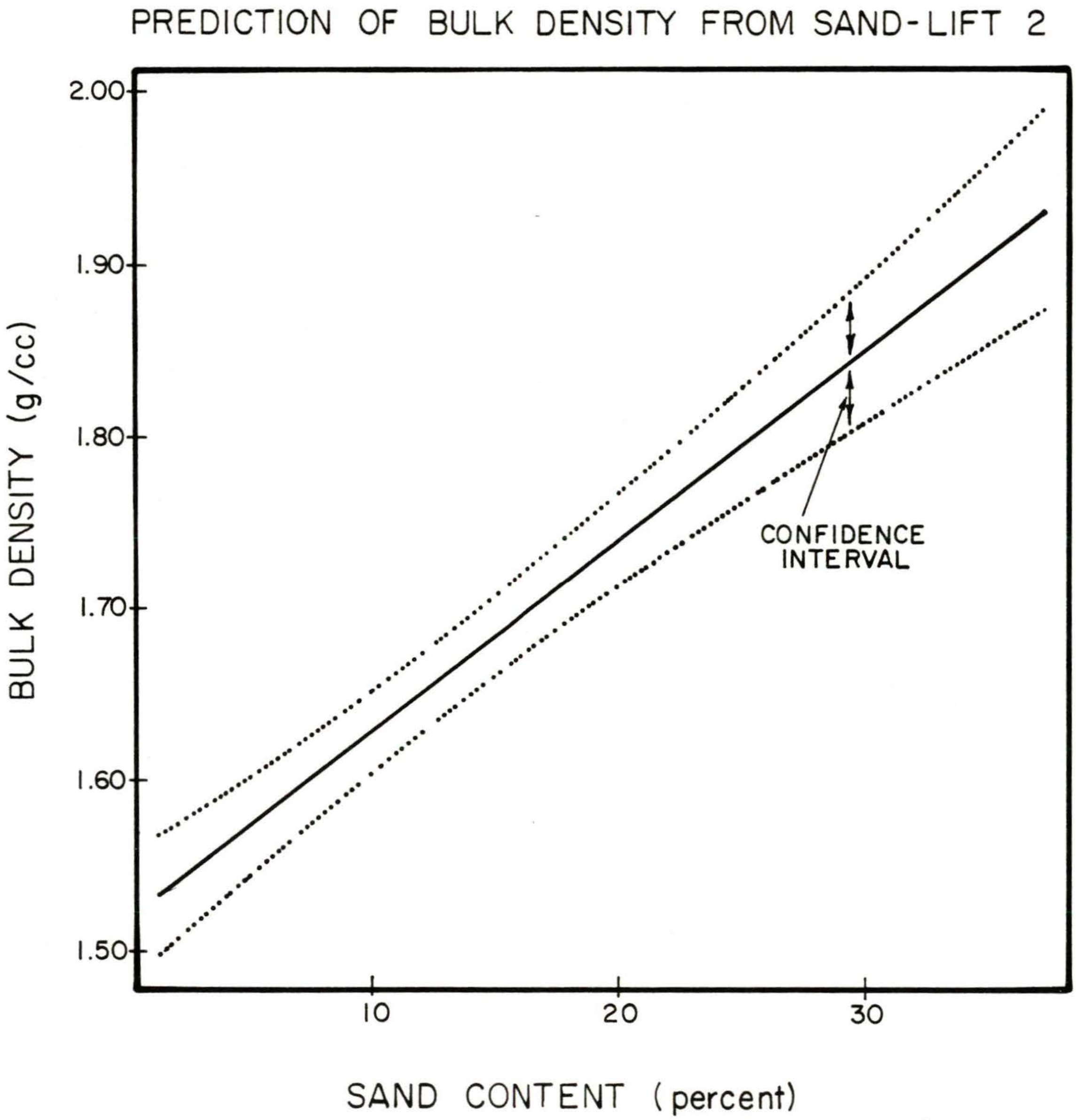

FIGURE 70. Prediction Curves for Bulk Density from Sand Content for Lift 2

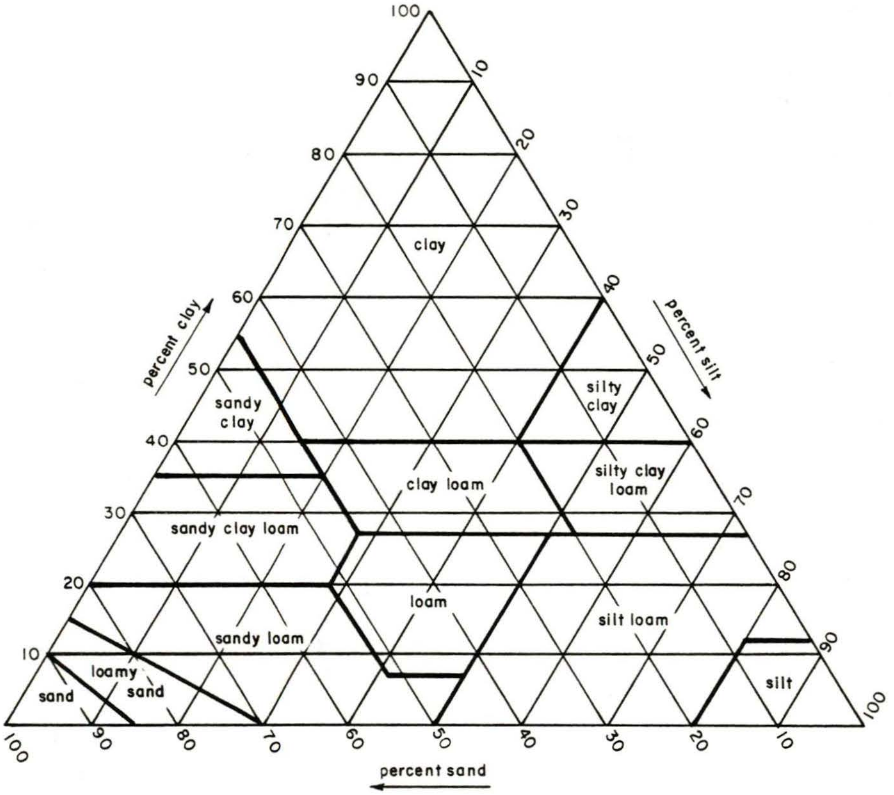

FIGURE 71. Soil Conservation Service Soil Textural Triangle

## TABLE 21. PREDICTION OF BULK DENSITY FROM SAND AND CLAY

| VALUES OF SAND AND CLAY | LIFT 1 ESTIMATE | 95% CONFIDENCE LIMITS |
|---|---|---|
| Sand 0% Clay 10% | 1.6917 | 1.6174 -- 1.7660 |
| Sand 0% Clay 30% | 1.5508 | 1.5112 -- 1.5904 |
| Sand 0% Clay 50% | 1.4099 | 1.3480 -- 1.4718 |
| Sand 10% Clay 10% | 1.7462 | 1.6903 -- 1.8021 |
| Sand 10% Clay 30% | 1.6053 | 1.5796 -- 1.6310 |
| Sand 10% Clay 50% | 1.4644 | 1.3980 -- 1.5308 |
| Sand 20% Clay 10% | 1.8007 | 1.7548 -- 1.8466 |
| Sand 20% Clay 30% | 1.6598 | 1.6263 -- 1.6933 |
| Sand 20% Clay 50% | 1.5189 | 1.4391 -- 1.5987 |
| Sand 30% Clay 10% | 1.8552 | 1.8058 -- 1.9046 |
| Sand 30% Clay 30% | 1.7143 | 1.6600 -- 1.7686 |
| Sand 30% Clay 50% | 1.5734 | 1.4750 -- 1.6718 |
| Sand 40% Clay 10% | 1.9097 | 1.8452 -- 1.9742 |
| Sand 40% Clay 30% | 1.7688 | 1.6904 -- 1.8472 |
| Sand 40% Clay 50% | 1.6279 | 1.5081 -- 1.7477 |
| Sand 50% Clay 10% | 1.9642 | 1.8791 -- 2.0493 |
| Sand 50% Clay 30% | 1.8233 | 1.7200 -- 1.9266 |
| Sand 50% Clay 50% | 1.6824 | 1.5397 -- 1.8251 |
| Sand 60% Clay 10% | 2.0187 | 1.9107 -- 2.1267 |
| Sand 60% Clay 30% | 1.8778 | 1.7490 -- 2.0066 |
| Sand 60% Clay 40% | 1.8073 | 1.6609 -- 1.9537 |
| Sand 70% Clay 10% | 2.0732 | 1.9411 -- 2.2053 |
| Sand 70% Clay 20% | 2.0027 | 1.8616 -- 2.1438 |
| Sand 70% Clay 30% | 1.9323 | 1.7777 -- 2.0869 |
| Sand 80% Clay 0% | 2.1981 | 2.0464 -- 2.3498 |
| Sand 80% Clay 10% | 2.1277 | 1.9707 -- 2.2847 |
| Sand 80% Clay 20% | 2.0572 | 1.8904 -- 2.2240 |
| Sand 90% Clay 0% | 2.2526 | 2.0772 -- 2.4280 |
| Sand 90% Clay 05% | 2.2174 | 2.0390 -- 2.3958 |
| Sand 90% Clay 10% | 2.1821 | 2.0000 -- 2.3642 |
| Sand 100% Clay 0% | 2.3071 | 2.1072 -- 2.5070 |

## TABLE 22. PREDICTION OF BULK DENSITY FROM SAND AND CLAY

| VALUES OF SAND AND CLAY | LIFT 2 ESTIMATE | 95% CONFIDENCE LIMITS |
|---|---|---|
| Sand 0% Clay 10% | 1.6917 | 1.6174 -- 1.7660 |
| Sand 0% Clay 30% | 1.5508 | 1.5112 -- 1.5904 |
| Sand 0% Clay 50% | 1.4099 | 1.3480 -- 1.4718 |
| Sand 10% Clay 10% | 1.7649 | 1.7083 -- 1.8215 |
| Sand 10% Clay 30% | 1.6240 | 1.5995 -- 1.6485 |
| Sand 10% Clay 50% | 1.4831 | 1.4182 -- 1.5480 |
| Sand 20% Clay 10% | 1.8381 | 1.7918 -- 1.8844 |
| Sand 20% Clay 30% | 1.6972 | 1.6678 -- 1.7266 |
| Sand 20% Clay 50% | 1.5563 | 1.4799 -- 1.6327 |
| Sand 30% Clay 10% | 1.9113 | 1.8633 -- 1.9593 |
| Sand 30% Clay 30% | 1.7704 | 1.7216 -- 1.8192 |
| Sand 30% Clay 50% | 1.6295 | 1.5364 -- 1.7226 |
| Sand 40% Clay 10% | 1.9845 | 1.9235 -- 2.0455 |
| Sand 40% Clay 30% | 1.8436 | 1.7721 -- 1.9151 |
| Sand 40% Clay 50% | 1.7028 | 1.5899 -- 1.8157 |
| Sand 50% Clay 10% | 2.0577 | 1.9779 -- 2.1375 |
| Sand 50% Clay 30% | 1.9169 | 1.8214 -- 2.0124 |
| Sand 50% Clay 50% | 1.7760 | 1.6415 -- 1.9105 |
| Sand 60% Clay 10% | 2.1309 | 2.0298 -- 2.2320 |
| Sand 60% Clay 30% | 1.9901 | 1.8703 -- 2.1099 |
| Sand 60% Clay 40% | 1.9196 | 1.7828 -- 2.0564 |
| Sand 70% Clay 10% | 2.2042 | 2.0803 -- 2.3281 |
| Sand 70% Clay 20% | 2.1337 | 2.0022 -- 2.2652 |
| Sand 70% Clay 30% | 1.0633 | 1.9190 -- 2.2076 |
| Sand 80% Clay 0% | 2.3478 | 2.2039 -- 2.4917 |
| Sand 80% Clay 10% | 2.2774 | 2.1300 -- 2.4248 |
| Sand 80% Clay 20% | 2.2069 | 2.0509 -- 2.3629 |
| Sand 90% Clay 0% | 2.4210 | 2.2548 -- 2.5872 |
| Sand 90% Clay 5% | 2.3858 | 2.2176 -- 2.5540 |
| Sand 90% Clay 10% | 2.3506 | 2.1793 -- 2.5219 |
| Sand 100% Clay 0% | 2.4942 | 2.3051 -- 2.6833 |

$R^2$ for the prediction of bulk density using clay and sand is 51.6 percent, indicating that slightly over one-half of the variation in bulk density is explained by sand and clay.

Some investigators have used the sum of two of the three soil texture variables to predict bulk density. Such an approach makes prediction simpler since the sum of two variants gives a single variable and a simple linear regression results. In comparison, the use of two separate variables results in a multiple regression, the results of which cannot be neatly graphed. In effect our multiple regression approach gives a linear regression of clay effects on bulk density for each value of sand.

More importantly, the use of the sum of any two soil texture variables to predict bulk density is no more accurate than the use of the third variable to predict bulk density. To illustrate this, the regressions for sand+clay, sand+silt, and clay+silt are given in TABLES C-13 through C-15 in APPENDIX C. The prediction of bulk density from the sum of sand and clay, for example, is as accurate as the prediction of bulk density from silt alone. Note from TABLES C-7 AND C-13 that the $R^2$ for both predictions is 1.5 percent, that is, the prediction of bulk density for the sum of sand and clay is as accurate as the prediction of bulk density from silt. Similar results hold for the other sums. The fact that the prediction of bulk density from the sum of two variables is equivalent to the prediction of bulk density from the third variable follows from the functional relationship: sand+clay+silt=100 percent.

### Summary of Prediction Analysis and Use

Given the previous statistical analysis, using clay and sand as a predictor the $R^2$ value is 51.6 percent the implications for practical application are significant. Because a typical silt loam soil contains 50 percent solids, 20 percent gas, and 30 percent liquid, the solids phase, largely texture class, is explained by this analysis. The limitations of bulk density prediction are seen when the liquid and gas phases are considered. For they have an effect on overall changes in bulk density due to natural and equipment impacts. In the application of this predictive analysis the liquid and gaseous phases have a significant impact on overall bulk density, but are not specifically represented in the predictive analysis. However, the liquid phase of the soil composition is indirectly included in the analysis. In essence both liquid and gas phases are included because one soil component cannot be considered without evaluating its impact on the other two components. Since the soil data are collected for a broad range of soils, the diversity adds validity to the upper and lower prediction limits as indicated on the two dimensional graphs for sand and clay.

The most accurate representation of the data for compaction prediction is given by the evaluation of sand and clay graphed as a three-dimensional relationship. In practical use, the most accurate predictors using sand and clay in combination are shown in Tables 21 and 22. The use of these tables for estimating bulk density in the field is relatively straightforward. Linear interpretation can be accomplished to represent any percentage of sand and clay for application of a bulk density estimate within the 95 percent confidence interval. Table 21 indicates predictive values for all data for the Lift 1 analysis. As stated previously, Lift 1 analyzes subsoil materials without scraper impact. Lift 1 accounts for material replaced with bucket-wheel excavator, end-dump haulback or dragline methods. Since this soil material is replaced without tracking, bulk density values in this analysis are less than for strictly scraper impact.

Use of these predictive tables is straightforward as is demonstrated in the following example. Turn to the predictive analysis in the Lift 1 data table (Table 21). A soil in the field is found to have 10 percent sand, 30 percent clay and 60 percent silt. Reading across the graph, the estimate is 1.6053 with a confidence band between 1.58 and 1.63. This straightforward evaluation can be made for any soil analyzed in the field in the natural condition for prediction of ultimate soil compaction problems. If soils are mixed, an evaluation can be made for each soil series in the field through averages of soil textures. The predictive analysis is then applied to estimate compaction problems. The Lift 2 data table which is totally for scraper replacement of soils is used in exactly the same manner for compaction prediction. For convenience in using this analysis an SCS soil textural triangle is provided in Figure 71.

The prediction of bulk density after reclamation using a natural soil texture value is a powerful tool to a prime farmland mine planner for detecting subsequent soil compaction problems. Since soil compaction affects mining engineering and hydrology (due to reduced infiltration) as well as prime farmland recovery properties, a soil compaction prediction tool is a valuable asset. A prediction analysis such as this is limited in broad application effectiveness by the diversity of soil parameters in different geographical regions. The prediction analysis is best suited for the prime farmland areas of the Midwest. From a soil science standpoint, the bulk density estimates through the predictive analysis are helpful, but the need exists to relate this bulk density to a crop growth value appropriately named "growth limiting bulk density".

## Correlation to a Crop Response

Under the constraints of this study, no field evaluation was made relating a given bulk density to a particular crop limiting value. However, a study identifying growth limiting bulk densities was published and for the purposes of completion, the findings are briefly summarized for possible application to the bulk density prediction analysis. This study was developed by Richard L. Daddow and Gordon E. Warrington Watershed Systems Development Group, USDA, Fort Collins, Colorado.

Table 23 shows soil types, crops, textures and subsequent bulk densities analyzed in different studies to develop a limiting bulk density for a particular crop. This table is adapted directly from the USDA study only as an informative addendum to this report. As shown in Table 23, growth limiting bulk density values are indicated for each crop type along with a corresponding texture. Given that these growth limiting bulk densities relate to texture, a growth limiting bulk density triangle was developed utilizing isodensity lines as a guideline for limiting root penetration at particular texture contents and densities.

The growth limiting bulk density textural triangle developed by Daddow and Warrington is presented in Figure 72. The application of this textural triangle is to aid western forest soil scientists in evaluating soil compaction effects on plant growth. As with any analysis where different studies are combined, this study has many limitations and does not conclusively predict growth limiting bulk densities. Use of this textural triangle should take into consideration the limitations used in developing the growth limiting bulk density triangle. The importance of obtaining a copy of Daddow and Warrington's original report for these data cannot be overemphasized. This method of relating texture and density is just one example of the correlation of data which is needed to tie a growth limiting bulk density to an ultimate crop response.

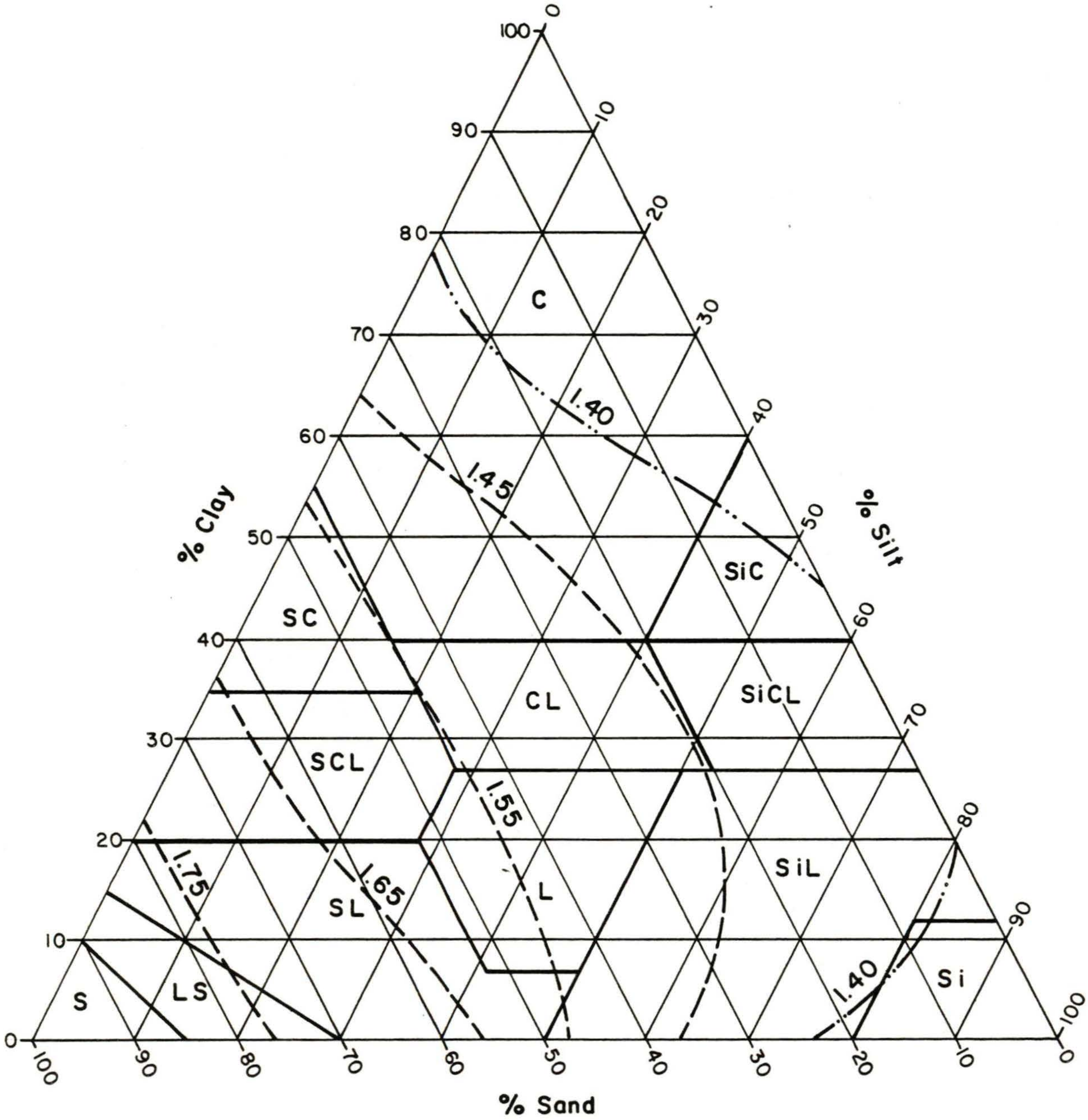

FIGURE 72. Growth Limiting Bulk Density Textural Triangle (Daddow and Warrington, 1983) (Sand, Silt, Clay, and Loam are represented by S, Si, C, and L)

## TABLE 23. CROP AND GROWTH LIMITING BULK DENSITY VALUES

| Soil Type | Plant | Sand | Silt | Clay | Limiting Bulk Density | Comments |
|---|---|---|---|---|---|---|
| Colo Clay | Corn | 27 | 31 | 42 | 1.30 | Severe reduction (75%) in root elongation |
| Loam | Pea | 71 | 17 | 12 | 1.70 | Severe reduction (69%) in length of all roots |
| Miles Loamy Fine Sand | Cotton | 83 | 8 | 9 | 1.82 | No root penetration, 19 bars penetrometer resistance |
| Naron Fine Sandy Loam | Cotton | 79 | 11 | 10 | 1.79 | No root penetration, 20 bars penetrometer resistance |
| Quinlan Fine Sandy Loam | Cotton | 73 | 20 | 7 | 1.77 | No root penetration, 25 bars penetrometer resistance |
| Columbia Loam | Cotton | 44 | 37 | 19 | 1.55 | No root penetration, 25 bars penetrometer resistance |
| Tripps Sandy Loam | Corn-Soybean | 63 | 25 | 12 | 1.60 | No root elongation, 22 bars penetrometer resistance |
| Tripps Loam | Corn-Soybean | 41 | 41 | 18 | 1.40-1.60 | No root elongation,11-28 bars penetrometer resistance |
| Urrbrae Fine Sandy Loam | Pea | 16 | 19 | 65 | 1.46 | No root elongation-void ratio-0.81 |

**TABLE 23 (CON'T). CROP AND GROWTH LIMITING BULK DENSITY VALUES**

| Soil Type | Plant | Sand | Silt | Clay | Limiting Bulk Density | Comments |
|---|---|---|---|---|---|---|
| Sandy Loam | Red Alder<br>Lodgepole Pine<br>Douglas-Fir | 52 | 31 | 17 | 1.59 | No root penetration |
| Sand | Sorghum<br>Beans, Millet<br>Sudangrass | 96 | 2 | 2 | 1.74 | No root penetration |
| Sverdrup Sandy Loam | Pea | 63 | 27 | 10 | 1.61 | Severe reduction (79%) primary root elongation |
| Nutley Clay | Pea | 6 | 39 | 55 | 1.37 | Severe reduction (70%) primary root elongation |
| -- | Apple | 64±5 | 25±3 | 11±3 | 1.75 | Restricted root growth, porosity - 34% |
| -- | Apple | 61±8 | 29±5 | 10±5 | 1.72 | Restricted root growth, porosity - 35% |
| -- | Apple | 58±9 | 31±7 | 11±4 | 1.85 | Restricted root growth, porosity - 30% |
| -- | Apple | 69±5 | 18±4 | 13±3 | 1.77 | Restricted root growth, porosity - 33% |
| -- | Apple | 86±4 | 9±4 | 5±3 | 1.62 | Restricted root growth, porosity - 39% |

## TABLE 23 (CON'T). CROP AND GROWTH LIMITING BULK DENSITY VALUES

| Soil Type | Plant | Sand | Silt | Clay | Limiting Bulk Density | Comments |
|---|---|---|---|---|---|---|
| -- | Apple | 75±11 | 19±8 | 6±3 | 1.88 | Restricted root growth, porosity - 29% |
| Nixon Silt Loam | Pitch Pine<br>Austrian Pine<br>Norway Spruce | 22 | 64 | 14 | 1.40 | Severe reduction (75%) in root penetration |
| Lakewood Sandy Loam | Pitch Pine<br>Austrian Pine<br>Norway Spruce | 66 | 26 | 8 | 1.60-1.80 | Severe reduction (70%) in root penetration |

-- Not Available

# COST ANALYSIS

## Cost Evaluation Criteria

The following discussion and description of scenarios outlines the applicability of costs for prime farmland soil removal and reclamation on a predefined mine site. The cost analysis centers on the evaluation of the following equipment and revegetation related costs:

- **Bucket-wheel excavators**
- **End-dump haulback**
- **Scrapers**
- **Chisel plowing and subsoiling**
- **Revegetation**

For each of these cost evaluations a cost analysis scenario is compiled to evaluate costs of using particular equipment. The cost analysis is based on the evaluation of the above equipment systems for the analysis of the following general cost categories:

- **Equipment operating costs and production rates,**
- **Calculation of total volume of material handled,**
- **Time required for material movement,**
- **Cost of material movement,**
- **Total cost as related to total production.**

Calculations for evaluating costs for prime farmland soil movement including removal, transport and replacement, stockpiling and revegetation require that certain assumptions be made for equipment cost and utilization. For example, topsoil removal depth is assumed to be 12 inches as required in the current regulations. Subsoils are required to be moved to a depth of 36 inches.

The cost calculations for soil movement are calculated on a basis of a predetermined mine size. This uniform mine size allows comparison between equipment utilization techniques for soil removal, transport and replacement. The mine size utilized for this study is that used for OSM regulatory analysis for prime farmland areas of the Midwest. The mine size is 335 acres with a linear measurement of 1,450 feet by 10,000 feet. Annual coal production in tons per year for purposes of this analysis is estimated at 2,300,000 tons.

Equations which are used to calculate costs depend upon individual equipment types applied to the mine model. These costs are, in turn, dependent upon actual mine acreages considered in this study. The following discussions revolve around the types of calculations for soil movement by scrapers, with scraper loads and dozer loads for cost determination within the three equipment systems.

Production figures and costs for all equipment, except for bucket-wheel excavator, are supplied from data available in the Caterpillar Performance Handbook, and based on assumed equipment size and travel distance. Approximate bucket-wheel excavator costs are given in the OSM regulatory analysis and are an estimate for the mine size and characteristics of the production model. The assumptions for equipment size and travel distances dictate cycle times and subsequently the production rate. Individual equipment costs are given when needed in the cost analysis scenarios. The following section provides calculations of all cost analyses for use in prime farmland cost evaluations in the form of time-motion studies.

## Time-Motion Studies

The following time-motion studies evaluate soil movement as simulated on the predescribed model size. Costs are evaluated and summarized on a cost-per-ton-basis for the following equipment or revegetation systems:

- **Bucket-wheel excavator**
- **End-dump haulback**
- **Scrapers**
- **Stockpiling**
- **Compaction alleviation tillage**
- **Revegetation.**

Each cost scenario provided is totally self-supporting and supplies all information on equipment utilization, equipment production and all equipment operations. Cost scenarios are presented in Tables 24 through 29. The abbreviations BCY and LCY represent soil volume in bank cubic yards and loose cubic yards, respectively.

## TABLE 24. BUCKET-WHEEL EXCAVATOR SCENARIO

| | |
|---|---|
| Annual Disturbance: | 335 acres = 14,592,600 $ft^2$ |
| Linear Measurement: | 1450' x 10,000' |
| Annual Coal Production (TPY): | 2,300,000 |

### SCENARIO OF EQUIPMENT UTILIZATION:

- o Remove 1' of topsoil with scraper to stockpile
- o Remove 3' of subsoil with bucket-wheel and transport around the pit on conveyors
- o Move 1' of stockpiled topsoil around the pit using the bucket-wheel
- o Spread the topsoil with scrapers
- o Level of topsoil with a D9H

### SCRAPER REMOVAL OF TOPSOIL:

Equipment and Production

Scraper: 657 B/PP

o Total Effective Grade: 5%
Assuming rolling resistance (p.497, CAT) = 5% and % Grade = 0

o Fixed Times (p. 166, CAT)
Load time: 1.0 min
Maneuver and dump: 0.7 min Total= 1.7 min

o Travel Times (Average Distance - 2500 ft) (p. 208-209, CAT)
Loaded: 0.5 min
Empty: 0.3 min Total= 0.8 min

o Cycle Time = (Fixed Times) + (Travel Times) = 2.5 min

o Production Rate (p. 224, CAT): 875 BCY/hr x (2) = 1750 BCY/hr

o Volume to Move = (Annual Disturbance) x (Depth of Removal) x $\frac{1\ yd^3}{27\ ft^3}$ = 540,467 BCY

o Time Required = $\frac{\text{Volume to Move}}{\text{Production}} = \frac{540{,}467}{1750}$ = 309 hrs

o Cost = (Time) ($/hr) = (309)($85)(2) = $26,265

### BUCKET REMOVAL OF 3' OF SUBSOIL:

- Volume to Move = (Annual Disturbance) x (Depth of Removal) x $\frac{1\ \text{yd}^3}{27\ \text{ft}^3}$ = (14,592,600 ft$^2$)(3) $\frac{1\ \text{yd}^3}{27\ \text{ft}^3}$ = 1,621,400 BCY

- Cost = \$1.00/BCY (1,621,400 BCY) = \$1,621,400

### MOVEMENT OF 1' OF TOPSOIL AROUND THE PIT BY BUCKET-WHEEL:

- Volume to Move = 540,467 BCY

- Cost = \$540,467

### SPREADING THE STOCKPILED TOPSOIL BY SCRAPER:

- Volume to Move = 540,467 BCY

- Fixed Times (p. 166, CAT)
  Load time: 1.0 min
  Maneuver and dump: 0.7 min — Total= 1.7 min

- Travel Times (Average Distance = 2500 ft) (p. 204-5, CAT)
  Loaded: 0.5 min
  Empty: 0.3 min — Total= 0.8 min

- Cycle Time = (Fixed Times) + (Travel Times) = 2.5 min

- Production Rate (p. 224, CAT): 875 BCY/hr (2) = 1750 BCY/hr

- Volume to Move = (Annual Disturbance) x (Depth of Removal) x $\frac{1\ \text{yd}^3}{27\ \text{ft.}^3}$ = 540,467 BCY

- Time Required = $\frac{\text{Volume to Move}}{\text{Production Rate}} = \frac{540,467}{1750}$ = 309 hrs

- Cost = (Time) (\$/hr) = (309)(\$85)(2) = \$26,265

### D9H DOZER LEVELING OF TOPSOIL:

Dozer: D9H

- Total Effective Grade: 5%
  Assuming rolling resistance (p.496, CAT) = 5% and % Grade = 0

- Production 1100 LCY/hr

o Correction Factor

-- Average operator: 0.75
-- 50 min/hr job efficiency: 0.83
-- Grade (0%): 1.0
-- Easy to cut: 1.20
-- Weight correction: $\frac{2300}{2100} = 1.10$

o Correction Production

$(1100\ \text{LCY/hr.})(0.75)(0.83)(1.20)(1.0)(1.10) = 904\ \text{LCY/hr}$

Volume = 270233 $yd^3$

$(335\ \text{Acres})(43560)(.5'\ \text{depth})\ \frac{1\ yd^3}{27\ ft^3} = 270233\ \text{BCY}$

Load factor = 0.70

Corrected volume = $\frac{270233}{.70} = 386047$ LCY

Time = $\frac{386047}{904} = 427$ hrs

Cost = (427)($90) = $38,434

**COST SUMMARY**

| | |
|---|---|
| Scraper remove topsoil | $ 26,265 |
| Scraper replace topsoil | $ 26,265 |
| Bucket-wheel remove 3' of subsoil | $1,621,400 |
| Bucket-wheel remove 1' of topsoil around pit | $ 540,467 |
| Dozer grade topsoil | $ 38,434 |
| Total Cost (.979/ton) | $2,252,831 |

## TABLE 25. END-DUMP HAULBACK SCENARIO

| | |
|---|---|
| Annual Disturbance: | 335 acres = 14,592,600 $ft^2$ |
| Linear Measurement: | 1450' x 10,000' |
| Annual Coal Production (TPY): | 2,300,000 |

### SCENARIO OF EQUIPMENT UTILIZATION:

- o Remove 1' of topsoil with scraper to stockpile
- o Remove 3' of subsoil with a front shovel and load into 50 ton trucks
- o Level dumped subsoil with a dozer
- o Replace topsoil with a scraper

### EQUIPMENT AND PRODUCTION:

| | |
|---|---|
| Truck Type: | 773 B |
| Shovel: | 245 |
| Dozer: | D7G LPG |
| Scraper: | 657 B/PP |

o Total Effective Grade: 5%
(Assuming rolling resistance (p. 497, CAT) = 5% and % Grade = 0)

### SCRAPER COSTS:

Removal of Topsoil

o Fixed Times (p. 166, CAT)
Load time: 1.0 min
Maneuver and dump: 0.7 min — Total= 1.7 min (per pair.)

o Travel Times (Max. distance assuming 200 ft pit width) = 2700 ft
Loaded: 1.3 min
Empty: 1.2 min — Total= 2.5 min

o Cycle Time = (Fixed Times) + (Travel Times) = 4.2 min

o Production Rate (p. 224, CAT) = 520 BCY/hr x (2) = 1040 BCY/hr

o Volume to Move = (Annual Disturbance) x (Depth of Removal) x $\frac{1\ yd^3}{27\ ft^3}$ = (14,592,600)(1) $\frac{1\ yd^3}{27\ ft^3}$ = 540,467 BCY /

1040 BCY/hr = 520 hrs x $35/hr(2) = $88,400

**SHOVEL COSTS:**

Removal of Subsoil

- o Cycle Time (p. 133, CAT) = .31 min

- o Production Rate (p. 133, CAT) = (110$)(4 $yd^3$)(194 cycle/hr) = 852 BCY

- o Volume to Move = (Annual Disturbance) x (Depth of Removal) x $\frac{1\ yd^3}{27\ ft^3}$ = 1,621,400 BCY

- o Time Required = $\frac{\text{Volume to Move}}{\text{Production Rate}} = \frac{1{,}621{,}400}{852}$ = 1903 hrs

- o Cost = (Time)($75/hr) = $142,729

**TRUCK COSTS:**

For Hauling Subsoil

- o Fixed Times (p. 228, CAT)
  Cycle Time = Exchange time at loading point + load + haul, maneuver and dump + return
  Cycle Time = .7 min + 1.4 min + 1 min 2.9 min + 1.9 min

- o Travel Times (Max. distance assuming 200 ft pit width) = 5200 ft
  Loaded: 2.9 min
  Empty: 1.9 min Total= 4.8 min

- o Cycle Time = Exchange time + load + haul, maneuver and dump + return = 7.9 min

- o Production Rate (p. 248, CAT) = 313 BCY/hr.

- o Volume to Move = (Annual Disturbance) x (Depth of Removal) x $\frac{1\ yd^3}{27\ ft^3}$ = (14,592,600)(3) $\frac{1\ yd^3}{27\ ft^3}$ = 1,621,400 BCY

- o Time Required = $\frac{\text{Volume to Move}}{\text{Production Rate}} = \frac{1{,}621{,}400}{313}$ = 5180 hrs

- o Cost = (Time)($/hr) = (5180)($70/hr) = $362,563

## DOZER COSTS:

### Regrading Subsoil

- Production (LCY/hr) = (Maximum production) x (Correction factors)

- Estimated Dozing Maximum Production = 700 LCY/hr
  (Based on Graph, P. 41, CAT Manual)
  Avg. Dozing Distance: 75 ft.
    - Job Condition Correction Factor
        - Average Operator: 0.75 (Table, p. 43, CAT)
        - Job Efficiency - 50 min/hr: 0.84 (Table, p. 43 CAT)
        - Grade of Model - 0%: 1 (Graph, p. 43, CAT)
        - Weight Correction = $\frac{2300}{1600}$ = 1.437 = 144%
    - Calculated Corrected Production:
      (700 LCY/hr) x (1.20)(1.44)(.75)(1.20)(.84) = 915 LCY/hr

### Volume of Material Moved Annually

- Annual Disturbance: 335 Acres = 14,592,600 $ft^2$
- Depth of Material to be Graded: 18" = 1.5 ft
- Load Factor (LF) = 0.81 (Table, p.496, CAT)
- Volume = (Annual Disturbance) x (Depth) x $\frac{1}{LF}$ x $\frac{1\ yd^3}{27\ ft^3}$ = $(14{,}592{,}600\ ft^2)(1.5)\ \frac{1}{.70}\ \frac{1\ yd^3}{27\ ft^3}$ = 1,158,143 LCY /

  915 LCY/hr = 1266 hrs x $75/hr = $94,930

## SCRAPER COSTS:

### Replacement of Topsoil

- Fixed Times (p. 166, CAT)
  Load Time: 1.0 min
  Maneuver and Dump: .7 min Total= 1.7 min

- Travel Times (Max. distance assuming 200 ft pit width) = 2700 ft
  Loaded: 1.3 min
  Empty: 1.2 min Total=2.5 min

- Cycle Time = (Fixed Times) + (Travel Times) = 4.2 min

- Production Rate (p. 224, CAT) = 520 BCY/hr x (2) = 1040 BCY/hr

- Volume to Move = (Annual Disturbance) x (Depth of Removal) x $\frac{1\ yd^3}{27\ ft^3}$ = $(14{,}592{,}600)(1)\ \frac{1\ yd^3}{27\ ft^3}$ = 540,467 BCY /

  1040 BCY/hr = 520 hrs x $85/hr x (2) = $88,400

## TOTAL EQUIPMENT COSTS SUMMARY

| | |
|---|---|
| Scraper - Remove topsoil | $ 88,400 |
| Scraper - Replace topsoil | $ 88,400 |
| Truck - Haul subsoil | $362,563 |
| Shovel - Load subsoil | $142,729 |
| Dozer - Spread subsoil | $ 94,930 |
| Total Cost | $777,022 |

($777,022/2,300,000 ton/yr. = .34/ton/yr.)

## TABLE 26. SCRAPER SCENARIO

| | |
|---|---|
| Annual Disturbance: | 335 acres = 14,592,600 $ft^2$ |
| Linear Measurement: | 1460' x 10,000' |
| Annual Coal Production (TPY): | 2,300,000 |

### EQUIPMENT AND PRODUCTION:

Scrapers

Scraper Type and Quantity: 2 - 657 B/PP
Dozer: None

- Total Effective Grade: 5%
  (Assuming rolling resistance (p. 497, CAT) = 5% and % Grade = 0)
- Fixed Times (p. 166, CAT)
  Load time: 1.0 min
  Maneuver and dump: 0.7 min — Total= 1.7 min
- Travel Times (Max. distance assuming 200 ft pit width) = 2700 ft
  (p. 208-9, CAT)
  Loaded: 1.3 min
  Empty: 1.2 min — Total= 2.5 min
- Cycle Time = (Fixed Times) + (Travel Times) = 4.2 min
- Production Rate (p. 224, CAT) = 520 BCY/hr(2) = 1040 BCY/hr
- Volume to Move = (Annual Disturbance) x (Depth of Removal) x $\frac{1\ yd^3}{27\ ft^3}$ = 540,466.7 BCY
- Time Required = $\frac{\text{Volume to Move}}{\text{Production Rate}} = \frac{540{,}466.7}{1040}$ = 520 hrs
- Cost = (Time) ($/hr) = (900.7)(2)($85/hr) = $88,400

| | |
|---|---|
| Removal of 12" of soil material - | $ 88,400 |
| Removal of 48" of soil material - | $353,600 |
| Replacement of 12" of soil material - | $ 88,400 |
| Replacement of 48" of soil material - | $353,600 |
| Total ($.38/ton) | $884,000/yr/2,300,000 |

## TABLE 27. SOIL STOCKPILING SCENARIO

| | |
|---|---|
| Annual Disturbance: | 335 acres = 14,592,600 $ft^2$ |
| Annual Coal Production (TPY): | 2,300,000 |
| Pit Size: | Length - 10,000' Width - 1,460' |

**NOTE: For one year operation** **Assumption: Each pit = 200' width**

No. of pits = $\frac{1,460'}{200'}$ = 7.3 pits/yr

o Volume for Stockpiling (Scrapers)

Total Stockpile $\frac{\text{Volume}}{\text{Pit}} = \frac{\text{Soil Volume}}{\text{No. of Pits}} = \frac{21,618,668 \text{ BCY}}{7.3}$ =

296,146 BCY ~ 384,990 LCY

25% of LCY for A Horizon = 74,036 LCY ~ 96,247 BCY
50% of LCY for B Horizon = 148,073 LCY ~ 192,495 BCY
25% of LCY for C Horizon = 74,036 LCY ~ 96,247 BCY
Total = 384,990 LCY (30% Swell)

o Maneuver and Dump for Stockpiling

10% of the soil removal time is spent to maneuver and dump in stockpile.
.33/ton for soil removal x 10 percent (.25) = .0333/ton for stockpiling.

o Vegetative Establishment on Stockpile Areas
No. of piles = 6/Pit x 7.3 Pits = 43.8/yr
Size of piles:
A Horizon = 74,036 LCY x .5 = 37,018 LCY
B Horizon = 148,073 LCY x .5 = 74,036 LCY
C Horizon = 74,036 LCY x .5 = 37,018 LCY

**NOTE: 1/2 of total material on each end of pit**

Average pile size = 86,375 LCY

Surface Area of the Stockpile:
(385 yds) x (43.2 yds) = 16632 $yds^2$

$\frac{16632 \text{ yds}^2}{4840 \text{ yds}^2\text{/acre}}$ = 3.4 acres per Stockpile

43.8 Stockpiles/yr x 3.4 Acres/Stockpile = 150.6 Acres/yr
$281/Acre Revegetation x 150.6 Acres/yr = $42,313.5/yr
$42,313.5/yr/2,300,000 Tons/yr = $.018/Ton

## Revegetation and Tillage Scenarios

Revegetation in the prime farmland areas of the Midwest is diverse in the variety of techniques utilized for reclamation. As an example, legumes may be seeded initially or, in some cases, the land may be seeded directly in wheat. The varied crop rotation schemes make revegetation difficult to analyze for cost impacts. As a part of this revegetation cost, tillage is also a variable management practice. If compaction is a severe problem, implements such as subsoilers and chisel plows are sometimes used in addition to normal tillage for seedbed preparation.

In summary, the major cost items for analysis are:

- **Revegetation to row crops and**
- **Additional tillage required.**

### Revegetation to Row Crops

For the purposes of this analysis, several assumptions are made before cost data is applied to revegetation. Costs are calculated for seeding of the following crop rotations:

- **Corn/cover crop rotation,**
- **Wheat/soybean rotation, and**
- **Hay crop.**

Data for revegetation costs is taken from information supplied through the "FARMBUDGET COMPUTER MODEL" at the University of Kentucky. This model provides average costs for all aspects of crop production. The mining industry performs the same basic tasks for crop production as the farmer.

An additional cost factor exists for reclamation of prime land, the return on the crop produced. Examples of methods used for crop production are:

- **Leasing reclaimed land to area farmers,**
- **Splitting work load with farmers and**
- **Mining company performing all the work.**

This diversity creates problems in evaluating costs accurately. In some instances a profit may be realized by the mining industry due to proper farming practices. The cost scenarios reflect a return to the mining operator for crop sales. In some cases all farming is performed by local farmers with the agreement that they receive the crop return.

## Additional Tillage Required

Additional tillage other than conventional tillage, may be required to improve soil structure and reduce the affects of compaction. Two additional tillage methods which are analyzed for costs are:

**o Chisel plowing and**
**o Subsoiling**

Details of cost breakdowns are shown in the cost scenarios.

## TABLE 28. REVEGETATION SCENARIO

Annual Disturbance: 335 acres

### Corn/Cover Crop Rotation

198.08/acre x 335 = $66,357
Cover Crop = $31.35/acre x 335 = $10,502

Return = $3.00/bushel x 56 bushels = 168 x 335 = $56,280
Farmer = 60% of 56,280 33,768
MINE OPERATOR RETURN = $22,512

Yearly Cost = 55,357 22,512 + 10,502 = $54,347

### Wheat/Soybean Rotation

197.70/acre x 335 = $66,229

Return = Wheat $4.00 x 27 bushels x 335 = $36,180
Soybeans $7.00 x 19 bushels x 335 = 44,555
$80,735
Farmer = 60% of 80,735 = 48,441
MINE OPERATOR RETURN = $32,294

Yearly Cost = 66,229 - 32,294 = $33,935

### Hay (Alfalfa)

163.50/acre x 335 acres = $54,773

Return = $60.00 x 45 tons x 335 acres = $90,450
Farmer = 60% of 90,450 = 54,270
MINE OPERATOR RETURN = $36,180

Yearly Costs = 54,773 - 36,180 = $18,593

## TABLE 29. TILLAGE SCENARIO

| | |
|---|---|
| Annual Disturbance: | 335 acres |
| Linear Measurement: | 1460' x 10,000' |
| Annual Production (TPY): | 2,300,000 |

*Assuming one chiseling to a depth of 18" and one subsoiling to a depth of 20 inches.

**EQUIPMENT AND PRODUCTION:**

Dozers

Dozer Model: D7G LPG

- Drawbar power required to pull an 8-foot wide V. chisel 18 inches deep in a medium textured soil.

  (CAT) 10 ft x 2160 lb = 21,600 lbs total drawbar pull

- Acres per hour with an 82.5 percent rate of efficiency.

$$\frac{10 \text{ ft width of implement} \times 3.3 \text{ mph}}{10} = 3.3 \text{ acres/hr}$$

- Cost for chiseling the total mine acreage.

$$\$75/\text{hr} \times \frac{335 \text{ mine acres}}{3.3 \text{ acres/hr}} = \$7613.60 \text{ total cost}$$

- Cost per ton of coal mined.

  $7,613.60 total costs for mine / 2,300,000 annual production = $.0033 per ton of coal

- Drawbar power required to pull an 8-foot chisel 20 inches deep in a medium textured soil. (CAT)

  2800 lb x 10 ft = 28,000 total drawbar pull

- Acres per hour with an 82.5 percent rate of efficiency.

$$\frac{10 \text{ ft width of implement} \times 2.3 \text{ MPH}}{10} = 2.3 \text{ acres/hr.}$$

- Cost for subsoiling the total mine acreage.

$$\$75/\text{hr.} \times \frac{335 \text{ mine acres}}{2.3 \text{ acres/hr}} = \$10{,}923.90 \text{ total cost}$$

- Cost per ton of coal mined.

  $10,923.90 total costs for mine / 2,300,000 annual production = $.0047 per ton of coal

## Cost Implications

This cost evaluation is presented under the premise that no two mining operations are equal in their overall application of equipment, depreciation schedules and thus ultimate costs for equipment use. This analysis provides an example analysis for evaluating the factors and soil movement characteristics that are contained in prime farmland reclamation. Cost data as presented should be evaluated by the reader for each individual circumstance or application and not as a general guide.

In the evaluation of equipment system cost for prime farmland reclamation, the bucket-wheel excavator system is the most expensive, while scrapers are second and end-dump haulback is the least expensive for topsoil and subsoil movement. Bucket-wheel excavator costs for the mine model are calculated to be 97.9 cents per ton, while the end-dump haulback method calculated to 34 cents per ton. Scraper movement of prime farmland soil is calculated at 38 cents per ton of coal. Total reclamation system costs are evaluated when equipment system costs are added to revegetation, stockpiling and tillage costs (provided in cost scenarios).

The overall costs for reclamation on an individual mining operation vary greatly depending on equipment use and operator cost. Each individual professional makes judgments as to the trade-offs between equipment system combination and the ultimate environmental effect, soil compaction. Equipment combinations yield varied costs in actual production circumstances, but the key is weighing these costs against costs incurred in alleviating compaction or bond release violations. The selection of an equipment system from strictly a cost standpoint may not be the most cost effective long range decision.

## SUMMARY OF PROJECT CONCLUSIONS

### Overview of the Problem

Over the past 3 years the U.S. Bureau of Mines has undertaken field studies to evaluate the impact of surface mining on soil compaction in the Midwest. The results of this study indicate that the soil compaction problem lies not in the topsoil, which can be ameliorated using tillage, but in the upper and lower subsoil regions that are significantly influenced by equipment traffic. Due to their physical location alone, subsoils pose a very difficult problem to surface mine reclamation professionals.

Proven methods for subsurface amelioration techniques for soil compaction are not available at the present time. Subsurface tillage is a difficult problem due to increased moisture contents in the subsoil regions below 12 inches. High moisture content does not provide a good medium for tillage application. Observation of ripped areas in the field indicates that tillage below the 12- to 16-inch depth can cause more compaction and overall damage than that of no treatment at all. Under dry conditions subsurface tillage is a viable approach to subsoil compaction.

The difficult problem facing the mining industry is the management of prime farmlands which lie above coal reserves and reclaiming these soils to provide the highest possible crop production. The mining industry is also faced with the problems of meeting crop production goals set by the Office of Surface Mining and Soil Conservation Service that in essence state ," the land must be returned to a productivity level equal to or greater than that which existed prior to mining."

The objective of this Project Conclusions section is to summarize subsoil experiments performed and to attempt to apply this research technology to practical conclusions. These conclusions represent brief summaries of data trends discussed in more detail in previous sections of this report. Many diverse results and applications are possible through data review and manipulation for use in individual technical or research needs.

### Discussion of Experiment Results

In the 1982 General Field Data Summaries section a broad base analysis of the impacts of heavy equipment on soil compaction is displayed and analyzed. This general overview of the effects of soil compaction is on a broad range of soils with four major equipment systems analyzed for soil compaction characteristics. In this analysis the interface between topsoil and subsoil regions is identified as one of the major problem areas in the control of soil compaction. When reviewing the four mine sites tested, it is immediately apparent that the topsoil/subsoil interface is the major area of soil compaction on all four mine sites.

Texture data in the 1982 General Summary section indicates that changing texture characteristics coincide to a great extent with changing bulk density. This initial finding is the basic premise for the prediction analysis. Particular attention should be given to the sand content interaction with bulk density, that in brief states that increasing sand contents coincide with increasing bulk density values. Basic soil texture characteristics play a vital role in the overall compactibility of a prime farmland soil. This is evident through review of the general data summary comparing resultant bulk density values with texture analyses on each of the four mine sites. The general data summary provides a broad base background of bulk density and texture information on which to build future soil compaction recommendations.

The 1984 Bucket-Wheel and Scraper Analysis reflects the impact of two different machine combinations for soil transport and replacement analyzed on the same soil type. The bucket-wheel excavator system and scraper systems are compared for their overall effect on subsoil compaction. These two equipment systems are representative of every system currently in use in the Midwest. End-dump haulback and dragline replaced subsoils supply the same subsoil type compaction as that of the bucket-wheel excavator. All equipment types replace the subsoil or rooting medium in a deep lift and replace 12 inches of topsoil, while scrapers replace soils in shallow lifts from 12 to 16 inches and leave three to four distinctly compacted zones.

Comparison of the bucket-wheel excavator and scraper for subsoil replacement indicates that each has a distinct soil compaction result. The bucket-wheel excavator, while providing excellent bulk density values for reclaimed land in the lower subsoil regions, still forms a compacted zone where topsoils are replaced. In contrast, scraper pans compact the soil in the lower subsoil regions to a greater extent due to repeated traffic. The bucket-wheel excavator has the advantage of only one compacted zone due to topsoil replacement with scrapers. Scrapers produce repeated compacted zones throughout the soil profile to the depth of replacement. Results indicate that while the bucket-wheel excavator provides overall lower bulk density values in the subsoil regions, it still has the same problems as scrapers in topsoil replacement. Increased management in the topsoil replacement traffic patterns, such as the use of windrowing, reduces the overall amount of compaction in wheel replaced subsoils. The soil spreader utilized for subsoil spreading on the bucket-wheel site is shown in Figure 73.

The Scrapers by Lift Analysis evaluates the impact on a lift by lift basis of scraper pan activity. This experiment indicates that the theory that 90 percent of the soil compaction is caused by the first pass of the machine is basically correct. As defined graphically in the Lift Analysis Summaries section, soil density varies over a very narrow range for subsoil replacement when testing lift by lift to a 4-foot depth. Although there is variation in subsoils between lifts, these variations are not significant with respect to a 5 percent level of statistical significance.

The scraper by lift analysis provides interesting information in substantiating the 90 percent compaction theory. There appears to be very little

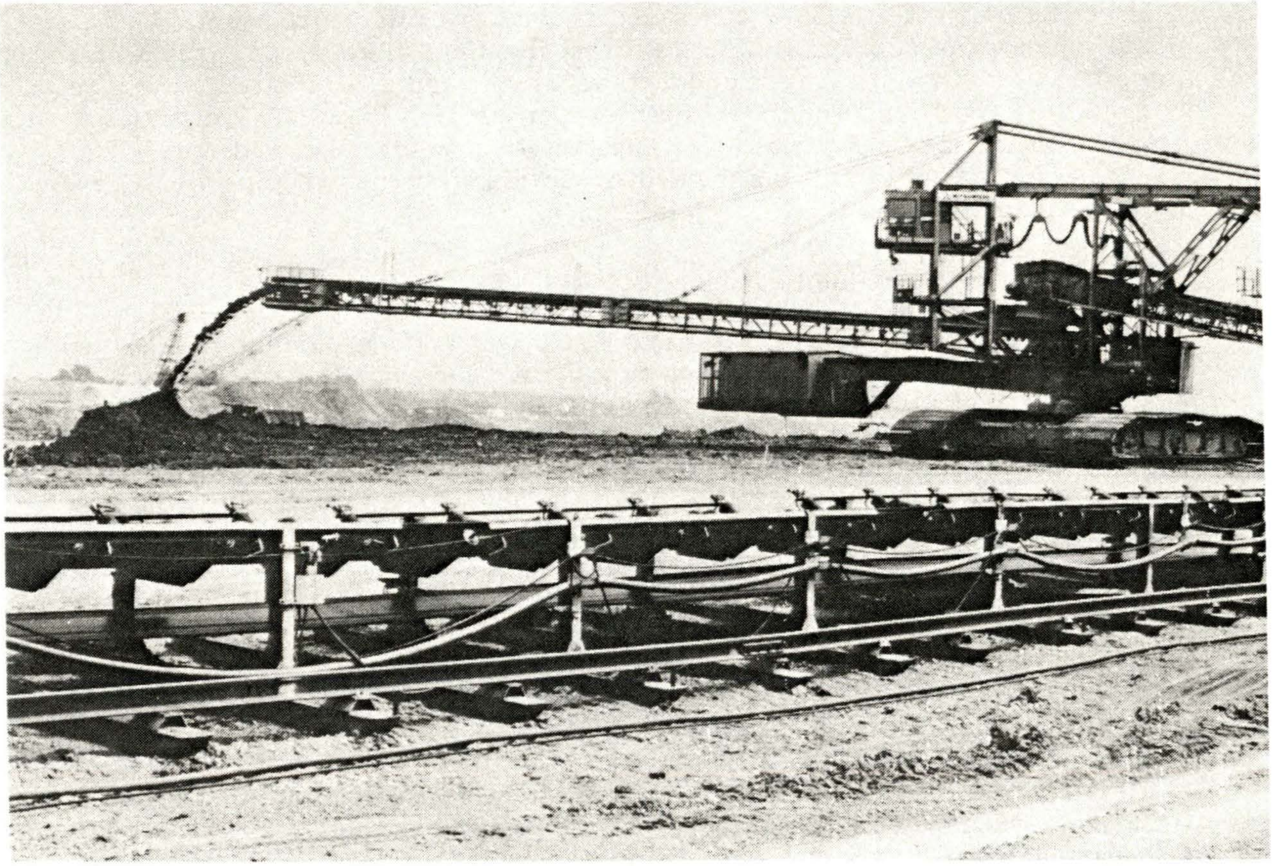

FIGURE 73. Soil Spreading After Wheel Removal and Belt Systems (Foreground) Transport

affect between lifts in bulk density on a lift by lift basis. As indicated in this analysis, texture values in each lift are virtually identical and cause no change in overall bulk density readings. The total soil compaction analysis with respect to scrapers indicates that even with very low moisture, soils can be compacted to levels that greatly inhibit crop root penetration.

The evaluation of soil windrowing indicates that the soil windrow has a strong effect on overall soil compaction. Testing of identical soil types using windrowing and not using windrowing indicates that a .1 $g/cm^3$ decrease in density can occur if traffic is controlled in windrow soil replacement. The windrowing technique can also be less expensive than direct scraper replacement of topsoil. Topsoil windrowing is one method which should be utilized whenever possible in topsoil replacement to limit scraper traffic. Figure 74 illustrates graphically the major physical difference between windrowing and non-windrowing. As indicated, the windrowing process lessens the impact of the scraper thus narrowing the zone of influence.

The cumulative findings of all data analyses is the specific identification of the impact of subsoil compaction on overall reclaimed soil densities. Data evaluations are performed for all major equipment systems currently in operation in the Midwest. The extent to which subsoils are compacted in equipment operations are clearly documented through data analysis. Through the understanding of the extent to which subsoil regions are compacted by heavy equipment, different management techniques, such as that of windrowing and better equipment selection, can help in alleviating this problem with respect to restoring crop growth. The application of all field data in a useful tool is demonstrated in the soil compaction prediction analysis.

## Soil Compaction Prediction

Significant reductions in overall soil compaction problems are possible by applying the prediction analysis formulated in this report. The application of the total data base of soil information, and the statistical analysis applied through linear combinations creates a method for professionals to better assess the impact of a particular equipment system on subsoil compaction. The entire soil compaction prediction analysis stems from the relationship of soil texture to a resultant bulk density.

The prediction analysis indicates that soils with a higher sand content can be compacted to a higher level than those containing fine-sized particles. One example of this relationship is shown in Figure 75. Notice that the silt loam soil under the same number of loads or impacts creates a lower overall bulk density than the sandy loam soil shown as the upper line. After extensive analysis the best soil compaction predictor was found to be any two of the sand, silt and clay texture sizes. This soil compaction prediction analysis identifies sand and clay as the best predictors with an $R^2$ of over 51 percent.

In using this soil compaction prediction analysis it is important to note that 50 percent of the change in density is explained by soil texture, the other 50 percent is governed by soil water and gas. The individual professional must make

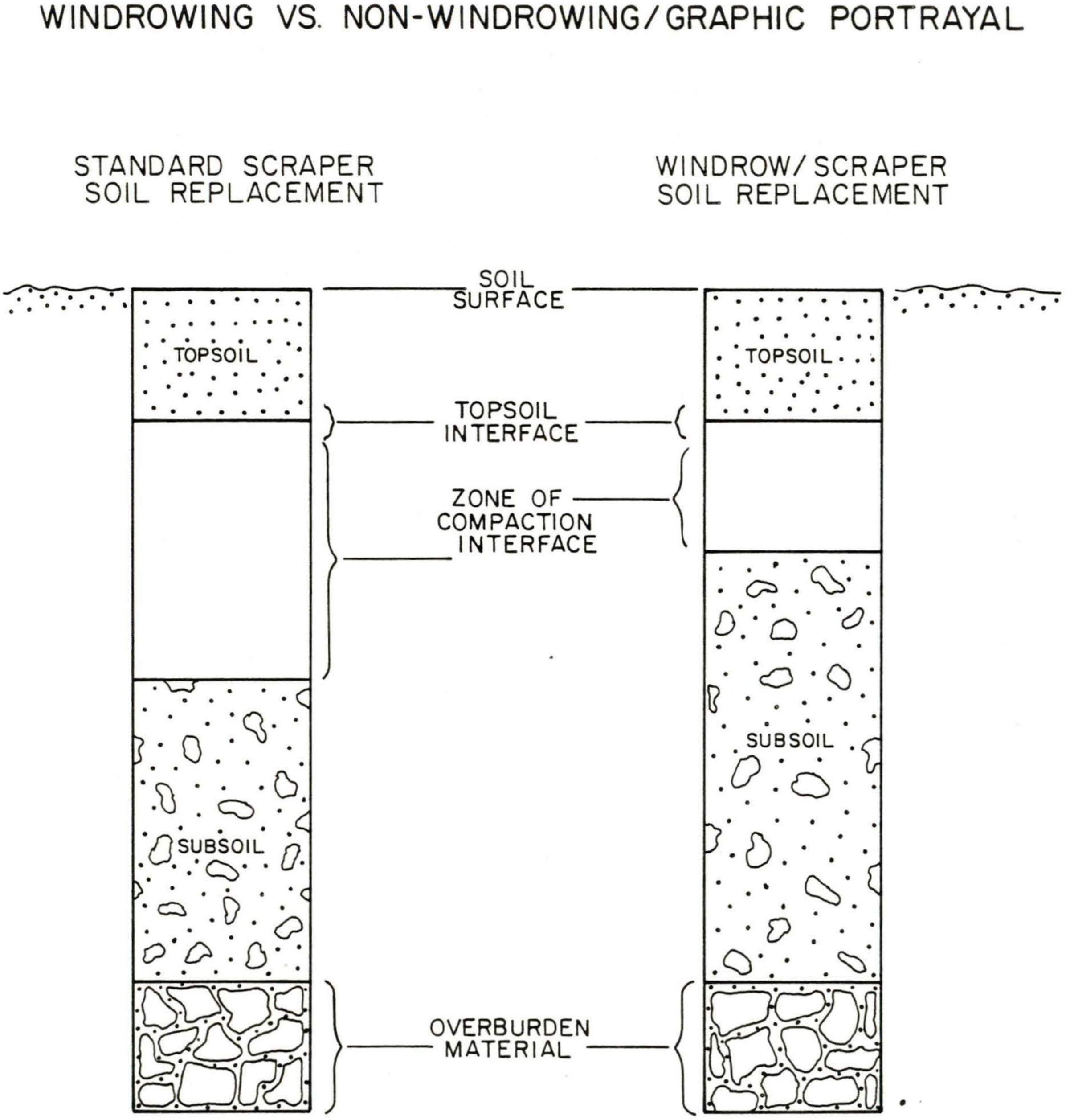

**FIGURE 74.** Windrowing vs. Non-Windrowing/Graphic Portrayal

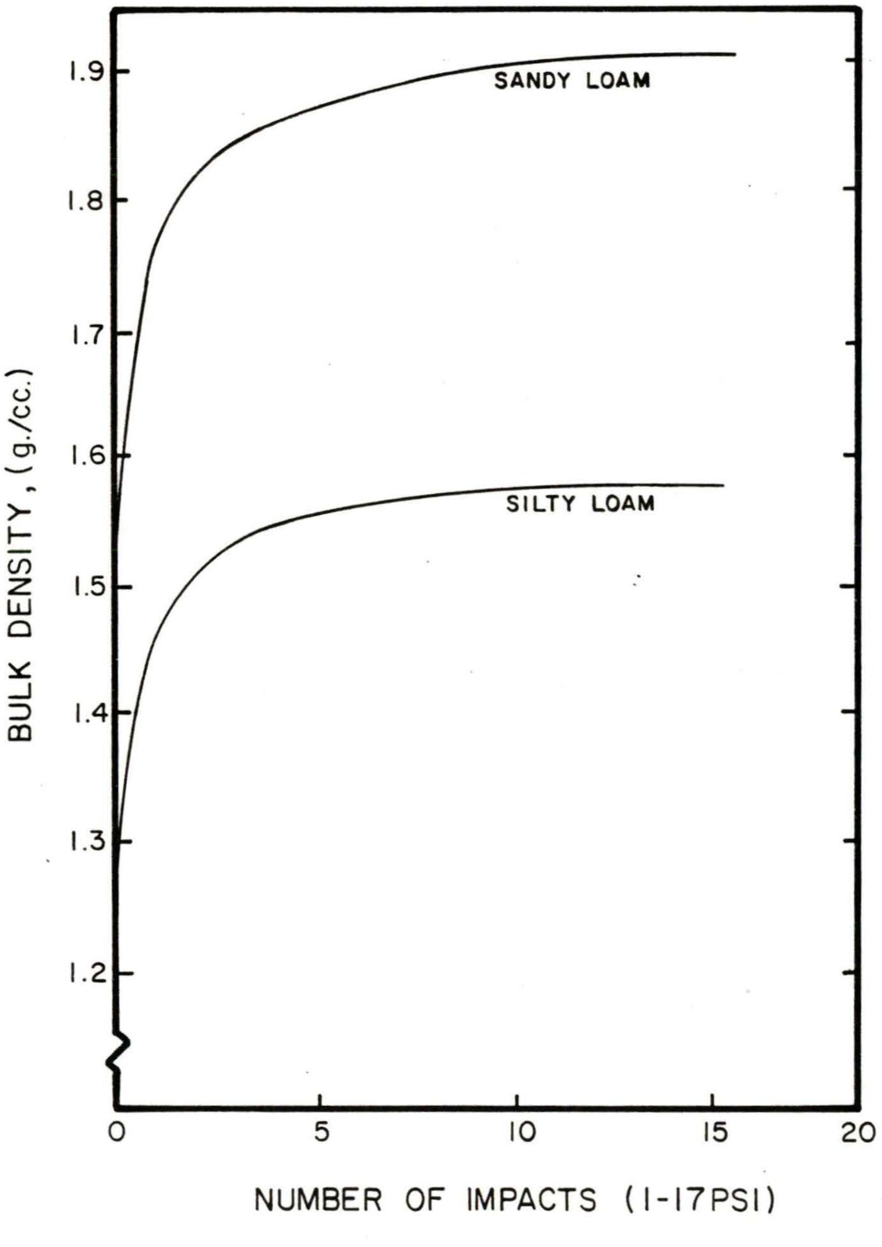

**FIGURE 75. Soil Compaction on Two Soils Using Repetitive Impact Loads (Hovanesian and Buchele, 1959)**

his own judgment on how much impact a soil of higher moisture content will have on overall density. Figure 76 illustrates one example of the effect of soil moisture content under different compactive efforts. Soil moisture is a difficult parameter to evaluate with respect to compaction prediction. As a general guide the confidence limits shown in each analysis can be used to evaluate moisture. The upper confidence limit indicates a soil of high moisture content while the lower confidence limit represents a drier soil. The use of the graph in this manner is substantiated by the broad base of water contents when these soils were initially compacted in the field.

This soil compaction prediction analysis is a significant tool in the overall management of prime farmland soils in that it provides a desktop tool for professionals and scientists involved in Midwestern prime farmland reclamation.

## Future Research

Future soil research related to prime farmland reclamation is the vehicle by which goals are achieved to restore the land to original production levels. Enhanced tools for the mining professionals, such as the predictive analysis shown in this report, are practical tools developed through research. The importance of studying the long-term effects of prime farmland reclamation is imperative to the long-term food production industry in the Midwestern United States. Areas of future research include:

- **Identifying crop tolerance to increased soil density**
- **Developing desktop tools for professionals in mine planning**
- **Developing tillage controls for subsoil compaction**
- **Defining the point of restricted root penetration in compacted soils**

Future research will ensure the ultimate objective of returning the land to a production level equal to or greater than that which existed prior to mining.

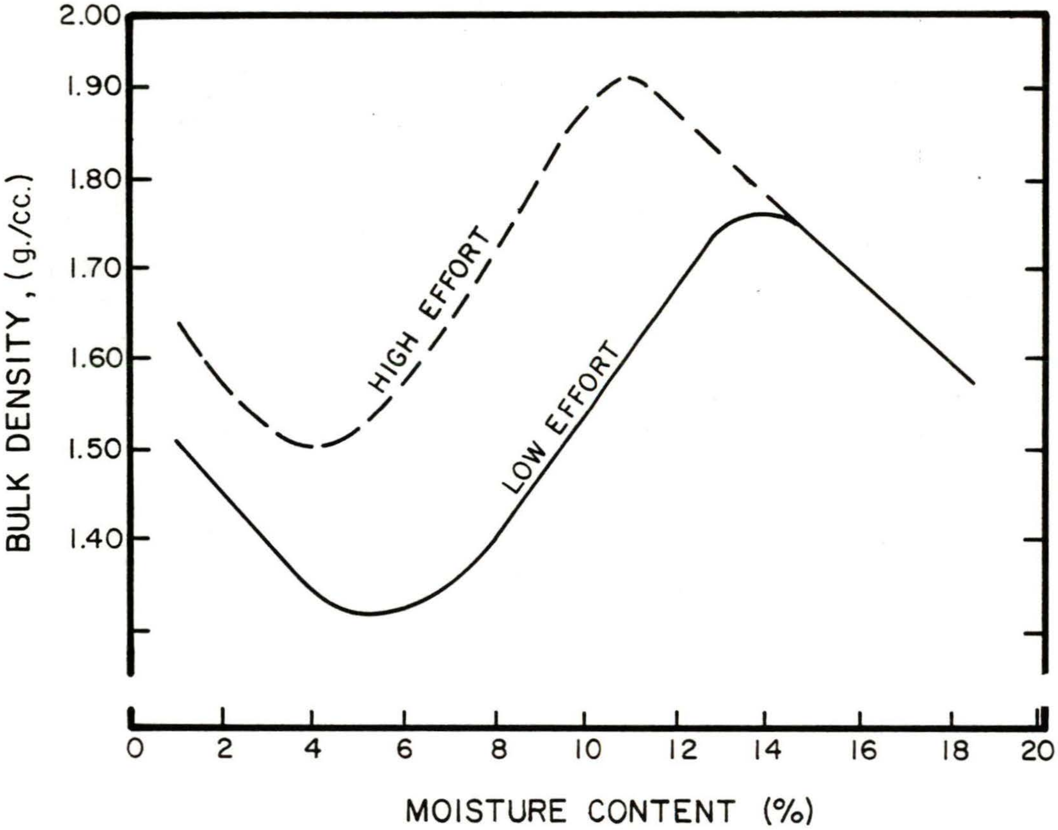

FIGURE 76. Density/Moisture Relationships of a Clay Loam Soil for Two Levels of Compactive Effort (Weaver and Jamison, 1951)

# GLOSSARY

A Horizon. The surface horizon of a mineral soil having maximum biological activity, or eluviation (removal of materials dissolved or suspended in water), or both.

Aerobic. (1) Having molecular oxygen as a part of the environment. (2) Growing only in the presence of molecular oxygen, as aerobic organisms. (3) Occuring only in the presence of molecular oxygen (said of certain chemical or biochemical processes such as aerobic decomposition).

Affected Area. With respect to surface mining activities, any land or water upon or in which those activities are conducted or located. With respect to underground mining activities, "affected area" means: (1) any water or surface land upon or in which those activities are conducted or located; and (2) land or water which is located above underground mine workings.

Agricultural Activities. With respect to alluvial valley floors, the use of any tract of land for the production of animal or vegetable life, where the use is enhanced or facilitated by subirrigation or flood irrigation associated with alluvial valley floors. The uses including, but no limited to, the pasturing, grazing, or watering of livestock, and the cropping, cultivation, or watering of livestock, and the cropping, cultivation, or harvesting of plants whose production is aided by the availability of water from subirrigation of flood irrigation.

Agricultural Use. The use of any tract of land for the production of animal or vegetable life. The uses include, but are not limited to, the pasturing, grazing, and watering of livestock and the cropping, cultivation, and harvesting of plants.

Air-Dry. The state of dryness (of a soil) at equilibrium with moisture content in the surrounding atmosphere.

Amendment. Any material worked into soil to make it more productive (lime, gypsum, sawdust, or synthetic conditioners).

Anaerobic. (1) The absence of molecular oxygen. (2) Growing in the absence of molecular oxygen (such as anaerobic bacteria). (3) Occurring in the absence of molecular oxygen (as a biochemical process).

B Horizon. A soil horizon, usually beneath an A horizon, or surface soil, in which (1) clay, iron, or aluminum, with accessory organic matter, have accumulated by receiving suspended material from the A horizon above it or by clay development in place; (2) the soil has a blocky or prismatic structure; or (3) the soil has some combination of these features. In soils with distict profiles, the B horizon is roughly equivalent to the general term "subsoil".

Backfilling. Placing spoil back into an excavation pit and returning the area to a predetermined configuration.

Baseline Conditions. Site characteristics prior to mining.

Bulk Density, Soil. The mass of dry soil per unit bulk volume. The bulk volume is determined before drying to constant weight at 105 degrees centigrade.

C Horizon. A mineral horizon or layer, excluding bedrock, that is either like or unlike the material from which the solum is presumed to have formed, relatively little-affected by pedogenic processes.

Chroma. The relative purity, strength, or saturation of a color; directly related to the dominance of the determining wavelength of the light and inversely related to grayness; one of the three variables of color.

Clay. (1) A soil separate consisting of particles < 0.002 millimeter in equivalent diameter. (2) A textural class.

Clay Films. Coatings of clay on the surface of soil peds and mineral grains and in soil pores (Also called clay skins, clay flows, illuviation cutans, argillans, or tonhautchen).

Claypan. A dense, compact layer in the subsoil having a much higher clay content than the overlying material, from which it is separated by a sharply defined boundary; formed by downward movement of clay or by synthesis of clay in place during soil formation. Claypans are usually hard when dry, and plastic and sticky when wet. Also, they usually impede the movement of water and air and the growth of plant roots.

Compaction. Increasing the density of a material by reducing the voids between the particles; generally accomplished by controlled placement and mechanical effort such as from repeated application of wheel, track, or roller loads from heavy equipment.

Concretion. A local concentration of a chemical compound, such as calcium carbonate or iron oxide, in the form of a grain or nodule of varying size, shape, hardness, or color.

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

Denitrification. The biochemical reduction of nitrate or nitrite to gaseous nitrogen either as molecular nitrogen or as an oxide of nitrogen.

Drainage. Removal of excess surface and ground water through surface or subsurface drains.

Fallow. The practice of leaving land uncropped and weedfree for periods of time to accumulate and retain water and mineralized nutrient elements.

Fertility, Soil. The status of a soil with respect to its ability to supply the nutrients essential to plant growth.

Field Capacity (Field Moisture Capacity). Obsolete in technical work. The percentage of water remaining in a soil 2 or 3 days after having been saturated and after free drainage has practically ceased. (The percentage may be expressed on the basis of weight or volume).

Fixation. The process of conversin of an element in the soil essential to plants from a readily available to a less available form.

Fragipan. A natural subsurface horizon with high bulk density relative to the solumn above, seemingly cemented when wet, but when moist showing a moderate to weak brittleness. The layer is low in organic matter, mottled, slowly or very slowly permeable to water, and usually shows occasional or frequent bleached cracks forming polygons. It may be found in profiles of either cultivated or virgin soils but not in calcareous material.

Friable. A consistence term pertaining to the ease of crumbling soils.

Fritted Structure. An artificial soil structure created by removal of soil with the bucket-wheel excavator system and transport of the soil on vibrating belts.

Gravitational Water. Water that moves into, through, or out of soil under the influence of gravity.

Green-Manure Crop. A crop grown for use as a green manure; to be incorporated into soil when green.

Gypsum Requirement. The quantity of gypsum or its equivalent required to reduce the exchangeable sodium percentage of a given increment of soil to an acceptable level.

Hardpan. A hardness soil layer, in the lower A or in the B horizon, caused by cementation of soil particles with organic matter or with materials such as silica, sesquioxides, or calcium carbonate. The hardness does not change appreciable with changes in the moisture content and pieces of hard layer do not slake in water.

Historically Used for Cropland. (1) lands that have been used for cropland for any 5 years or more out of the 10 years immediately precending the acquisition, including the purchase, lease, or option, of the land for the purpose of conducting or allowing through resale, lease or option the conduct of surface coal mining and reclamation activities; (2) lands that the regulatory authority determines, on the basis of additional cropland history of the surrounding lands and the lands under consideration, that the permit area is clearly cropland but falls outside the 5-years-in-10 criterion, in which case the regulations for prime farmland acreage to be preserved; or (3) lands that would likely have been used as cropland for any 5 out of 10 years, immediately preceding such acquisition but for the same fact of ownership or control of the land unrelated to the productivity of the land.

Hue. The dominant spectral color which is directly related to the dominant wavelength of light.

Hydraulic Conductivity. An expression of the readiness of water to flow through a soil in response to a given water potential gradient.

Immobilization. The conversion of an element from the inorganic to the organic form in microbial tissues or in plant tissues.

Infiltration. The downward entry of water into the soil.

In Situ Processes. Activities conducted on the surface or underground in connection with in-place distillation, retorting, leaching, or other chemical or physical processing of coal. The term includes, but is not limited to in situ gasification in situ leaching, slurry mining, solution mining, borehole mining, and fluid recovery mining.

Irrigation. The artificial application of water to the soil for the benefit of growing crops.

Landscape. All the natural features, such as fields, hills, forests, water, etc. that distinguish one part of the earth's surface from another part. Usually that portion of land or territory that the eye can comprehend in a single view, including all its natural characteristics.

Land Use. Specific uses or management-related activities, rather than the vegetation or cover of the land. Land uses may be identified in combination when joint or seasonal uses occur. Changes of land use or uses from one of the following categories to another shall be considered as a change to an alternative land use which is subject to approval by the regulatory authority.

Leaching. The removal of materials in solution from the soil.

Liquid Limit. The minimum percentage (by weight) of moisture at which a small sample of soil will barely flow under a standard treatment.

Loam. A soil textural class.

Loess. Material transported and deposited by wind and consisting of predominantly silt-sized particles.

Mesic. A soil temperature regime that has mean annual soil temperatures of 8 degrees centigrade or more but less than 15 degrees centigrade, and more than 5 degrees centigrade difference between mean summer and mean winter soil temperature at 50 centimeters. Isomesic is the same except the summer and winter temperatures differ by less than 5 degrees centigrade.

Mine Plan Area. The area of land and water within the boundaries of all permit areas during the entire life of the surface coal mining and reclamation operations. At a minimum, it includes all areas which are or will be affected during the entire life of those operations. Other terms defined in this section which relate closely to mine plan area are: (1) permit area, which will always be within or the same as the mine plan area; (2) affected area, which will always be within or the same as the permit area; and (3) adjacent area, which may surround or extend beyond the affected area, permit area, or mine plan area.

Mineralization. The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Moist Bulk Density. The weight of soil (oven dry) per unit volume. Volume is measured when the soil is at field moisture capacity (1/3 bar moisture tension). Weight is determined after drying the soil at 105 degrees centigrade.

Moisture Volume Percentage. The ratio of the volume of water in a soil to the total bulk density volume of the soil.

Moisture Weight Percentage. The moisture content expressed as a percentage of the oven-dried weight of soil.

Montmorillonite. An aluminosilicate clay mineral with a 2:1 expanding crystal structure; that is, with two silicon tetrahedral layers enclosing an aluminum octahedral layer. Considerable expansion may be caused along the C axis by water moving between silica layers of continguous units.

Mottled Zone. A layer that is marked with spots or blotches of different color or shades of color. The pattern of mottling and the size, abundance, and color contrast of the mottles may vary considerably and should be specified in soil description.

Mottling. Spots or blotches of different color or shades of color interspersed with the dominant color.

Mulch. (1) Any material such as straw, sawdust, leaves, plastic film, loose soil, etc., that is spread on the surface of the soil to protect the soil and plant roots from the efects of raindrops, soil crusting, freezing, evaporation, etc. (2) To apply to the soil surface.

Mulch Farming. A system of farming in which the organic residues are not plowed into or otherwise mixed with the soil, but are left on the surface as a mulch.

Nitrification. Biological oxidation of ammonium to nitrate and nitrite, or a biologically induced increase in the oxidation state of nitrogen.

Nitrogen Fixation. Biological conversion of molecular dinitrogen ($N_2$) to organic combinations or to forms utilizable in biological processes.

Nutrient, Diffusion. The movement of nutrients in soil that results from a concentration gradient.

Overburden. Material of any nature, consolidated or unconsolidated, that overlies a coal deposit, excluding topsoil.

Pans. Horizons or layers in soils that are strongly compacted, indurated, or very high in clay content.

Pan, Generic. A natural subsurface soil layer of low or very low permeability, with a high concentration of small particles, and differing in certain physical and chemical properties from the soil immediately above or below the pan.

Pan, Pressure or Induced. A subsurface horizon or soil layer having a higher bulk density and a lower total porosity than the soil directly above or below it, as a result of pressure that has been applied by normal tillage operations or by other artificial means. Frequently referred to as plowpan, plowsole, or traffic pan.

Parent Material. The unconsolidated and more or less chemically weathered mineral or organic matter from which the solum of soils is developed by pedogenic processes.

Particle Density. The mass per unit volume of the soil particles. In technical work, usually expressed as grams per cubic centimeter.

Particle-Sized Analysis. Determination of the various amounts of the different separates in a soil sample, usually by sedimentation, sieving, micrometry, or combinations of these methods.

Pedon. A three-dimensional body of soil with lateral dimensions large enough to permit the study of horizon shapes and relationships. Its area ranges from 1 to 10 square meters. Where horizons are intermittent or cyclic, and recur at linear intervals of 2 to 7 meters, the pedon includes one-half of the cycle. Where the cycle is less than 2 meters, or all horizons are continuous and of uniform thickness, the pedon has an area of approximately 1 square meter. If the horizons are cyclic, but recur at intervals greater than 7 meters, the pedon reverts to the 1 square meter size, and more than one soil will usually be represented in each cycle.

Percolation, Soil Water. The drawdown movement of water through soil. Especially, the downward flow of water in saturated soil at hydraulic gradients of the order of 1.0 or less.

Performance Bond. Cash or cash equivalent posted by operator to ensure that mining and reclamation is accomplished according to regulations and provisions of the mining permit.

Permeability, Soil. The ease with which gases, liquids, or plant roots penetrate or pass through a bulk mass of soil or a layer of soil. Since different soil horizons vary in permeability, the particular horizon under question should be designated.

Permit Area. The area of land and water within the boundaries of the permit which are designated on the permit application maps, as approved by the regulatory authority. This area will include, at a minimum, all areas which are or will be affected by the surface coal mining and reclamation operations during the term of the permit.

pH, Soil. The negative logarithm of the hydrogen activity of a soil. The degree of acidity (or alkalinity) of a soil as determined by means of a glass, quinhydrone, or other suitable electrode or indicator at a specified moisture content or soil-water ratio, and expressed in terms of the pH scale.

Plastic Soil. A soil capable of being molded or deformed continuously and permanently, by relatively moderate pressure, into various shapes.

Prairie Soils. A zonal great soil group consisting of soils formed under temperate to cool-temperate humid regions under tall grass vegetation.

Presmatic Soil Structure. A soil structure type with prism-like aggregates that have a vertical axis much longer than the horizontal axis.

Productivity, Soil. The capactity of a soil, in its normal environment, for producing a specified plant or sequence of plants under a specified system of management. The "specified" limitations are necessary, since no soil can produce all crops with equal success nor can a single system of management produce the same effect on all soils. Productivity emphasizes the capacity of soil to produce crops and should be expressed in terms of yields.

Profile, Soil. A vertical section of the soil through all its horizons and extending into the parent material.

P-Value. The probability of a result this much or more deviant from expectation, given that the hypothesis is really true.

Reclamation. Restoring mined land to its pre-mining condition or to an improved condition.

Reference Area. A land unit maintained under appropriate management for the purpose of measuring vegetation ground cover, productivity and plant species diversity that are produced naturally or by crop production methods approved by the regulatory authority. Reference areas must be representative of geology, soil, slope, and vegetation in the permit area.

Renewable Resource Lands. Aquifers and areas for the recharge of aquifers and other underground waters, areas for agricultural or silvacultural production of food and fiber, and grazing.

Sand. (1) a soil particle between 0.05 and 2.0 millimeters in diameter. (2) Any one of five soil separates: Very coarse sand, coarse sand, medium sand, fine sand, very fine sand.

Scarified. Roughened; spoil surfaces which are roughened to decrease compaction and increase the soil/spoil interface.

Self-Mulching Soil. A soil in which the surface layer becomes so well aggregated that it does not crust and seal under the impact of rain but, instead, serves as a surface mulch upon drying.

Silt. (1) A soil separate consisting of particles between 0.05 and 0.002 millimeters in equivalent diameter. (2) A soil textural class.

Sodic Soil. (1) A soil containing sufficient exchangeable-sodium to interfere with the growth of most crop plants; (2) A soil in which the sodium-adsorption ratio of the saturation extracts 15 or more.

Soil Association. (1) A group of defined and named taxonomic soil units occurring together in an individual and characteristic pattern over a geographic region, comparable to plant associations in many ways. (Sometimes called "natural land types.") (2) A mapping unit used on general soil maps in which two or more defined taxonomic units occurring together in a characteristic pattern are combined because the scale of the map or the purpose for which it is being made does not require delineation of the individual soils.

Soil Horizon. A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics such as color, structure, texture, consistency, kinds and numbers of organisms present, degree of acidity or alkalinity, etc.

Soil Map. A map showing the distribution of soil types or other soil mapping units in relation to the prominent physical and cultural features of the earth's surface.

Soil Science. The science dealing with soils as a natural resource on the surface of the earth, including soil formation, classification, and mapping, and the physical, chemical, biological, and fertility properties of soils per se; and these properties in relation to their management of crop production.

Soil Structure. The combination or arrangement of primary soil particles into secondary particles, units or peds. These secondary units may be, but usually are not, arranged in the profile in such a manner as to give a distinctive characteristic pattern. The secondary units are charcterized and classified on the basis of size, shape, and degree of distinctness into classes, types, and grades, respectively.

Soil Survey. The systematic examination, description, classification, and mapping of soils in an area. Soil surveys are classified according to kind and intensity of field examination.

Solum (plural: sola). The upper and most weathered part of the soil profile; the A and B horizons.

Stabilize. To control movement of soil, spoil piles, or areas of disturbed earth by modifying the geometry of the mass, or by otherwise modifying physical or chemical properties, such as by providing the protective surface coating.

Subsoils. Generally considered to be the B horizon of soil where distinct profiles are present.

Subsoiling. Breaking of compact subsoils, without inverting them, with a special knife-like instrument (chisel) that is pulled through the soil at depths usually of 12 to 24 inches and at spacings usually of 2 to 5 feet.

Thermic. A soil temperature regime that has mean annual soil temperatures of 15 degrees centigrade or more but less than 22 degrees centigrade, and more than 5 degrees centigrade difference between mean summer and mean winter soil temperatures at 50 centimeters. Isothermic is the same except the summer and winter temperatures differ by less than 5 degrees centigrade .

Till. (1) Unstratified glacial drift depostied directly by the ice and consisting of clay, sand, gravel, and boulders intermingled in any proportion. (2) To plow and prepare for seeding; to seed or cultivate the soil.

Tillage. The mechanical manipulation of soil for any purpose; in agriculture it is usually restricted to the modifying of soil conditions for crop production.

Tilth. The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and its impedance to seedling emergence and root penetration.

Topsoil. (1) The layer of soil moved in cultivation. (2) The A horizon. (3) The A1 horizon.

Unconsolidated. Rock or soil material in loose aggregation; not compact or solid.

Value. Refers to the relative lightness of color and is a funtion of the total amount of light.

Vertisols. Mineral soils that have 30 percent or more clay, deep wide cracks when dry, and either gilgai microrelief, intersecting slickensides, or wedgeshaped structural aggregates tilted at an angle from the horizontal.

Water Table. The upper surface of ground water or that level below which the soil is saturated with water; focus of points in soil water at which the hydraulic pressure is equal to atmospheric pressure.

Water Table, Perched. The water table of a saturated layer of soil that is separated from an underlying saturated layer by an unsaturated layer.

Weathering. All physical and chemical changes produced in rocks, at or near the earth's surface, by atmospheric agents.

Xeric. A soil moisture regime common to Mediterranean climates that have moist, cool winters and warm, dry summers. A limited amount of moisture is present but does not occur at optimum periods for plant growth. Irrigation or summerfallow is commonly necessary for crop production.

# REFERENCES

1. Adams, W.A., The Effects of Organic Matter on the Bulk and True Densities of Some Uncultivated Podzolic. Journal of Soil Science 24:10-17, 1973.

2. Akran, Mohd. and W.D. Kemper. Infiltration of Soils as Affected by the Pressure and Water Content at the Time of Compaction. Soil Science Society American Journal 43:1080-6, 1979.

3. Albert, Grable R, 1966. Soil Aeration and Plant Growth. Adv. Agron. 18:57-106.

4. Albrecht, C.S. and E.R. Thompson. Impact of Surface Mining on Soil Compaction in the Midwestern U.S.A. U.S. Bureau of Mines. February, 1982. NTIS J0208016.

5. Allmaras, R.R., R.E. Burwell, W.E. Larson, and R.F. Holt, 1966. Total Parosity and Random Roughness of the Interrow Zone as Influenced by Tillage. Conservation Resource Report No. 2, USDA. U.S. Government Printing Office, Washington, D.C.

6. Archer, J.R. and P.D. Smith. The Relation Between Bulk Density, Available Water Capacity, and Air Capacity of Soils. Journal of Soil Science 23:475-80, 1972.

7. Arthur, Jack D., Novel Spreaders Aid Reclamation. Coal Age 85(7); 92-94, 1980.

8. Baligar, V.C., V.E. Nash, and F.L. Shuman, Jr. A Compaction Apparatus for the Preparation of Soil Cores of Different Bulk Densities and Thickness. Soil Science Society American Journal 39:1002-3, 1975.

9. Baligar, V.C., V.E. Nash, M.L. Hare, and J.A. Price, Jr. Soybean Root Anatomy as Influenced by Soil Bulk Density. Agronomy Journal 67:842-4, 1975.

10. Barnes, K.K., W.M. Carleton, H.M. Taylor, R.I. Throckmorton, and G.E. Vandenberg. Compaction of Agricultural Soils. American Society of Agricultural Engineers, St. Joseph, Michigan, 1971.

11. Bekker, M.G., G.E. Vandenberg, William R. Gill, J.A. Vomocil, W.J. Flockerr, W.A. Raney, and T.W. Edminster. Soil Compaction: Agronomic and Engineering Approaches. Transactions of the ASAE 4(2):231-248, 1961.

12. Bekker, M.G., Mechanical Properties of Soil and Problems of Compaction. Transactions of ASAE 4(2):231-248, 1961.

13. Bernard, David P., Prime Farmland Disturbance From Coal Surface Mining in the Corn Belt, 1980-2000. September, 1979.

14. Bertrand, A.R., and H. Kohnke. Subsoil Conditions and Their Effects on Oxygen Supply and the Growth of Corn Roots. Soil Science Society Proceedings 11:135-140, 1957.

15. Bilanski, W.K. and R.K. Varma. Effect of Bulk Density and Moisture Tension on Corn Shoot Growth. Transactions of the ASAE 19:337-40, 1976.

16. Blake, G.R., W.W. Nelson, and R.R. Allmaras. Persistence of Subsoil Compaction in a Mollisol. Soil Science Society of American Journal 40(6):943-948, 1976.

17. Blake, G.R. and J.B. Page. Direct Measurement of Gaseous Diffusion in Soils. Soil Science Society Amer. Proc. 13:37-42, 1948.

18. Blakely, Wes., Captain Mine: A National Showcase for Surface Mining and Reclamation. Coal Mining and Processing 17(7):88-91, 1980.

19. Braunack, M.V., J.S. Hewitt, and A.R. Dexter. Brittle Fracture of Soil Aggregates and the Compaction of Aggregate Beds. Journal of Soil Science 30:653-67, 1979.

20. Bray, R.H. and Kurtz, L.T. Determinations of Total, Organic, and Available Forms of Phosphate in Soils. Soil Science 59:39-45, 1945.

21. Bridge, B.J. and J.Tunyy. The Effect of Gypsum Treatment on the Swelling of Natural Clods of a Clay Soil. Soil Science 115; 414-19, 1973.

22. Buckingham, Frank. Controlled Traffic Can Stop Compaction of Agricultural Soils. Crops and Soils 27:13-15, 1975.

23. Campbell, G.S. and Walter H. Gardner. Physcholmetric Measurement of Soil Water Potential: Temperature and Bulk Density Effects. Soil Science American Proceedings 35:8-15, 1971.

24. Chancellor, W.J. Effects of Compaction on Soil Strength. Compaction of Agricultural Soils. American Society of Agricultural Engineers, St. Joseph, Michigan, ASAE Monograph, 1971.

25. Chironis, Nicholas P., Arch Mineral's Versatile BWE's. Coal Age 86(5), 134-140, 1981.

26. Cohron, G.T. Soil Sheargraph. Agricultural Engineering 44:554-556, 1963.

27. Cooper, A.W. Minimizing Soil Compaction. The Cotton Trade Journal International Edition pp. 55 and 58, 1960-61.

28. Cooper, A.W., Problems, Causes, and Remedies of Soil Compaction. The Cotton Gin and Oil Mill Press., Dallas Texas, October 19, 1957.

29. Daddow, R.L., and G.E. Warrington. Growth-Limiting Soil Bulk Densities as Influenced by Soil Texture. WSDG Report WSDG-TN-00005, January, 1983, USDA Forest Service.

30. Davis, D.B., J.B. Finney, and S.J. Richardson. Relative Effects of Tractor Weight and Wheel-Slip in Causing Soil Compaction. Journal of Soil Science 24:399-409, 1973.

31. Dexter, A.R. and J.S. Hewitt. The Deflection of Plant Roots. Journal of Agricultural Engineering Research 23:17-22, 1978.

32. Diabold, C.H. Permeability and Intake Rates of Medium Textured Soils in Relation to Silt Content and Degree of Compaction. Soil Science Society American Proceedings 18:339-343, 1954.

33. Dickerson, B.P., Soil Compaction After Tree-Length Skidding in Northern Mississippi. Soil Science Society American Journal 40(6):965-6, 1976.

34. Diebold, C.H. Permeability and Intake Rates of Medium Textured Soils in RElation to Silt Content of Compaction and Degree. Soil Science Society 19:339-343, 1954.

35. Doty, Coy W., Robert B. Campbell, and Donald C. Reicosky. Crop Response to Chiseling and Irrigation in Soils with a Compact A2 Horizon. Proceedings of ASAE 19:668-672, 1975.

36. Dumas, W.T., A.C. Trouse, L.A. Smith, F.A. Kummer, and W.R. Gill. Development and Evaluation of Tillage and Other Cultural Practices in a Controlled Traffic System for Cotton in the Southern Coastal Plains. Transactions of ASAE 16:872-5, 1973.

37. Elgabaly, M.M. and W.M. Elghamry. Air Permeability as Related to Particle Size and Bulk Density in Sand Systems. Soil Science 110:10-12, 1976.

38. Flach, K.W., W.D. Nettleton, L.H. Gile, and J.G. Cady. Pedocumentation: Induration by Silica, Carbonates, and Sesquoizides in the Quantenary. Soil Science 107:442-53, 1968.

39. Flocker, W.J. and H. Timm. Plant Growth and Root Distribution in Layered Sand Columns. Agronomy Journal 61:530-4, 1969.

40. Ghydyal, B.P.and T. Satyanarayana. Influence of Soil Compaction on Shoot and Root Growth of Rice. Indian Journal of Agronomy 14:187-192, 1969.

41. Gifford, Gerald F., Robert H. Faust, and George B. Coltharp. Measuring Soil Compaction on Rangeland. Journal of Range Management 30:457-60, 1977.

42. Gill, William R. Soil Compaction by Traffic. Journal of the ASAE 40(7):392-394, and 400, 402, 1959.

43. Gill, William R. and Arthur W. Cooper. Soil Compaction - Its Causes and Remedies. Summary Proceedings, Western Cotton Production Conference, Bakersfield, California, March 1-3, 1972.

44. Goddard, Tyrone M., E.C.A. Range, and W.M. Walker. Use of Soil Covers in Determining Bulk Density. Soil Science Society American Proceedings 35:660-1, 1971.

45. Grable, A.R. Transmission of Air in Soils. Compaction of Agricultural Soils. American Society of Agricultural Engineers, St. Joseph, Michigan, ASAE Monograph, 1971.

46. Grable, A.R. Soil Aeration and Plant Growth. Adv. Agronomy 18:57-106, 1966.

47. Gradwell, M.W. Overnight Heat Losses from the Soil in Relation to its Density. New Zeal. J. Sci. 6:463-473, 1963.

48. Grandt, Alten F., Reclaiming Prime Farmland in Illinois. Society of Mining Engineers of AIME, February 24-28, 1980.

49. Grandt, Alten F., Reclaiming Mined Land in Illinois for Row Crop Production. Journal of Soil and Water Conservation 33(5):243-4, 1978.

50. Grimes, D.W., W.R. Sheesley, and P.L. Wiley. Alfalfa Root Development and Shoot Regrowth in Compact Soil of Wheel Traffic Patterns. Agronomy Journal 70:955-8, 1978.

51. Gumbs, F.A. and B.P. Warkentin. The Effect of Bulk Density and Initial Water Content on Infiltration in Clay Soil Samples. Soil Science Society American Proceedings 36:720-4, 1972.

52. Hageman, N.R. and W.D. Shrader. Effects of Crop Sequence and Nitrogen Fertilizer Levels on Soil Bulk Density. Agronomy Journal 71:1005-1008, 1979.

53. Hatchell, G.E., C.W. Ralston, and R.R. Foil. Soil Distribution in Logging; Effects on Soil Characteristics and Growth of Loblolly Pine in the Atlantic Coastal Plan. Journal of Forrestry 68:772-5, 1970.

54. Harris, W.L. The Soil Compaction Process. Compaction of Agricultural Soils. American Society of Agricultural Engineers, St. Joseph, Michigan, ASAE Monograph, 1971.

55. Hegarty, T.W. and Sheila M. Royle. Combined Effects of Moisture Content Prior to Compaction, Compactive Effort, and Rainfall Quality on Soil Crust Strength. Journal of Soil Science 29:167-73, 1978.

56. Hira, G.S. and N.T. Singh. Influence of a Compacted Zone on Solute Transportation During Infiltration of Water. Soil Science Society of America Journal 43:1251-2, 1979.

57. Hopkins, R.M. and W.H. Patrick, Jr. Combined Effect of Oxygen Content and Soil Compaction on Root Penetration. Soil Science 108:408-13, 1967.

58. Hovanesian, J.D. and W.R. Buchele. Development of a Recording Volumetric Transducer for Studying Effects of Soil Parameters on Compaction. Transaction of the ASAE 2:78-81, 1959.

59. Jamison, V.C. Changes in Air-Water Relationships Due to Structural Improvement of Soils. Soil Science 76:154-151, 1953.

60. Jamison, V.C. Heavy Machinery: New Problem in Soil Management. What's New in Crops and Soils 5(1):11-12, 38, 1952.

61. Jansen, I.J., Current Reclamation Research at the University of Illinois and Some Considerations in Constructing a Productive Soil Prime Farmlands Reclamation Workshop March 15-16, 1979.

62. Jansen, I.J. and S.J. Indorante. Soil Variability on Surface Mined and Undisturbed Land in Southern Illinois. Soil Science Society of America Journal. Vol. 45, No. 3 May-June 1981.

63. Kar, S., S.B. Varade. Influence of Mechanical Impedance on Rice Seedling Root Growth. Agronomy Journal 64:80-1, 1972.

64. Kar, S., S.B. Varade, T.K. Subramanyan, and B.P. Ghildyal. Soil Physical Condition Affecting Rice Root Growth: Bulk Density and Submerged Soil Temperature Regime Effects. Agronomy Journal 68:23-6, 1976.

65. Kemper, W.D., B.A. Stewart and L.K. Porter. Effects of Compaction on Soil Nutrient Status, Compaction of Agricultural Soils. American Society of Agricultural Engineers, St. Joseph, Michigan, ASAE Monograph, 1971.

66. Kirkham, D., DeBoodt, J., and Deleenheer, L. Air Permeability at the Field Capacity as Related to Soil Structure and Yields. International Symposium, Soil Structure (G. Hent):377-391, 1958.

67. Kulkarni, B.K. and N.K. Savant. Effect of Soil Compaction on Root-Cation Exchange of Crop Plants. Plants and Soils 48:269-78, 1977.

68. Lindstrom, M.J., W.B. Voorhees, and G.W. Rondall, 1981. Long-term Tillage Effects on Interrow Runoff and Infiltration. Soil Science Society of America Journal 45:945-948.

69. Mayfield, William, Raymond A. Hoyum, W.T. Dumas, and A.C. Trouse. Tillage of Correct Soil Compaction. Circular ANR-41, Alabama Cooperative Extension Service, Auburn University.

70. Miles, J.A., Soil Compaction Produced by Logging and Residue Treatment. Transactions of ASAE 21:60-62, 1978.

71. Mirreh, H.F. and J.W. Ketcheson. Influence of Soil Water Matric Potential and Resistance to Penetration on Corn Root Elongation. Canadian Journal of Soil Science 53:385-6, 1977.

72. Nelson, W.E., O.S. Rahi, and L.Z. Reeves. Yield Potential of Soybean as Related to Soil Compaction by Farm Traffic. Agronomy Journal 67:769-772, 1975.

73. Nichols, M.L., Soil Compaction by Farm Machinery. Soil Conservation 13(9):183-186, 1957.

74. Nichols, M.L., Soil Compaction by Farm Machinery. U.S. Soil Conservation 23:183-186, 1957.

75. Northup, M.L. and J.R. Boyle. Soil Bulk Densities After 30 Years Under Different Management Regimes. Soil Science Society American Proceedings 39:588, 1975.

76. Parker, M.B., N.A. Minton, O.L. Brooks, and C.E. Perry. Soybean Yields and Lance Menatode Populations as Affected by Subsoiling, Fertility, and Menaticide Treatments. Agronomy Journal 67:663-6, 1975.

77. Petroue, A.M., J.E. Siebert, and P.E. Rieke. Soil Bulk Density Analysis in Three Dimensions by Computer Tomographic Scanning. Soil Science Society of America Journal 46:445-450, 1982.

78. Phillips, R.E. and D. Kirkham. Soil Compaction in the Field and Corn Growth. Agronomy Journal 54:24-34, 1962.

79. Pollard, F. and J.G. Elliott. The Effect of Soil Compaction and Method of Fertilizer Placement on the Growth of Barley Using a Concrete Track Technique. Journal of Agricultural Engineering Research 23:203-16, 1978.

80. Prebble, R.E., Root Penetration of Smeared Soil Surfaces. Experimental Agriculture 6:303-8, 1979.

81. Raghavan, G.S.V., E. McKyes, G. Gendron, B. Borglum, and H.H. Le. Effects of Soil Compaction on Development and Yield of Corn. Canadian Journal of Plant Science 58:435-43, 1978.

82. Raghavan, G.S.V., E.McKyes, and B.Beaulieu. Clay Soil Compaction Due to Wheel Slip. Transactions of the ASAE 21:646-649, 1978.

83. Raghavan, G.S.V., E. McKyes, E. Stemshorn, A. Gray, B. Beaulieu. Vehicle Compaction Patterns in Clay Soil. Transactions of the ASAE 20:218-220, 1977.

84. Raghavan, G.S.V., E. McKyes, F. Taylor, P. Richard, and A. Watson. The Relationship Between Machine Traffic and Corn Yield Reductions in Successive Years. Transactions of ASAE 22:1256-9, 1979.

85. Raney, W.A., and T.W. Edminster. Approaches to Soil Compaction Research. Annual Meeting of the American Society of Agricultural Engineers at Columbus, Ohio, June, 1960.

86. Raney, W.A., I.L. Saveson, and W.R. Gill. Study of Soil Compaction on Mississippi River Delta Soils. Siniene Congress De La Science Du Sol 4(7):521-524, 1956.

87. Robertson, L.S. and A.E. Erickson. Soil Compaction Symptoms, Causes, Rmedies, Crops and Soils 30:11-14, 1978.

88. Saini, G.R., Root Elongation and Plant Growth in a Basal Till Compact Soil Treated with 3,5-Diiodo-4-hydroxy-benzoic Acid and Gibberellic Acid. Agronomy Journal 71:1067-1070, 1979.

89. Schmude, K. Soil Conservation Service, Department of Agriculture, Washington, D.C., 1977.

90. Schollenberger, C.J. and Simon, R.H. Determination of Exchange Capacity and Exchangeable Bases in Soil-Ammonium Acetate Method. Soil Science 13-24, 1945.

91. Sharda, A.K., Influence of Soil Bulk Density on Horizontal Water Infiltration. Australian Journal of Soil Resources 15:83-6, 1977.

92. Sharma, R.P. and Ambika Singh. Effect of Berseen (T. Alexandrinum L.) on the Growth of Maize Crop on Artificially Compacted Soil. Plants and Soils 31:11-21, 1969.

93. Shulka, Lal N., Soil Compaction Due to Harvest Traffic in Sugarcane Fields on a Lajas Valley Farm of Puerto Rico. The Journal of Agriculture of The University of Puerto Rico 58(3):279-292, 1974.

94. Singh, N.T., M.S. Patel, Rachhpal Singh, and A.C. Vig. Effect of Soil Compaction on Yield and Water Use Efficiency of Rice in a Highly Permeable Soil. Agronomy Journal 72:499-502, 1980.

95. Smittle, D.A. and R.E. Williamson. Effect of Soil Compaction on Nitrogen and Water Use Efficiency, Root Growth, Yield, Fruit Shape of Pickling Cucumbers. American Society Horticultural Science Journal 102:822-5, 1977.

96. Soane, B.D., Techniques for Measuring Changes in the Packing State and Cone Resistance of Soil After the Passage of Wheels and Tracks. Journal of Soil Science 24:311-23, 1973.

97. Spoor, G. and R.J. Godwin. Soil Deformation and Shear Strength Characteristics of Some Clay Soils and Different Moisture Contents. Journal of Soil Science 30:483-98, 1979.

98. Strandberg, J.O. and J.M. White. Effect of Soil Compaction on Carrot Roots. American Society Horticultural Science Journal 104:344-9, 1979.

99. Sutton, O.G. Micrometerorology. McGraw-Hill Book Company, Inc., New York, 1953.

100. Taylor, James H., Energy Savings Through Improved Tractive Efficiency. Biomass Energy, Crop Production 2:422-425, 1980.

101. Taylor, James H., Albert C. Trouse, Eddie C. Burt, and Alvin C. Bailey. Multipass Behavior of a Pneumatic Tire in Tilled Soils. Winter Meeting American Society of Agricultural Engineers, December 11-14, 1979.

102. Taylor, James H., Eddie C. Burt, and Alvin C. Bailey. Tire Options and Consequences for Four-Wheel Drive Tractors. Earthmoving Industry Conference Central Illinois Section, Peoria, Illinois, April 23-25, 1979.

103. Trouse, A.C., Jr. and C.A. Reaves. The Bottom of the Wheel in the Orchard. Southeastern Pecan Growers Association 65th Annual Convention, Atlanta, Georgia, March 12-14, 1972.

104. Trouse, Albert C., Jr. Soil Compaction - 1970 Style. Proceedings of the 5th Annual Conference of the Georgia Pecan Growers Association, Albany, Georgia, 1:29-33, May, 1970.

105. Trouse, Albert C., Jr. Tillage and Traffic Effects on Soil. 33rd Annual Mtg., Soil Conservation Society of America, July 30-August 3, 1978, Denver, Colorado.

106. Trouse, Albert C., Jr. Traffic Compaction and Irrigation. The Irrigation Association's 1977 Annual Meeting Conference Proceedings, Irrigation for All Reasons, Hilton Hotel, Salt Lake City, Utah, February 13-15, 1977, pp. 50-53.

107. Trouse, Albert C., Jr., and Arthur W. Cooper. Control of the In-Field Traffic Practices To Maintain Good Soil Conditions for Plant Growth. Proceedings of Fiei Power Sprayer and Duster Council. What's Coming Conference, December 9-10, 1969.

108. Van Bavel, C.H.M. A Soil Aeration Theory Based on Diffusion. Soil Science 72:33-46, 1951.

109. Vandenberg, G.E. and W.R. Gill, Pressure Distribution Between a Smooth Tire and the Soil. Transactions of the ASAE 5:105-107, 1962.

110. Van Duin, R.H.A. On the Influence of Tillage on Conduction of Heat, Diffusion of Air and Infiltration of Water in Soil. Reports on Agricultural Invest. 62.7 (W.E. Larson, ed., and C.E. deMooy, Trans.), 1956.

111. Van Wijk, W.R. (ed.). Physics of Plant Environment, 2nd, edition, North Holland Publishing Co., Amsterdam, 1966.

112. Veihmeyer, F.J. and A.H. Hendrickson. Soil Density and Root Penetration. Soil Science 65:487-493, 1948.

113. Vomocil, J.A. and W.J. Flocker. Effect of Soil Compaction on Storage and Movement of Soil Air and Water, Paper Presented at ASAE Annual Meeting, June, 1960.

114. Voorhees, W.B. Our Newest Natural Resource Soil Compaction: How it Influences Moisture, Temperature, Yield, Root Growth. Crops and Soils 29:7-10, 1977.

115. Voorhees, W.B. Relative Effectiveness of Tillage and Natural Forces in Alleviating Wheel-Induced Soil Compaction. Soil Science Society of America Journal 47:129-133, 1983.

116. Voorhees, W.B. Soil Tilth Deterioration Under Row Cropping in the Northern Corn Belt: Influence of Tillage and Wheel Traffic. Journal of Soil Water Conservation 34:184-185, 1979.

117. Voorhees, W.B., C.G. Senst, and W.W. Nelson. Compaction and Soil Structure Modification by Wheel Traffic in the Northern Corn Belt. Soil Science Society of America Journal 42:344-349, 1978.

118. Voorhees, W.B. and J.G. Hendrick. Our Newest Natural Resource Compaction; Good and Bad Effects on Energy Needs. Crops and Soils 29:11-13, 1977.

119. Voorhees, W.B., R.A. Young, and Leon Lyles. Wheel Traffic Considerations in Erosion Research. Transactions of the ASAE 22(4):786-790, 1979.

120. Warkentin, B.P. Content and Transmission of Water in Soils. Compaction of Agricultural Soils. American Society of Agricultural Engineers, St. Joseph, Michigan, A.S.A.E. Monograph, 1971.

121. Waldron, L.J., J.L. McMurdie, and J.A. Vomocil. Hydraulic Conductivity of an Isotropically Compressed Soil. Soil Science Society American Proceedings 34:393-6, 1970.

122. Weaver, H.A. and V.C. Jamison. Effects of Moisture on Tractor Tire Compaction of Soil. Soil Science 71(1):15-23, 1951.

123. Wever, S.J., M.E. Essington, G.A. O'Connor, and W.L. Gould. Infiltration Studies with Sodic Mine Spoil Material. Soil Science 128:312-18, 1979.

124. White, Everett M., Effect on Plant Growth of Constricting Forces Applied to the Upper Parts of Roots. Agronomy Journal 69:437-9, 1977.

125. Wilkerson, James F. and D. Thomas Duff. Rooting of Poa annua L., Poa pratensis L., and Agrostis palustris Huds. at Three Soil Bulk Densities. Agronomy Journal 64:66-68. 1972.

126. Willis, W.O. and W.A. Raney. Effects of Compaction on Content and Transmission of Heat in Soils. Compaction of Agricultural Soils. American Society of Agricultural Engineers, St. Joseph, Michigan, ASAE Monograph, 1971.

127. Wittsell, L.E., and J.A. Hobbs. Soil Compaction Effects on Field Plant Growth. Agronomy Journal 57:534-537, 1965.

128. Yang, S.J. and E.D. Jong. Effects of Soil Water Potential and Bulk Density on Water Uptake Patterns and Resistance to Flow of Water in Wheat Plants. Canadian Journal of Soil Science 51:211-15, 1977.

## APPENDIX IDENTIFICATION KEY FOR DATA SUMMARIES

Included in the data summaries is the complete set of raw data values for all mine study sites. This data includes both the 1984 and 1982 field data collected with respect to physical properties of natural as well as reclaimed soils. The data for each plot are grouped by plot type for each soil lift tested in the 1982 study and data is shown in Appendix B. The 1984 study deals primarily with reclaimed areas or construction of test plots and data is shown in Appendix A. The sample identification number locates the sample by mine, plot, and sample position. Instructions for interpreting sample identification are illustrated below.

**EXAMPLE: B-1-1-1**

- **B - Brazil Mine**
- **1st 1 - Plot Number**
- **2nd 1 - Core Number**
- **3rd 1 - Sample Position in Core**

The third number can denote any of the three horizons by either using 1 for topsoil, 2 for the second sample, and 3 for the third. By this method any sample can be located quickly and accurately. In addition to the above sample identification Code this code is used to identify the field study relating to soil replacement by lift. The sample identification code for the test plots by Lift are as follows:

**EXAMPLE: S-1-1-1-1**

- **S - Scraper Plot by Lift**
- **1st 1 - Plot Number**
- **2nd 1 - Lift Number as Replaced**
- **3rd 1 - Core Number**
- **4th 1 - Sample by Location of Depth**

Table A-1 illustrates the plot identification code for each field study test site. Both 1982 and 1984 identification codes are provided to categorize plots. As indicated the 1984 study was conducted on the Captain mine only.

## TABLE A-1. SOIL STUDY PLOT LOCATION

### 1982 FIELD STUDY IDENTIFICATION CODE

| Plot Number | Brazil Mine | Captain Mine | Delta Mine | Power Mine |
|---|---|---|---|---|
| 1 | Natural<br>B-1 | Replaced<br>C-1 | Replaced<br>D-1 | Replaced<br>P-1 |
| 2 | Replaced<br>B-2 | Replaced<br>C-2 | Replaced<br>D-2 | Replaced<br>P-2 |
| 3 | Natural<br>B-3 | Natural<br>C-3 | Natural<br>D-3 | Natural<br>P-3 |
| 4 | Replaced<br>B-4 | Natural<br>C-4 | Natural<br>D-4 | Natural<br>P-4 |

### 1984 FIELD STUDY IDENTIFICATION CODE

Wheel Replaced
W-1

Wheel Replaced
W-2

Retest of Plot C-2 Above
O-1

Scraper Replaced by Lift
S-1

Scraper Replaced
S-2

Natural
C-3

Natural
C-4

## APPENDIX A

## DATA SUMMARIES - 1984 FIELD STUDY

## SUMMARY DATA / SET 1

## BUCKET-WHEEL EXCAVATOR PLOTS

## TABLE A-1. WHEEL PLOT W-1 / FIRST LIFT

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| W-1-1-3 | 42 | 1.64 | 17.6 | 14.4 | 60.1 | 25.5 |
| W-1-2-3 | 42 | 1.63 | 18.0 | | | |
| W-1-3-3 | 42 | 1.61 | 18.4 | 12.9 | 60.8 | 26.3 |
| W-1-4-3 | 42 | 1.64 | 18.5 | | | |
| W-1-5-3 | 42 | 1.63 | 17.6 | 14.2 | 67.4 | 18.5 |
| W-1-6-3 | 42 | 1.65 | 17.9 | | | |
| W-1-7-3 | 42 | 1.58 | 19.2 | 13.0 | 61.1 | 25.9 |
| W-1-8-3 | 42 | 1.64 | 18.0 | | | |
| W-1-9-3 | 42 | 1.60 | 17.8 | 15.8 | 67.9 | 16.4 |
| W-1-10-3 | 42 | 1.62 | 17.2 | | | |
| Plot Means | 42 | 1.62 | 18.02 | 14.1 | 63.5 | 22.5 |

## TABLE A-2. WHEEL PLOT W-1 / SECOND LIFT

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| W-1-1-2 | 28 | 1.73 | 17.0 | 13.4 | 60.9 | 25.7 |
| W-1-2-2 | 28 | 1.60 | 18.2 | | | |
| W-1-3-2 | 28 | 1.63 | 17.1 | 13.5 | 61.2 | 25.3 |
| W-1-4-2 | 28 | 1.56 | 20.5 | | | |
| W-1-5-2 | 28 | 1.63 | 17.7 | 16.1 | 57.2 | 26.8 |
| W-1-6-2 | 28 | 1.68 | 17.6 | | | |
| W-1-7-2 | 28 | 1.68 | 17.1 | 17.5 | 59.1 | 23.4 |
| W-1-8-2 | 28 | 1.64 | 18.1 | | | |
| W-1-9-2 | 28 | 1.66 | 17.5 | 17.3 | 54.5 | 28.3 |
| W-1-10-2 | 28 | 1.69 | 17.4 | | | |
| Plot Means | 28 | 1.65 | 17.8 | 15.6 | 58.6 | 25.8 |

## TABLE A-3. WHEEL PLOT W-1 / THIRD LIFT

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| W-1-1-1 | 16 | 1.73 | 16.0 | 12.1 | 60.6 | 27.3 |
| W-1-2-1 | 16 | 1.70 | 15.8 | | | |
| W-1-3-1 | 16 | 1.66 | 16.7 | 15.4 | 54.9 | 29.7 |
| W-1-4-1 | 16 | 1.68 | 16.7 | | | |
| W-1-5-1 | 16 | 1.66 | 17.3 | 12.7 | 58.4 | 28.9 |
| W-1-6-1 | 16 | 1.71 | 16.5 | | | |
| W-1-7-1 | 16 | 1.74 | 15.0 | 17.5 | 57.4 | 25.1 |
| W-1-8-1 | 16 | 1.77 | 15.1 | | | |
| W-1-9-1 | 16 | 1.78 | 14.2 | 17.5 | 58.0 | 24.5 |
| W-1-10-1 | 16 | 1.67 | 16.0 | | | |
| Plot Means | 16 | 1.71 | 15.9 | 15.0 | 57.9 | 27.1 |

## TABLE A-4. WHEEL PLOT W-2 / FIRST LIFT

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| W-2-1-3 | 42 | 1.64 | 18.4 | 13.5 | 52.2 | 34.3 |
| W-2-2-3 | 42 | 1.63 | 17.7 | | | |
| W-2-3-3 | 42 | 1.50 | 18.0 | 15.1 | 53.1 | 31.8 |
| W-2-4-3 | 42 | 1.46 | 17.7 | | | |
| W-2-5-3 | 42 | 1.65 | 17.0 | 13.6 | 54.9 | 31.5 |
| W-2-6-3 | 42 | 1.62 | 17.6 | | | |
| W-2-7-3 | 42 | 1.52 | 17.3 | 18.1 | 50.2 | 31.7 |
| W-2-8-3 | 42 | 1.67 | 17.2 | | | |
| W-2-9-3 | 42 | 1.58 | 17.4 | 14.2 | 53.1 | 32.7 |
| W-2-10-3 | 42 | 1.58 | 19.5 | | | |
| Plot Means | 42 | 1.59 | 17.8 | 14.9 | 52.7 | 32.4 |

## TABLE A-5. WHEEL PLOT W-2 / SECOND LIFT

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| W-2-1-2 | 28 | 1.63 | 18.0 | 13.4 | 54.5 | 32.1 |
| W-2-2-2 | 28 | 1.65 | 18.3 | | | |
| W-2-3-2 | 28 | 1.60 | 17.2 | 14.7 | 53.2 | 32.1 |
| W-2-4-2 | 28 | 1.53 | 18.0 | | | |
| W-2-5-2 | 28 | 1.58 | 19.3 | 14.9 | 51.6 | 33.5 |
| W-2-6-2 | 28 | 1.66 | 17.8 | | | |
| W-2-7-2 | 28 | 1.64 | 19.0 | 15.2 | 55.4 | 29.4 |
| W-2-8-2 | 28 | 1.62 | 19.2 | | | |
| W-2-9-2 | 28 | 1.60 | 17.8 | 13.1 | 56.0 | 30.8 |
| W-2-10-2 | 28 | 1.65 | 18.5 | | | |
| Plot Means | 28 | 1.62 | 18.3 | 14.3 | 54.1 | 31.6 |

## TABLE A-6. WHEEL PLOT W-1 / THIRD LIFT

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| W-2-1-1 | 16 | 1.74 | 15.2 | 18.3 | 50.4 | 30.8 |
| W-2-2-1 | 16 | 1.69 | 16.8 | | | |
| W-2-3-1 | 16 | 1.77 | 14.5 | 20.1 | 52.4 | 27.5 |
| W-2-4-1 | 16 | 1.71 | 16.8 | | | |
| W-2-5-1 | 16 | 1.82 | 14.2 | 20.0 | 54.7 | 25.3 |
| W-2-6-1 | 16 | 1.73 | 14.8 | | | |
| W-2-7-1 | 16 | 1.70 | 17.0 | 19.8 | 58.3 | 21.9 |
| W-2-8-1 | 16 | 1.47 | 17.1 | | | |
| W-2-9-1 | 16 | 1.69 | 14.8 | 19.4 | 54.8 | 25.8 |
| W-2-10-1 | 16 | 1.75 | 15.7 | | | |
| Plot Means | 16 | 1.71 | 15.7 | 19.5 | 54.2 | 26.3 |

## SUMMARY DATA / SET 2

## SCRAPER REPLACEMENT BY LIFT

## A-10. SCRAPER REPLACEMENT BY LIFT / FIRST LIFT / PLOT S-1

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-1-1-1 | 8 | 1.86 | 10.7 | 17.9 | 53.6 | 28.5 |
| S-1-1-2-1 | 8 | 1.68 | 12.6 | 20.3 | 51.5 | 28.2 |
| S-1-1-3-1 | 8 | 1.60 | 12.1 | 18.2 | 54.7 | 27.1 |
| S-1-1-4-1 | 8 | 1.77 | 13.0 | 18.2 | 54.9 | 26.9 |
| S-1-1-5-1 | 8 | 1.66 | 15.7 | 16.2 | 55.7 | 28.2 |
| S-1-1-6-1 | 8 | 1.58 | 11.2 | 20.9 | 51.5 | 27.6 |
| S-1-1-7-1 | 8 | 1.52 | 11.4 | 19.2 | 52.5 | 28.3 |
| S-1-1-8-1 | 8 | 1.69 | 10.7 | 15.1 | 56.4 | 28.5 |
| S-1-1-9-1 | 8 | 1.60 | 13.2 | 13.9 | 58.1 | 28.1 |
| S-1-1-10-1 | 8 | 1.71 | 13.0 | 17.0 | 55.5 | 27.6 |
| Plot Means | 8 | 1.67 | 12.4 | 17.7 | 54.4 | 27.9 |

## A-11. SCRAPER SECOND LIFT REPLACEMENT/FIRST LIFT/SECOND PASS

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-2-1-2 | 18 | 1.59 | 10.0 | 17.0 | 55.0 | 28.0 |
| S-1-2-2-2 | 18 | 1.77 | 11.3 | | | |
| S-1-2-3-2 | 18 | 1.64 | 10.4 | 21.4 | 52.5 | 26.1 |
| S-1-2-4-2 | 18 | 1.77 | 11.3 | | | |
| S-1-2-5-2 | 18 | 1.74 | 11.5 | 20.6 | 52.3 | 27.1 |
| S-1-2-6-2 | 18 | 1.68 | 12.3 | | | |
| S-1-2-7-2 | 18 | 1.66 | 13.1 | 22.1 | 49.1 | 28.8 |
| S-1-2-8-2 | 18 | 1.58 | 12.5 | | | |
| S-1-2-9-2 | 18 | 1.55 | 13.5 | 17.7 | 55.1 | 27.3 |
| S-1-2-10-2 | 18 | 1.69 | 12.4 | | | |
| Plot Means | 18 | 1.67 | 11.8 | 19.7 | 52.8 | 27.5 |

## A-12. SCRAPER SECOND LIFT REPLACEMENT/SECOND LIFT/FIRST PASS

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-2-1-1 | 8 | 1.51 | 8.6 | 17.4 | 55.7 | 27.0 |
| S-1-2-2-1 | 8 | 1.41 | 10.8 | | | |
| S-1-2-3-1 | 8 | 1.59 | 10.5 | 19.0 | 53.9 | 27.1 |
| S-1-2-4-1 | 8 | 1.63 | 11.2 | | | |
| S-1-2-5-1 | 8 | 1.57 | 10.4 | 17.8 | 54.8 | 27.4 |
| S-1-2-6-1 | 8 | 1.69 | 14.4 | | | |
| S-1-2-7-1 | 8 | 1.59 | 11.5 | 18.9 | 49.3 | 31.9 |
| S-1-2-8-1 | 8 | 1.58 | 12.5 | | | |
| S-1-2-9-1 | 8 | 1.46 | 10.3 | 19.0 | 51.6 | 29.5 |
| S-1-2-10-1 | 8 | 1.79 | 13.5 | | | |
| Plot Means | 8 | 1.58 | 11.4 | 18.4 | 53.0 | 28.6 |

## A-13. SCRAPER THIRD LIFT REPLACEMENT/FIRST LIFT/THIRD PASS

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-3-1-3 | 34 | 1.72 | 12.1 | 21.6 | 49.2 | 29.2 |
| S-1-3-2-3 | 34 | 1.55 | 9.7 | 16.1 | 55.9 | 28.0 |
| S-1-3-3-3 | 34 | 1.67 | 10.6 | 16.7 | 56.7 | 26.6 |
| S-1-3-4-3 | 34 | 1.62 | 10.9 | 20.0 | 54.5 | 25.5 |
| S-1-3-5-3 | 34 | 1.67 | 12.9 | 14.6 | 57.6 | 27.7 |
| S-1-3-6-3 | 34 | 1.69 | 15.3 | 13.9 | 57.4 | 28.7 |
| S-1-3-7-3 | 34 | 1.75 | 12.4 | 19.1 | 53.7 | 27.2 |
| S-1-3-8-3 | 34 | 1.68 | 16.8 | 17.1 | 53.0 | 29.9 |
| S-1-3-9-3 | 34 | 1.80 | 10.4 | 21.3 | 53.0 | 25.7 |
| S-1-3-10-3 | 34 | 1.74 | 14.6 | 14.7 | 57.8 | 27.6 |
| Plot Means | 34 | 1.69 | 12.6 | 17.5 | 54.9 | 27.6 |

## A-14. SCRAPER THIRD LIFT REPLACEMENT/SECOND LIFT/SECOND PASS

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-3-1-2 | 18 | 1.61 | 10.4 | 15.1 | 54.0 | 31.0 |
| S-1-3-2-2 | 18 | 1.62 | 11.6 | 26.6 | 46.4 | 27.0 |
| S-1-3-3-2 | 18 | 1.98 | 10.9 | 18.9 | 55.5 | 25.6 |
| S-1-3-4-2 | 18 | 1.64 | 11.9 | 15.6 | 57.6 | 26.9 |
| S-1-3-5-2 | 18 | 1.66 | 16.8 | 21.4 | 43.2 | 35.4 |
| S-1-3-6-2 | 18 | 1.66 | 10.0 | 23.3 | 50.4 | 26.3 |
| S-1-3-7-2 | 18 | 1.66 | 11.2 | 23.8 | 49.0 | 27.1 |
| S-1-3-8-2 | 18 | 1.66 | 11.4 | 20.7 | 51.7 | 27.6 |
| S-1-3-9-2 | 18 | 1.74 | 13.8 | 17.2 | 54.4 | 28.4 |
| S-1-3-10-2 | 18 | 1.73 | 11.7 | 19.5 | 51.6 | 28.9 |
| Plot Means | 18 | 1.70 | 12.0 | 20.2 | 51.4 | 28.4 |

## A-15. SCRAPER THIRD LIFT REPLACEMENT/THIRD LIFT/FIRST PASS

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-3-1-1 | 8 | 1.67 | 9.7 | 22.4 | 50.7 | 26.9 |
| S-1-3-2-1 | 8 | 1.61 | 9.9 | 23.1 | 51.0 | 26.0 |
| S-1-3-3-1 | 8 | 1.62 | 11.5 | 22.0 | 53.8 | 24.3 |
| S-1-3-4-1 | 8 | 1.66 | 9.8 | 19.6 | 54.2 | 26.2 |
| S-1-3-5-1 | 8 | 1.67 | 11.7 | 21.8 | 52.5 | 25.6 |
| S-1-3-6-1 | 8 | 1.59 | 11.2 | 19.1 | 55.1 | 25.8 |
| S-1-3-7-1 | 8 | 1.66 | 11.5 | 17.0 | 56.1 | 26.9 |
| S-1-3-8-1 | 8 | 1.54 | 10.3 | 14.5 | 57.8 | 27.7 |
| S-1-3-9-1 | 8 | 1.59 | 11.1 | 18.4 | 53.7 | 27.9 |
| S-1-3-10-1 | 8 | 1.63 | 9.2 | 17.6 | 54.6 | 27.8 |
| Plot Means | 8 | 1.62 | 10.6 | 19.5 | 54.0 | 26.5 |

## A-16. SCRAPER FOURTH LIFT REPLACEMENT/FIRST LIFT/FOURTH PASS

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-4-1-4 | 44 | 1.71 | 13.3 | 18.0 | 51.0 | 31.0 |
| S-1-4-2-4 | 44 | 1.65 | 9.5 | | | |
| S-1-4-3-4 | 44 | 1.81 | 11.7 | 18.9 | 53.2 | 27.9 |
| S-1-4-4-4 | 44 | 1.63 | 15.2 | | | |
| S-1-4-5-4 | 44 | 1.47 | 10.3 | 19.3 | 54.2 | 26.5 |
| S-1-4-6-4 | 44 | 1.64 | 12.2 | | | |
| S-1-4-7-4 | 44 | 1.67 | 11.9 | 16.0 | 59.8 | 24.1 |
| S-1-4-8-4 | 44 | 1.56 | 10.8 | | | |
| S-1-4-9-4 | 44 | 1.53 | 9.2 | 17.1 | 55.3 | 27.7 |
| S-1-4-10-4 | 44 | 1.61 | 11.2 | | | |
| Plot Means | 44 | 1.63 | 11.5 | 17.9 | 54.7 | 27.4 |

## A-17. SCRAPER FOURTH LIFT REPLACEMENT/SECOND LIFT/THIRD PASS

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-4-1-3 | 34 | 1.61 | 9.9 | 14.7 | 57.4 | 27.8 |
| S-1-4-2-3 | 34 | 1.61 | 12.0 | | | |
| S-1-4-3-3 | 34 | 1.54 | 13.2 | 19.4 | 54.4 | 26.1 |
| S-1-4-4-3 | 34 | 1.67 | 11.0 | | | |
| S-1-4-5-3 | 34 | 1.58 | 10.8 | 17.2 | 57.3 | 25.5 |
| S-1-4-6-3 | 34 | 1.80 | 9.8 | | | |
| S-1-4-7-3 | 34 | 1.55 | 10.2 | 15.8 | 58.0 | 26.2 |
| S-1-4-8-3 | 34 | 1.57 | 9.8 | | | |
| S-1-4-9-3 | 34 | 1.78 | 12.6 | 17.9 | 55.5 | 26.7 |
| S-1-4-10-3 | 34 | 1.58 | 10.2 | | | |
| Plot Means | 34 | 1.63 | 11.0 | 17.0 | 56.5 | 26.5 |

## A-18. SCRAPER FOURTH LIFT REPLACEMENT/THIRD LIFT/SECOND PASS

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-4-1-2 | 18 | 1.66 | 14.0 | 18.3 | 51.0 | 30.7 |
| S-1-4-2-2 | 18 | 1.59 | 9.3 | | | |
| S-1-4-3-2 | 18 | 1.51 | 9.5 | 21.3 | 52.6 | 26.2 |
| S-1-4-4-2 | 18 | 1.62 | 12.4 | | | |
| S-1-4-5-2 | 18 | 1.62 | 10.0 | 14.6 | 56.9 | 28.5 |
| S-1-4-6-2 | 18 | 1.62 | 9.4 | | | |
| S-1-4-7-2 | 18 | 1.57 | 10.5 | 17.3 | 55.6 | 27.1 |
| S-1-4-8-2 | 18 | 1.69 | 13.6 | | | |
| S-1-4-9-2 | 18 | 1.72 | 11.0 | 44.2 | 30.2 | 25.6 |
| S-1-4-10-2 | 18 | 1.61 | 10.8 | | | |
| Plot Means | 18 | 1.62 | 11.1 | 23.1 | 49.3 | 27.6 |

## A-19. SCRAPER FOURTH LIFT REPLACEMENT/FOURTH LIFT/FIRST PASS

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-1-4-1-1 | 8 | 1.79 | 11.4 | 16.8 | 55.5 | 27.7 |
| S-1-4-2-1 | 8 | 1.77 | 14.4 | | | |
| S-1-4-3-1 | 8 | 1.58 | 12.9 | 18.6 | 54.2 | 27.2 |
| S-1-4-4-1 | 8 | 1.62 | 11.0 | | | |
| S-1-4-5-1 | 8 | 1.60 | 9.7 | 18.4 | 55.1 | 26.5 |
| S-1-4-6-1 | 8 | 1.68 | 11.2 | | | |
| S-1-4-7-1 | 8 | 1.61 | 11.6 | 18.3 | 53.4 | 28.2 |
| S-1-4-8-1 | 8 | 1.73 | 11.8 | | | |
| S-1-4-9-1 | 8 | 1.67 | 10.9 | 15.7 | 60.4 | 23.9 |
| S-1-4-10-1 | 8 | 1.71 | 13.2 | | | |
| Plot Means | 8 | 1.68 | 11.8 | 17.6 | 55.7 | 26.7 |

## A-20. SCRAPER PLOT S-2 / FIRST LIFT

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-2-1-3 | 39 | 1.70 | 16.4 | 16.8 | 55.9 | 27.3 |
| S-2-2-3 | 39 | 1.72 | 16.5 | | | |
| S-2-3-3 | 39 | 1.68 | 15.8 | 13.3 | 65.3 | 21.4 |
| S-2-4-3 | 39 | 1.67 | 18.5 | | | |
| S-2-5-3 | 39 | 1.68 | 15.9 | 20.8 | 57.5 | 21.7 |
| S-2-6-3 | 39 | 1.76 | 13.1 | | | |
| S-2-7-3 | 39 | 1.75 | 15.4 | 27.3 | 52.8 | 19.9 |
| S-2-8-3 | 39 | 1.77 | 15.5 | | | |
| S-2-9-3 | 39 | 1.71 | 18.4 | 16.0 | 57.0 | 27.0 |
| S-2-10-3 | 39 | 1.73 | 16.5 | | | |
| Plot Means | 39 | 1.72 | 16.2 | 18.8 | 57.7 | 23.5 |

## A-21. SCRAPER PLOT S-2 / SECOND LIFT

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-2-1-2 | 23 | 1.62 | 18.8 | 12.9 | 62.3 | 24.8 |
| S-2-2-2 | 23 | 1.60 | 17.4 | | | |
| S-2-3-2 | 23 | 1.68 | 15.8 | 16.2 | 59.1 | 24.7 |
| S-2-4-2 | 23 | 1.65 | 17.9 | | | |
| S-2-5-2 | 23 | 1.66 | 16.0 | 10.0 | 68.0 | 22.0 |
| S-2-6-2 | 23 | 1.63 | 19.4 | | | |
| S-2-7-2 | 23 | 1.74 | 12.9 | 26.1 | 51.4 | 22.5 |
| S-2-8-2 | 23 | 1.75 | 12.6 | | | |
| S-2-9-2 | 23 | 1.71 | 15.7 | 27.6 | 46.0 | 26.4 |
| S-2-10-2 | 23 | 1.76 | 15.5 | | | |
| Plot Means | 23 | 1.68 | 16.2 | 18.5 | 57.4 | 24.1 |

## A-22. SCRAPER PLOT S-2 / THIRD LIFT

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| S-2-1-1 | 11 | 1.65 | 13.9 | 8.4 | 72.4 | 19.2 |
| S-2-2-1 | 11 | 1.64 | 15.0 | | | |
| S-2-3-1 | 11 | 1.65 | 14.1 | 11.9 | 69.5 | 18.6 |
| S-2-4-1 | 11 | 1.67 | 15.7 | | | |
| S-2-5-1 | 11 | 1.71 | 14.5 | 11.8 | 69.5 | 18.7 |
| S-2-6-2 | 11 | 1.56 | 14.9 | | | |
| S-2-7-2 | 11 | 1.58 | 14.1 | 10.0 | 70.6 | 19.4 |
| S-2-8-1 | 11 | 1.60 | 14.1 | | | |
| S-2-9-1 | 11 | 1.74 | 15.4 | 25.4 | 52.8 | 21.8 |
| S-2-10-1 | 11 | 1.69 | 14.3 | | | |
| Plot Means | 11 | 1.60 | 14.6 | 13.5 | 67.0 | 19.5 |

## SUMMARY DATA / SET 3

## PLOTS SAMPLED IN 1982 FIELD STUDY / RESAMPLED IN 1984

## A-23. PLOT 0-1 SAMPLED IN 1984 - SUBSOIL SAMPLE

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| O-1-1-2 | 20 | 1.77 | 12.5 | 14.2 | 57.6 | 28.2 |
| O-1-2-2 | 24 | 1.67 | 16.1 | | | |
| O-1-3-2 | 25 | 1.71 | 16.4 | 12.8 | 55.8 | 31.4 |
| O-1-4-2 | 25 | 1.78 | 15.6 | | | |
| O-1-5-2 | 25 | 1.75 | 14.4 | 16.6 | 55.7 | 27.8 |
| O-1-6-2 | 24 | 1.79 | 10.3 | | | |
| O-1-7-2 | 16 | 1.78 | 8.0 | 20.6 | 53.6 | 25.8 |
| O-1-8-2 | 14 | 1.40 | 6.7 | | | |
| O-1-9-2 | 22 | 1.88 | 10.4 | 17.9 | 55.4 | 26.8 |
| O-1-10-2 | 21 | 1.76 | 9.1 | | | |
| Plot Means | 22 | 1.73 | 12.0 | 16.4 | 55.6 | 28.0 |

### A-24. PLOT O-1 SAMPLED 1984 - SUBSOIL SAMPLE

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| O-1-1-3 | 34 | 1.67 | 17.1 | 20.5 | 51.5 | 28.0 |
| O-1-2-3 | 42 | 1.75 | 14.1 | | | |
| O-1-3-3 | 43 | 1.89 | 10.2 | 32.9 | 44.2 | 22.9 |
| O-1-4-3 | 44 | 1.75 | 11.1 | | | |
| O-1-5-3 | 44 | 1.82 | 13.3 | 27.4 | 48.2 | 24.5 |
| O-1-6-3 | 44 | 1.72 | 11.3 | | | |
| O-1-7-3 | 44 | 1.83 | 11.0 | 18.2 | 54.2 | 27.6 |
| O-1-8-3 | 42 | 1.80 | 12.6 | | | |
| O-1-9-3 | 42 | 1.80 | 12.2 | 19.2 | 50.1 | 30.7 |
| O-1-10-3 | 44 | 1.75 | 14.6 | | | |
| Plot Means | 42 | 1.78 | 12.8 | 23.6 | 49.6 | 26.8 |

# APPENDIX B

# DATA SUMMARIES - 1982 STUDY

## TABLE B-1. PHYSICAL PARAMETERS OF TOPSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| B-1-1-1 | 6 | 1.46 | 24.37 | 13.1 | 76.9 | 10.0 |
| B-1-2-1 | 6 | 1.31 | 20.65 | 14.9 | 77.8 | 7.3 |
| B-1-3-1 | 4 | 1.42 | 23.35 | 13.9 | 77.8 | 8.3 |
| B-1-4-1 | 5 | 1.42 | 22.87 | 12.2 | 78.1 | 9.7 |
| B-1-5-1 | 5 | 1.28 | 21.61 | 11.0 | 79.3 | 9.7 |
| B-1-6-1 | 4 | 1.48 | 21.36 | 7.9 | 83.5 | 8.6 |
| B-1-7-1 | 5 | 1.42 | 19.79 | 12.1 | 79.5 | 8.4 |
| B-1-8-1 | 5 | 1.25 | 22.43 | 6.6 | 84.9 | 8.5 |
| B-1-9-1 | 5 | 1.31 | 22.76 | 12.2 | 80.3 | 7.5 |
| B-1-10-1 | 5 | 1.39 | 22.51 | 13.3 | 78.6 | 8.1 |
| B-3-1-1 | 5 | 1.35 | 20.59 | 5.5 | 83.0 | 11.5 |
| B-3-2-1 | 10 | 1.43 | 21.65 | 10.9 | 78.4 | 10.7 |
| B-3-3-1 | 7 | 1.34 | 17.53 | 5.9 | 83.8 | 10.3 |
| B-3-4-1 | 9 | 1.41 | 19.07 | 5.1 | 83.5 | 11.4 |
| B-3-5-1 | 5 | 1.29 | 17.68 | 6.6 | 81.4 | 12.0 |
| B-3-6-1 | 7 | 1.50 | 15.60 | 6.2 | 77.6 | 16.2 |
| B-3-7-1 | 10 | 1.32 | 19.16 | 5.0 | 82.9 | 12.1 |
| B-3-8-1 | 5 | 1.39 | 18.98 | 11.7 | 76.9 | 11.4 |
| B-3-9-1 | 9 | 1.35 | 19.84 | 9.0 | 81.9 | 9.1 |
| B-3-10-1 | 6 | 1.47 | 16.44 | 11.8 | 73.6 | 14.6 |

## TABLE B-2. PHYSICAL PARAMETERS OF TOPSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| B-2-1-1 | 5 | 1.37 | 13.06 | 11.6 | 69.8 | 18.6 |
| B-2-2-1 | 5 | 1.59 | 22.48 | 14.9 | 77.8 | 5.8 |
| B-2-3-1 | 5 | 1.39 | 15.06 | 13.9 | 77.8 | 8.3 |
| B-2-4-1 | 5 | 1.49 | 13.43 | 9.7 | 78.0 | 12.3 |
| B-2-5-1 | 8 | 1.52 | 15.15 | 11.8 | 79.8 | 8.4 |
| B-2-6-1 | 5 | 1.63 | 16.87 | 14.4 | 64.1 | 21.5 |
| B-2-7-1 | 5.5 | 1.59 | 12.45 | 9.4 | 72.9 | 17.7 |
| B-2-8-1 | 8 | 1.50 | 16.78 | 10.7 | 73.5 | 15.8 |
| B-2-9-1 | 5 | 1.69 | 20.01 | 11.3 | 70.6 | 18.1 |
| B-2-10-1 | 6 | 1.51 | 18.65 | 11.2 | 72.7 | 16.1 |
| B-4-1-1 | 7.5 | 1.64 | 18.97 | 8.7 | 70.3 | 21.0 |
| B-4-2-1 | 5 | 1.50 | 19.69 | 17.3 | 61.8 | 20.9 |
| B-4-3-1 | 6 | 1.64 | 12.19 | 10.6 | 78.6 | 10.8 |
| B-4-4-1 | 5 | 1.64 | 19.94 | 12.0 | 75.4 | 12.6 |
| B-4-5-1 | 5 | 1.55 | 19.79 | 11.3 | 74.1 | 14.6 |
| B-4-6-1 | 5 | 1.63 | 13.74 | 11.7 | 79.4 | 8.9 |
| B-4-7-1 | 5 | 1.62 | 14.67 | 15.9 | 72.0 | 12.1 |
| B-4-8-1 | 5 | 1.60 | 11.94 | 9.0 | 82.2 | 8.8 |
| B-4-9-1 | 7 | 1.77 | 12.34 | 16.1 | 64.5 | 19.4 |
| B-4-10-1 | 5 | 1.53 | 10.18 | 11.4 | 78.9 | 9.7 |

## TABLE B-3. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| B-1-1-2 | 30 | 1.40 | 27.21 | 5.9 | 63.2 | 30.9 |
| B-1-2-2 | 28 | 1.51 | 26.11 | | | |
| B-1-3-2 | 29 | 1.50 | 22.99 | 7.6 | 79.5 | 12.9 |
| B-1-4-2 | 31 | 1.64 | 23.50 | | | |
| B-1-5-2 | 30 | 1.63 | 22.74 | 4.8 | 69.7 | 25.5 |
| B-1-6-2 | 28 | 1.62 | 22.39 | | | |
| B-1-7-2 | 30 | 1.60 | 21.49 | 19.9 | 58.9 | 21.2 |
| B-1-8-2 | 32 | 1.54 | 22.65 | | | |
| B-1-9-2 | 29 | 1.49 | 26.14 | 6.1 | 74.4 | 19.5 |
| B-1-10-2 | 29 | 1.48 | 26.36 | | | |
| B-3-1-2 | 19 | 1.52 | 24.12 | 3.2 | 67.6 | 29.2 |
| B-3-2-2 | 32 | 1.48 | 22.35 | | | |
| B-3-3-2 | 29 | 1.51 | 22.67 | 7.0 | 64.6 | 28.4 |
| B-3-4-2 | 27 | 1.62 | 23.62 | | | |
| B-3-5-2 | 27 | 1.59 | 21.02 | 5.6 | 72.2 | 22.2 |
| B-3-6-2 | 24 | 1.55 | 17.44 | | | |
| B-3-7-2 | 27 | 1.59 | 18.26 | 14.4 | 61.8 | 23.8 |
| B-3-8-2 | 32 | 1.57 | 22.22 | | | |
| B-3-9-2 | 27 | 1.59 | 22.18 | 6.6 | 67.6 | 25.8 |
| B-3-10-2 | 33 | 1.53 | 23.97 | | | |

## TABLE B-4. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| B-2-1-2 | 15 | 1.94 | 14.65 | 37.4 | 41.6 | 21.0 |
| B-2-2-2 | 17 | 1.77 | 18.79 | | | |
| B-2-3-2 | 17 | 1.82 | 15.99 | 27.1 | 48.9 | 24.0 |
| B-2-4-2 | 17 | 1.60 | 15.67 | | | |
| B-2-5-2 | 15 | 1.79 | 15.60 | 22.8 | 52.8 | 24.4 |
| B-2-6-2 | 11 | 1.89 | 13.47 | | | |
| B-2-7-2 | 18 | 1.83 | 17.50 | 10.0 | 67.3 | 22.7 |
| B-2-8-2 | 18 | 1.72 | 18.19 | | | |
| B-2-9-2 | 11 | 1.82 | 15.46 | 36.9 | 38.5 | 24.6 |
| B-2-10-2 | 18 | 1.56 | 19.05 | | | |
| B-4-1-2 | 8 | 1.78 | 16.80 | 17.2 | 60.4 | 22.4 |
| B-4-2-2 | 12 | 1.65 | 22.10 | | | |
| B-4-3-2 | 12 | 1.77 | 16.27 | 13.2 | 62.6 | 24.2 |
| B-4-4-2 | 12 | 1.73 | 17.21 | | | |
| B-4-5-2 | 12 | 1.60 | 23.97 | 7.4 | 71.0 | 21.6 |
| B-4-6-2 | 14 | 1.70 | 19.61 | | | |
| B-4-7-2 | 13 | 1.80 | 16.49 | 19.8 | 56.2 | 24.0 |
| B-4-8-2 | 17 | 1.77 | 16.43 | | | |
| B-4-9-2 | 15 | 1.79 | 14.97 | 17.7 | 59.2 | 23.1 |
| B-4-10-2 | 22 | 1.87 | 13.48 | | | |

## TABLE B-5. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| B-1-1-3 | 40 | 1.59 | 25.21 | 13.8 | 61.7 | 24.5 |
| B-1-2-3 | 40 | 1.42 | 26.75 | | | |
| B-1-3-3 | 48 | 1.63 | 21.23 | 13.5 | 62.9 | 23.6 |
| B-1-4-3 | 44 | 1.57 | 23.81 | | | |
| B-1-5-3 | 44 | 1.64 | 21.43 | 10.6 | 66.8 | 22.6 |
| B-1-6-3 | 49 | 1.67 | 19.96 | | | |
| B-1-7-3 | 41 | 1.63 | 20.16 | 14.2 | 64.7 | 21.1 |
| B-1-8-3 | 47 | 1.58 | 24.19 | | | |
| B-1-9-3 | 40 | 1.48 | 29.14 | 4.1 | 71.0 | 24.9 |
| B-1-10-3 | 39 | 1.48 | 25.94 | | | |
| B-3-1-3 | 37 | 1.61 | 23.08 | 81.1 | 67.4 | 24.5 |
| B-3-2-3 | 39 | 1.53 | 24.11 | | | |
| B-3-3-3 | 47 | 1.59 | 20.70 | 8.6 | 68.1 | 23.3 |
| B-3-4-3 | 39 | 1.43 | 24.25 | | | |
| B-3-5-3 | 41 | 1.56 | 25.11 | 3.3 | 80.5 | 16.2 |
| B-3-6-3 | 34 | 1.72 | 16.53 | | | |
| B-3-7-3 | 42 | 1.65 | 19.60 | 16.3 | 65.9 | 17.8 |
| B-3-8-3 | 44 | 1.58 | 22.64 | | | |
| B-3-9-3 | 43 | 1.62 | 21.80 | 7.9 | 67.8 | 24.3 |
| B-3-10-3 | 44 | 1.63 | 24.53 | | | |

## TABLE B-6. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| B-2-1-3 | 42 | 1.62 | 19.92 | 12.9 | 61.7 | 25.4 |
| B-2-2-3 | 44 | 1.66 | 20.5 | | | |
| B-2-3-3 | 44 | 1.67 | 20.55 | 8.9 | 69.7 | 21.4 |
| B-2-4-3 | 44 | 1.61 | 20.88 | | | |
| B-2-5-3 | 42 | 1.55 | 20.01 | 36.7 | 41.1 | 22.2 |
| B-2-6-3 | 42 | 1.82 | 18.29 | | | |
| B-2-7-3 | 43 | 1.62 | 22.23 | 16.2 | 61.3 | 22.5 |
| B-2-8-3 | 37 | 1.61 | 22.61 | | | |
| B-2-9-3 | 31 | 1.61 | 21.39 | 14.8 | 65.1 | 20.1 |
| B-2-10-3 | 39 | 1.60 | 23.48 | | | |
| B-4-1-3 | 29 | 1.67 | 19.62 | 19.7 | 57.4 | 22.9 |
| B-4-2-3 | 31 | 1.68 | 20.36 | | | |
| B-4-3-3 | 25 | 1.70 | 20.70 | 16.5 | 60.4 | 23.1 |
| B-4-4-3 | 32 | 1.74 | 18.43 | | | |
| B-4-5-3 | 32 | 1.62 | 22.50 | 5.1 | 73.9 | 21.0 |
| B-4-6-3 | 34 | 1.86 | 14.40 | | | |
| B-4-7-3 | 32 | 1.78 | 18.36 | 19.2 | 59.1 | 21.7 |
| B-4-8-3 | 32 | 1.82 | 14.21 | | | |
| B-4-9-3 | 32 | 1.77 | 17.45 | 22.6 | 56.4 | 21.0 |
| B-4-10-3 | 36 | 1.64 | 17.07 | 16.6 | 61.4 | 21.9 |

## TABLE B-7. PHYSICAL PARAMETERS OF TOPSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| C-3-1-1 | 8 | 1.37 | 16.56 | 2.9 | 88.7 | 8.4 |
| C-3-2-1 | 8 | 1.42 | 15.24 | 3.1 | 85.7 | 11.2 |
| C-3-3-1 | 8 | 1.53 | 13.70 | 2.4 | 87.7 | 9.9 |
| C-3-4-1 | 6 | 1.51 | 15.49 | 2.2 | 84.0 | 13.8 |
| C-3-5-1 | 6 | 1.39 | 20.82 | 2.6 | 84.4 | 13.0 |
| C-3-6-1 | 6 | 1.50 | 15.95 | 2.8 | 89.6 | 7.6 |
| C-3-7-1 | 4 | 1.54 | 15.17 | 2.9 | 89.3 | 7.8 |
| C-3-8-1 | 6 | 1.40 | 18.84 | 5.1 | 87.5 | 7.4 |
| C-3-9-1 | 6 | 1.33 | 20.42 | 5.4 | 82.7 | 11.9 |
| C-3-10-1 | 6 | 1.41 | 19.58 | 2.5 | 88.7 | 8.8 |
| C-4-1-1 | 6 | 1.44 | 17.95 | 4.8 | 70.3 | 24.9 |
| C-4-2-1 | 7 | 1.46 | 17.74 | 5.4 | 82.7 | 11.9 |
| C-4-3-1 | 7 | 1.39 | 18.90 | 6.0 | 82.5 | 11.5 |
| C-4-4-1 | 7 | 1.41 | 24.63 | 7.7 | 73.4 | 18.9 |
| C-4-5-1 | 7 | 1.34 | 12.03 | 5.7 | 82.6 | 11.7 |
| C-4-6-1 | 7 | 1.36 | 19.42 | 3.0 | 83.1 | 13.9 |
| C-4-7-1 | 5 | 1.36 | 15.87 | 4.5 | 85.9 | 9.6 |
| C-4-8-1 | 6 | 1.32 | 22.15 | 5.1 | 81.5 | 13.4 |
| C-4-9-1 | 6 | 1.36 | 22.43 | 4.4 | 83.3 | 12.3 |
| C-4-10-1 | 7 | 1.55 | 16.41 | 7.7 | 81.7 | 10.6 |

## TABLE B-8. PHYSICAL PARAMETERS OF TOPSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| C-1-1-1 | 7 | 1.50 | 22.41 | 5.1 | 73.3 | 21.6 |
| C-1-2-1 | 7 | 1.36 | 15.70 | 7.2 | 72.1 | 20.7 |
| C-1-3-1 | 7 | 1.36 | 17.49 | 3.3 | 75.3 | 21.4 |
| C-1-4-1 | 7 | 1.42 | 14.49 | 7.4 | 83.3 | 12.0 |
| C-1-5-1 | 7 | 1.50 | 13.70 | 4.3 | 80.8 | 14.9 |
| C-1-6-1 | 13 | 1.45 | 14.11 | 1.9 | 81.3 | 16.8 |
| C-1-7-1 | 7 | 1.36 | 13.97 | 4.2 | 76.0 | 19.8 |
| C-1-8-1 | 7 | 1.52 | 13.61 | 7.0 | 75.0 | 18.0 |
| C-1-9-1 | 7 | 1.38 | 16.91 | 6.5 | 73.7 | 19.8 |
| C-1-10-1 | 7 | 1.56 | 19.76 | 3.9 | 75.9 | 20.2 |
| C-2-1-1 | 7 | 1.52 | 13.29 | 4.8 | 70.3 | 24.9 |
| C-2-2-1 | 5 | 1.39 | 13.32 | 5.1 | 80.2 | 14.7 |
| C-2-3-1 | 6 | 1.38 | 13.42 | 3.4 | 81.0 | 15.6 |
| C-2-4-1 | 6 | 1.56 | 17.93 | 5.1 | 79.9 | 15.0 |
| C-2-5-1 | 6 | 1.55 | 14.82 | 5.1 | 77.1 | 17.8 |
| C-2-6-1 | 7 | 1.37 | 17.43 | 5.2 | 76.8 | 18.0 |
| C-2-7-1 | 7 | 1.44 | 18.33 | 4.2 | 74.8 | 21.0 |
| C-2-8-1 | 7 | 1.60 | 17.64 | 16.7 | 67.8 | 15.5 |
| C-2-9-1 | 7 | 1.43 | 13.63 | 5.7 | 78.0 | 16.3 |
| C-2-10-1 | 7 | 1.46 | 14.97 | 7.6 | 77.5 | 14.9 |

## TABLE B-9. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| C-3-1-2 | 25 | 1.45 | 21.75 | 1.9 | 52.4 | 45.7 |
| C-3-2-2 | 24 | 1.43 | 21.70 | | | |
| C-3-3-2 | 24 | 1.38 | 22.21 | 1.7 | 52.1 | 46.2 |
| C-3-4-2 | 21 | 1.44 | 21.44 | | | |
| C-3-5-2 | 24 | 1.32 | 13.71 | 3.5 | 63.2 | 33.3 |
| C-3-6-2 | 24 | 1.28 | 20.11 | | | |
| C-3-7-2 | 31 | 1.57 | 15.78 | 4.5 | 63.8 | 31.7 |
| C-3-8-2 | 24 | 1.51 | 17.56 | | | |
| C-3-9-2 | 24 | 1.42 | 22.25 | 2.1 | 56.7 | 41.2 |
| C-3-10-2 | 25 | 1.54 | 14.83 | | | |
| C-4-1-2 | 29 | 1.71 | 13.07 | 6.7 | 74.5 | 18.8 |
| C-4-2-2 | 25 | 1.54 | 15.90 | | | |
| C-4-3-2 | 24 | 1.60 | 11.32 | 1.8 | 78.4 | 19.8 |
| C-4-4-2 | 24 | 1.58 | 15.10 | | | |
| C-4-5-2 | 24 | 1.44 | 22.49 | 5.6 | 60.1 | 34.3 |
| C-4-6-2 | 25 | 1.35 | 18.54 | | | |
| C-4-7-2 | 33 | 1.51 | 16.16 | 8.4 | 62.3 | 29.3 |
| C-4-8-2 | 24 | 1.53 | 15.54 | | | |
| C-4-9-2 | 25 | 1.51 | 18.25 | 6.9 | 60.7 | 32.4 |
| C-4-10-2 | 24 | 1.40 | 13.75 | | | |

## TABLE B-10. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| C-1-1-2 | 24 | 1.69 | 18.78 | 8.6 | 51.5 | 39.9 |
| C-1-2-2 | 25 | 1.76 | 17.10 | | | |
| C-1-3-2 | 29 | 1.82 | 14.82 | 12.3 | 63.4 | 24.3 |
| C-1-4-2 | 24 | 1.81 | 16.44 | | | |
| C-1-5-2 | 28 | 1.73 | 13.74 | 9.6 | 63.5 | 26.9 |
| C-1-6-2 | 24 | 1.46 | 11.00 | | | |
| C-1-7-2 | 25 | 1.66 | 17.86 | 6.9 | 73.6 | 19.5 |
| C-1-8-2 | 15 | 1.51 | 16.09 | | | |
| C-1-9-2 | 24 | 1.76 | 17.64 | 12.4 | 64.0 | 23.6 |
| C-1-10-2 | 24 | 1.81 | 17.33 | | | |
| C-2-1-2 | 24 | 1.76 | 19.06 | 15.3 | 62.9 | 21.8 |
| C-2-2-2 | 24 | 1.73 | 20.55 | | | |
| C-2-3-2 | 24 | 1.72 | 21.37 | 22.2 | 53.0 | 24.8 |
| C-2-4-2 | 24 | 1.72 | 20.47 | | | |
| C-2-5-2 | 24 | 1.72 | 21.04 | 13.2 | 59.1 | 27.7 |
| C-2-6-2 | 25 | 1.79 | 14.98 | | | |
| C-2-7-2 | 24 | 1.79 | 17.89 | 15.3 | 62.7 | 22.0 |
| C-2-8-2 | 24 | 1.73 | 20.40 | | | |
| C-2-9-2 | 24 | 1.80 | 15.87 | 20.6 | 60.4 | 19.0 |
| C-2-10-2 | 24 | 1.73 | 18.64 | | | |

## TABLE B-11. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| C-3-1-3 | 49 | 1.53 | 21.76 | 2.8 | 78.7 | 18.5 |
| C-3-2-3 | 53 | 1.56 | 21.78 | | | |
| C-3-3-3 | 52 | 1.48 | 24.21 | 4.1 | 63.6 | 32.3 |
| C-3-4-3 | 49 | 1.52 | 17.30 | | | |
| C-3-5-3 | 50 | 1.53 | 17.95 | 5.5 | 75.6 | 18.9 |
| C-3-6-3 | 48 | 1.51 | 17.33 | | | |
| C-3-7-3 | 48 | 1.50 | 18.88 | 6.7 | 68.8 | 24.5 |
| C-3-8-3 | 50 | 1.60 | 21.41 | | | |
| C-3-9-3 | 50 | 1.62 | 15.71 | 9.6 | 69.3 | 21.1 |
| C-3-10-3 | 48 | 1.58 | 22.92 | | | |
| C-4-1-3 | 48 | 1.64 | 18.36 | 8.0 | 73.1 | 18.9 |
| C-4-2-3 | 48 | 1.68 | 19.80 | | | |
| C-4-3-3 | 48 | 1.62 | 20.73 | 6.8 | 77.6 | 15.6 |
| C-4-4-3 | 48 | 1.61 | 19.17 | | | |
| C-4-5-3 | 48 | 1.61 | 18.26 | 12.9 | 66.0 | 21.1 |
| C-4-6-3 | 48 | 1.59 | 14.22 | | | |
| C-4-7-3 | 53 | 1.53 | 15.56 | 2.7 | 77.3 | 20.0 |
| C-4-8-3 | 48 | 1.58 | 17.68 | | | |
| C-4-9-3 | 47 | 1.70 | 15.14 | 17.7 | 59.1 | 23.2 |
| C-4-10-3 | 54 | 1.55 | 20.63 | | | |

## TABLE B-12. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| C-1-1-3 | 48 | 1.71 | 18.41 | 11.9 | 63.9 | 24.2 |
| C-1-2-3 | 48 | 1.71 | 19.73 | | | |
| C-1-3-3 | 48 | 1.77 | 16.28 | 9.5 | 64.2 | 26.3 |
| C-1-4-3 | 47 | 1.72 | 17.58 | | | |
| C-1-5-3 | 47 | 1.73 | 18.97 | 9.3 | 66.7 | 24.0 |
| C-1-6-3 | 47 | 1.78 | 17.62 | | | |
| C-1-7-3 | 48 | 1.75 | 19.41 | 12.8 | 61.1 | 26.1 |
| C-1-8-3 | 48 | 1.79 | 18.09 | | | |
| C-1-9-3 | 47 | 1.80 | 15.30 | 8.9 | 63.7 | 27.4 |
| C-1-10-3 | 45 | 1.78 | 17.72 | | | |
| C-2-1-3 | 48 | 1.73 | 20.44 | 14.9 | 57.5 | 27.6 |
| C-2-2-3 | 50 | 1.73 | 19.71 | | | |
| C-2-3-3 | 44 | 1.71 | 21.07 | 11.8 | 64.3 | 23.9 |
| C-2-4-3 | 45 | 1.62 | 23.87 | | | |
| C-2-5-3 | 48 | 1.71 | 23.98 | 17.2 | 58.3 | 24.5 |
| C-2-6-3 | 48 | 1.71 | 23.02 | | | |
| C-2-7-3 | 48 | 1.60 | 25.80 | 12.3 | 62.4 | 25.4 |
| C-2-8-3 | 44 | 1.71 | 21.04 | | | |
| C-2-9-3 | 48 | 1.70 | 20.63 | 14.6 | 62.1 | 23.3 |
| C-2-10-3 | 44 | 1.64 | 19.83 | | | |

## TABLE B-13. PHYSICAL PARAMETERS OF TOPSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| D-3-1-1 | 6 | 1.48 | 23.49 | 4.0 | 81.5 | 14.5 |
| D-3-2-1 | 6 | 1.51 | 20.04 | 3.7 | 83.7 | 12.6 |
| D-3-3-1 | 6 | 1.46 | 22.56 | 2.8 | 78.2 | 19.0 |
| D-3-4-1 | 6 | 1.48 | 20.22 | 4.4 | 82.0 | 13.6 |
| D-3-5-1 | 6 | 1.50 | 22.17 | 8.2 | 78.5 | 13.3 |
| D-3-6-1 | 7 | 1.52 | 22.95 | 5.8 | 82.7 | 11.5 |
| D-3-7-1 | 6 | 1.53 | 24.70 | 3.4 | 83.2 | 13.4 |
| D-3-8-1 | 6 | 1.37 | 23.70 | 4.4 | 77.7 | 17.9 |
| D-3-9-1 | 6 | 1.50 | 22.80 | 4.1 | 82.4 | 13.5 |
| D-3-10-1 | 6 | 1.55 | 22.42 | 5.0 | 76.8 | 18.2 |
| D-4-1-1 | 7 | 1.55 | 22.09 | 11.9 | 64.9 | 23.2 |
| D-4-2-1 | 9 | 1.44 | 22.17 | 8.8 | 75.8 | 15.4 |
| D-4-3-1 | 8 | 1.39 | 25.07 | 4.9 | 75.9 | 15.6 |
| D-4-4-1 | 8 | 1.27 | 23.27 | 4.4 | 80.8 | 14.8 |
| D-4-5-1 | 6 | 1.36 | 22.44 | 6.6 | 78.8 | 14.6 |
| D-4-6-1 | 5 | 1.30 | 24.21 | 5.1 | 79.9 | 15.0 |
| D-4-7-1 | 5 | 1.30 | 26.95 | 6.0 | 78.8 | 15.2 |
| D-4-8-1 | 6 | 1.33 | 27.23 | 8.7 | 76.9 | 14.4 |
| D-4-9-1 | 8 | 1.46 | 22.55 | 13.6 | 71.8 | 14.6 |
| D-4-10-1 | 7 | 1.47 | 23.85 | 12.7 | 68.4 | 18.9 |

## TABLE B-14. PHYSICAL PARAMETERS OF TOPSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| D-1-1-1 | 5 | 1.49 | 21.41 | 5.3 | 77.6 | 17.1 |
| D-1-2-1 | 4 | 1.37 | 20.73 | 5.2 | 78.1 | 16.7 |
| D-1-3-1 | 6 | 1.68 | 18.74 | 6.9 | 75.0 | 18.1 |
| D-1-4-1 | 5 | 1.31 | 21.79 | 6.9 | 73.7 | 19.4 |
| D-1-5-1 | 5 | 1.53 | 19.24 | 5.3 | 76.5 | 18.2 |
| D-1-6-1 | 7 | 1.55 | 18.54 | 16.9 | 65.6 | 17.5 |
| D-1-7-1 | 5 | 1.52 | 19.41 | 4.6 | 75.8 | 19.6 |
| D-1-8-1 | 5 | 1.49 | 17.45 | 6.0 | 74.7 | 19.3 |
| D-1-9-1 | 5 | 1.46 | 18.73 | 6.2 | 75.3 | 18.5 |
| D-1-10-1 | 5 | 1.36 | 19.71 | 6.1 | 74.5 | 19.5 |
| D-2-1-1 | 5 | 1.49 | 21.85 | 6.6 | 73.9 | 19.5 |
| D-2-2-1 | 7 | 1.66 | 22.05 | 9.6 | 70.0 | 20.4 |
| D-2-3-1 | 6 | 1.47 | 19.46 | 10.4 | 70.1 | 19.5 |
| D-2-4-1 | 6 | 1.59 | 18.12 | 7.4 | 74.0 | 18.6 |
| D-2-5-1 | 5 | 1.61 | 19.33 | 6.6 | 74.7 | 18.7 |
| D-2-6-1 | 5 | 1.48 | 15.61 | 8.2 | 72.5 | 19.3 |
| D-2-7-1 | 6 | 1.64 | 17.71 | 11.5 | 71.0 | 17.5 |
| D-2-8-1 | 6 | 1.65 | 17.45 | 8.7 | 73.4 | 17.9 |
| D-2-9-1 | 6 | 1.51 | 18.32 | 10.7 | 73.4 | 15.9 |
| D-2-10-1 | 6 | 1.53 | 21.67 | 8.4 | 73.2 | 18.4 |

## TABLE B-15. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| D-3-1-2 | 24 | 1.53 | 19.67 | 1.9 | 64.0 | 34.1 |
| D-3-2-2 | 24 | 1.55 | 18.14 | | | |
| D-3-3-2 | 24 | 1.57 | 18.87 | 0.7 | 68.0 | 31.3 |
| D-3-4-2 | 31 | 1.43 | 19.69 | | | |
| D-3-5-2 | 24 | 1.63 | 15.74 | 11.4 | 61.2 | 27.4 |
| D-3-6-2 | 24 | 1.53 | 25.52 | | | |
| D-3-7-2 | 24 | 1.56 | 21.12 | 2.4 | 66.2 | 31.4 |
| D-3-8-2 | 31 | 1.57 | 13.91 | | | |
| D-3-9-2 | 24 | 1.53 | 18.71 | .6 | 69.1 | 30.3 |
| D-3-10-2 | 24 | 1.52 | 19.10 | | | |
| D-4-1-2 | 24 | 1.64 | 19.14 | 8.9 | 62.3 | 28.8 |
| D-4-2-2 | 25 | 1.51 | 21.36 | | | |
| D-4-3-2 | 24 | 1.51 | 23.07 | 1.7 | 58.4 | 39.9 |
| D-4-4-2 | 24 | 1.50 | 19.81 | | | |
| D-4-5-2 | 24 | 1.52 | 18.72 | 4.9 | 61.5 | 33.6 |
| D-4-6-2 | 25 | 1.53 | 21.36 | | | |
| D-4-7-2 | 26 | 1.48 | 24.49 | 3.2 | 63.4 | 33.4 |
| D-4-8-2 | 24 | 1.50 | 24.02 | | | |
| D-4-9-2 | 25 | 1.51 | 17.84 | 7.4 | 53.2 | 39.4 |
| D-4-10-2 | 29 | 1.61 | 22.34 | | | |

## TABLE B-16. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| D-1-1-2 | 26 | 1.92 | 14.18 | 32.8 | 49.8 | 17.4 |
| D-1-2-2 | 23 | 1.93 | 12.90 | | | |
| D-1-3-2 | 16 | 1.77 | 16.71 | 32.4 | 46.0 | 21.6 |
| D-1-4-2 | 12 | 1.91 | 13.45 | | | |
| D-1-5-2 | 12 | 1.79 | 13.34 | 31.0 | 50.3 | 18.7 |
| D-1-6-2 | 15 | 1.94 | 13.03 | | | |
| D-1-7-2 | 14 | 1.70 | 11.14 | 10.7 | 70.9 | 18.4 |
| D-1-8-2 | 19 | 1.71 | 16.04 | | | |
| D-1-9-2 | 18 | 1.95 | 12.61 | 10.7 | 70.3 | 19.0 |
| D-1-10-2 | 22 | 1.96 | 11.17 | | | |
| D-2-1-2 | 16 | 1.91 | 13.71 | 33.0 | 50.5 | 16.5 |
| D-2-2-2 | 17 | 1.94 | 14.79 | | | |
| D-2-3-2 | 16 | 1.72 | 17.63 | 8.7 | 71.0 | 20.3 |
| D-2-4-2 | 16 | 1.86 | 11.35 | 31.5 | 53.5 | 15.0 |
| D-2-5-2 | 16 | 1.91 | 13.30 | 35.1 | 47.2 | 17.7 |
| D-2-6-2 | 16 | 1.98 | 11.11 | | | |
| D-2-7-2 | 17 | 1.96 | 11.95 | 34.3 | 52.4 | 13.3 |
| D-2-8-2 | 21 | 1.88 | 12.71 | | | |
| D-2-9-2 | 14 | 1.92 | 13.82 | 31.2 | 49.4 | 19.9 |
| D-2-10-2 | 18 | 1.86 | 14.24 | | | |

## TABLE B-17. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| D-3-1-3 | 52 | 1.54 | 19.25 | 5.0 | 70.3 | 24.7 |
| D-3-2-3 | 50 | 1.58 | 17.16 | | | |
| D-3-3-3 | 48 | 1.62 | 18.50 | 27.6 | 57.0 | 15.4 |
| D-3-4-3 | 48 | 1.67 | 14.29 | | | |
| D-3-5-3 | 48 | 1.62 | 16.19 | 11.3 | 66.2 | 22.5 |
| D-3-6-3 | 44 | 1.52 | 24.06 | | | |
| D-3-7-3 | 47 | 1.57 | 20.06 | 6.3 | 71.1 | 22.6 |
| D-3-8-3 | 56 | 1.67 | 17.80 | | | |
| D-3-9-3 | 46 | 1.60 | 19.39 | 5.9 | 75.7 | 18.4 |
| D-3-10-3 | 46 | 1.53 | 20.29 | | | |
| D-4-1-3 | 46 | 1.75 | 17.58 | 11.3 | 67.9 | 20.8 |
| D-4-2-3 | 50 | 1.66 | 20.47 | | | |
| D-4-3-3 | 55 | 1.71 | 18.09 | 21.5 | 62.7 | 15.8 |
| D-4-4-3 | 52 | 1.54 | 23.36 | | | |
| D-4-5-3 | 53 | 1.54 | 21.58 | 7.6 | 64.9 | 27.5 |
| D-4-6-3 | 50 | 1.58 | 22.50 | | | |
| D-4-7-3 | 50 | 1.58 | 22.23 | 5.5 | 72.0 | 22.5 |
| D-4-8-3 | 43 | 1.56 | 16.16 | | | |
| D-4-9-3 | 54 | 1.74 | 17.86 | 8.8 | 68.6 | 22.6 |
| D-4-10-3 | 48 | 1.71 | 16.34 | | | |

## TABLE B-18. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| D-1-1-3 | 44 | 1.89 | 14.62 | 33.2 | 50.5 | 16.3 |
| C-1-2-3 | 50 | 1.88 | 14.84 | | | |
| D-1-3-3 | 48 | 1.76 | 19.59 | 29.9 | 51.0 | 19.1 |
| D-1-4-3 | 43 | 1.87 | 15.48 | | | |
| D-1-5-3 | 46 | 1.85 | 15.77 | 33.4 | 53.9 | 12.7 |
| D-1-6-3 | 46 | 1.81 | 17.39 | | | |
| D-1-7-3 | 48 | 1.88 | 15.67 | 28.1 | 55.6 | 16.3 |
| D-1-8-3 | 46 | 1.82 | 17.30 | | | |
| D-1-9-3 | 48 | 1.86 | 17.00 | 32.4 | 49.4 | 18.2 |
| D-1-10-3 | 48 | 1.88 | 15.85 | | | |
| D-2-1-3 | 48 | 1.85 | 16.39 | 26.1 | 54.0 | 19.9 |
| D-2-2-3 | 48 | 1.88 | 15.34 | | | |
| D-2-3-3 | 48 | 1.83 | 16.14 | 8.8 | 72.6 | 18.6 |
| D-2-4-3 | 49 | 1.87 | 14.65 | | | |
| D-2-5-3 | 48 | 1.67 | 15.45 | 34.8 | 47.4 | 17.8 |
| D-2-6-3 | 51 | 1.79 | 17.96 | | | |
| D-2-7-3 | 47 | 1.82 | 17.04 | 27.4 | 53.5 | 19.1 |
| D-2-8-3 | 43 | 1.87 | 15.04 | | | |
| D-2-9-3 | 48 | 1.89 | 14.62 | 33.1 | 49.4 | 17.5 |
| D-2-10-3 | 49 | 1.90 | 13.97 | | | |

## TABLE B-19. PHYSICAL PARAMETERS OF TOPSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| P-3-1-1 | 6 | 1.40 | 16.69 | 7.1 | 70.1 | 22.8 |
| P-3-2-1 | 6 | 1.38 | 19.33 | 5.5 | 69.6 | 24.9 |
| P-3-3-1 | 6 | 1.42 | 16.18 | 4.2 | 77.8 | 18.0 |
| P-3-4-1 | 6 | 1.54 | 16.47 | 8.8 | 72.9 | 18.3 |
| P-3-5-1 | 6 | 1.27 | 17.49 | 7.2 | 64.0 | 28.8 |
| P-3-6-1 | 6 | 1.31 | 19.89 | 5.8 | 66.7 | 27.5 |
| P-3-7-1 | 6 | 1.36 | 28.12 | 1.7 | 41.9 | 56.4 |
| P-3-8-1 | 6 | 1.45 | 20.38 | 4.5 | 63.6 | 31.9 |
| P-3-9-1 | 6 | 1.40 | 18.78 | 4.8 | 67.6 | 27.6 |
| P-3-10-1 | 6 | 1.33 | 19.89 | 6.2 | 62.9 | 30.9 |
| P-4-1-1 | 6 | 1.27 | 23.81 | 15.9 | 46.2 | 37.9 |
| P-4-2-1 | 6 | 1.44 | 21.32 | 15.1 | 54.1 | 30.8 |
| P-4-3-1 | 6 | 1.45 | 15.03 | 20.1 | 54.1 | 25.8 |
| P-4-4-1 | 6 | 1.37 | 17.85 | 22.1 | 51.6 | 26.3 |
| P-4-5-1 | 6 | 1.41 | 15.93 | 18.3 | 54.0 | 27.7 |
| P-4-6-1 | 6 | 1.49 | 15.83 | 12.0 | 63.2 | 24.8 |
| P-2-7-1 | 6 | 1.49 | 16.79 | 13.3 | 62.2 | 24.5 |
| P-2-8-1 | 6 | 1.25 | 17.68 | 15.6 | 59.6 | 24.8 |
| P-4-9-1 | 6 | 1.40 | 18.28 | 15.0 | 56.4 | 28.6 |
| P-4-10-1 | 6 | 1.43 | 18.83 | 15.8 | 56.8 | 27.4 |

TABLE B-20. PHYSICAL PARAMETERS OF TOPSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| P-1-1-1 | 10 | 1.52 | 23.76 | 10.9 | 56.6 | 32.5 |
| P-1-2-1 | 10 | 1.24 | 20.99 | 7.7 | 63.2 | 29.1 |
| P-1-3-1 | 7 | 1.30 | 15.74 | 16.5 | 57.6 | 25.9 |
| P-1-4-1 | 8 | 1.20 | 16.88 | 16.9 | 62.4 | 20.7 |
| P-1-5-1 | 6 | 1.29 | 20.02 | 8.8 | 57.2 | 34.0 |
| P-1-6-1 | 6 | 1.25 | 26.02 | 8.4 | 56.1 | 35.5 |
| P-1-7-1 | 9 | 1.37 | 28.46 | 8.8 | 67.7 | 23.5 |
| P-1-8-1 | 6 | 1.24 | 20.92 | 13.2 | 53.7 | 33.1 |
| P-1-9-1 | 6 | 1.17 | 20.30 | 8.2 | 64.7 | 27.1 |
| P-1-10-1 | 6 | 1.43 | 19.69 | 9.6 | 61.4 | 29.0 |
| P-2-1-1 | 6 | 1.31 | 24.72 | 6.9 | 62.9 | 30.2 |
| P-2-2-1 | 6 | 1.16 | 22.57 | 7.8 | 68.9 | 23.3 |
| P-2-3-1 | 6 | 1.22 | 21.13 | 5.6 | 71.3 | 23.1 |
| P-2-4-1 | 5 | 1.32 | 23.93 | 2.1 | 62.9 | 35.0 |
| P-2-5-1 | 6 | 1.17 | 24.32 | 5.5 | 69.6 | 24.9 |
| P-2-6-1 | 6 | 1.18 | 28.44 | 2.7 | 55.7 | 41.6 |
| P-2-7-1 | 6 | 1.21 | 22.22 | 5.7 | 64.9 | 29.4 |
| P-2-8-1 | 6 | 1.15 | 20.75 | 4.8 | 66.5 | 28.7 |
| P-2-9-1 | 5 | 1.30 | 20.64 | 6.9 | 65.6 | 27.5 |
| P-2-10-1 | 6 | 1.17 | 20.61 | 6.1 | 69.4 | 24.5 |

## TABLE B-21. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| P-3-1-2 | 14 | 1.41 | 17.90 | 6.6 | 59.2 | 34.2 |
| P-3-2-2 | 14 | 1.36 | 24.45 | | | |
| P-3-3-2 | 14 | 1.07 | 26.48 | 6.7 | 41.9 | 51.4 |
| P-3-4-2 | 14 | 1.30 | 22.60 | | | |
| P-3-5-2 | 14 | 1.30 | 29.46 | 5.1 | 33.6 | 58.3 |
| P-3-6-2 | 14 | 1.27 | 26.84 | | | |
| P-3-7-2 | 14 | 1.30 | 19.99 | 6.0 | 66.4 | 27.6 |
| P-3-8-2 | 14 | 1.25 | 25.23 | | | |
| P-3-9-2 | 14 | 1.37 | 24.23 | 1.8 | 48.5 | 49.7 |
| P-3-10-2 | 14 | 1.34 | 24.41 | | | |
| P-4-1-2 | 14 | 1.37 | 26.47 | 9.2 | 37.7 | 53.1 |
| P-4-2-2 | 14 | 1.29 | 22.39 | | | |
| P-4-3-2 | 14 | 1.35 | 19.63 | 20.4 | 44.8 | 34.8 |
| P-4-4-2 | 14 | 1.29 | 24.72 | | | |
| P-4-5-2 | 14 | 1.30 | 20.76 | 19.1 | 38.3 | 42.6 |
| P-4-6-2 | 17 | 1.30 | 21.49 | | | |
| P-4-7-2 | 14 | 1.38 | 17.83 | 8.9 | 52.0 | 39.1 |
| P-4-8-2 | 14 | 1.35 | 23.99 | | | |
| P-4-9-2 | 17 | 1.26 | 25.13 | 9.8 | 36.2 | 54.0 |
| P-4-10-2 | 14 | 1.28 | 20.83 | | | |

## TABLE B-22. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| P-1-1-2 | 18 | 1.64 | 22.51 | 10.1 | 53.7 | 36.2 |
| P-1-2-2 | 15 | 1.30 | 30.70 | | | |
| P-1-3-2 | 15 | 1.51 | 19.44 | 10.5 | 60.1 | 29.4 |
| P-1-4-2 | 16 | 1.34 | 22.13 | | | |
| P-1-5-2 | 14 | 1.33 | 21.78 | 9.0 | 63.0 | 28.0 |
| P-1-6-2 | 15 | 1.46 | 30.21 | | | |
| P-1-7-2 | 18 | 1.51 | 20.17 | 9.8 | 57.9 | 32.3 |
| P-1-8-2 | 16 | 1.51 | 26.46 | | | |
| P-1-9-2 | 16 | 1.50 | 27.30 | 4.6 | 47.4 | 48.0 |
| P-1-10-2 | 16 | 1.52 | 27.69 | | | |
| P-2-1-2 | 14 | 1.33 | 27.46 | 1.2 | 41.1 | 57.7 |
| P-2-2-2 | 14 | 1.27 | 23.96 | | | |
| P-2-3-2 | 16 | 1.53 | 26.34 | 4.9 | 37.2 | 57.9 |
| P-2-4-2 | 20 | 1.48 | 28.14 | | | |
| P-2-5-2 | 16 | 1.25 | 15.94 | 5.2 | 64.7 | 30.1 |
| P-2-6-2 | 16 | 1.57 | 22.02 | | | |
| P-2-7-2 | 16 | 1.38 | 18.22 | 2.3 | 48.3 | 49.4 |
| P-2-8-2 | 22 | 1.60 | 22.89 | | | |
| P-2-9-2 | 15 | 1.31 | 20.43 | 4.8 | 68.7 | 26.5 |
| P-2-10-2 | 16 | 1.43 | 29.68 | | | |

## TABLE B-23. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density ($g/cm^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| P-3-1-3 | 44 | 1.26 | 31.91 | 11.2 | 31.5 | 57.3 |
| P-3-2-3 | 42 | 1.54 | 20.84 | | | |
| P-3-3-3 | 39 | 1.59 | 19.11 | 8.9 | 44.5 | 46.6 |
| P-3-4-3 | 39 | 1.56 | 19.31 | | | |
| P-3-5-3 | 35 | 1.61 | 18.14 | 15.5 | 61.7 | 22.8 |
| P-3-6-3 | 37 | 1.55 | 17.99 | | | |
| P-3-7-3 | 37 | 1.50 | 21.97 | 2.8 | 45.6 | 51.6 |
| P-3-8-3 | 41 | 1.36 | 18.08 | | | |
| P-3-9-3 | 37 | 1.94 | 18.56 | 4.9 | 50.3 | 44.8 |
| P-3-10-3 | 47 | 1.51 | 22.33 | | | |
| P-4-1-3 | 41 | 1.63 | 22.61 | 6.1 | 44.6 | 49.3 |
| P-4-2-3 | 40 | 1.60 | 19.91 | | | |
| P-4-3-3 | 41 | 1.57 | 21.33 | 21.3 | 33.5 | 45.2 |
| P-4-4-3 | 37 | 1.53 | 21.24 | | | |
| P-4-5-3 | 35 | 1.38 | 21.58 | 15.2 | 35.4 | 49.4 |
| P-4-6-3 | 40 | 1.48 | 22.18 | | | |
| P-4-7-3 | 40 | 1.54 | 21.40 | 17.0 | 41.5 | 41.5 |
| P-4-8-3 | 40 | 1.53 | 20.97 | | | |
| P-4-9-3 | 44 | 1.62 | 20.19 | 12.4 | 43.9 | 43.7 |
| P-4-10-3 | 37 | 1.57 | 20.88 | | | |

TABLE B-24. PHYSICAL PARAMETERS OF SUBSOIL SAMPLES

| Sample Number | Depth (Inches) | Bulk Density (g/cm$^3$) | Water (%) | Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|---|---|
| P-1-1-3 | 40 | 1.43 | 30.36 | 6.3 | 42.3 | 51.4 |
| P-1-2-3 | 39 | 1.78 | 22.35 | | | |
| P-1-3-3 | 37 | 1.50 | 26.96 | 8.4 | 47.9 | 43.7 |
| P-1-4-3 | 40 | 1.63 | 22.53 | | | |
| P-1-5-3 | 40 | 1.49 | 22.55 | 8.5 | 49.7 | 41.8 |
| P-1-6-3 | 42 | 1.66 | 21.69 | | | |
| P-1-7-3 | 40 | 1.66 | 23.59 | 10.3 | 48.2 | 41.5 |
| P-1-8-1 | 40 | 1.61 | 24.01 | | | |
| P-1-9-1 | 40 | 1.57 | 23.81 | 9.7 | 61.2 | 29.1 |
| P-1-10-3 | 42 | 1.54 | 25.15 | | | |
| P-2-1-3 | 38 | 1.41 | 21.57 | 3.6 | 55.8 | 40.6 |
| P-2-2-3 | 48 | 1.34 | 21.88 | | | |
| P-2-3-3 | 37 | 1.51 | 25.85 | .8 | 44.2 | 55.0 |
| P-2-4-3 | 36 | 1.43 | 31.40 | | | |
| P-2-5-3 | 40 | 1.45 | 28.58 | 1.5 | 40.3 | 58.2 |
| P-2-6-3 | 37 | 1.43 | 30.34 | | | |
| P-2-7-3 | 39 | 1.54 | 25.14 | 2.5 | 40.6 | 56.9 |
| P-2-8-3 | 40 | 1.54 | 26.85 | | | |
| P-2-9-3 | 40 | 1.57 | 25.61 | 5.4 | 45.3 | 49.3 |
| P-2-10-3 | 40 | 1.39 | 31.75 | | | |

# APPENDIX C

# ANALYSIS OF VARIANCE SUMMARIES

### TABLE C-1. ANOVA for Analysis of Soil Replacement Data

MODEL: Bulk Density=CONSTANT PASS LIFT PASS*LIFT;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 271.5574 | 1 | 271.5574 | 0.0000 |
| LIFT (A) | 0.0549 | 3 | 0.0183 | 0.0640 |
| PASS | 0.0370 | 3 | 0.0124 | 0.1734 |
| LIFT*PASS | 0.0479 | 3 | 0.0160 | 0.0947 |
| RESIDUAL | 0.6563 | 90 | 0.0073 | |

(A)The cell frequencies are not proportional so that the order in which the main effects are put into the model affects the test results. Sequential sums of squares are reported; consequently, the p-value and sum of squares for LIFT come from an analysis of the model CONSTANT PASS LIFT LIFT*PASS. The test for interaction is the same for both models, while the test for PASS comes from the model noted above.

### TABLE C-2. ANOVA for Analysis of Scraper Data

MODEL: Bulk Density=CONSTANT SOIL PLOT(SOIL) LIFT SOIL*LIFT;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 262.3428 | 1 | 262.3428 | 0.0000 |
| SOIL | 0.5822 | 1 | 0.5822 | 0.1900 |
| PLOT(SOIL) (A) | 0.0570 | 1 | 0.0570 | 0.0002 |
| LIFT | 0.1261 | 1 | 0.1261 | 0.0000 |
| LIFT*SOIL | 0.0137 | 1 | 0.0137 | 0.0623 |
| RESIDUAL | 0.3663 | 95 | 0.0039 | |

(A) The soil effect is tested by the plot within soil type as an error term. All other effects are tested by the residual error.

NOTE: There is only one degree of freedom for plot (soil) so that the test of a difference between soil type lacks power.

**TABLE C-3. ANOVA for Analysis of Bucket-Wheel Excavator Data**

MODEL: Bulk Density=CONSTANT SOIL PLOT(SOIL) LIFT SOIL*LIFT;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 255.9040 | 1 | 255.9040 | 0.0000 |
| SOIL | 0.3597 | 1 | 0.3597 | 0.0800 |
| PLOT(SOIL) (A) | 0.0666 | 2 | 0.0333 | 0.0017 |
| LIFT | 0.0007 | 1 | 0.0007 | 0.6966 |
| LIFT*SOIL | 0.1608 | 1 | 0.1608 | 0.0000 |
| RESIDUAL | 0.4565 | 94 | 0.0049 | |

(A) See footnote for ANOVA 3.

**TABLE C-4. ANOVA for Analysis of End-Dump Haulback Data**

MODEL: Bulk Density=CONSTANT SOIL PLOT(SOIL) LIFT SOIL*LIFT;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 215.8902 | 1 | 215.8902 | 0.0000 |
| SOIL | 0.4930 | 1 | 0.4930 | 0.0100 |
| PLOT(SOIL) (A) | 0.0133 | 2 | 0.0067 | 0.3850 |
| LIFT | 0.0101 | 1 | 0.0101 | 0.2296 |
| LIFT*SOIL | 0.0605 | 1 | 0.0605 | 0.0041 |
| RESIDUAL | 0.5106 | 74 | 0.0069 | |

(A) See footnote for ANOVA 2.

**TABLE C-5. ANOVA for Prediction of Bulk Density from Sand**

MODEL: Bulk Density=CONSTANT SAND;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| SAND | 0.7822 | 1 | 0.7822 | 0.0000 |
| RESIDUAL | 1.2018 | 110 | 0.0109 | |

$R^2 = 39.4\%$

**TABLE C-6. ANOVA for Prediction of Bulk Density from Clay**

MODEL: Bulk Density=CONSTANT CLAY;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| SAND | 0.7280 | 1 | 0.7280 | 0.0000 |
| RESIDUAL | 1.2560 | 110 | 0.0114 | |

$R^2 = 36.7\%$

**TABLE C-7. ANOVA for Prediction of Bulk Density from Silt**

MODEL: Bulk Density=CONSTANT SILT;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| SAND | 0.0294 | 1 | 0.0294 | 0.2007 |
| RESIDUAL | 1.9545 | 110 | 0.0789 | |

$R^2 = 1.5\%$

## TABLE C-8. ANOVA for Prediction of Bulk Density from Sand and Lift

MODEL: Bulk Density=CONSTANT LIFT SAND LIFT*SAND;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| LIFT | 0.0035 | 1 | 0.0035 | 0.5617 |
| SAND | 0.7799 | 1 | 0.7799 | 0.0000 |
| LIFT*SAND | 0.0851 | 1 | 0.0851 | 0.0049 |
| RESIDUAL | 1.1154 | 108 | 0.0103 | |

$R^2 = 43.8\%$

## TABLE C-9. ANOVA for Prediction of Bulk Density from Clay and Lift

MODEL: Bulk Density=CONSTANT LIFT CLAY LIFT*CLAY;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| LIFT | 0.0035 | 1 | 0.0035 | 0.5831 |
| SAND | 0.7323 | 1 | 0.7323 | 0.0000 |
| LIFT*SAND | 0.0007 | 1 | 0.0007 | 0.8064 |
| RESIDUAL | 1.2474 | 108 | 0.0116 | |

$R^2 = 37.1\%$

**TABLE C-10. ANOVA for "Best" Prediction of Bulk Density from Sand and Lift**

MODEL: Bulk Density=CONSTANT SAND*LIFT;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| LIFT*SAND | 0.8068 | 2 | 0.4034 | 0.0000 |
| RESIDUAL | 1.1771 | 109 | 0.0108 | |

$R^2 = 40.7\%$

**TABLE C-11. ANOVA for Prediction of Bulk Density from Sand and Clay**

MODEL: Bulk Density=CONSTANT LIFT SAND CLAY SAND*LIFT CLAY*LIFT

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| LIFT | 0.0035 | 1 | 0.0035 | 0.5287 |
| SAND | 0.7799 | 1 | 0.7799 | 0.0000 |
| CLAY | 0.2149 | 1 | 0.2149 | 0.0000 |
| SAND*LIFT | 0.0550 | 1 | 0.0550 | 0.0137 |
| CLAY*LIFT | 0.0019 | 1 | 0.0019 | 0.6422 |
| RESIDUAL | 0.9288 | 106 | 0.0088 | |

$R^2 = 53.2\%$

### TABLE C-12. ANOVA for "Best" Prediction of Bulk Density from Sand and Clay

MODEL: Bulk Density=CONSTANT CLAY SAND*LIFT CLAY;

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| CLAY | 0.7280 | 1 | 0.7280 | 0.0000 |
| SAND*LIFT | 0.2963 | 2 | 0.1482 | 0.0000 |
| RESIDUAL | 0.9597 | 108 | 0.0089 | |

$R^2 = 51.6\%$

### TABLE C-13. ANOVA for Prediction of Bulk Density from Sand + Clay

MODEL: Bulk Density=CONSTANT (SAND+CLAY);

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| SAND+CLAY | 0.0294 | 1 | 0.0294 | 0.2007 |
| RESIDUAL | 1.9545 | 110 | 0.0178 | |

$R^2 = 1.5\%$

**TABLE C-14. ANOVA for Prediction of Bulk Density from Sand + Clay**

MODEL: Bulk Density=CONSTANT (SAND+SILT);

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| SAND+SILT | 0.7280 | 1 | 0.7280 | 0.0000 |
| RESIDUAL | 1.2560 | 110 | 0.0114 | |

$R^2 = 36.7\%$

**TABLE C-15. ANOVA for Prediction of Bulk Density from Silt + Clay**

MODEL: Bulk Density=CONSTANT (SILT+CLAY);

ANALYSIS OF VARIANCE

| SOURCE | SUM OF SQUARES | D.F. | MEAN SQUARE | P-VALUE |
|---|---|---|---|---|
| CONSTANT | 323.0343 | 1 | 323.0343 | 0.0000 |
| SILT+CLAY | 0.7822 | 1 | 0.7822 | 0.0000 |
| RESIDUAL | 1.2018 | 110 | 0.0109 | |

$R^2 = 39.4\%$

# APPENDIX D

# ANALYTICAL PROCEDURES USED FOR SAMPLE ANALYSIS

## PROCEDURES FOR BULK DENSITY SOIL TESTING

1. The total weight of the core sample plus the bag was determined to the nearest gram.
2. The core sample was removed from the bag and split lengthwise into approximately two equal portions.
3. Each half was placed into previously weighed containers to determine the wet weight of each half. NOTE: The sum of the wet weight of both halves compared to the original weight of the whole sample served as a check for weight loss due to evaporation of water. Any difference in wet weight from the original weighing and the sum of the two halves was shared proportionally between each half.
4. Half of each core was placed in a forced-air oven at a temperature above $110^o$ C and, after 72 hours, the oven-dried weight was determined.
5. The remaining half was subdivided into small portions and air dried. NOTE: The air-dried sample was used for all the fertility determinations (i.e., pH, phosphorus, potassium) and texture.
6. The bulk density calculations were made with the assumption that both halves of the core had the same percent water. To calculate the mass of the soil core, the oven-dried weight of one-half of the first core was used, along with the net wet-weight of both portions.
7. The volume of the core was calculated using average length and diameter measurements ($cm^3$).
8. The bulk density is the mass of the core divided by its volume.

## PARTICLE SIZE ANALYSES (PIPETTE METHOD)

A. Preparation of Sample:

1. Air-dried sample

2. Pass through sample grinder and 2mm sieve.

    a. Weigh sample that remains on sieve (> 2mm) to nearest g.
    b. Weigh smaple that passes through sieve (< 2mm) to nearest g.
    c. Mix sample to insure uniformity.

B. Removal of Organic Matter:

1. Weigh 10 gm of sample < 2mm on triple beam balance and place in 1000-ml tall-form pyrex beaker.

2. Add about 10 ml distilled water (thoroughly wet sample) adjust pH to 3-4 using dilute HCl (0.1N) and pH meter. Add 10 ml of 30% $H_2O_2$, cover with watch glass.

    a. Leave "cold".
    b. Add 5 ml increments of 30% $H_2O_2$ about every 30-45 minutes until frothing disappears. (3 or 4 increments for dark soils, 1 or 2 for light colored soils).

3. Place on 90°C hotplate (usually done following day).

    a. Add 5 ml increments of 30% $H_2O_2$ about every 30-45 minutes until no Organic Matter is seen by visual inspection.
    b. After final increment of $H_2O_2$, continue heating for an additional 30 minutes to remove excess $H_2O_2$.
    c. Do not let sample become dry at any time.

C. Removal of Dissolved Mineral Matter:

1. Allow beaker and soil from B-3b, above, to cool; then add about 400-500 ml distilled water as a jet stream to thoroughly stir the sample.

2a. Filter suspension using Pasteur-Chamberlain filter of "F" fineness.

2b. Salts may be removed by transferring sample to centrifuge tubes and spinning at high speed for 10-15 min (4000 x gravity). A longer time is required if a lower centrifugal force is used. Add deionized water, resuspend soil, and repeat centrifugation process. (Go to step 4 if centrifuge is used).

3. Repeat addition of 400-500 ml distilled water and filtration 4 or 5 times. (More may be needed in gypsum soils - not in KY).

    a. Remove soil adhering to filter candle with gentle back-pressure and wash with jet of distilled water. (A rubber policeman or finger top may be used to assist in dislodging material).

D. Dispersion of the Sample:

1. Add about 100 ml of distilled $H_20$ to the oven-dried sample in the 1000-ml tall-form beaker. Adjust to pH 10 using 0.5 N $Na_2CO_3$.

2. Transfer to baffle mixing cup (milk shake mixer), using jet of distilled water to complete the transfer.

3. Bring volume in mixer cup up about 1/2 or 2/3.

4. Mix for 5 minutes and immediately transfer to 300- or 270-mesh sieve placed in a funnel above a 1000-ml cylinder. Work the silt and clay through the screen with distilled water until the cylinder contains about 900 ml.

    a. Transfer sand remaining on screen into a pre-weighed beaker, dry in oven, and reweigh after cooling.
    b. Fill cylinder to 1000-ml mark with distilled $H_2O$.

5. Also prepare a cylinder with water and dispersion agent only to serve as a check (blank).

E. Pipetting (for 2 mu clay only; check booklet for other fractions):

1. Allow sedimentation cylinder to come to constant temperature in closed room.

2. Mix the contents of the cylinder thoroughly by either:

    a. Slow-speed stirrer for about 3-5 minutes
    b. Hand-operated perforated plunger in up-and-down motion
    c. Stoppering, and end-over-end inversion.

3. Allow cylinder to stand for 6-1/2 hours without disturbance in a constant-temperature room.

4. Using a Lowy pipette, remove a 25-ml aliquot with a filling time of about 12-15 seconds. Pipette should be lowered to proper tip depth, based on temperature (depth table attached as Appendix 1 for 2 mu clay), using a Shaw pipette rack. Temperature should be measured in a separate

cylinder of water equilibrated under the same condition as the soil cylinders.

5. Empty pipette into a clean, weighed weighing bottle (60-ml or larger).

   a. Fill pipette again with distilled water as a rinse and add to previous aliquot in weighing bottle.

6. Dry bottle at low temperature (below 100$^{o}$C), then place in 110$^{o}$C oven for about 4 hours (or overnight).

7. Remove from oven, cool and dry in dessicator, and weigh and record to nearest milligran (i.e., -0.001).

8. In same manner pipette the blank (or check) cylinder to obtain amount of dispersion agent present in each aliquot. This step <u>must</u> be done every time a new dispersion solution is prepared. However, it is wise to include this step with each set of samples pipetted.

<u>NOTE</u>: Before pipetting each set of samples, make a trial run on distilled water so as to adjust the vacuum to give the proper rate of fill. This may vary with depth of tip in the suspension. Caution should be exercised to make sure that the pipette stopcock is <u>closed</u> before the pipette is lowered into the suspension.

F. <u>Determine the Amount of Soil in Each Aliquot</u>:

From the weight of oven-dried material determined for each aliquot taken from the soil suspension, you must subtract the amount of material (dispersion agent) determined on the blank (check) cylinder that contained only water and dispersing agent.

G. <u>Calculations</u>:

1. Sand - Pipette as described in Section E. Calculations are as follow:

   a. Total amount of sand in sample as a percentage of total soil sample:

$$\% \text{ Sand} = \frac{\text{Total Sand, gms}}{\text{Total O.D. Soil Sample, gms}} \times 100$$

   b. Amount of any one sand fraction as a percentage of total soil sample:

% of Particular Sand Fraction =

$$\frac{\text{Wt. That Fraction, gms}}{\text{Total O.D. Soil Sample, gms}} \times 100$$

2. Clay - Perform steps under sections F and G1 above.

The total amount of clay (2 mu) in sample as a percentage of total soil sample:

$$\%\ \text{Clay} = \frac{\text{O.D. Aliquot Wt. Clays - O.D. Aliquot of Blank}}{\text{Total O.D. Soil Sample, gms}} \times \frac{1000}{\begin{array}{c}\text{Volume}\\ \text{by}\\ \text{Aliquot}\end{array}} \times 100$$

3. Silt (By Difference).

   a. $\%\ \text{Silt} = 100 - (\%\ \text{Clay} + \%\ \text{Sand})$, or

   b. $\%\ \text{Silt} = 100 - \dfrac{\text{(Wt. Clay + Wt. Sand)}}{\text{Total O.D. Soil Sample Wt.}} \times 100$ or

   c. $\%\ \text{Silt} = \dfrac{\text{Total Soil Sample Wt.-(Wt. Clay + Wt. Sand)}}{\text{Total O.D. Soil Sample by Wt.}} \times 100$

# APPENDIX E

## Prime Farmland Regulatory Analysis Key

## TABLE E-1. PRIME FARMLAND REGULATIONS KEY

| State | Prime Farmland Regulations Differing from State Address Regulations | State Regulatory Authority |
|---|---|---|
| Arkansas | None | Mining Division<br>Pollution and Control<br>P.O. Box 9589<br>Little Rock, AK. 72219<br>(Phone: 501-371-1135) |
| Illinois | Yes | Ill. Dept. of Mines<br>Land Reclamation Div.<br>227 S. 7th Str. Rm.204<br>Springfield, IL. 62706<br>(Phone: 217-782- 4970) |
| Indiana | None | Div. of Reclamation<br>309 W. Washington<br>Room 201<br>Indianapolis, IN. 46204<br>(Phone: 317-232-1555) |
| Iowa | None | Mines & Minerals Div.<br>Div. of Soil Conser.<br>Wallace Office Bldg.<br>Des Moines, IA. 50319<br>(Phone: 515-281-5011) |
| Kansas | None | OSM<br>Division of Mining<br>Technical Service<br>818 Grand Ave.<br>Scaritt Bldg.<br>Kansas City, KS. 64106<br>(Phone: 816-374-2193) |
| Kentucky | None | Kentucky Dept. For<br>Natural Resources and<br>Env. Protection<br>6th Floor, Capital Tower<br>Frankfort, KY. 40601<br>(Phone 502-564-2356) |

## TABLE E-1. PRIME FARMLAND REGULATIONS KEY (Con't)

| State | Prime Farmland Regulations Differing from State Address Regulations | State Regulatory Authority |
|---|---|---|
| Missouri | Yes | Land Reclamatiod Comm.<br>Env. Quality<br>2010 Missouri Blvd.<br>Jefferson City, MO. 65102<br>(Phone: 314-751-3241) |
| Ohio | Yes | OSM<br>Div. of Reclamation<br>Terminal Boulevard<br>850 Airport Rd.<br>Zanesville, OH. 43701<br>(Phone: 614-454-8508) |
| Oklahoma | None | Dept. of Mines<br>440 N. Lincoln Blvd.<br>Oklahoma City, OK 73105<br>(Phone: 405- 521-3859) |

# APPENDIX F

## COST ANALYSIS SUMMARIES

# CORN/COVER CROP ROTATION

Inputs Adapted From Farm Budget Model

## COSTS OF PRODUCTION

| | | | | | |
|---|---|---|---|---|---|
| Nitrogen | $ .25 | x | 120 lbs. | = | $30.00 |
| Phosphate | .20 | x | 60 lbs. | = | 12.00 |
| Potash | .12 | x | 60 lbs. | = | 7.20 |
| Lime | 8.00 | x | .5 tons | = | 4.00 |
| Seed | 1.00 | x | 16 lbs. | = | 16.00 |
| Chemicals | 15.00 | x | 1 acre | = | 15.00 |
| Building & Equipment Insurance | .015 | x | 600 | = | 9.00 |
| Building & Equipment Repairs | .015 | x | 600 | = | 9.00 |
| Machinery Operation | 5.00 | x | 5 hrs. | = | 25.00 |
| Marketing & Hauling | .20 | x | 110 bu. | = | 22.00 |

## LABOR COSTS

| | | | | | |
|---|---|---|---|---|---|
| Hours and Wages | 3.50 | x | 5 hrs. | = | 17.50 |

## COST FOR COVER CROP (Grass Legume)

| | |
|---|---|
| Cost/Acre - From Model | 31.35 |

| | |
|---|---|
| TOTAL COST/ACRE = Yearly Operation Cost/Acre | $198.05 |
| = Depreciable Cost/Acre | 300.00 |

## WHEAT/SOYBEAN ROTATION

Inputs Adapted From Farm Budget Model

### COSTS OF PRODUCTION

| | | | | | |
|---|---|---|---|---|---|
| Nitrogen | $ .25 | x | 60 lbs. | = | $15.00 |
| Phosphate | .20 | x | 60 lbs. | = | 12.00 |
| Potash | .12 | x | 60 lbs. | = | 7.20 |
| Lime | 8.00 | x | .5 tons | = | 4.00 |
| Seed | 40.00 | x | 1 acre | = | 40.00 |
| Chemicals | 25.00 | x | 1 acre | = | 25.00 |
| Building & Equipment Insurance | .015 | x | 600 | = | 9.00 |
| Building & Equipment Repairs | .015 | x | 600 | = | 9.00 |
| Machinery Operation | 5.00 | x | 7 hrs. | = | 35.00 |
| Marketing & Hauling | .20 | x | 70 bu. | = | 14.00 |

### LABOR COSTS

| | | | | | |
|---|---|---|---|---|---|
| Hours and Wages | 3.50 | x | 7 hrs. | = | 24.50 |

TOTAL COST/ACRE = Yearly Operation Cost/Acre $197.70

## HAY CROP (Alfalfa)

Inputs Adapted From Farm Budget Model

### COSTS OF PRODUCTION

| | | | | | |
|---|---|---|---|---|---|
| Nitrogen | .25 | x | 10 lbs. | = | $ 2.50 |
| Phosphate | .20 | x | 80 lbs. | = | 16.00 |
| Potash | .12 | x | 200 lbs. | = | 24.00 |
| Lime | 8.00 | x | .5 tons | = | 4.00 |
| Seed | 12.00 | x | 1 acre | = | 12.00 |
| Chemicals | 25.00 | x | 1 acre | = | 25.00 |
| Building & Equipment Insurance | .015 | x | 400 | = | 6.00 |
| Building & Equipment Repairs | .015 | x | 400 | = | 6.00 |
| Machinery Operation | 5.00 | x | 8 hrs. | = | 40.00 |

### LABOR COSTS

| | | | | | |
|---|---|---|---|---|---|
| Hours and Wages | 3.50 | x | 8 hrs. | = | 28.00 |

TOTAL COST/ACRE = Yearly Operation Cost/Acre $163.50