Stabilizing mineral wastes

Chemical, physical, and vegetative methods — and combinations thereof — are being tried, often successfully, on all sorts of mineral wastes that range from copper mill tailings to uranium waste piles.

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MINE, MILL, AND SMELTER wastes are scattered across the country as unattractive barren piles that mar the natural beauty of the land.

Congress and the Solid Waste Disposal Act of 1965 delegated to US Bureau of Mines responsibility to conduct research designed to prevent air and water pollution from such mineral accumulations. The Bureau brochure, "Wealth Out of Waste," states that in 1965, the accumulated tonnage of waste from the processing of minerals and fuels amounted to 1,122 million tons covering approximately 2 million acres. "Over a billion tons of such mineral-processing wastes are produced in this country each year." Of this, approximately 40% is fine-sized material. Stabilization of such wastes to prevent air and water pollution — and to preserve the contained values for possible later utilization — is a challenging task. Several stabilization methods (physical, chemical, and vegetative, and combinations thereof) are used or have been tested and proposed.

For instance, massive coverings of coarse slag, concrete, and soil may be used to prevent erosion of waste piles; and a variety of chemicals can bond particles of fine waste into a relatively inert mass. However, the most promising method of producing an esthetically appealing storage site is vegetative stabilization. Numerous species of plants can germinate, grow, and reseed in waste materials that have been adequately prepared to support plant life if environmental conditions are not overly severe.

Preplanning of waste disposal is now a common practice for many companies initiating new operations. But preplanning was frequently ignored in the past, and waste accumulations are often haphazardly deposited in piles with dangerously steep banks. Thus, although stabilization by vegetation might be preferred because of esthetic considerations, it is often not applicable. Therefore, physical and chemical as well as vegetative methods will be reviewed here.

PHYSICAL STABILIZATION

Many materials have been tried for physical stabilization of fine tailings. Other than water for sprinkling, perhaps the material most used is rock and soil obtained from areas adjacent to the wastes to be covered. Soil often has a dual advantage in that it provides an effective cover and a habitat for encroachment of local vegetation. Soil, however, is not always available in areas contiguous to the wastes and, even where available, it may be too costly to apply.

Crushed or granulated smelter slag has stabilized a variety of fine wastes, notably inactive tailings ponds. In active tailings ponds, however, the slag-covered portions are subject to burial from shifting sands or from new tailings deposits. Unlike soils or country rock, slag cannot provide a favorable habitat for vegetation. Furthermore, suitable slag, like soil and rock, must be locally available.

Other physical methods of stabilization evaluated include the use of bark covering, the harrowing of straw into the top few inches of tailings, and the placement of windbreaks. Bark and straw have proved beneficial at the Anaconda, Mont., copper operations, and reed windbreaks were successfully employed in South African[1] plantings on gold and uranium mill tailings.

CHEMICAL STABILIZATION

Chemical stabilization involves reacting chemical with the waste to form an air- and water-resistant crust or layer. Laboratory studies have taken into account the heterogeneous nature of tailings accumulations. The mix of sands and slimes change suddenly, as do permeability, pH, and salt content.

A wide variety of chemicals have been laboratory-tested on samples obtained from copper, lead-zinc, clay, uranium, and vanadium process plant wastes. Because the amount of moisture in the tailings affects the bonding characteristics of the reagents, this variable has also been investigated by moistening the tailings to various degrees before adding the chemicals. The chemicals are first applied to the samples and the samples are then subjected to alternating wetting-and-drying and freezing-and-thawing cycles to determine the resistance to these

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disruptive forces. The coherency of the tailings surfaces after treatment is determined by using airjets and waterjets to simulate wind and water erosion. The 65 chemicals tested include sodium and potassium silicates, lignosulphonates, pyrite treated with sulphuric acid, cement, lime, cationic neoprene emulsion, elastomeric polymers, resinous materials, bituminous base products, cellulose compounds, various tall oil fractions, amines, and wax, tar and pitch emulsions. Of the chemicals tested, the resinous, elastomeric polymer, lignosulphonate, bituminous base, wax, tar and pitch products have proved effective stabilizers for one or more types of fine-sized mineral wastes. Several of the more promising chemicals have subsequently been evaluated by field tests on tailings from different mineral processing plants.

A 34-acre uranium tailing accumulation at Tuba City, Ariz.,[3] was stabilized during the summer of 1968 as the first field trial of chemical stabilization. An elastomeric polymer,* DCA-70, was applied to the dike areas of the tailings pond in quantities varying with the susceptibility of the specific areas to wind erosion. Calcium lingnosulphonate, a waste product from paper manufacturing, was applied to the beach areas of the ponds. Both water-soluble chemicals were applied with an automated sprinkling system at a total stabilization cost of $335 per acre. An evaluation of the stabilization achieved, made one year after treatment, showed that from 8% to 10% of the dike area had been disrupted by high winds where irregular overhanging material permitted the wind to rip out sections. After 2 years, an additional disruption of about 20% had occurred, mainly in those areas that had broken out in the previous year.

VEGETATIVE STABILIZATION

To be sucessful, the initiation and perpetuation of vegetation on fine wastes depends on improving a number of adverse factors. Mill wastes usually (1) are deficient in plant nutrients; (2) contain excessive salts and heavy metal phytotoxicants; (3) consist of unconsolidated sands that, when windblown, destroy young plants by sandblasting or burial, or both; and (4) lack normal microbial populations. Other less easily defined problems also complicate vegetative procedures. The sloping sides of waste piles receive greatly varying amounts of solar radiation depending on direction of exposure. Studies by Gates[3] have indicated that, contrary to popular belief, photosynthesis of plants is not continuous while the sun is shining; under high temperature conditions, photosynthesis may almost completely stop. Furthermore, most accumulations of mill tailings are light in color and may reflect excessive radiation to plant surfaces, thus intensifying physiological stresses. For these reasons, vegetation that may be effective on northern and eastern exposures may not be suitable for southern or western exposures.

Ideally, vegetative stabilization should produce a self-perpetuating plant cover directly; or it should foster entrapment and germination of native plant seeds that will be self-regenerating without the need for irrigation or special care. If the area were not cropped or grazed, only an initial fertilization would be required because the essential nutrients would be largely cycled in place.

Several mining companies have planted old tailings accumulations in efforts to achieve both stabilization and an attractive site. Tailings at the Miami Copper Co., M ami, Ariz., were covered with about 4 in. of country so obtained from areas adjacent to the tailings. This countr soil was of darker color than the tailings and provide some protection from heat reflection and offered a favo able environment for germination and seeding establishment. The Miami researchers seeded this material wit mixtures of seeds representing scores of species to obta diversity. Seedlings or sprouts of various trees and shrub also were placed by hand. Such practices resulted in vigorous growth of planted species and the rapid encroachment of native species onto the stabilized sites. Eventuall such natural succession will produce a cover capable o self-perpetuation without irrigation or fertilization.

Vegetative testing

Bureau of Mines research at the Salt Lake City Metallurgy Research Center is designed to develop improve methods for achieving better initial germination and mor rapid growth than is now common on mill tailings withou the necessity for a soil cover. Bureau work is concerne with selecting proper vegetation, studying the interactio of fertilizers with residual heavy minerals and salts contained within the wastes, improving the structure of th wastes to enhance vegetative growth, and developing combination chemical-vegetative procedure to obviate th problems of highly reflective surfaces and sandblasting.

Species selection

Seeds of many species were tested for germination an growth in representative samples of various types of tailings. Both domestic and wild plant species were evaluate in as-received tailings and with various fertilizer amendments. Almost always, the domestic species were mor reliable germinators than were the wild species. Plant that showed considerable promise include the following: sweet clover, various varieties of alfalfa, winter wheat rye, barley, various wheatgrasses (western, crested, intermediate, tall pubescent), other grasses (sorghum, love Kentucky blue, orchard, etc.), and shrubs such as big sagebrush, rabbit brush and Siberian pea tree. A special barley, Charlottetown 80 (grown on Prince Edward Island), has been effectively grown in acidic wastes at a pH as low as 3.0.

Preliminary tests using Indian ricegrass *(oryzopsis hymenoids)*, which is a hardy native grass[4], are encouraging because if proved capable of nitrogen fixation, this plant will be especially beneficial for stabilizing infertile wastes.

Effect of salinity

Salts present in the wastes or mill water are major deterrents to plant growth. Considerable difficulty was encountered in growing vegetation in milling wastes from Kennecott's Utah Copper Division. To determine the reasons, duplicate plantings were made (1) in the normal flotation tailings, containing considerable water-soluble salts but assaying only 0.05% copper, mostly as sulphides; and (2) in a simulated tailing containing little soluble salts but almost 0.25% copper. Seeded test plots were watered with tap water and tailings effluent water. Both germination and growth were adversely affected when effluent water was used. For samples watered with tap water, germination and growth were much better in the simulated tailing material despite the higher content of copper. These

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*Reference to company and trade names is made for identification only and does not imply endorsement by the Bureau of Mines.

tests indicated that the toxicity was due primarily to the high salt content of the water and tailings.

Supplementary tests were made to determine which salts or organic reagents in the copper mill tailings solutions most affected plant growth. The reclaimed tailings water was compared with a prepared solution simulating organic-free effluent and one containing all the organics used in the mill. Water hyacinths were used as the test plant.

Dehydration problems

Hyacinths in the artificial solution bearing organic extracting agents thrived for several weeks with no visible harm. But plants in mill effluent (or in artificial solutions with sufficient inorganic salts added to produce an osmotic concentration comparable to organic-free mill water) wilted immediately. The measured osmotic concentrations of the latter two solutions were 2.36 and 2.46 atmospheres. The osmotic gradient between the plant fluids and the environment around the roots presumably caused the plants to become dehydrated. A control test was run in which a hyacinth was placed in a non-reactive mannitol solution having an osmotic concentration of 2.4 atm. The hyacinth wilted as rapidly as in the mill effluent, indicating that death of the test plants was due more to the salt content than to either toxic organic compounds or metallic elements. The principal salt in the mill effluents is sodium chloride, but testing indicates that dehydration is produced with all types of salts at the osmotic concentrations considered.

To determine the effect of salinity on germination, tomato seeds were tested with mannitol solutions at osmotic concentrations ranging from 0 to 5 atm in increments of 0.5 atm. The germination rate dropped with increasing concentration until there was almost no germination at 4.5 atm. In other tests, seeds of several species were planted in copper tailings containing sufficient salts to produce osmotic concentrations between 2.2 and 2.5 atm. These tests indicated that such osmotic concentrations will not materially hinder initial germination of most plants, but will limit growth unless the tailings are leached to remove the soluble salts.

A series of plant growth tests was made on several uranium mining wastes. Tests on samples of stripped overburden from the Federal Partners Mine at Gas Hills, Wyo., showed that a growth of yellow sweet clover, crested wheat, and tomatoes could be established, but that salts solubilized by watering are brought to the surface by evaporation and after a month inhibit or destroy growth.

Considerable research was conducted to devise means of overcoming the deleterious effects of salts and acids within mill tailings. Three methods were considered: (1) Percolation leaching of the salts from the tailings; (2) stratification of the sand and slime fractions of the tailings during deposition; and (3) solar orientation of mounds of tailings to produce differential concentrations of salt on shaded and sunlit sides of the mound.

A minimum of work was done on percolation leaching, since Dr. A. L. James[1] had apparently devised a satisfactory means of leaching highly acidic tailings. According to James, flooding is not an effective means of leaching acidity from tailings because (1) prolonged flooding compacts the materials, producing conditions unfavorable for plant growth; and (2) when flooding is halted, evaporation brings the acid to the surface again. James' investigations indicated that the downward movement of acidity can be encouraged by an extremely fine spray of water which forms a mist over the surface and retards evaporation. If the spray of water applied does not exceed the rate at which it can penetrate the fine slimes, the zone of high acidity can be moved to a sufficient depth to permit vegetative growth within a period of 3 to 4 weeks.

Studies made in the Bureau indicated that stratification and mounding of tailings improved salinity problems. Comparative vegetative growth tests were made in unstratified plots of tailings material, and in "as-deposited" tailings capped with a layer of sands and then with a stratum of slimes. Both plots were permitted to dry thoroughly, and then watered once with sufficient salt-free water to force the "wetting front" several feet into the underlying tails. Subsequently, water was added only when plants showed signs of wilting. Appreciably more profuse and healthy plant growth was obtained in the stratified plots. Apparently, the sand layer hindered the migration of salts to the upper slime layer in which most of the vegetative growth took place.

When tailings were piled on long mounds (approximately 12 in. high) oriented in an east-west direction, vegetative growth was manifold greater on the northern slopes of the mounds than on south-facing slopes where increased evaporation had concentrated on the soluble salts. In this testing, similar to that of Bains and Singh[6], five mounds were established with saline copper tailings having a soil solution with an osmotic concentration of about 2.4 atm. The mounded tailings were then planted in April with tall wheatgrass, yellow sweet clover, and Ladak alfalfa in two rows each on north and south slopes of the mounds and one on the top. These tests showed that plant germination and survival after 9 weeks was three times greater on the north slope than on the south slope and that the topmost row of vegetation on the mounds was subject to more solar radiation than even the south slopes and plant growth suffered commensurately. Samples were taken from the surface inch of the mounds near the planted rows on the northern and southern exposure and leached to determine soluble salt content 15 weeks after planting. The results showed 30% more salts on the south than on the north slopes. After 28 weeks, the survival rate of vegetation on the north slopes was 17 times greater than on the south slopes.

Coping with erosion

In an attempt to reduce the rate at which the mounds erode, five different chemical stabilizers were applied to newly erected and seeded ridges. Results of these trials indicate that the stabilizers influence erosion rates, and also the germination and survival of plants. Chemical stabilizers tested included Coherex (a resinous adhesive), Orzan A (ammonium lignosulphonate), Rezosol, DCA-70 (elastomeric polymers), and a catonic neoprene emulsion. After 28 weeks, seedling survival counts showed that almost 40% more seedlings grew on the Coherex-treated plots than on the control. In comparison, the catonic neoprene emulsion treatment supported only 50% as many seedlings as the control plot; Orzan A, 70%; and Rezosol and DCA-70, 90%. Thus, Coherex appears to aid seedling establishment and survival in saline waste.

Effect of heavy metal salts on germination

The presence of copper sulphides in tailings was not as deleterious as originally supposed. Additional plant growth tests were made in tailings—containing 0.07% and 0.2%

copper—indicated that copper content in the sulphide form was not a significant factor. To ascertain if soluble metal salts are toxic, copper, nickel, zinc, and composite salts of these elements were added to test plots and tomato seeds were planted. Tomato was used because it is a relatively quick-growing plant that is sensitive to heavy metal phytotoxicants. These tests showed that 1,000 ppm copper had little effect, and that nickel concentrations above 100 ppm, and zinc concentrations above 10 ppm were toxic. When using a composite of these elements, toxic effects became evident at 10 ppm and became pronounced at about 100 ppm. The effect achieved with the low concentrations tested indicates toxicity to be independent of osmotic pressure.

Interactions of fertilizers and heavy metal minerals

Contradictory results were derived from initial tests when nitrogen, phosphorus, and potassium fertilizers were added to test plots of copper flotation tailings from different mills. Addition of fertilizers enhanced germination and growth on some tailings, but had the opposite effect on other tailings. These opposing effects were deemed to depend principally on two factors: First, if salt-containing tailings produced an appreciable osmotic concentration when watered, the fertilizer appeared to increase this concentration with deleterious effect on the plants. Second, if components of the heavy-metal-containing minerals were easily solubilized by the ammonia in the fertilizer, the metal ions hindered plant growth.

Preliminary tests on several types of mineral wastes indicated that adding 45 lb per acre of urea and calcium treble superphosphate provided sufficient fertilizer to stimulate growth of most plants.

Modification of tailing pH

Basic and acidic tailings, conditions adverse for plant growth, can be neutralized by adding lime or limestone and sulphuric acid, respectively, but problems arise if the amount required is appreciable. Impervious crusts are sometimes formed if the neutralizing agent interacts with the acidic or basic causative agent. The use of a fine water spray, previously described, provides another technique that may be effective for eliminating excess acidity.

Tailing samples from various locations would not support vegetation without neutralization. Among these were uranium tailings from Wyoming and Colorado which had pH values of 2.3 to 4.5. Additions of 70 and 6.7 lb of lime, respectively, to the top 2 in. of tailings per acre—raised the pH sufficiently to sustain plant life. Vitro Minerals & Chemical Co. of Salt Lake City, Utah, had both acidic uranium tailings (pH 3.5) and basic vanadium tailings (pH 8.5). These were mixed in equal portions to produce a material of pH 6.3 in which seeds readily germinated. Fertilization, however, was necessary to sustain adequate plant growth.

Combination chemical-vegetative stabilization

This is perhaps the most innovative study conducted by the Bureau of Mines. The use of suitable chemicals to stabilize surfaces of mill tailings and encourage growth has several advantages. Sandblasting of the plants is minimized. Moisture is retained in the tailings. Germination is promoted and wilting is minimized by creating a dark heat-absorbing surface. Plant food may be added.

Several chemicals that effectively stabilize tailings were evaluated as to beneficial effect when used with vegetation. A series of tests was made in which ranger alfalfa, crested wheat, yellow sweet clover, rabbit brush, sagebrush, and Marglobe tomatoes were planted in leached and unleached tailings which had been treated with several chemical soil stabilizers. The group planted in leached tailings included a control and four plots treated with Coherex (a resinous adhesive), Peneprime (a bituminous base product), and Soil Gard and Compound SP-400 (elastomeric polymers). The group planted in unleached tailings included a control and two plots treated with Coherex and Soil Gard. Coherex and Soil Gard stimulated germination and sustained plant growth; Peneprime and SP-400 hindered germination under the conditions tested. On leached tailings, the effects of Coherex and Soil Gard were nearly the same; on unleached tailings, Coherex performed better than Soil Gard. The respective germination and survival rates were as follows, in percent:

Tailings	Coherex		Soil Gard	
	Germination	Survival	Germination	Survival
Leached	64.1	61.0	54.7	52.6
Unleached	30.5	16.0	14.5	5.6

Subsequent tests have corroborated the preliminary results, which showed that resinous compounds produce the best overall plant growth and surface stability. Several types of elastometric polymers also proved effective.

The combination system ultimately developed was applied to a 10-acre plot of Kennecott's McGill, Nev., tailings in mid-September of 1967. The McGill tailings are located in a climatically harsh site for vegetation. The growing season is short, the temperature range is wide, and precipitation is only 8.4 in. per year. Different proportions of wheatgrasses and various tree seeds were mixed and planted by drill seeder at a rate of about 35 seeds per sq ft. Prilled urea and superphosphate fertilizers were added to the seeding mixture at a rate of about 45 lb per acre each of P_2O_5 and nitrogen. The mixture was planted in furrows 10 in. apart. A week after, Coherex diluted with 4 parts water was applied over the entire area at rates of 0.18 to 0.66 gal of dilute solution per sq yd.

A germination count of the plants was made one month after seeding. This count showed that 24, 12, and 52% of the legumes, grasses, and winter wheat, respectively, had germinated. The seedling plants were vigorous and healthy, up to 5 in. tall. One week later, a killing frost destroyed most of the legumes, which were still in the cotyledon (earliest leaf) stage.

Another survey of the seeded area, in May and September 1968, proved that the primary objective was attained—the area was stabilized against wind erosion and native plant species were encroaching onto the stabilized plots. The Siberian pea tree was the only one of the 11 species originally planted that either did not germinate or failed to survive to the September 1968 survey. Eleven wild species had encroached and were growing.[9]

An accounting was kept of material and application costs associated with treatment of the 10-acre plot. The Coherex was applied in quantities ranging from 0.18 to 0.66 gal per sq yd. During a year of observation, no appreciable differences were noted in the stabilization of plots treated with the different amounts of Coherex. Table 1 presents the costs based on application of 0.18 gal Coherex per sq yd. The estimated cost of $1,355 for the 10 acres could probably be reduced if larger acreages were treated or if proper equipment were available.

Table 1—Cost of stabilization procedure per 10 acres

Item		Cost
Seeds	37 seeds per square foot	$ 56
Calcium treble superphosphate	45 pounds P_2O_5 per acre	51
Prilled urea	45 pounds N per acre	62
Coherex:		
At 20 cents per gallon	0.18 gallon per square yard[1]	348
Freight at 8 cents per gallon		140
Labor, at $3 per hour	3 men for 3 days	216
Equipment expense:[2]		
Seeder and grader		100
Water truck		382
Total		$1,355

[1] Coherex solution diluted with 4 parts by volume.
[2] Equipment costs estimated.

Though no irrigation was applied to the plot during the 3 years since planting, growth was deemed excellent for the conditions. As of May 1970, the plot accommodated approximately 25 different plant species, all growing well, 15 of which were encroaching native species.

Eight different nitrogen, phosphate, and potash fertilization regimes plus limestone amendments were applied to different parts of the vegetated area in October 1968. Each plot was evaluated as to fertilizer effect in the spring of 1969 and the entire area was refertilized with 25 lb per acre each of nitrogen and phosphorus and 12.5 lb potash. In May 1970, the plots were again evaluated. These showed the following ratings for the initially fertilized plots:

Rating*	Fertilizer, pounds per acre
1	18-N, 18K (urea plus potash)
2	18-N, 18-P (treble superphosphate (TSP) plus urea)
3	18-N (ammonium sulphate)
4	18-N (urea)
5	18-N, 124-$CaCO_3$ (urea plus limestone)
6	18-N, 18-P (ammonium sulphate plus TSP)
7	Control (nothing added)
8	18-P (treble superphosphate)
9	2.5-N, 6.3-P, 1.8-K (Megamp)†

* Best plot to worst plot by increasing number.
† Commercial magnesium, ammonium phosphate fertilizer, best fed to root system.

The plots were again refertilized May 1970 using nine different regimes. These will be evaluated in the spring of 1971.

Stabilizations in other areas

The success of the combined chemical-vegetative stabilization procedure at McGill, Nev., prompted testing of that method in other localities with differing environments. Tailing ponds in areas representative of markedly varying climatic conditions and with differing mineral bases were planted using different modifications suited to the areas.

One acre of the beach area of the White Pine Copper Co. tailing at White Pine, Mich., was vegetatively and chemically stabilized in September 1969, in cooperation with the company. The test plot was planted with seeds of six different grasses, three legumes, and an oat grain. Calcium treble superphosphate, ammonium nitrate, and potassium chloride were applied as fertilization. After planting, Coherex was applied to prevent blowing of the sand and to eliminate cutting or burying of the plants. A germination count made by the company 6 weeks after planting showed a germination rate of 20%. The White Pine Copper Co. has planted much more extensive acreages in July of 1970 and the growth has been deemed encouraging.

Approximately 2 acres of a lead-zinc tailings pond at Flat River, Mo., was stabilized in a similar fashion in September 1969, in cooperation with the St. Joe Lead Co. The plot was inspected in March of this year and the plants were enjoying healthy, vigorous growth. A flock of about 400 geese were feeding on the plants and had been doing so for over 3 weeks, as this was the most succulent feed in the area.

An acre of lead-zinc tailings pond at Page, Idaho, belonging to American Smelting and Refining Co., was also cooperatively stabilized by the basic vegetative-chemical procedure in September 1969. An inspection of the area in June 1970 showed that most of the fall germination plants had died during the winter and early spring. Plant growth is now spotty and only 2 to 6 in. high. The reason for the death of the plants, whether by winter kill, heavy metal toxicity, lack of water, or whatever, is yet to be determined.

Initiation of plant growth on Interpace Co. halloysite clay tailings from Mica, Wash., has been difficult to obtain in laboratory tests because the material indurates upon drying and prevents proper air, water, and soil relationships. Tests to overcome this difficulty were made and Interpace Co. was supplied with the results; in the late fall of 1969, the wastes at Mica were prepared and planted. A 10-acre plot of the area was covered with 5 to 12 in. of overburden from the mining operations, and 500 lb per acre of gypsum was disked into the surface. The area was fertilized with 18, 60, and 30 lb per acre, respectively, of N_2, P_2O_5, and K_2O. Rice hulls were spread over the surface and the area was planted with hard fescue, bluegrass, and crested wheatgrass. Another acre adjacent to the 10-acre plot was fertilized with N_2, P_2O_5, and K_2O at 34, 144, and 42 lb per acre, respectively, and then planted. The plant seeds used included eight varieties of grasses, four legumes, and three grains. Portions of the two areas were stabilized with Coherex.

Inspection of the Interpace property in June 1970 showed remarkable plant growth on the areas. The grains were about 3 ft high and full seed heads had developed. The crested wheatgrass was about 2 ft tall with seed heads developing. Short grasses were growing exceptionally well, and although the legumes were sparse, the growth was healthy.

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