Abandoned coal waste reclamation in Montana

by Martha Jeanne Gitt

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University

Abstract:
Coal refuse waste piles are a legacy of prelaw coal. mining activities. These barren, steeply-sloped piles have adverse physical and chemical properties which preclude vegetation establishment. The state of Montana has many coal refuse disposal sites, and the Abandoned Mine Lands Program is faced with successfully reclaiming these areas.

Experimental plots to test the effects of lime rate and coversoil application on coal refuse were implemented at an abandoned coal mine near Stockett, Montana. The coal refuse at this site was black (2.5 Y 2/0), acidic (pH=2.8), had an average coarse fragment content of 85 percent by weight and low water holding capacity. The Computerized Automatic Rapid Weathering Apparatus (CARWA) was used to estimate the lime required to neutralize present and potential acidity of the coal refuse. A heavy lime rate (five fold CARWA) was included as a treatment. Deep lime incorporation (100 cm) was also tested. Calcium carbonate ($CaCO3$) and calcium oxide (CaO) were tested as liming agents. Coversoil was applied at rates of 15 and . 30 cm. Response to treatment was monitored over a two year period. Soil and spoil temperature and water content were also monitored.

The CARWA lime rates of both liming agents neutralized the coal refuse pH for the surface 0 to 10 cm depth in all treatments. Increasing the lime rate five times the CARWA recommendation often resulted in significant increase in coal refuse pH, yet the vegetation was adversely affected. Vegetation response was significantly lower on the 5 fold CARWA lime treatment than other limed treatments, possibly due to high salt concentrations from over-liming. All treatments had significantly greater plant response than the control, which had no plant growth by the second season. Vegetation response was greatest on coversoiled treatments. Increasing coversoil application from 15 to 30 cm did not significantly increase plant performance.

Maximum root penetration depth in coal waste was near the depth of lime incorporation in all treatments. Root penetration was deepest in the deep lime (100 cm) and 30 cm coversoil treatments. Root distribution was neither confined nor concentrated in coversoil. Root proliferation in limed coal waste was similar to that present in overlying coversoil.

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APPROVAL

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Martha Jeanne Gitt

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

March 9, 1987 — Date

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Date March 9, 1987

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ABSTRACT

Coal refuse waste piles are a legacy of prelaw coal mining activities. These barren, steeply-sloped piles have adverse physical and chemical properties which preclude vegetation establishment. The state of Montana has many coal refuse disposal sites, and the Abandoned Mine Lands Program is faced with successfully reclaiming these areas.

Experimental plots to test the effects of lime rate and coversoil application on coal refuse were implemented at an abandoned coal mine near Stockett, Montana. The coal refuse at this site was black (2.5 Y 2/0), acidic (pH=2.8), had an average coarse fragment content of 85 percent by weight and low water holding capacity. The Computerized Automatic Rapid Weathering Apparatus (CARWA) was used to estimate the lime required to neutralize present and potential acidity of the coal refuse. A heavy lime rate (five fold CARWA) was included as a treatment. Deep lime incorporation (100 cm) was also tested. Calcium carbonate ($CaCO_3$) and calcium oxide (CaO) were tested as liming agents. Coversoil was applied at rates of 15 and 30 cm. Response to treatment was monitored over a two year period. Soil and spoil temperature and water content were also monitored.

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Maximum root penetration depth in coal waste was near the depth of lime incorporation in all treatments. Root penetration was deepest in the deep lime (100 cm) and 30 cm coversoil treatments. Root distribution was neither confined nor concentrated in coversoil. Root proliferation in limed coal waste was similar to that present in overlying coversoil.

INTRODUCTION

The federal coal mining law, Public Law 95-87 provides funding at the state level for the reclamation of land affected by abandoned mining operations. The coal waste disposal sites scattered through the coal mining regions are major reclamation challenges faced by the state of Montana. Barren steeply sloped coal waste piles are a pollution hazard to the acreage they occupy and degrade surrounding water systems. The Abandoned Mines Lands Program of Montana, directed by the Department of State Lands has inventoried the coal waste sites across the state at 1,620 hectares (4,000 acres) of land disturbed, and has begun reclamation on many sites.

Reclaiming abandoned coal waste poses a number of problems. These sites must be stabilized and revegetated without significantly increasing the land disturbance. Site reclamation should be self maintaining and permanent. Adverse physical and chemical characteristics of the coal waste must be ameliorated in the plant rooting zone to allow vegetation establishment and permanent cover.

Most coal wastes are acid generating due to pyrite oxidation from exposure to atmospheric oxygen. The total lime requirement must be determined to insure permanent neutralization of acid yielding wastes. Lime recommendations which do not account for long term acid production may result in waste reacidification and revegetation failure. Overliming is expensive and can cause salt and fertility problems, reducing revegetation success.

Supply of adequate coversoil, shown to be vital to vegetation establishment on coal waste is often limiting (Hoving et al. 1984 and Jastrow et al. 1981b). Unlike current mining activities, no coversoil was salvaged prior to disturbance.

Montana's Abandoned Mine Lands Program has been actively reclaiming coal waste disposal sites in the Sand Coulee and Stockett area since the Spring of 1985. One of the larger coal waste sites was set aside for the purpose of reclamation research. The objectives of this study were:

1) to field test the total lime requirement determination of the Computerized Automatic Rapid Weathering Apparatus (CARWA);
2) to compare the effects of agricultural lime ($CaCO_3$) and cement plant kiln dust (CaO) as liming agents;
3) to compare the effects of 0, 15 and 30 cm of coversoil on vegetation performance;
4) to characterize root distribution in amended coal refuse;
5) to monitor water availability and surface temperature as influenced by coversoil and vegetation establishment.

LITERATURE REVIEW

Before mined land reclamation laws were enacted, the coal mining industry disposed of its mining and preparation wastes according to economics and proximity to the operation. This quick and easy disposal method generated coal waste heaps on the landscape throughout the coal mining areas of the United States. At the time of disposal, there was little knowledge of or concern for the environmental consequences of such practices, and land area was not limiting. Out of equilibrium with the environment, coal wastes usually generate acid from pyrite oxidation and leach high levels of salts into the surrounding surface and ground water systems (Zellmer et al. 1978 and 1979). Chemical, physical and topographical features of coal refuse piles preclude vegetation establishment, resulting in material instability and erosion. Without reclamation it may take hundreds to thousands of years for the coal refuse to equilibrate with the environment, with constant degradation in the process.

Prior to the passage of Public Law 95-87 in 1977, there were no federal laws regulating coal refuse disposal. By the time federal or state legislation intervened there were approximately 70,800 hectares of abandoned, unreclaimed coal refuse throughout the United States (Johnson and Miller 1979). These sites have no real land use or economic value and can become pubic health hazards in addition to their environmental hazard. An abandoned site, by definition is not the responsibility of any single mine company and therefore is left to the state to reclaim (Jastrow et al. 1981b). Reclamation of coal refuse piles across the United States is an expensive proposition due to the large area affected, magnitude of the environmental degradation and cost of reclamation. Research on amending and reclaiming the refuse has been undertaken in many coal mining states, and some progress has been made.

Coal Refuse Reclamation

Coal refuse has a multitude of characteristics which preclude vegetation invasion (Jastrow et al. 1981, Jastrow et al. 1984 and Michalovic and Fisher 1984). Coal waste is comprised principally of waste coal intermixed with black shale and other rock fragments. Dominated by coal, the material is black and very high in coarse fragments. The high coarse fragment content causes low water holding capacity and nutrient deficiency (Jastrow et al. 1981b). Coal waste piles are typically steep-sloped, with the unconsolidated material continually eroding and moving downslope. This instability removes any vegetation attempting to establish in the refuse.

The chemical properties of coal waste are often toxic or inhibitory to plant establishment. Iron pyrite (FeS_2), a reduced form of sulfur, is often associated with coal deposition. Crystalline pyrite (framboidal) will readily react with oxygen and water to produce acidity. Acid generation by pyrite oxidation is common to all mining where weatherable pyrite is brought to the surface. This complex chemical reaction is catalyzed by iron oxidizing bacteria of the genera Thiobacillus and Ferrobacillus and is summarized below.

$$2FeS_2 + 7O_2 + 2H_2O \Rightarrow 2Fe^{++} + 4SO_4^{=} + 4H^{+}$$

There are also high levels of organic sulfur compounds in coal refuse which may be contributing to acid production. Acid production causes a drastic drop in pH, recorded as low as 1.3 (Miller and Cameron 1978) with values of 2.0 to 3.0 common. Iron, aluminum, manganese and other metals become soluble at these pH values (Bohn et al. 1979). Many of these metals are highly toxic to plant and aquatic life. In the form of soluble salts, these compounds further inhibit plant establishment. Without plant establishment, leaching occurs at a faster rate through the pyritic coal waste materials (Mele and Prodan 1983). As water runs off or leaches through the refuse, toxic salts enter the surface and ground water aquifers.

Amending and Reclaiming Coal Refuse

Although some coal refuse is returned underground, most must be reclaimed at the surface. Reclaiming coal waste entails neutralizing the produced and potential acidity, impeding pyrite oxidation, and ameliorating the physical properties restricting plant growth. Establishment and maintenance of self-sustaining plant populations is key to long-term reclamation of coal refuse (Jastrow et al. 1984).

Liming agents have long been utilized to raise soil and spoil pH. Determining the amount of lime required to neutralize the potential and produced acidity from pyrite oxidation of surface spoils has met with difficulty (Michalovic and Fisher 1984). Traditional methods of lime requirement determination on agricultural soils via buffer tests do not account for the large potential acidity of acid mine spoils, and generally underestimate the lime requirement (Jastrow et al. 1981a). Acid-base accounting (Smith et al. 1974) often overestimates acid production. This method determines total pyritic sulfur for acid production, when much of the pyrite may be in massive form. Massive pyrite is relatively unreactive due to its low surface area, and will contribute little to acid production. Acid production from the organic sulfur compounds in coal waste is uncertain, and their presence result in difficult interpretations of acid-base account data (Dollhopf 1984).

Soil-lime incubation was used by Jastrow et al. (1981b) to determine liming rates for the Staunton 1 project in Illinois. Lime was mixed at various rates with the coal waste and pH was monitored until it stabilized for several days. Problems can occur in choosing test rates and the time involved in waiting for equilibrium.

Simulated weathering in humidity cells has been used to determine acid production (Caruccio 1968, Sobek et al. 1978, Russell and Dollhopf 1984, Harvey and Dollhopf 1985). Laboratory weathering generates acid production curves for each spoil sample and by mathematical extrapolation predicts long-term acid production and lime requirement. Previous laboratory weathering involved six to twelve weeks for results. Harvey and Dollhopf (1985) automated the process, receiving weathering results in 24 hours. The Computerized Automatic Rapid Weathering Apparatus (CARWA) determines the long-term acid production from weathering and generates a lime requirement.

Solubility and particle size of liming agents are extremely important in terms of short and long term neutralization potential. The solubility of a liming agent is influenced by the amount of surface area in contact with the spoil solution. Meyer and Volk (1952) found ground limestone should be less than 0.25 mm in diameter (60 mesh) for optimum dissolution.

Coversoiling

Reducing water stress, especially at the surface of a coal refuse pile is essential for plant establishment. High thermal insulation at the surface of the black refuse and low water holding capacity of the coarse material creates an adverse environment for plant establishment. Application of coversoil over neutralized coal waste provides a more suitable medium for plant growth. Surface temperature is reduced and native soil has a much higher water holding capacity than coal refuse.

The Argonne National Laboratory research project at the Staunton 1 site, near Staunton, Illinois was designed to evaluate coversoil depth, lime application and plant species response (Jastrow et al. 1984). Rates of coversoil were 0, 15, 30, and 60 cm. After two years the 0 cm plots failed to establish sufficient vegetation to control erosion even with lime application, fertilization and seeding. It was deemed necessary to apply 15 cm of coversoil to these plots for vegetation establishment. In four years, two of which were drought years, there was approximately 75 percent cover on the 15 and 30 cm plots and 90 percent cover on the 60 cm plots. The study concluded that coversoil was important for adequate rooting depth to maintain a diverse plant community, particularly when moisture was limiting. The main factor affecting plant establishment was rooting depth.

Layering coversoil over coal waste improves water holding capacity at the surface but may cause subsurface water deficiencies. Less moisture was found in the coal waste overlain by coversoil than in the same depth of coal waste without coversoil application. Water moves much slower through a layered soil where fine materials overlay coarse materials. Water is held longer in the topsoil due to decreased movement into the coarser coal refuse (Mueller and Vance 1981). Mixing coal waste and coversoil at the interface, and then placing a layer of soil above has been proposed to increase water movement into coal waste (Jastrow et al. 1984).

Covering coal refuse with a layer of soil physically limits the accessibility of oxygen to the pyritic material. Soil and vegetation cover reduce water and atmospheric oxygen contact with the pyritic refuse, retarding or eliminating the production of acid (Hoving and Hood 1984).

Coal refuse reclamation activities throughout the United States have exhibited plant germination and signs of revegetation. Questions of cost effective coversoil depth, appropriate lime requirement determination, species selection and long-term success still remain. Regional climate, coversoil resource, public opinion and money allocated will help dictate how the vast acreages of these materials are reclaimed.

MATERIALS AND METHODS

Site Description

The Sand Coulee and Stockett areas, 20 miles southeast of Great Falls, Montana had extensive, underground coal mining from the late 1800's until the 1940's. No active coal mining has occurred in the area since 1947 when the Giffen Mine closed. Coal waste piles were scattered throughout the area and ranged from a few square meters to many hectares. The Giffen site, with 300,000 cubic meters of coal waste covering 9 hectares (Anderson 1985) was set aside by the Abandoned Mine Lands Program for reclamation research. The site was located on both sides of Number Five Coulee Road, three miles southeast Stockett (Figure 1).

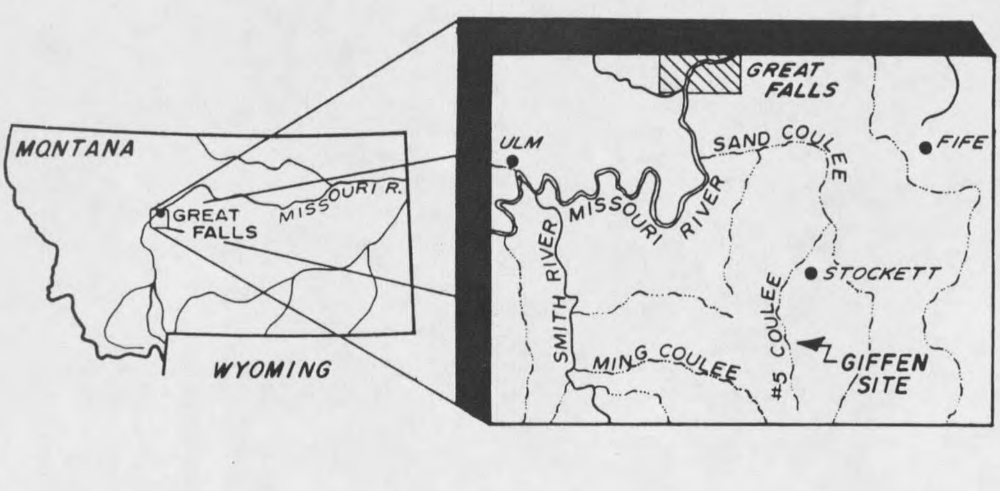


Figure 1. Location of the Giffen site, Stockett, Montana.

Field Plot Design

In April, 1985 much of the coal refuse pile southeast of Number Five Coulee Road was regraded resulting in a gently sloping area (7% W) for the test plots. The field plot design was randomized complete block in three replications. Plots 7.75 m on a side were staked with a three meter alley between replications. One plot was split to accommodate all treatments in the restricted regraded area. Areas designated for coversoiling were excavated to keep all plot treatments on the same plane once soil layers were applied.

Based on lime and coversoil application rates, seven treatments were implemented at the Giffen site. Table 1 describes the treatments applied and Figure 2 demonstrates the field plot design.

Table 1. Treatments applied at the Giffen site.

Plot	Treatment
1	Control
2	CaCO3, CARWA rate, 0-35 cm
3	CaO, five fold CARWA rate, 0-35 cm
4	CaO, CARWA rate, 0-35 cm
5	CaO, CARWA rate, 0-100 cm
6	CaO, CARWA rate, 0-35 cm, 15 cm coversoil
7	CaO, CARWA rate, 0-35 cm, 30 cm coversoil

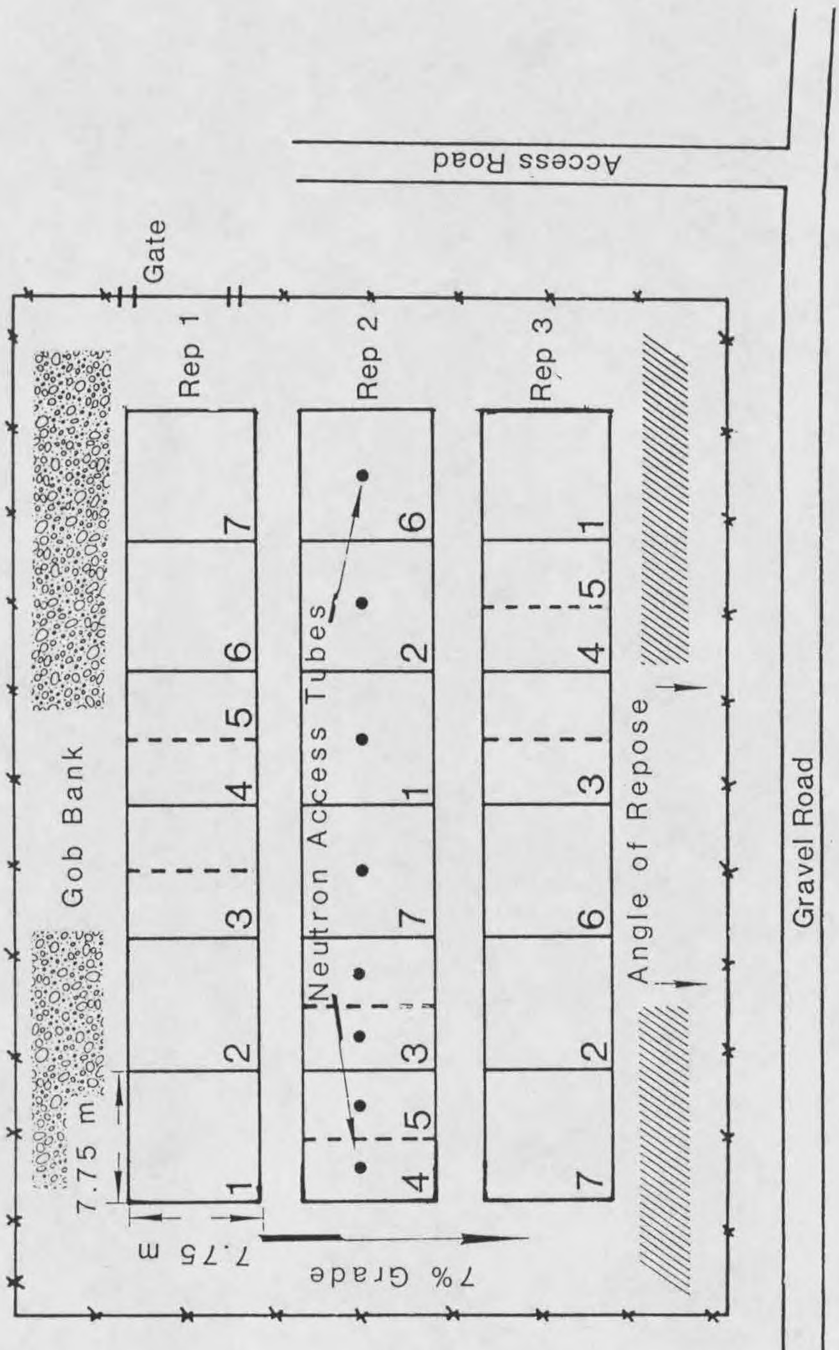


Figure 2. Field plot design implemented at the Giffen site.

Lime Requirement Determination

The Computerized Automatic Rapid Weathering Apparatus (CARWA) as described by Harvey and Dollhopf (1986) was employed to determine lime requirements on 18 coal waste samples selected from the center of each plot. The 18 bulk samples were mechanically flailed with a Hewitt soil grinder to disaggregate the coal waste into soil sized particles (less than 2 mm in diameter). Two hundred gram samples of prepared coal waste were placed in weathering chambers after bacteria inoculation, and were subjected to six weathering cycles (Harvey and Dollhopf 1986). Spoil solutions were extracted after each cycle and the titratable acidity was determined. Titratable acidity for the 200 gram sample was converted to pure calcium carbonate equivalence required to neutralize a spoil profile depth of 15 cm. Utilizing the logarithmic extrapolation of acid production over weathering cycles, calcium carbonate required to neutralize acid production was summated for a 30 year period for each coal waste sample. A sample from each plot of the center replication was sent to Energy Laboratories of Billings, Montana for acid-base account (Smith et al. 1974) for comparison to CARWA recommendations.

The CARWA lime recommendations between samples varied notably due to the non-uniform nature of the coal waste material. Sample variability in coal waste materials was noted by Kracpac et al. (1983). The largest 30 year lime rate was chosen to assure complete acid neutralization throughout the site. The CARWA and heavy lime rate were adjusted for lime agent purity, incorporation efficiency and depth of incorporation.

Liming Agents

Two liming agents were tested at the Giffen site. Agricultural lime ($CaCO_3$) is a common neutralization agent for acidic materials, and is mined and processed for sale. The solubility of calcium carbonate is low; o.0014 g/100 cm3 in cold water (pH=5.5) (Weast et al. 1981). The limestone utilized at the Giffen site was determined 90 percent pure calcium carbonate equivalent by the titration method (AOAC 1975). The particle sizes of the ground limestone were all less than 0.42 mm, with 55 percent of the material less than 0.25 mm (50 mesh).

Kiln dust, a waste product of the cement manufacturing industry, consists primarily of calcium oxide (CaO). Presently, kiln dust can be purchased very cheaply, often for shipment costs. The solubility of CaO is much higher than $CaCO_3$ at 0.131 g/100 cm^3 in cold water (pH=5.5) (Weast et al. 1981). Cement kiln dust from Trident, Montana was determined 85 percent pure calcium carbonate equivalent by titration (AOAC 1975). Over 99 percent of the kiln dust

(CaO) was 0.25 mm in size or less (50 mesh). The increased reactivity, significantly lower costs and utilization of an industrial waste product, make the usage of cement kiln dust for acid material reclamation very attractive.

Field Plot Implementation

During the first week of May, 1985, the plots were limed, topsoiled and seeded (Figure 2). Liming agents were weighed and hand applied to all plots (excluding the control) to insure proper amounts and distributions. Each lime rate was increased 25 percent to compensate for lack of incorporation efficiency. A ditch witch was used to obtain the 100 cm depth necessary for the deep lime incorporation treatment. A chisel plow was used to incorporate the lime to a depth of 35 cm on the other limed plots. Soil from a nearby source was stripped and used for coversoil on two treatments. One treatment received 15 cm of loamy A horizon material containing less than 20 percent coarse fragments. Another treatment consisted of 15 cm of loamy B horizon material overlain by 15 cm of the A horizon, totalling 30 cm of coversoil.

All plots were seeded with 11 species chosen for acid and drought tolerance (Table 2). Equal amounts of each species were seeded at 3.27 kg PLS/ha, with a total rate of 36 kg PLS/ha.

Table 2. Plant species seeded at the Giffen site.

Species	Seeds/m^2
Grasses	
Agropyron dasystachyum	28
Agropyron intermedium	14
Agropyron riparian	24
Agropyron smithii	19
Agropyron spicatum	17
Festuca ovina	84
Oryzopsis hymenoides	28
Poa compressa	370
Forbs	
Astragulus cicer	21
Linum lewisii	44
Lotus corniculatus	62

All plots were fertilized with 54 kg/ha N and 36 kg/ha P_2O_5. A topdressing of Jacklin organic hydromulch was applied. A rain gauge was used to estimate precipitation at the site during the two field seasons.

Plot Irrigation

Due to the lack of precipitation in the area during the Spring of 1985, it was deemed necessary to irrigate the site for seedling emergence. On May 22, 1985, 13 mm of water from a local stockpond was applied to the site with an anticipated depth of penetration of 67 mm.

Minesoil Chemical Analysis

A bulk sample of coal refuse collected from numerous points across the experimental site was sent to Energy Laboratories for chemical analysis. Table 3 describes the parameters analyzed and the methods used.

Minesoil Physical Analysis

Core samples were collected in each plot of the center replication. Samples from one core in each plot were used for particle size analysis. A second set of cores were collected for water holding capacity estimation, determined with a pressure plate apparatus.

Core sample increments destined for particle size analysis were prepared by mechanical flailing. All samples were air dried and prepared with a soil flailer. The flailing process entails the placement of coal refuse in a chamber where spinning beater bars disaggregate the sample and produce a less than 2 mm fraction as well as rock fragments ($\geq$2 mm diameter). The hydrometer method (Day 1965) was used on the less than 2 mm diameter fraction. Hydrometer readings were taken at various time intervals over an eight hour period. Soil textural classes were determined using percent sand (<2-0.05 mm), silt (<0.05-0.002 mm) and clay

Table 3. Methods of chemical analysis of coal refuse from the Giffen site.

Parameter	Procedure	Reference
pH	Electrode in water saturated paste	McLean (1973) p. 77-95.
Electrical Conductivity	Water saturated paste extract	Sandoval and Power (1982) p. 22-24.
Cation Exchange Capacity	Sodium acetate saturation	Rhoades (1982) p.154.
Exchangeable Ca, Mg, Na, K	Ammonium acetate extraction	Thomas (1982) p. 160.
Exchangeable Sodium Percentage	Exchangeable sodium / CEC	U.S. Salinity Lab Staff (1954) p. 155.
Base Saturation	Exchangeable bases / CEC	U.S.D.A. (1984) p. 31.
Extractable Aluminum	Ammonium Acetate (pH=5.5)	Barnhisel and Bertsh (1982) p. 275-300.
Trace Metals, Total (Ag, As, Cd, Fe, Pb, Mn, Zn)	Nitric acid-hydrogen peroxide digestion	E.P.A. method 3050.
Selenium	Same as Metals	E.P.A. method 3050.
Boron	Hot water extractable	Bingham (1982) p. 443-444.
Molybdenum	Acid Ammonium oxalate method	Reisenauer (1965) p. 1056-1057.
Anions (Cl, SO_4, NO_3, CO_3, HCO_3)	Saturated paste extraction	Rand (1976) p. 253-257.
Phosphorus	Bray Method	Olsen (1982) p. 416-418.
Organic Carbon	Dichromate oxidation	Nelson and Sommers (1982) p. 570-571.
Total Carbon	Dry combustion	Nelson and Sommers (1982) p. 545-549.

(<0.002 mm) particle sizes. Clay mineralogy was determined on the clay sized fraction by x-ray diffraction.

Core sample material collected for plant available water estimation were prepared with a mortar and pestle. Materials less than 4.75 mm diameter (passing the # 4 sieve) were saturated overnight, and then were subjected to 0.1 and 15 bars of pressure on a pressure plate apparatus (Hillel 1980) until no more water was collected. The samples were immediately weighed, oven dried at 105 degrees C and then re-weighed to determine water content on a dry weight basis.

Small coarse fragments (2 mm - 4.75 mm) were included in the pressure plate analysis due to the coarse nature of coal waste, and the effect of sample pretreatment on soil moisture retention (Elrick and Tanner 1955). Hanson and Blevins (1979) found that water held in coarse fragments plays an important role in water availability of materials high in coarse fragments.

The water content held at 0.1 bars suction approximates the amount of water held against gravity in a coarse textured material. The water content at 15 bars suction approximates the lower limit of soil moisture available to plants, called permanent wilting percentage (Hillel 1980). The difference between gravimetric and permanent wilting (0.1 minus 15 bar water in coal waste) approximates plant available water.

No reliable value for bulk density was determined. Attempts to determine bulk density resulted in a wide range of numbers, which were not reproducible. All water measurements were therefore on a gravimetric basis.

Minesoil pH Measurement

Core samples were collected in the Fall of 1985, Spring of 1986, and Fall of 1986 for pH analysis. Three core samples were taken in each plot making a total of 63 cores. Each core was incremented in the field to obtain three samples in the zone of lime incorporation, and one below. Depth increments in the coversoil and 100 cm lime treatment differ from the other treatments to compensate for the depth of lime incorporation and coversoil application. Table 4 contains the depth increments for each plot used for pH analysis.

Table 4. Profile core depth increments (cm) of coal refuse used for pH analysis at the Giffen site.

Treatment						
Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO[1] 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO[2] 9.0 mt/ha to 35 cm, 30 cm coversoil
0-10	0-10	0-10	0-10	0-30	0-10	0-10
10-20	10-20	10-20	10-20	30-60	10-20	10-20
20-35	20-35	20-35	20-35	60-100	20-35	20-35
35-50	35-50	35-50	35-50	100-115	35-50	35-50

1 - 15 cm overlying coversoil was incremented at 0-10 cm and 10-15 cm for pH analysis.
2 - 30 cm overlying coversoil was incremented at 0-15, 15-25 and 25-30 cm for pH analysis.

Minesoil core materials were mechanically flailed for pH analysis as described for physical analysis. The fraction less than 2 mm was collected and placed in cups. Distilled, deionized water was added until the soil and spoil materials were saturated. The pastes were extracted the following day and pH was measured with a glass electrode (McLean 1973). An Orion research ionalyzer, model 801 digital pH meter was used to record pH to the nearest hundredth of a unit.

Vegetation Monitoring

Seedling density was recorded on June 13, 1985. The emerged vegetation was subdivided into four plant categories; seeded grass, seeded forb, non-seeded forb and non-seeded shrub. Non-seeded shrubs volunteered from the applied coversoil. Seedling counts of each plant category within 20 X 50 cm frame were recorded along a north-south diagonal. Data from 35 frames at 20 cm intervals were collected in each plot.

Plant canopy cover and production were measured on July 24, 1985. Two transects were established in each plot. The transects were equidistant from the edges of the plot and each other. A one meter buffer zone was established on all plot edges where no sampling occurred. Percent cover was recorded in fourteen 20 x 50 cm frames along one transect (Daubemire 1959). The frames were separated by 20 cm intervals. Vegetation readings were grouped into the four plant categories. Production was determined by clipping above ground biomass within 50 x 50 cm frames. All frames were clipped on the same side of the second transect. Five frames were clipped per transect, with a 20 cm interval between each frame. Vegetation was clipped by plant category. The plant materials were oven dried for 72 hours at 60 degrees C before weighing.

The second year plant data collection was similar to the first years collection. Percent canopy cover was recorded in the same locations as the first year. Production frames were clipped on the alternate side of the second transect, in areas undisturbed by the first years sample collection. All non-seeded, volunteering shrubs died by the second season, and measurable non-seeded grasses (annuals) were recorded on many plots. Second year plant classes became; seeded grass, seeded forb, non-seeded forb and non-seeded grass.

Statistical Analysis of Vegetation Data

Plant categories designed to accommodate vegetation volunteering from coversoil and vegetation response to treatment resulted in data sets with distributions skewed to the right. Data transformations were necessary before these data could be analyzed statistically for analysis of variance. The logarithmic transformation of log(x + 1.01) was used on all vegetation data before statistical summarization. Use of the logarithmic transformation changes data skewed to the right (Poisson distribution) to normal distributions. Once these data were summarized statistically, they transformed back without significant data alteration (LaClerg et al. 1962).

Root Abundance Study

On September 27, 1986, data were collected to determine maximum rooting depth and relative root abundance in each treatment. A pit was dug in every plot where vegetation was well established to expose the root profile. Pits were intentionally located near healthy, vigorous plants on all treatments.

After maximum rooting depth was determined, visual observations of root abundance were made at the depths used for pH analysis (Table 4). The nature of the coal refuse and time limitations made reliable root counting difficult. Root observations were recorded as few, some, common, and many. This technique was a modified version of one described by the Soil Survey Staff (1975). Numerical values of 1 to 4 were assigned to the classifications of few, some, common, and many to permit analysis of variance on the observations (Table 5).

Table 5. Root abundance by number and size, per dm^2.

Class	Number Assigned	Very fine (<1 mm)	Fine (1-2 mm)	Medium (>2-5 mm)	Coarse (>5-10 mm)
Few	1	< 10	< 10	< 1	< 1
Some	2	10-50	10-50	1-5	1-3
Common	3	> 50-100	> 50-100	> 5-10	> 3-5
Many	4	> 100	> 100	> 10	> 5

Field Minesoil Water Measurements

Field moisture was monitored with a Type A Troxler neutron moisture probe, americium-beryllium source, model 1255. Aluminum access tubes slightly larger in diameter than the 5 cm probe were inserted to the 200 cm depth in holes resulting from available water sample collection. Water was monitored by neutron probe in materials surrounding those on which plant available water was estimated to relate plant available water to actual water held in the coal waste. Readings were taken at 15 cm depth intervals to 90 cm, then 30 cm intervals down to the 180 cm depth. Nine depth increments were measured for each tube.

The moisture probe was calibrated by relating count ratios to water contents of soil cores. Shallow pits were dug and 0, 12, 20 and 40 liters (0, 3, 5 and 10 gallons) of water were applied. Water immediately infiltrated into the coal waste due to its coarse nature. Soil cores were cut and core samples were collected. Access tubes were inserted in each test hole and neutron probe readings were taken at the core increment depths.

The samples were placed in air tight bags and returned to the lab. Spoil material weight was determined before and after oven drying at 105 degrees C for 48 hours, and gravimetric moisture was determined on a dry weight basis. Gravimetric moisture was correlated to the neutron probe count ratios by linear regression. The correlation coefficient was $r = 0.67$, which indicated a moderate correlation between gravimetric moisture and count ratio. The calibration equation was $y = 18.81x - 12.27$. This relationship was used to convert neutron probe count ratios to gravimetric water content for each measurement throughout the growing season.

The neutron probe could not accurately measure profile water in the 0 to 22.5 cm zone due to loss of neutrons out through the soil surface. All water measurements in the surface increment were extremely low due to reduced slow neutron count used to determine water content. For all treatments except the 30 cm coversoil treatment, the 22.5 to 37.5 cm zone was the shallowest recorded increment. Extremely low water contents were also recorded at the 22.5 to 37.5 cm zone in the plot with the 30 cm of coversoil. These data had to be discarded. It was suspected that large voids were present at the coversoil/spoil interface immediately adjacent to the neutron probe access tube. Such voids would contribute to the loss of neutrons, thereby causing low water content readings.

Temperature Monitoring

Thermocouple psychrometers were placed at 1, 10, 25 and 50 cm in six plots. Temperatures were measured with an Omega Type T digital meter thermocouple thermometer during the two field seasons. A Barnes Instatherm infra-red thermometer, model 14-220-4 was used to measure surface temperature. Readings were taken by aiming at the center of each plot, which enabled over 50 percent of the plot to be monitored. Temperature readings were taken at approximately 2:00 PM each time, when surface temperatures were the highest.

Statistical Analysis

Analysis of variance was performed on all data sets for data summarization and comparison. Least significant difference coefficients were assigned to each mean with 95 percent confidence. Sample size was reported with every data summary. The ANOVA components are reported in Appendix B.

RESULTS AND DISCUSSION

Lime Requirement Determination

The 30 year CARWA lime recommendations on the 18 weathered coal waste samples from the Giffen site ranged 0.16 to 2.64 mt/ha for a 15 cm profile. To assure neutralization across the site, the 2.64 rate was used for calculating lime necessary for each plot. After adjusting the lime rate of 2.64 mt/ha for lime agent purity, incorporation efficiency and depth of incorporation, a total lime requirement for each treatment was determined (Table 6).

Table 6. Lime rates applied at the Giffen site.

Plot	Treatment
1	Control
2	$CaCO_3$, 8.6 mt/ha[1] to 35 cm
3	CaO, 45.8 mt/ha to 35 cm
4	CaO, 9.0 mt/ha to 35 cm
5	CaO, 25.7 mt/ha to 100 cm
6	CaO, 9.0 mt/ha to 35 cm, 15 cm coversoil
7	CaO, 9.0 mt/ha to 35 cm, 30 cm coversoil

[1] 1 mt/ha equals 0.446 U.S. tons/acre.

Acid-Base Account

A bulk coal waste sample was taken from each plot of the center replication for acid-base account analysis.

Subsamples were sent to Energy Laboratories of Billings for acid-base account analysis (ABA). A CARWA lime recommendation was determined on the remainder of each sample for comparison. Results of sulfur fractionation, ABA and CARWA are presented in Table 7.

Table 7. Sulfur fractionation, acid-base account and CARWA liming recommendations.

	Plots					
	1	2	3	4	5	6
Total Sulfur (%)	0.90	0.73	0.67	0.77	0.90	0.61
Sulfate Sulfur (%)	0.13	0.01	0.01	0.01	0.07	0.01
Pyritic Sulfur (%)	0.04	0.14	0.04	0.09	0.12	0.07
Organic Sulfur (%)	0.73	0.59	0.63	0.68	0.71	0.53
Neutralization[1] Potential (ppt)	0.50	1.00	1.33	0.50	0.50	0.50
Acid-base Account[1]	21.47	20.27	18.78	21.28	23.24	16.54
CARWA Lime Rate[1]	1.84	0.35	0.21	0.29	0.81	0.39

[1] - mt $CaCO_3$/ha required to neutralize a 15 cm depth.

Acid-base account data ranged from 16.5 to 23.2 mt $CaCO_3$/ha for a 15 cm depth of coal waste. The corresponding CARWA recommendations ranged from 0.21 to 1.84 mt $CaCO_3$/ha for a 15 cm coal waste depth. Acid-base account recommendations were 1 to 2 orders of magnitude higher than CARWA.

Sulfur fractionation shows organic sulfur as the major component (80 to 90 percent) of the total sulfur in the coal waste sample. Frederick et al. (1957) studied decomposition of organic sulfur compounds in soils and found that 13 of the 21 organic sulfur species studied did not measurably decompose over the 20 week study period. Due to its organic nature, coal refuse predictably has more organic sulfur compounds than mineral soils. Organic sulfur compounds which do not readily decompose to form acids will not have much influence on the acid production of these materials. The large discrepancy between ABA and CARWA recommendations is at least partially due to the reactivity of the dominant sulfur compounds.

Coal Waste Chemical Analysis

The dominant chemical characteristics of the coal refuse from the Giffen site were the high organic carbon content and high iron and sulfate contents (Table 8). The coal waste was 20.3 percent organic carbon and 26.8 percent total carbon. High levels of iron (3,660 ug/g) and sulfate (2,660 ug/g) were evidence of pyrite and its oxidation product, sulfate. Sulfate production may also result from the oxidation of some organic sulfides.

The cation exchange capacity was 12.4 meq/100 g, well within the 3-15 meq/100 g range typical of kaolinitic clay (Hillel, 1980). Base saturation was 39 percent, and was predominately due to the exchangeable calcium level of 4.32 meq/100 g. The base saturation of 39 was low and was due to the high concentration of hydrogen ions in the coal refuse (Donahue et al. 1977). The extract pH was 2.8. The EC was 3.59 mmhos/cm, near saline (U.S. Salinity Staff 1954) due to

Table 8. Results of the chemical analysis of coal refuse from the Giffen site.

Parameter	Chemical Analysis
pH	2.80
Electrical Conductivity (EC)	3.59 mmhos/cm
Cation Exchange Capacity (CEC)	12.40 meq/100 g
Exchangeable Calcium	4.32 meq/100 g
Exchangeable Magnesium	0.23 meq/100 g
Exchangeable Sodium	0.01 meq/100 g
Exchangeable Potassium	0.26 meq/100 g
Base Saturation Percentage	39.0 %
Exchangeable Sodium Percentage	< 0.01 %
Extractable Aluminum	33.2 ug/g soil
Total Silver	28.2 ug/g soil
Total Arsenic	1.4 ug/g soil
Total Cadmium	0.18 ug/g soil
Total Iron	3660 ug/g soil
Total Lead	78.0 ug/g soil
Total Manganese	4.0 ug/g soil
Total Zinc	7.7 ug/g soil
Selenium	<0.1 ug/g soil
Boron	0.4 ug/g soil
Molybdenum	0.18 ug/g soil
Chlorine	4.16 mg/l
Sulfate	2660 mg/l
Nitrate	0.33 mg/l
Carbonate	0.0 mg/l
Bicarbonate	0.0 mg/l
Phosphorus	4.83 ppm
Organic Carbon	20.3 %
Total Carbon	26.8 %

elevated sulfate. Exchangeable sodium percentage was low (<0.01 percent).

The fertility of coal waste was low. The phosphorus (4.83 ppm), potassium (0.26 meq/100 g) and nitrate (0.33 mg/l) levels were very low (Donahue et al. 1977). All anion levels were low except sulfate. Boron (0.4 ppm), molybdenum (0.18 ppm) and selenium (<0.1) levels were not restrictive to plant growth. All trace metals analyzed were below suspect phytotoxic levels except silver and aluminum (Reclamation Research Unit 1986). The coal refuse was enriched in total silver (28 ug/g) which was potentially phytotoxic. Background levels of total silver in soils throughout the United States seldom exceed 0.5 ug/g (Connor and Shaklette 1975). Kabata-Pendias and Pendias (1984) reported 2.0 ug/g total silver as phytotoxic. No other studies on phytotoxic silver levels in soils were found. Due to the lack of literature and difficulty in relating phytotoxic soil levels from one material to another, the phytotoxic silver concentration in coal refuse is uncertain.

The extractable aluminum in the coal refuse may also be toxic to the plants seeded at the Giffen site. This extractable aluminum level (33.2 ug/g soil) was lower than low levels recorded in natural, highly weathered soils in Hawaii (Ayres et al. 1965), yet may influence the growth of Montana range plants. Aluminum toxicity is dependant on plant tolerance to aluminum and the pH of the soil. Increasing the pH of the coal refuse with lime application will reduce or eliminate the potential for aluminum toxicity (Barnhisel and Bertsch 1982).

Coal Waste Physical Characteristics

Coarse fragment content by weight of the coal refuse at the Giffen site ranged from 75 to 95 percent with a mean of

85 percent, estimated from 10 bulk samples. Coversoil coarse fragment contents of four bulk samples ranged from 10 to 20 percent, and averaged 15 percent. The Munsell color of coal refuse was black (2.5 Y 2/0), and the color of the coversoil was dark yellowish brown (10 YR 4/4).

Gravimetric plant available water ranged from 0.8 to 15.8 percent in the coal refuse, with an average of 4.8 percent (Table 9). Plant available water ratings ranged from very low to high in the refuse, and averaged low (7.2 cm H_2O/150 cm profile). This large range implies high variability in the water holding capacity of the materials.

The textural class of coal refuse was loamy sand to sandy loam. The coarse texture of the material and high coarse fragment content resulted in rapid water drainage and low water holding capacity. Clay mineralogy by x-ray diffraction estimated the clay sized particles (<0.002 mm) to be 95 percent kaolinite and 5 percent quartz. Minesoils dominated by kaolinite clay minerals do not hold much water compared to other clay types due to its non-expanding nature and relatively small specific surface area for a clay particle (Hillel, 1980). Water content of coal waste available to plants was determined to be low based on pressure plate analysis, particle size analysis and clay mineralogy.

Plant available water in the coversoil ranged from 9.8 to 12.7 percent and averaged 11.3 percent (Table 9). Water

Table 9. Physical analysis of spoil profiles at the Giffen site.

Treatment	Increment Depth (cm)	Gravimetric Water Content (%) AT 1/10 bar	AT 15 bar	Plant Available (1/10-15 bar)	Cm Water/ 150 cm soil	Plant Available water Rating [1]	Particle Size Distribution (%) Sand	Silt	Clay	Texture Class
CONTROL	0-22.5	10.7[2]	10.8	---	---	---	73	23	4	Loamy Sand
	22.5-37.5	13.1	7.8	5.3	8.0	low	78	16	6	Sandy Loam
	37.5-52.5	12.3	8.8	3.5	5.2	very low	76	15	9	Sandy Loam
	52.5-105	9.8	7.3	2.5	3.8	very low	76	10	14	Sandy Loam
	105-195	20.9	5.1	15.8	23.7	high	75	20	5	Sandy Loam
$CaCO_3$, 8.6 mt/ha to 35 cm	0-22.5	13.7	8.1	5.6	8.4	low	78	13	9	Sandy Loam
	22.5-37.5	14.1	7.4	6.7	10.0	low	82	14	4	Loamy Sand
	37.5-52.5	10.4	8.2	2.2	3.3	very low	87	6	7	Loamy Sand
	52.5-105	11.1	6.4	4.7	7.0	low	75	13	12	Sandy Loam
	105-195	16.1	6.1	10.0	15.0	medium	78	14	8	Sandy Loam
CaO, 45.8 mt/ha to 35 cm	0-22.5	17.0	9.5	7.5	11.2	low	73	17	10	Sandy Loam
	22.5-37.5	9.9	6.7	3.2	4.8	very low	82	14	6	Loamy Sand
	37.5-52.5	10.2	8.7	1.5	2.3	very low	89	7	4	Loamy Sand
	52.5-105	8.2	6.1	2.1	3.2	very low	82	10	8	Sandy Loam
	105-195	18.9	7.4	11.5	17.2	medium	79	13	8	Sandy Loam
CaO, 9.0 mt/ha to 35 cm	0-22.5	11.5	9.2	2.3	3.5	very low	75	15	10	Sandy Loam
	22.5-37.5	10.1	9.3	0.8	1.2	very low	82	11	7	Loamy Sand
	37.5-52.5	19.3	13.5	5.8	8.7	low	82	11	7	Loamy Sand
	52.5-105	10.9	7.9	3.0	4.5	very low	78	12	10	Sandy Loam
	105-195	10.3	8.2	2.1	3.2	very low	76	13	11	Sandy Loam
CaO, 25.7 mt/ha to 100 cm	0-22.5	11.8	8.3	3.5	5.2	very low	75	15	10	Sandy Loam
	22.5-37.5	14.1	8.7	5.4	8.1	low	82	11	7	Loamy Sand
	37.5-52.5	13.5	9.4	4.1	6.2	very low	82	11	7	Loamy Sand
	52.5-105	13.5	7.2	6.3	9.4	low	78	12	10	Sandy Loam
	105-195	15.2	8.0	7.2	10.8	low	76	13	11	Sandy Loam
CaO, 9.0 mt/ha 15 cm coversoil	0-15.0[3]	20.5	10.7	9.8	14.7	medium	48	33	19	Loam
	15.0-37.5	9.7	6.4	3.3	5.0	very low	80	13	7	Loamy Sand
	37.5-52.5	9.1	6.7	2.4	3.6	very low	81	10	9	Sandy Loam
	52.5-105	10.1	6.2	3.9	5.8	very low	72	16	12	Sandy Loam
	105-195	9.9	5.0	4.9	7.4	low	72	18	10	Sandy Loam
CaO, 9.0 mt/ha to 35 cm 30 cm coversoil	0-30.0[3]	26.0	13.3	12.74	19.0	high	33	39	28	Loam
	30.0-37.5	15.7	7.1	8.6	12.9	low	61	23	12	Sandy Loam
	37.5-52.5	9.0	6.2	2.8	4.2	very low	71	17	12	Sandy Loam
	52.5-105	12.8	8.0	4.8	7.2	low	69	16	15	Sandy Loam
	105-195	12.4	4.7	4.7	7.1	low	79	13	8	Loamy Sand

[1] WATER RATING SYSTEM (Montagne et al. 1982)

Rating	cm H_2O/150 cm Soil
very low	7
low	7-13
medium	13-18
high	18-25
very high	25

[2] All gravimetric water contents reported are a mean of 3 values.

[3] Coversoil.

ratings ranged from medium to high, and averaged medium. Textural class was loam for both samples. Medium-textured soils (loams) can hold large amounts of available water (Donahue et al. 1977). Based on plant available water holding capacity, particle size analysis and coarse fragment content, the coversoil should hold substantially more water than the coal waste.

Minesoil pH Monitoring

The pH of the coversoil ranged from 7.0 to 7.69 (Tables 10,11,12). All lime applications resulted in significantly increasing the pH of the coal refuse compared to the control in the 0 to 10 cm depth increment, and in the 0 to 30 cm depth increment in the CaO incorporated treatment to 100 cm. The pH of the 0 to 10 cm increment remained above or near neutral through the Fall of 1986 in all limed plots.

Although statistical tests of significance indicated differences existed between limed plots for the 0 to 10 cm depth increment, methods of deep incorporation, lime product type ($CaCO_3$ and CaO), and the five fold lime rate all produced effective neutralization of coal waste acidity in this depth increment. The pH ranged from 6.48 to 7.65. This trend was present for all three sampling dates during 1985 and 1986.

Table 10. Fall, 1985 pH measurements for each treatment at the Giffen site.

Profile Depth (cm)	Treatment: Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO[1] 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
A							7.22
A						7.13	7.58
A						7.24	7.69
B 0-10	3.20[2] Aa[3]	7.65 Cc	7.58 Cc	7.17 CBc	6.69 Bc	7.21 CBc	7.39 CBc
B 10-20	3.35 Aa	5.02 ABb	5.23 Bb	4.62 ABb	4.87 ABb	5.57 Bb	5.31 Bb
B 20-35	2.93 Aa	2.90 Aa	3.83 Ba	2.98 Aa	3.81 Bab	2.96 Aa	2.92 Aa
B 35-50	2.83 Aa	2.89 Aa	3.34 Ba	2.99 ABa	2.88 Aa	2.84 Aa	3.16 ABa

A - Coversoil, 15 cm treatment incremented 0-10, 10-15 cm, 30 cm treatment incremented 0-15, 15-25, 25-30 cm.
B - Coal waste
1 - Depth increments in this treatment were 0-30, 30-60, 60-100 and 100-115 cm.
2 - Mean of 9 samples.
3 - Means followed by the same uppercase letter in the same row indicate no significant difference in spoil pH (P=0.05).
- Means followed by the same lowercase letter in the same column indicate no significant difference in spoil pH (P=0.05).

Table 11. Spring, 1986 pH measurements for each treatment at the Giffen site.

Profile Depth (cm)	Treatment: Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO[1] 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
A							7.23
A						7.00	7.42
A						6.93	7.39
B 0-10	3.00[2] Aa[3]	7.31 Cc	7.38 Cc	7.05 CBc	6.99 CBc	6.48 Bc	7.06 CBc
B 10-20	2.81 Aa	4.63 Bb	6.13 Cb	3.63 Abb	4.91 CBb	3.99 ABb	3.73 ABb
B 20-35	2.84 Aa	3.21 ABa	3.75 Ba	3.01 ABa	5.00 Cb	3.03 ABab	3.54 ABab
B 35-50	3.24 ABa	3.51 ABa	3.98 Ba	3.09 Aba	3.23 ABa	2.77 Aa	2.87 Aa

A - Coversoil, 15 cm treatment incremented 0-10, 10-15 cm, 30 cm treatment incremented 0-15 , 15-25, 25-30 cm.
B - Coal waste
1 - Depth increments in this treatment were 0-30, 30-60, 60-100 and 100-115 cm.
2 - Mean of 9 samples.
3 - Means followed by the same uppercase letter in the same row indicate no significant difference in spoil pH (P=0.05).
- Means followed by the same lowercase letter in the same column indicate no significant difference in spoil pH (P=0.05).

Statistical tests of significance indicated pH differences existed between treatments for the 10 to 20 cm depth increment of limed coal waste (30 to 60 cm in the 100 cm incorporation treatment) during the three sampling dates (Tables 10,11,12). Two years after lime application (Table 12) the pH of the 10 to 20 cm zone ranged from 4.13 to 6.98. Except for the 9.1 mt/ha CaO treatment incorporated to the

Table 12. Fall, 1986 pH measurements for each treatment at the Giffen site.

		Treatment					
Profile Depth (cm)	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO[1] 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
A							7.36
A						7.23	7.51
A						7.14	7.46
B 0-10	2.77[2] Aa[3]	7.59 Dc	7.43 CDc	7.29 BCDc	6.93 Bc	7.04 CBc	7.49 Dc
B 10-20	2.78 Aa	5.27 Bb	4.72 Bb	4.13 ABb	4.72 Bb	4.83 Bb	6.98 Cc
B 20-35	2.82 Aa	3.02 Aa	3.53 BCa	3.22 ABa	3.74 Ca	3.56 BCa	3.92 Cb
B 35-50	2.96 Aa	2.80 Aa	3.39 BCa	3.14 ABCa	3.54 Ca	3.12 ABCa	3.09 ABa

A - Coversoil, 15 cm treatment incremented 0-10, 10-15 cm, 30 cm treatment incremented 0-15, 15-25, 25-30 cm.
B - Coal waste
1 - Depth increments in this treatment were 0-30, 30-60, 60-100 and 100-115 cm.
2 - Mean of 9 samples.
3 - Means followed by the same uppercase letter in the same row indicate no significant difference in spoil pH (P=0.05).
- Means followed by the same lowercase letter in the same column indicate no significant difference in spoil pH (P=0.05).

35 cm depth, all lime treatments had a significantly higher pH compared to the control. However, the pH of the 10 to 20 cm zone was significantly lower compared to the 0 to 10 cm coal waste increment, except for the plots that received 30 cm coversoil. This result demonstrates that standard tillage equipment set to the 35 cm depth was not effective in mixing lime into the 10 to 20 cm zone since coal waste pH remained well below pH 7.

Statistical tests of significance indicated differences existed between treatments for the 20 to 35 cm depth increment of limed coal waste during the three sampling dates (Tables 10,11,12). Two years after lime application (Table 12) the pH of the 20 to 35 cm coal waste zone (60 to 100 cm in the 100 cm incorporation treatment) ranged from 3.02 to 3.92. Except for the 9.1 mt/ha CaO treatment incorporated to the 35 cm depth and the 8.6 mt/ha $CaCO_3$ treatment incorporated to the 35 cm depth, all lime treatments had significantly higher pH compared to the control. However, the pH of the 20 to 35 cm zone was significantly lower compared to the 0 to 10 cm and 10 to 20 cm limed coal waste increments. This result demonstrates that standard tillage equipment set to the 35 cm depth was not effective in mixing lime into the 20 to 35 cm zone since coal waste pH was well below 7. During field plot preparation, a chisel plow with duck feet shoes and chisels on 30 cm centers was used to incorporate lime into the coal waste. A minimum of three passes over each plot with the tool bar set at the 35 cm depth was performed. This practice was not effective in mixing lime into the 10 to 35 cm zone to enable neutralization of coal waste.

Two years after lime application, the zones below the depth of lime incorporation for both the five fold CaO treatment incorporated to 35 cm (35 to 50 cm) and for the CaO treatment incorporated to 100 cm (100 to 115 cm) had significantly higher pH levels compared to the control (Table 12). Although these two liming techniques enabled some lime to penetrate deeper into the coal waste profile, the resulting pH levels (3.39 and 3.54) were still well below a pH of 7 and would limit plant performance.

The five fold CaO treatment to the 35 cm depth was the only treatment that resulted in consistently higher pH values compared to the control in all depth increments of lime incorporation (and below). Apparently over liming with

45.8 mt/ha increased the opportunity for lime penetration into the 10 to 50 cm zone.

The distribution of pH values with depth are illustrated by Figures 3 through 8. Shaded areas indicate the zone of intended lime incorporation. The differences in pH trends between sampling dates for the control (Figure 3) imply the amount of pH variability due to sampling and laboratory analysis error. Coal waste pH was found to have an inherent variability of 0.5 pH unit over short distances. Except for the treatment that received 30 cm of coversoil (Figure 9), the range of pH values within a treatment, across the three sampling dates for each date was small, generally less than 1.0 pH unit. In Figure 9, the Spring, 1986 pH value of 3.73 and Fall, 1986 value of 6.98 for the 10 to 20 cm depth increment implies error in sample collection at this depth. Proper sample core incrementation was sometimes difficult due to the unconsolidated nature of coal waste, and contamination from lower increments was possible.

No reacidification trends were measured in these test plots. Although no reacidification was present after two years, continued sampling would be necessary to confirm whether applied lime was sufficient for permanent reclamation.

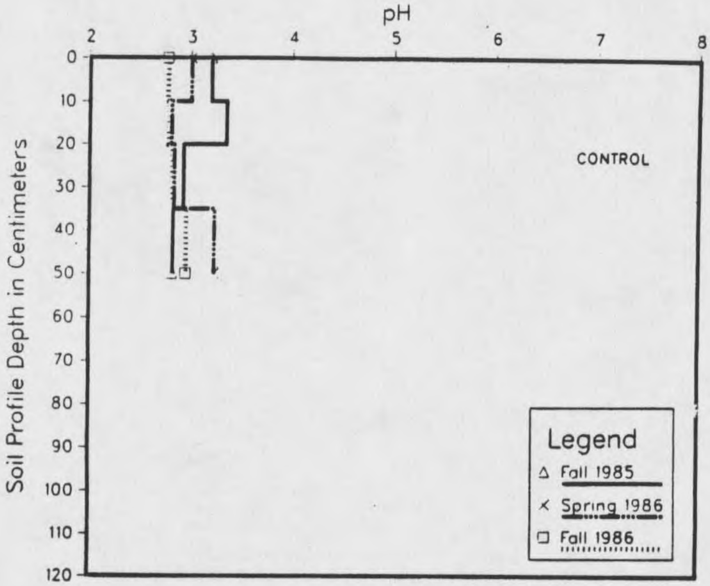


Figure 3. Minesoil pH with depth in the control.

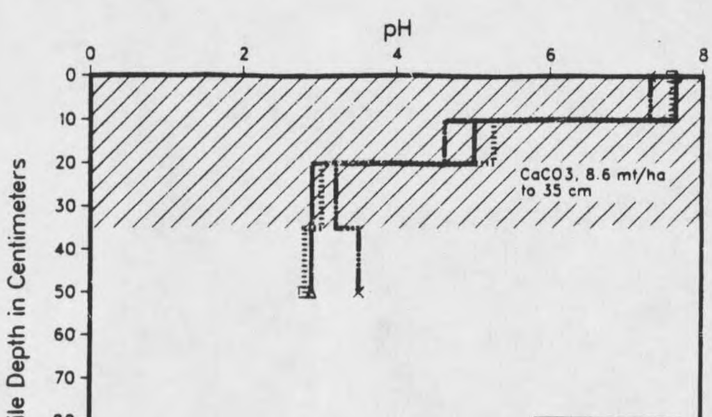


Figure 4. Minesoil pH with depth in the $CaCO_3$ treatment incorporated to 35 cm.

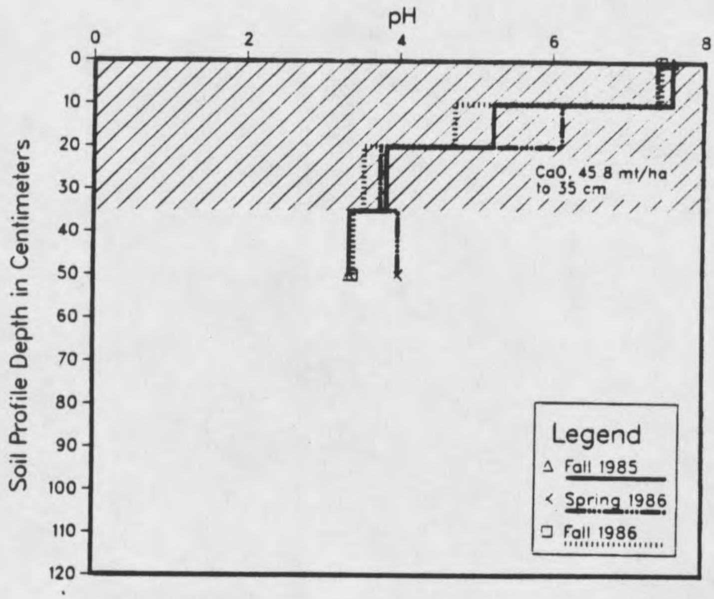


Figure 5. Minesoil pH value with depth in the five fold CaO treatment incorporated to 35 cm.

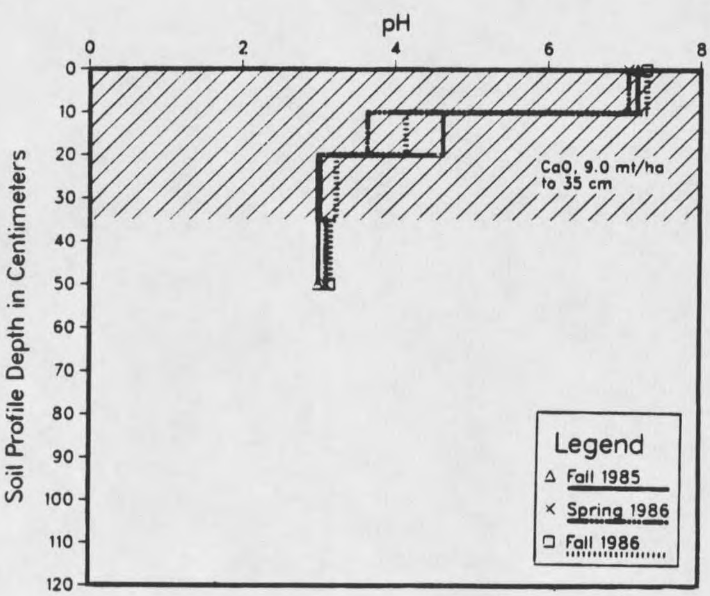


Figure 6. Minesoil pH with depth in the CaO treatment incorporated to 35 cm.

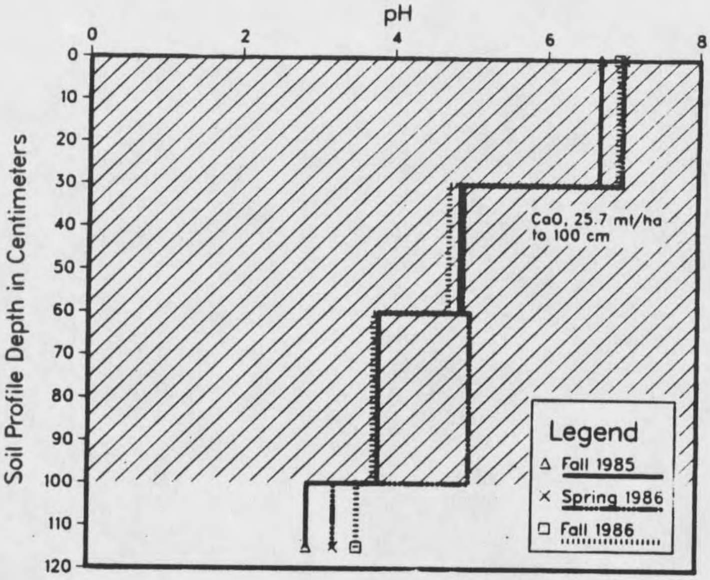


Figure 7. Minesoil pH with depth in the CaO treatment incorporated to 100 cm.

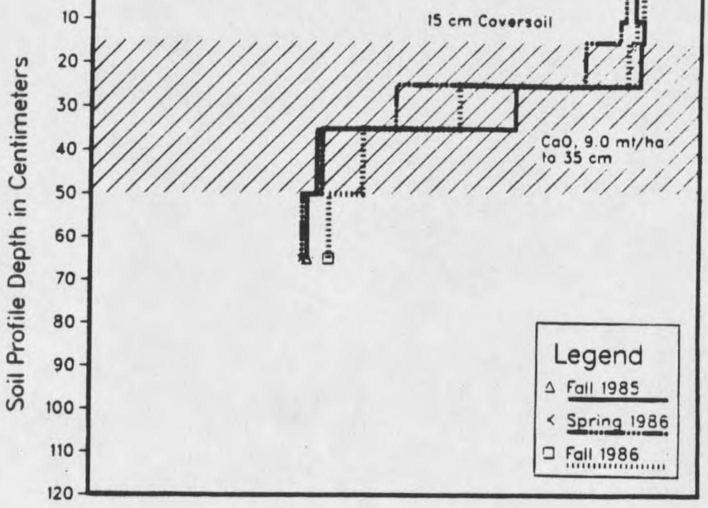


Figure 8. Minesoil pH with depth in the CaO treatment incorporated to 35 cm, 15 cm coversoil.

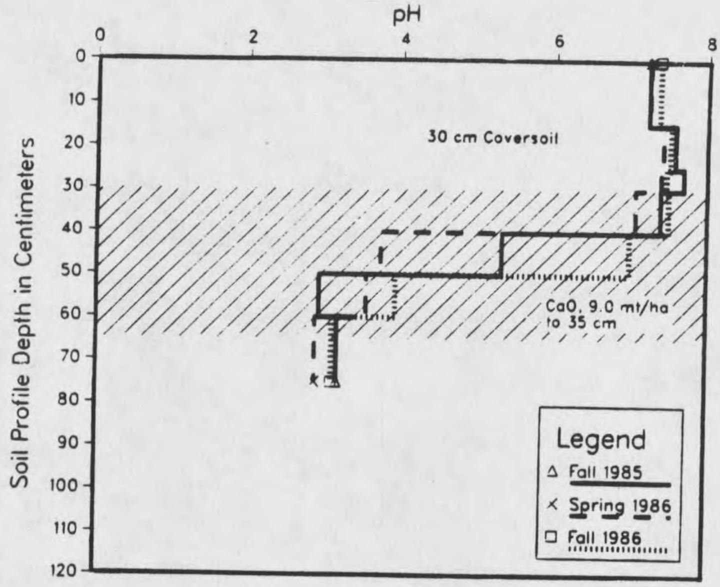


Figure 9. Minesoil pH with depth in the CaO treatment incorporated to 35 cm, 30 cm coversoil.

Vegetation Response

Seedling Density

All plots exhibited emerging seedling density. Seeded grasses had significantly greater seedling density compared to seeded forbs, non-seeded forbs and non-seeded shrubs in all treatments. Seeded forbs had significantly greater seedling density compared to non-seeded forbs and non-seeded shrubs (Table 13).

The 30 cm coversoil treatment had significantly greater density of seeded grasses and total vegetation compared to

Table 13. Seedling density ($plants/m^2$) at the Giffen site.

Plant Class	Treatment						
	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
S Grass	0.6[1] Ab[2]	3.9 Db	1.5 Bb	2.6 Cb	2.2 CBb	15.8 Ec	13.9 Ec
S Forb	0.0 Aa	0.0 Aa	0.0 Aa	0.2 Aa	0.7 Aa	0.9 Ba	1.4 Cab
NS Forb	0.0 Aa	0.2 Aa	0.0 Aa	0.0 Aa	0.0 Aa	2.2 Bb	2.4 Bb
NS Shrub	0.0 Aa	0.0 Aa	0.0 Aa	0.0 Aa	0.0 Aa	1.0 Ba	0.7 Ba
Total	0.6 A	4.1 A	1.5 AB	2.8 B	2.9 B	19.9 C	18.4 C

1 - Mean of 42 samples.
2 - Means followed by the same uppercase letter in the same row indicate no significant difference in plant response to treatment (P=0.05).
- Means followed by the same lowercase letter in the same column indicate no significant difference in plant response within a treatment (P=0.05).
S - Seeded.
NS- Non-seeded.

all other treatments. The 15 cm coversoil treatment had significantly greater density of seeded grasses and total vegetation compared to all treatments not receiving coversoil. The CaO treatment incorporated to the 100 cm coal waste depth was the only amended treatment where total seedling density was not significantly different compared to the control.

Non-seeded shrubs emerged from the direct-haul coversoil on the two coversoil treatments, which increased total vegetation density. Coversoil also provided a more suitable germination medium for seeded grasses, seeded forbs and non-seeded forbs, resulting in greater potential for successful vegetation establishment on amended coal refuse. These results for seedling density by plant category are graphically presented in Figure 10.

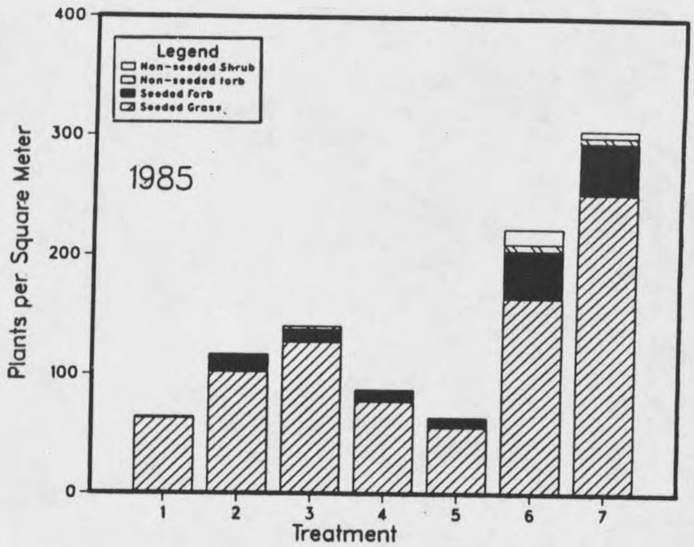


Figure 10. Seedling density by plant category at the Giffen site for the Control (1), $CaCO_3$ to 35 cm (2), five fold CaO to 35 cm (3), CaO to 35 cm (4), CaO to 100 cm (5), CaO to 35 cm with 15 cm coversoil (6) and CaO to 35 cm with 30 cm coversoil (7).

Canopy Cover

Percent canopy cover of seeded grasses was significantly greater compared to all other plant categories on all treatments. Percent canopy cover of seeded grasses and total vegetation was significantly greater on coversoil treatments compared to treatments not receiving coversoil (Table 14). In 1985, the 30 cm coversoil treatment did not have significantly greater percent canopy cover of seeded grasses and total vegetation compared to the 15 cm coversoil treatment. All limed treatments had significantly greater seeded grass canopy cover compared to the control. Total vegetation canopy cover was not significantly different on

Table 14. Percent cover at the Giffen site, 1985.

Plant Class	Treatment						
	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
S Grass	0.6[1] Ab[2]	3.9 Db	1.5 Bb	2.6 Cb	2.2 CBb	15.8 Ec	13.9 Ec
S Forb	0.0 Aa	0.0 Aa	0.0 Aa	0.2 Aa	0.7 Aa	0.9 Ba	1.4 Cab
NS Forb	0.0 Aa	0.2 Aa	0.0 Aa	0.0 Aa	0.0 Aa	2.2 Bb	2.4 Bb
NS Shrub	0.0 Aa	0.0 Aa	0.0 Aa	0.0 Aa	0.0 Aa	1.0 Ba	0.7 Ba
Total	0.6 A	4.1 A	1.5 AB	2.8 B	2.9 B	19.9 D	18.4 D

1 - Mean of 42 samples.
2 - Means followed by the same uppercase letter in the same row indicate no significant difference in plant response to treatment (P=0.05).
- Means followed by the same lowercase letter in the same column indicate no significant difference in plant response within a treatment (P=0.05).
S - Seeded.
NS- Non-seeded.

the $CaCO_3$ treatment incorporated to 35 cm and the five fold CaO treatment incorporated to 35 cm compared to the control.

Second year (1986) percent canopy cover further defined vegetation response to treatment. All vegetation in the control was dead by the second growing season (Table 15). None of the non-seeded shrubs from coversoil propagules survived into the second growing season. Non-seeded grasses were found in all amended treatments, and these replaced the non-seeded shrub plant category. Plant canopy cover was dominated by seeded grasses in all amended treatments.

Coversoil treatments had significantly greater canopy cover for all plant categories compared to treatments not receiving coversoil. Canopy cover of seeded grasses and total vegetation were not significantly different between the 15 and 30 cm coversoil treatments. Total percent canopy cover on the five fold CaO treatment incorporated to the 35 cm depth was significantly lower compared to all other treatments in 1986. Figure 11 illustrates canopy cover response to treatment by plant category for 1986.

Table 15. Percent cover at the Giffen site, 1986.

Plant Class	Treatment						
	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
S Grass	0.0[1] Aa[2]	10.8 Cb	4.7 Bb	8.0 Cb	10.3 Cb	35.7 Db	40.7 Dc
S Forb	0.0 Aa	0.0 Aa	0.1 Aa	0.1 Aa	0.1 Aa	1.5 Ba	2.2 Cb
NS Forb	0.0 Aa	0.1 Aa	0.2 Aa	0.1 Aa	0.1 Aa	1.3 Ba	1.2 Ba
NS Grass	0.0 Aa	0.1 Aa	0.1 Aa	0.2 Aa	0.1 Aa	1.5 Ba	1.3 Ba
Total	0.0 A	11.0 C	5.1 B	8.4 C	10.6 C	40.0 D	45.4 D

1 - Mean of 42 samples.
2 - Means followed by the same uppercase letter in the same row indicate no significant difference in plant response to treatment (P=0.05).
- Means followed by the same lowercase letter in the same column indicate no significant difference in plant response within a treatment (P=0.05).
S - Seeded.
NS- Non-seeded.

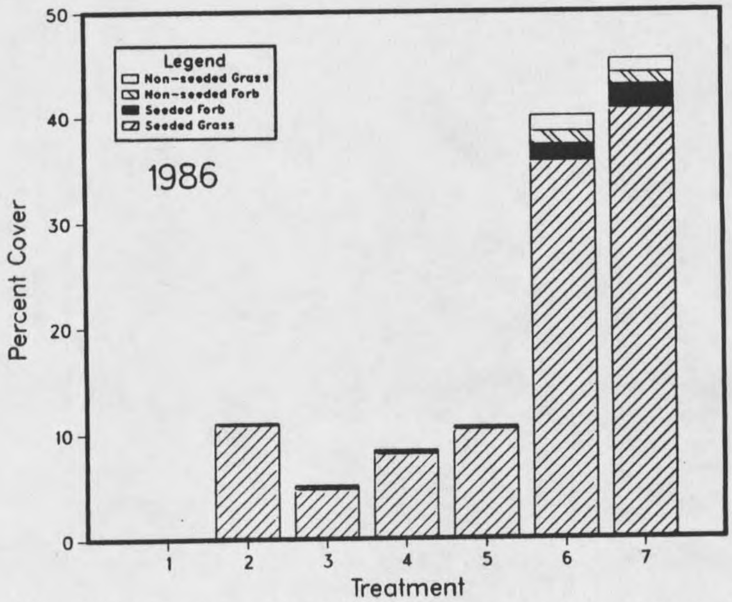


Figure 11. Percent cover at the Giffen site for 1986 for the Control (1), $CaCO_3$ to 35 cm (2), five fold CaO to 35 cm (3), CaO to 35 cm (4), CaO to 100 cm (5), CaO to 35 cm with 15 cm coversoil (6) and CaO to 35 cm with 30 cm coversoil (7).

Above Ground Biomass

Above ground biomass production of seeded grasses was significantly greater compared to all other plant categories in 1985 (Table 16). Coversoil application resulted in significantly greater above ground biomass production of all plant categories and total vegetation compared to above ground biomass production in treatments not receiving coversoil. Above ground biomass production of seeded grasses and total vegetation was significantly greater on the 30 cm coversoil treatment compared to the 15 cm coversoil treatment. Although seeded grass above ground biomass production was significantly greater on the $CaCO_3$ treatment incorporated to 35 cm compared to the control, total vegetation above ground biomass production on this and all other limed treatments without coversoil application was not significantly different than the control in 1985.

Table 16. Above ground biomass production (kg/ha) at the Giffen site, 1985.

	Treatment						
Plant Class	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
S Grass	0.6[1] Ab[2]	2.3 Bb	1.0 ABb	1.6 ABb	1.7 ABb	13.2 Cb	25.9 Db
S Forb	0.1 Aa	0.1 Aa	0.0 Aa	0.1 Aa	0.1 Aa	2.3 Bb	3.7 Ca
NS Forb	0.2 Aa	0.1 Aa	0.0 Aa	0.0 Aa	0.0 Aa	13.5 Ba	8.3 Ba
NS Shrub	0.0 Aa	0.0 Aa	0.0 Aa	0.0 Aa	0.0 Aa	5.8 Ba	7.2 Ba
Total	0.9 A	2.5 A	1.0 A	1.6 A	1.8 A	34.8 B	45.1 C

1 - Mean of 15 samples.
2 - Means followed by the same uppercase letter in the same row indicate no significant difference in plant response to treatment (P=0.05).
- Means followed by the same lowercase letter in the same column indicate no significant difference in plant response within a treatment (P=0.05).
S - Seeded.
NS- Non-seeded.

Above ground biomass production in 1986 continued to be dominated by seeded grasses on all amended treatments (Table 17). Seeded grass and total above ground biomass production was significantly greater on coversoil treatments, with no significant difference in seeded grass or total vegetation above ground biomass production between 15 and 30 cm coversoil applications. Above ground biomass production of seeded grasses and total vegetation on the $CaCO_3$ treatment incorporated to 35 cm and the CaO treatment incorporated to 100 cm was significantly greater compared to other limed treatments without coversoil application. All treatments had significantly greater above ground biomass production compared to the control, which had no vegetation in 1986. These results for above biomass production response to treatment for 1986 are graphically presented by plant category in Figure 12.

Table 17. Above ground biomass production (kg/ha) at the Giffen site, 1986.

	Treatment						
Plant Class	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
S Grass	0.0[1] Aa[2]	181.6 Db	15.5 Bb	60.4 Cb	132.5 Db	429.4 Ec	501.3 Ec
S Forb	0.0 Aa	0.1 Aa	0.3 Aa	0.0 Aa	0.0 Aa	4.0 Ba	12.4 Cb
NS Forb	0.0 Aa	0.5 ABa	2.2 ABa	0.7 ABa	0.8 ABa	9.7 Cb	3.3 Ba
NS Grass	0.0 Aa	0.4 Aa	0.0 Aa	0.0 Aa	0.4 Aa	15.6 Bb	20.0 Bb
Total	0.0 A	182.6 D	18.0 B	61.1 C	133.7 D	458.7 E	537.0 E

1 - Mean of 15 samples.
2 - Means followed by the same uppercase letter in the same row indicate no significant difference in plant response to treatment (P=0.05).
- Means followed by the same lowercase letter in the same column indicate no significant difference in plant response within a treatment (P=0.05).
S - Seeded.
NS- Non-seeded.

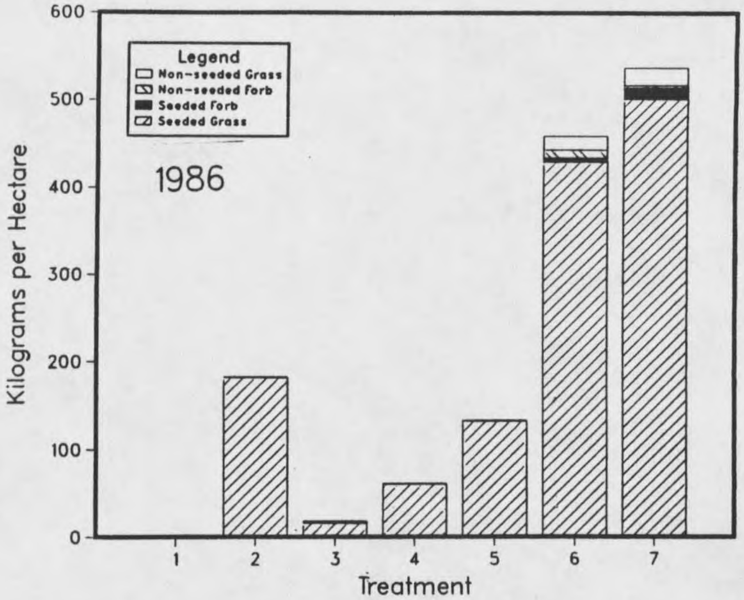


Figure 12. Plant production at the Giffen site for 1986 for the Control (1), $CaCO_3$ to 35 cm (2), five fold CaO to 35 cm (3), CaO to 35 cm (4), CaO to 100 cm (5), CaO to 35 cm with 15 cm coversoil (6) and CaO to 35 cm with 30 cm coversoil (7).

Seedling density, plant canopy cover and above ground biomass production were affected by coversoil and liming. In this study, lime was necessary for plant survival, yet high application (five fold CaO) inhibited plant growth. Reduced plant performance was probably due to elevated salt concentrations in the root zone (Bohn et al. 1979) caused by over liming. Coversoil application increased plant canopy cover four fold compared to the non-coversoiled treatments. Production was doubled on coversoil treatments compared to treatments not receiving coversoil by the second year. Coversoil provides a more suitable medium for germination, seedling emergence and early plant growth, demonstrated by the significantly greater plant performance on coversoil treatments compared to treatments without coversoil.

Minesoil Root Distribution

Maximum rooting depth for each treatment was near the base of the zone of intended lime incorporation for each treatment (Table 18). Maximum root penetration was significantly greater in the CaO treatment incorporated to the 100 cm depth, and the CaO treatment incorporated to 35 cm with 30 cm coversoil, compared to all the other treatments. Maximum root penetration depth was not significantly different in treatments where lime was incorporated to the 35 cm depth and where 15 cm of coversoil was applied. Therefore, additional coversoil (30 cm treatment) and deeper lime incorporation resulted in significantly increasing rooting depth.

Table 18. Depth of root penetration in centimeters for each plot of each replication at the Giffen site, 1986.

	Treatment						
Rep	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
1	0	38	28	30	70	46	62
2	0	40	35	30	65	42	65
3	0	25	35	36	90	40	65
Mean	0	34.3 a[1]	32.7 a	32.0 a	75.0 b	42.7 a	64.0 b

[1] - Means followed by the same letter indicate no significant difference in maximum root depth (P=0.05).

Roots had no difficulty growing through the coversoil into the underlying limed coal refuse (Table 19). The coversoil-refuse interface did not restrict root penetration. Table 19 shows root abundance observations were significantly lower in the 30 cm coversoil zone compared to the limed refuse. This was probably due to coversoil adhering to the roots, reducing root visibility during field observation. It is felt that root abundance in the coversoil was similar to that in the coal refuse and the error was in relying on observation. If root biomass had been measured, root content in the coversoil would probably not be significantly different than root content in the coal refuse.

Table 19. Observed root abundance with depth at the Giffen site.

	Treatment						
Profile Depth	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO[1] 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
A						1.9 a	2.0 a[2]
A						2.4 c	2.2 a
A							2.3 a
B 0-10	0	3.2 a	2.7 a	3.3 a	3.3 a	2.8 c	3.1 b
B 10-20	0	2.9 a	2.7 a	3.3 a	3.3 a	2.4 c	3.2 b
B 20-35	0	2.3 a	2.0 a	2.4 a	2.5 a	1.1 a	2.9 b

A - Coversoil, 15 cm treatment incremented 0-10, 10-15 cm, 30 cm treatment incremented 0-15, 15-25, 25-30 cm.
B - Coal waste
1 - Depth increments in this treatment were 0-30, 30-60, and 60-100 cm.
2 - Means followed by the same letter in the same row indicate no significant difference in root abundance value ($P=0.05$).
- Root abundance classes are: 1 = few, 2 = some, 3 = common, 4 = many.

Root abundance values were averaged across all depths (Table 20). Coarse root and fine root abundance values were not significantly different across all treatments. Although very fine and medium root observation values were statistically different between treatments, these differences were not notable.

Table 20. Comparison of root abundance by root size at the Giffen site, September, 1986.

	Treatment						
Root size	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
V. fine (<1mm)	0	2.6[1] b[2]	1.8 ab	1.9 ab	2.5 ab	1.6 a	2.4 ab
Fine (>1mm-2mm)	0	2.4 a	1.8 a	1.9 a	2.3 a	1.8 a	2.3 a
Medium (>2mm-5mm)	0	1.6 ab	1.5 ab	1.7 ab	1.8 ab	1.3 a	2.1 b
Coarse (>5mm-10mm)	0	1.4 a	1.5 a	2.0 a	1.7 a	1.3 a	1.4 a

1 - Root abundance classes are: 1 = few, 2 = some, 3 = common, 4 = many.
2 - Means followed by the same letter in the same row indicate no significant difference in root abundance value (P=0.05).

In summary, coversoil treatments had twice the plant production and four times the canopy cover compared to treatments without coversoil application, yet root abundance was similar. This was probably due to observation pit sites being selected adjacent to vigorous plant growth on each plot so that maximum root penetration and abundance measurements could be more easily observed.

Minesoil Field Water Content

Maximum and minimum profile water content dates were selected for each treatment and are illustrated in Figures 13 through 19. Plant available water estimated from pressure plate analysis for each profile is included in the figures to determine if the water held in the minesoil profile was within the plant available range (shaded area). The moisture values used in Figures 13 through 19 are contained in Appendix A, and the 0.1 and 15 bar water content values used were presented in Table 9.

Some coal waste profiles exhibited water contents in excess of field capacity (0.1 bar) during the growing season (Figures 14,15,16,18). This implied there was water held in the profile which should be draining in response to gravity. The presence of profile water in excess of the 0.1 bar values on the driest measurement dates (May 22, 1985 and June 12, 1986) in Figure 14 creates suspicion as to the reliability of either the 0.1 bar values or these neutron probe data. Coal waste water monitored in excess of the 0.1 bar values coincide with sharp decreases in the 0.1 bar values (Figures 14,15,16,18). It is felt that the occurrences of water contents in excess of field capacity in the field were actually rare, and their graphical representation is probably due to neutron probe measurement error associated with calibration difficulties.

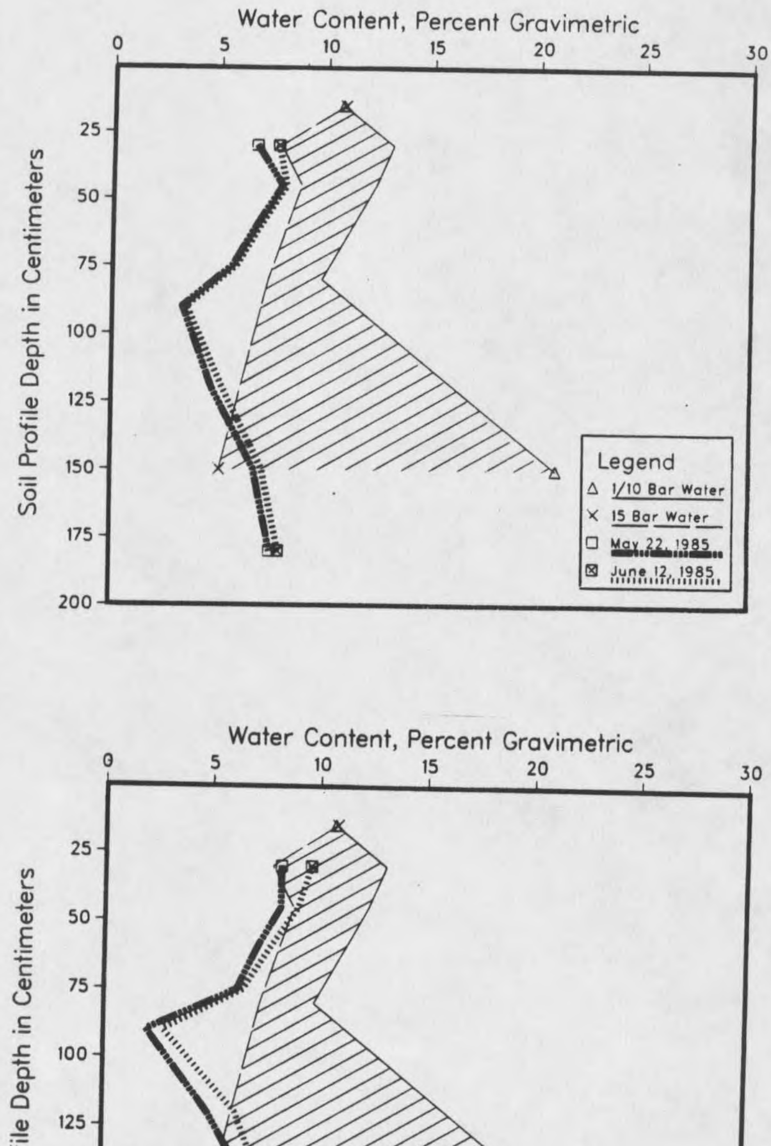


Figure 13. Comparison of the water content measured by neutron moisture probe, and the plant available water in the Control for 1985 and 1986.

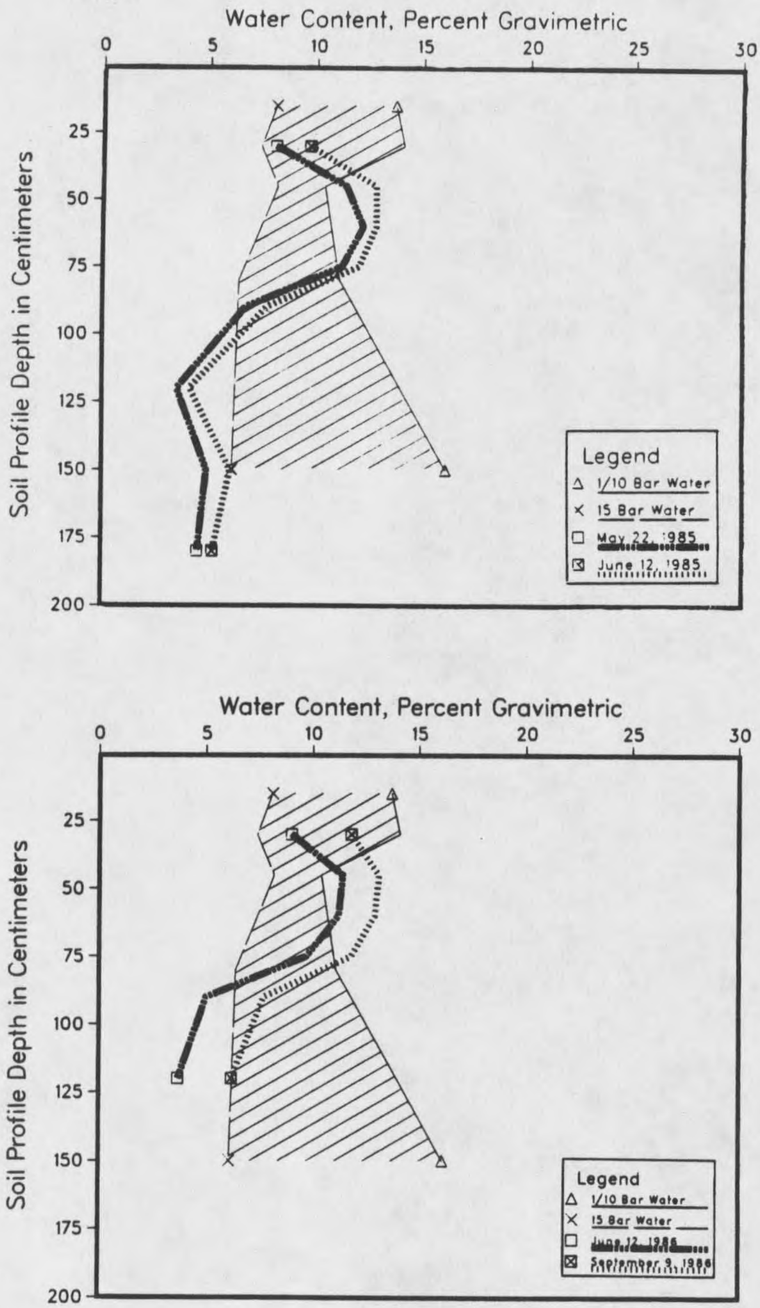


Figure 14. Comparison of the water content measured by neutron moisture probe, and the plant available water in the $CaCO_3$ treatment incorporated to 35 cm for 1985 and 1986.

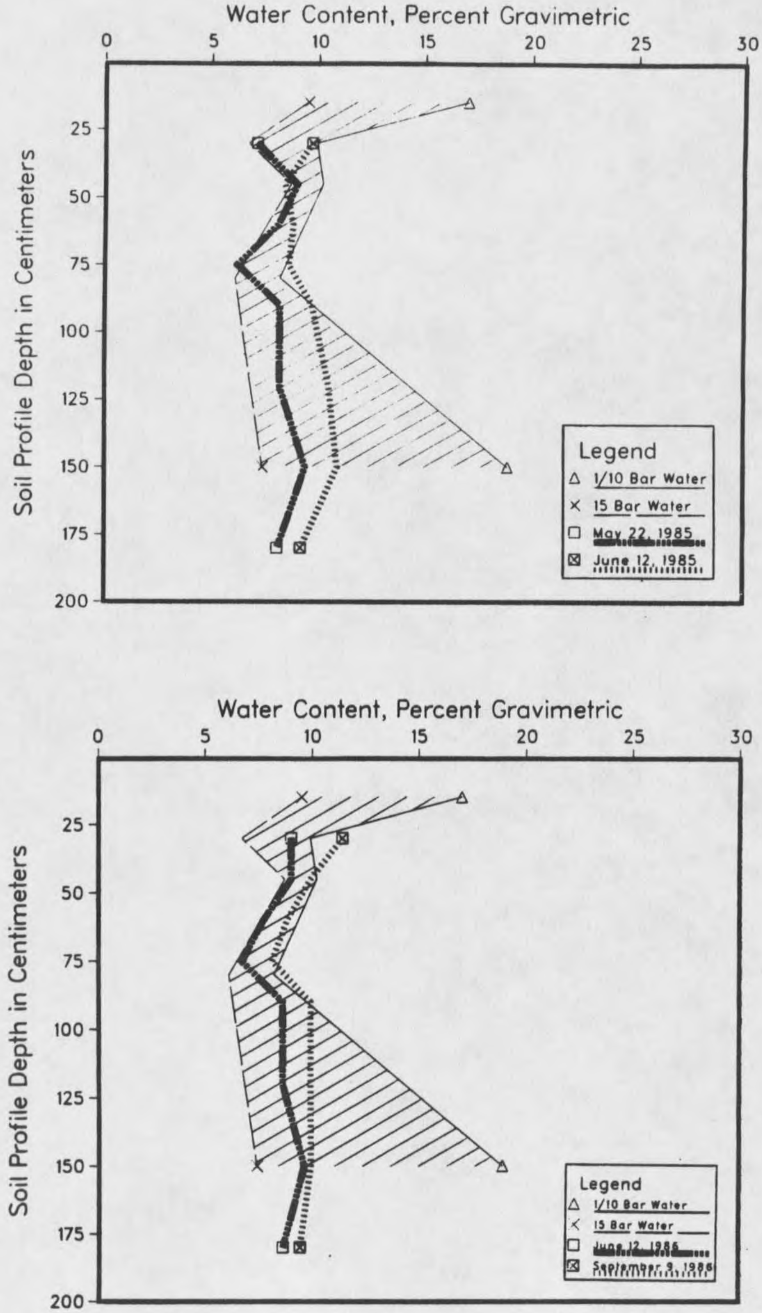
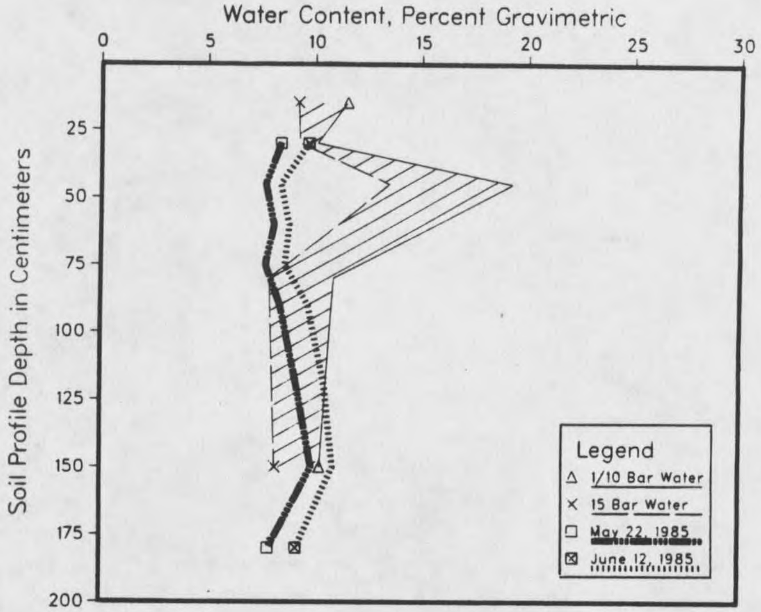


Figure 15. Comparison of the water content measured by neutron moisture probe, and the plant available water in the five fold CaO treatment incorporated to 35 cm for 1985 and 1986.



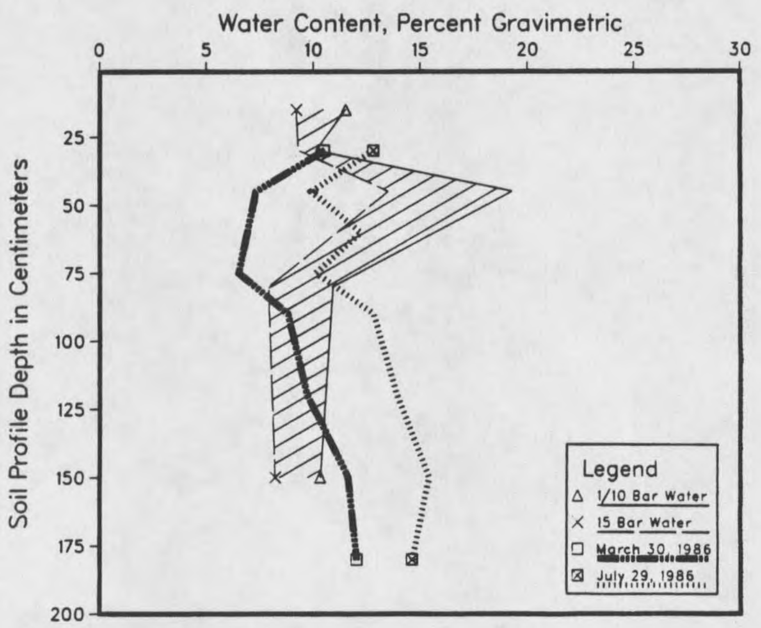
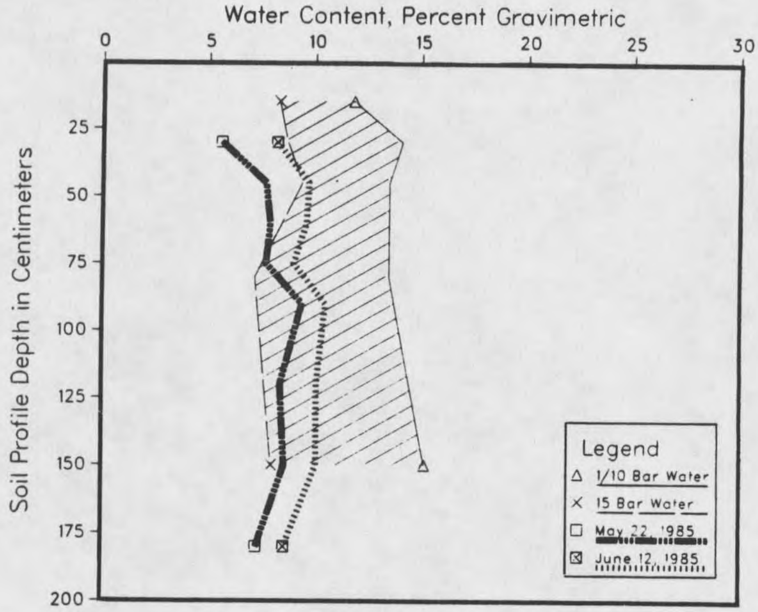


Figure 16. Comparison of the water content measured by neutron moisture probe, and the plant available water in the CaO treatment incorporated to 35 cm for 1985 and 1986.



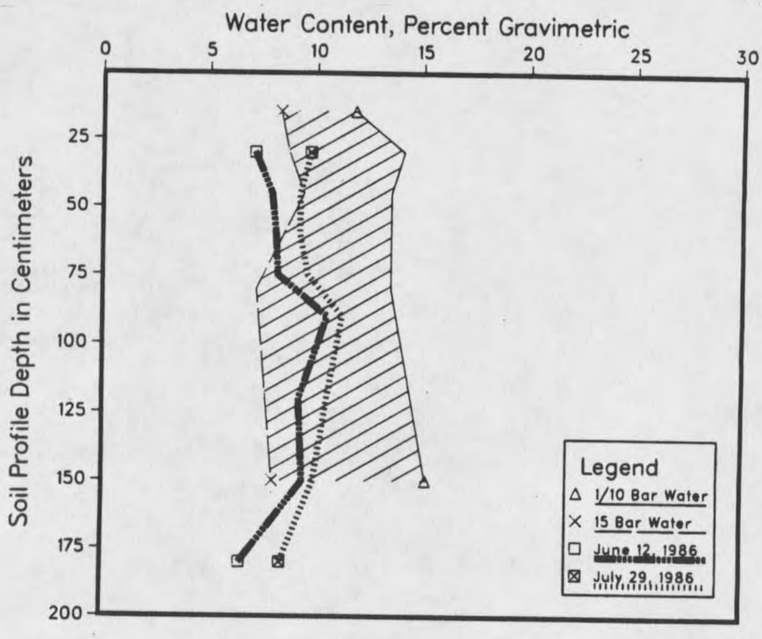


Figure 17. Comparison of the water content measured by neutron moisture probe, and the plant available water in the CaO treatment incorporated to 100 cm for 1985 and 1986.

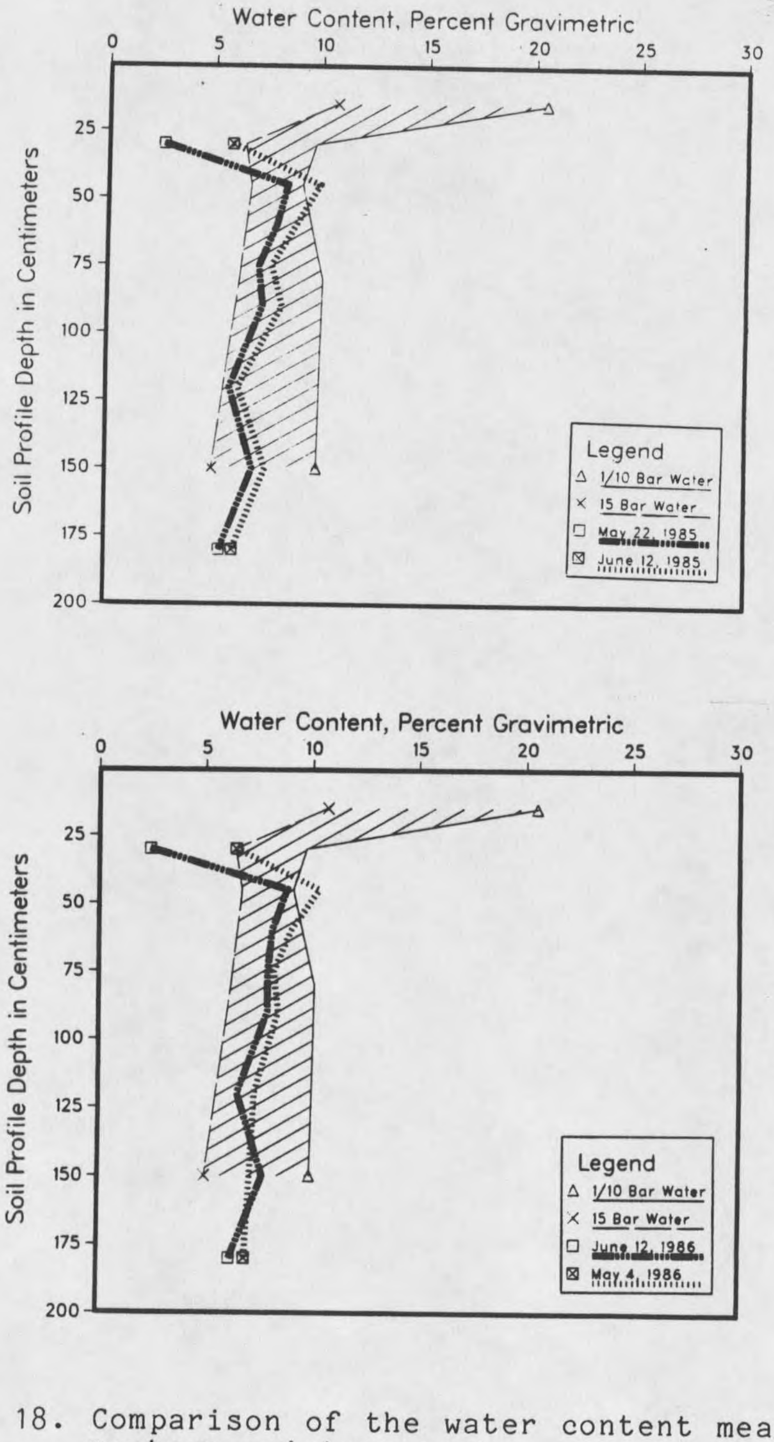
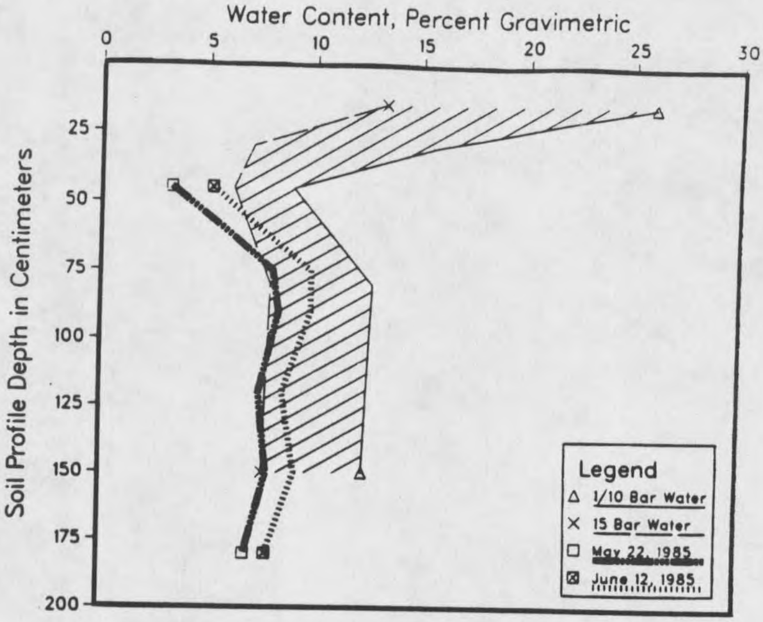


Figure 18. Comparison of the water content measured by neutron moisture probe, and the plant available water in the CaO treatment incorporated to 35 cm, 15 cm coversoil for 1985 and 1986.



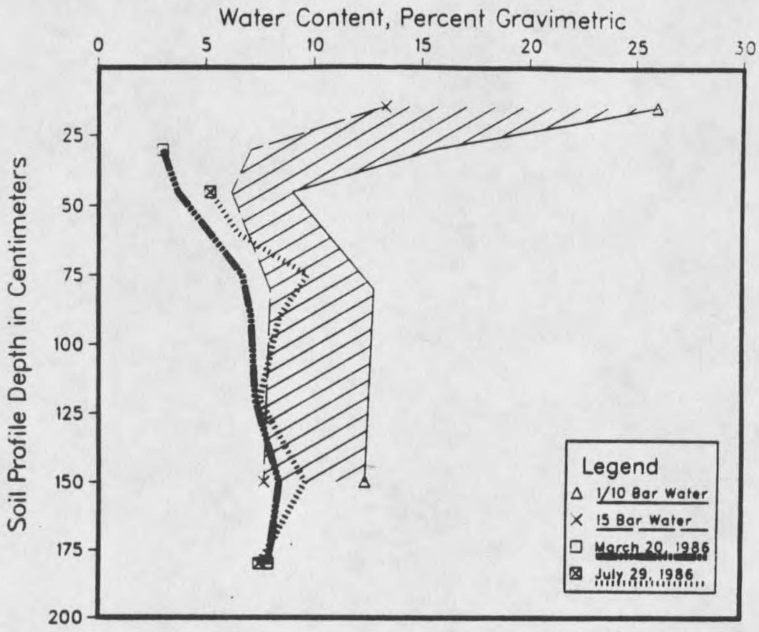


Figure 19. Comparison of the water content measured by neutron moisture probe, and the plant available water the CaO treatment incorporated to 35 cm, 30 cm coversoil for 1985 and 1986.

Water contents less than 15 bar, approximately permanent wilting percentage, were also common. The high coarse fragment content of coal waste and few fine particles create large voids, decreasing bulk density and the volume of water held. Accuracy in measuring water in coal with a neutron probe is questionable due to the high concentrations of hydrogen ions in coal. Since the neutron probe measures hydrogen ions, the presence of coal will wrongfully increase the moisture readings. Halvorson (1986) found that absolute soil-water content measurements in minesoils containing coal are difficult and that only relative differences in water content over time should be determined. In this study it appeared that the neutron probe was underestimating water content, and in light of the above difficulties, the reliability of the probe in determining water content in coal refuse is questionable.

The control coal refuse profile (Figure 13) tended to have the lowest water content compared to limed and coversoiled sites, which may have contributed to the lack of vegetation establishment. Other treatments exhibited low water contents, yet supported productive vegetation with extensive root systems. Figure 19 (30 cm coversoil treatment) illustrates marginal plant available water content in May of 1985, March and June of 1986, yet this treatment had the highest plant production due to the coversoil application. However, plants did not solely rely on coversoil for available water, as evidenced by the relatively even root distribution, and root proliferation, into the limed coal refuse. Due to only moderate calibration success with the neutron probe, and frequent water content recordings much lower than the estimated plant wilting point (15 bar) during periods when plants were observed in a healthy and productive state, it was felt that there was more profile water than that shown by the neutron probe.

Figures 14 and 18 illustrate unusual increases in water content from the 25 to 45 cm depth. These increases were surprising because roots were abundant in these zones, which should cause a decrease in water content by plant uptake. All other vegetated profiles had increased water content below the zone of root influence. Increased water content in the zone of active plant water uptake may be explained by coal refuse variability. Materials of higher water holding potential were probably present adjacent to the neutron probe access tube, and not encountered in the samples taken for available water determination. These data further demonstrate the difficulty in using the neutron probe technique in coal waste material.

Profile water loss can be estimated as the difference in maximum and minimum water content for the year in a 150 cm profile. Profile water loss includes water uptake by plants, evaporative loss at the surface, and water that drained through the profile. Water loss was calculated for each treatment for both years studied (Table 21).

Table 21. Profile water loss (cm H_2O/150 cm profile) by treatment for 1985 and 1986 at the Giffen site.

Treatment	1985	1986
Control	0.7	1.4
$CaCO_3$, 8.6 mt/ha to 35 cm	1.7	2.8
CaO, 45.8 mt/ha to 35 cm	3.2	2.9
CaO, 9.0 mt/ha to 35 cm	2.0	6.5
CaO, 25.7 mt/ha to 100 cm	2.7	2.3
CaO, 9.0 mt/ha to 35 cm 15 cm coversoil	1.6	1.2
CaO, 9.0 mt/ha to 35 cm 30 cm coversoil	2.3	1.7

Annual water loss calculations were very low, further questioning the ability of the neutron probe to measure water in coal refuse. Water loss increased in 1986 in the control, $CaCO_3$ treatment incorporated to 35 cm, and CaO treatment incorporated to 35 cm. Water loss decreased in 1986 in the five fold CaO treatment incorporated to 35 cm, 15 cm coversoil and 30 cm coversoil application treatments. No relationship of water use to plant production increase or to increased precipitation in 1986 was found. Total precipitation collected from the on site rain gauge was 15.4 cm from May to August, 1985 (including the 1.3 cm of irrigation water) and 28.2 cm from March to September, 1986. The 30 year precipitation norm for Great Falls is 38.7 cm (U.S. Weather Bureau).

Temperature Monitoring

Although statistically significant differences were generally not present, temperatures in the upper zone (0 to 10 cm) of the coversoiled sites were 8 to 15 percent lower than temperatures in coal waste without coversoil. The average temperature at 1 cm below the surface in the 30 cm coversoil treatment was significantly cooler than the corresponding depth in the CaO treatment incorporated to 35 cm. No other significant differences among treatments were found. In all treatments, the 10 cm depth was cooler than the 1 cm depth, and then no significant decreases in temperature were found with increasing depth.

Monitoring surface temperature with an infra-red thermometer showed greater diversity with treatment application (Table 23). Due to the increase in plant growth by the second season and its influence on surface temperature (Oke 1978), the temperature measurements were averaged by field season. Surface temperatures of all treatment plots were measured twice in 1985 and five times in 1986.

The surface temperature of the coversoil was significantly lower compared to the surface temperature of the coal refuse in 1985. No significant differences among treatments without coversoil were found in 1985 (Table 23). The surface temperature of the black coal waste averaged 47

Table 22. Average temperature in degrees celsius by depth at the Giffen site.

Profile Depth	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
	Treatment						
1cm	30.3[1] ABb[2]	30.5 ABb	32.0 ABb	34.7 Bb	no thermocouple installed	29.0 ABb	26.0 Ab
10cm	20.7 Aa	20.4 Aa	23.6 Aa	22.7 Aa		20.4 Aa	19.8 Aa
25cm	18.9 Aa	18.5 Aa	18.2 Aa	18.6 Aa		17.9 Aa	17.8 Aa
50cm	18.2 Aa	17.3 Aa	17.4 Aa	17.8 Aa		16.9 Aa	17.4 Aa

1 - Mean of 10 samples.
2 - Means followed by the same uppercase letter in the same row indicate no significant difference in temperature across treatments (P=0.05).
- Means followed by the same lowercase letter in the same column indicate no significant difference in temperature with depth (P=0.05).

Table 23. Average surface temperature in degrees C at the Giffen site.

Year	Control	$CaCO_3$ 8.6 mt/ha to 35 cm	CaO 45.8 mt/ha to 35 cm	CaO 9.0 mt/ha to 35 cm	CaO 25.7 mt/ha to 100 cm	CaO 9.0 mt/ha to 35 cm, 15 cm coversoil	CaO 9.0 mt/ha to 35 cm, 30 cm coversoil
	Treatment						
1985	47.3[1] b[2]	47.1 b	47.0 b	47.2 b	47.3 b	41.6 a	40.2 a
1986	38.2[3] c	33.9 b	35.6 bc	35.5 bc	33.8 b	27.4 a	26.9 a

1 - Mean of 6 temperature values.
2 - Means followed by the same letter in the same row indicate no significant differences in surface temperature with treatment (P=0.05).
3 - Mean of 15 temperature values.

degrees C (117 degrees F) and the coversoil surface temperature averaged 41 degrees C (106 degrees F). These significant differences in temperature may have affected surface evaporation, seedling transpiration and seedling establishment.

The 1986 results showed more differences in surface temperature with treatment compared to 1985 (Table 23). The 15 and 30 cm coversoil treatments continued to be significantly cooler than the non-coversoiled treatments with average temperatures of 27.4 and 26.9 degrees C, respectively. The $CaCO_3$ treatment incorporated to 35 cm and

CaO treatment incorporated to 100 cm had surface temperatures (33.9 and 33.8 degrees C) which were significantly cooler than the control (38.2 degrees C). Vegetation production on these two treatments was significantly greater in 1986 compared to other non-coversoiled treatments, and canopy cover was significantly greater than the control and five fold CaO treatment incorporated to 35 cm in 1986 (Tables 15 and 17). Increased vegetation cover on these treatments significantly reduced the surface temperature.

There were no significant differences in surface temperature of the control (38.2 degrees C) the five fold CaO treatment incorporated to 35 cm (35.6 degrees C) and the CaO treatment incorporated to 35 cm (35.5 degrees C). Vegetation on these two limed treatments was not sufficient to significantly decrease surface temperature compared to the control.

Measuring surface temperature from March to August in 1986 resulted in cooler average surface temperatures compared to the averages for 1985 for temperatures taken in July and August. The warmest surface temperature was recorded on the control at 53.5 degrees C (129 degrees F) on July 25, 1985 with an air temperature of 27 degrees C (82 degrees F).

SUMMARY AND CONCLUSIONS

Experimental plots to test the effects of lime rate and coversoil application on coal refuse were implemented at an abandoned coal mine near Stockett, Montana. The coal refuse at this site was black (2.5 Y 2/0), acidic (pH=2.8), had an average coarse fragment content of 85 percent by weight and low water holding capacity. The Computerized Automatic Rapid Weathering Apparatus (CARWA) was used to estimate the lime required to neutralize present and potential acidity of the coal refuse. A heavy lime rate (five fold CARWA) was included as a treatment. Deep lime incorporation (100 cm) was also tested. Calcium carbonate ($CaCO_3$) and calcium oxide (CaO) were tested as liming agents. Coversoil was applied at rates of 15 and 30 cm. Response to treatment was monitored over a two year period. Soil and spoil temperature and water content were also monitored.

Conclusions drawn from this study were as follows:

1) Lime rates determined by CARWA were successful at neutralizing coal refuse acidity at depths near the surface. Below 10 cm (30 cm in the deep incorporation treatment), the pH was significantly increased compared to the control ($P=0.05$), but complete acid neutralization did not occur. Increasing the CARWA rate five fold resulted in significant increases in pH, yet plant performance was reduced by the excess lime application.

2) Calcium carbonate and calcium oxide were successful as liming agents in increasing the pH of the acidic coal refuse. Vegetation was establishing on limed, non-coversoiled coal refuse. No vegetation survived on the control after the first season.

3) Plant growth performance was significantly greater on the coversoiled treatments compared to the non-coversoiled, limed coal refuse. This was probably due to greater initial plant establishment which would result in increased cover and production. It appeared that coversoil was necessary for high levels plant establishment, but was not essential as a medium for plant growth. By the second growing season, no significant differences in plant performance were found between the 15 cm coversoil treatment and the 30 cm coversoil treatment.

4) The water holding capacity of the coversoil was superior to the coal refuse at the Giffen site. This, along with reduced surface temperature on coversoil increased seedling establishment. Though the water holding capacity of the coal waste was rated low, some plants survived a droughty first season and were productive above and below ground in the second season on plots without coversoil. During the study, water availability did not appear to be limiting to the plants in the non-coversoiled coal refuse once they were established.

5) Roots proliferated in amended coal refuse, to the depth of the influence of liming agents. Roots were not restricted to the coversoil layers of those treatments; growth readily continued into the underlying coal waste. The coversoil did not impede water movement through the boundary to the coarser refuse, shown by the presence of root development, measured available water, and visible moist conditions of the coal waste during profile observation.

6) Pressure plate analysis estimated higher plant available water in coversoil compared to coal refuse. Measuring water with the neutron probe proved difficult. No comparisons of water contents in coversoil to coal refuse could be made.

7) Surface temperature was significantly lower on coversoil compared to any coal refuse treatment. Increasing levels of plant growth on non-coversoiled coal refuse significantly reduced the surface temperature compared to the control.

8) Grasses, especially the wheatgrasses were more successful in limed and limed-coversoiled coal refuse compared to forbs and volunteering vegetation.

9) Incorporating lime below 10 cm with a chisel plow proved difficult, evidenced by rapid pH decrease. Use of tillage equipment was not effective in incorporating lime to 35 cm.

RECOMMENDATIONS

1) Coal refuse lime requirements should be determined before lime application. In this study, CARWA was successful at determining the lime required to neutralize surface acidity, and should be considered a method for coal refuse reclamation.

2) Kiln dust (CaO), when available, should be used as a liming agent in coal refuse reclamation due to its ability to neutralize acidity and promote vegetation establishment at low material cost. Use of kiln dust provides a disposal method for a waste product of the cement industry.

3) Coversoil application over limed coal refuse is recommended for maximum plant performance. Increasing coversoil application from 15 to 30 cm did not significantly increase above ground plant performance in this study, implying a surface layer is adequate. Depth of coversoil application should be a function of material availability and cost. The effects on plant performance of applying shallower depths have not been studied, and such applications should be considered high risk.

4) Maximizing the zone of materials favorable for root growth is highly recommended. Increasing the depth of lime incorporation and coversoil application increases the depth of root penetration. The greater the root zone, the greater the chances of plants establishing on abandoned coal refuse,

especially in periods of drought. Agricultural tillage equipment is not adequate for deep lime incorporation, resulting in the need for higher applications of coversoil to increase rooting depth. Development of equipment to incorporate lime deeply into coal refuse would increase potential zones for root development and the chances for plant establishment.

5) Proper plant species selection is critical for successful vegetation establishment. Species selection for drought and acid tolerance is essential for plant survival in the low water holding coal refuse, which is not completely acid neutralized below the surface.

6) Monitoring plant performance and refuse pH of experimental plots and early reclaimed sites is strongly suggested as the recommendations here were made on a two year data base. Possibilities of reacidification, water stress, erosion and other factors could influence long-term vegetation establishment and site stabilization.

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APPENDICES

APPENDIX A

NEUTRON PROBE DATA

Table 24. Maximum and minimum percent water measured with the neutron probe at various depths (cm), 1985.

	Treatment 1			Treatment 2			Treatment 3			Treatment 4	
Depth	Maximum	Minimum	Depth	Maximum	Minimum	Depth	Maximum	Minimum	Depth	Maximum	Minimum
30	7.7	6.7	30	9.7	8.1	30	9.2	7.1	30	9.7	8.4
45	8.1	7.9	45	12.8	11.4	45	10.1	9.0	45	8.4	7.7
60	6.9	6.7	60	12.8	12.2	60	9.4	8.1	60	8.8	8.1
75	5.8	5.6	75	12.0	11.2	75	7.7	6.2	75	8.6	7.7
90	3.5	3.3	90	7.7	6.7	90	9.7	8.2	90	9.7	8.4
120	5.2	4.7	120	4.1	3.5	120	10.3	8.2	120	10.5	9.2
150	7.1	6.7	150	6.0	4.9	150	11.6	9.4	150	10.9	9.9
180	7.9	7.5	180	5.2	4.5	180	9.9	8.1	180	9.9	8.2

	Treatment 5			Treatment 6			Treatment 7	
Depth	Maximum	Minimum	Depth	Maximum	Minimum	Depth	Maximum	Minimum
30	8.2	5.6	30	5.8	2.6	30		
45	9.7	7.7	45	9.9	8.4	45	5.2	3.3
60	9.6	7.9	60	8.8	7.9	60	7.5	5.8
75	9.0	7.7	75	7.7	7.1	75	9.9	8.1
90	10.5	9.4	90	8.2	7.3	90	9.9	8.4
120	10.1	8.4	120	6.2	5.8	120	8.6	7.5
150	10.1	8.6	150	7.5	6.9	150	9.2	7.9
180	8.6	7.3	180	6.0	5.4	180	7.9	6.9

Table 25. Maximum and minimum percent water measured with the neutron probe at various depths (cm), 1986.

Treatment 1			Treatment 2			Treatment 3			Treatment 4		
Depth	Maximum	Minimum	Depth	Maximum	Minimum	Depth	Maximum	Minimum	Depth	Maximum	Minimum
30	9.6	8.2	30	11.8	9.0	30	11.4	9.0	30	12.8	10.5
45	9.0	8.2	45	13.1	11.4	45	9.9	9.0	45	9.9	7.3
60	7.7	7.1	60	12.9	11.2	60	8.8	7.7	60	12.2	6.9
75	6.5	6.2	75	11.8	9.7	75	8.1	6.7	75	10.1	6.5
90	2.8	2.0	90	7.7	5.0	90	9.9	8.6	90	12.8	8.8
120	6.2	4.9	120	6.2	3.7	120	9.9	8.6	120	13.9	9.7
150	7.7	7.1	150			150	9.9	9.6	150	15.4	11.6
180	8.2	7.9	180			180	9.4	8.6	180	14.6	12.0

Treatment 5			Treatment 6			Treatment 7		
Depth	Maximum	Minimum	Depth	Maximum	Minimum	Depth	Maximum	Minimum
30	9.7	7.1	30	6.0	2.4	30		
45	9.2	7.9	45	9.7	8.8	45	5.2	3.7
60	9.2	8.1	60	8.6	8.1	60	6.5	5.2
75	9.6	8.2	75	7.7	7.9	75	9.7	6.7
90	11.2	10.5	90	8.2	7.9	90	8.4	7.1
120	10.5	9.2	120	6.7	6.5	120	7.5	7.3
150	9.9	9.4	150	8.1	7.7	150	9.6	8.4
180	8.4	6.5	180	6.7	6.2	180	7.5	7.9

APPENDIX B

ANOV AND LSD TABLES

Table 26. Analysis of variance and least significant difference of Fall 1985 pH data by depth (P=0.05).

Depth 1 pH

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	1.194	.5971		
Treatments	6	134.3	22.39	37.61	0.00
Residual	54	32.15	.5953		

LSD Analysis

Factor	Identity	Mean pH
Depth 1	Treatment 1	3.20 A
	Treatment 2	7.65 C
	Treatment 3	7.58 C
	Treatment 4	7.17 CB
	Treatment 5	6.69 B
	Treatment 6	7.21 CB
	Treatment 7	7.39 CB

Depth 2 pH

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	11.49	5.743		
Treatments	6	29.30	4.883	1.465	.2070
Residual	54	180.0	3.333		

LSD Analysis

Factor	Identity	Mean pH
Depth 2	Treatment 1	3.35 A
	Treatment 2	5.02 AB
	Treatment 3	5.28 B
	Treatment 4	4.62 AB
	Treatment 5	4.87 AB
	Treatment 6	5.57 B
	Treatment 7	5.31 B

Table 26. Continued.

Depth 3 pH

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	3.332	1.666		
Treatments	6	10.01	1.669	2.510	.32E-01
Residual	54	35.90	.6649		

LSD Analysis		
Factor	Identity	Mean pH
Depth 3	Treatment 1	2.93 A
	Treatment 2	2.90 A
	Treatment 3	3.83 B
	Treatment 4	2.98 A
	Treatment 5	3.81 B
	Treatment 6	2.96 A
	Treatment 7	2.92 A

Depth 4 pH

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	3.126	1.563		
Treatments	6	2.014	.3357	1.491	.1981
Residual	54	12.15	.2251		

LSD Analysis		
Factor	Identity	Mean pH
Depth 4	Treatment 1	2.83 A
	Treatment 2	2.89 A
	Treatment 3	3.34 B
	Treatment 4	2.99 AB
	Treatment 5	2.88 A
	Treatment 6	2.84 A
	Treatment 7	3.16 AB

Table 27. Analysis of variance and least significant difference of Fall 1985 pH by treatment (P=0.05).

Treatment 1 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	4.558	2.279		
Depths	3	1.523	.5077	.5262	.6175
Residual	30	28.95	.9649		

LSD Analysis

Factor	Identity	Mean pH
Treatment 1	Depth 1	3.12 a
	Depth 2	3.35 a
	Depth 3	2.93 a
	Depth 4	2.83 a

Treatment 2 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	7.548	3.774		
Depths	3	137.9	45.95	37.22	0.000
Residual	30	37.04	1.235		

LSD Analysis

Factor	Identity	Mean pH
Treatment 2	Depth 1	7.65 c
	Depth 2	5.02 b
	Depth 3	2.90 a
	Depth 4	2.89 a

Treatment 3 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	6.028	3.014		
Depths	3	97.65	32.55	31.80	0.000
Residual	30	30.71	1.024		

LSD Analysis

Factor	Identity	Mean pH
Treatment 3	Depth 1	7.58 c
	Depth 2	5.28 b
	Depth 3	3.83 a
	Depth 4	3.34 a

Table 27. Continued.

Treatment 4 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	2.919	7.597		
Depths	3	105.7	35.23	12.64	0.000
Residual	30	19.86	.6621		

LSD Analysis

Factor	Identity	Mean pH
Treatment 4	Depth 1	7.17 c
	Depth 2	4.62 b
	Depth 3	2.98 a
	Depth 4	2.99 a

Treatment 5 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	15.19	7.597		
Depths	3	72.12	24.04	12.64	0.000
Residual	30	57.07	1.902		

LSD Analysis

Factor	Identity	Mean pH
Treatment 5	Depth 1	6.69 c
	Depth 2	4.87 b
	Depth 3	3.81 ab
	Depth 4	2.88 a

Treatment 6 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	8.351	4.175		
Depths	3	121.7	40.57	43.40	0.000
Residual	30	28.04	.9348		

LSD Analysis

Factor	Identity	Mean pH
Treatment 6	Depth 1	7.21 c
	Depth 2	5.57 b
	Depth 3	2.96 a
	Depth 4	2.84 a

Table 27. Continued.

Treatment 7 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	1.823	.9116		
Depths	3	118.2	39.39	37.85	0.000
Residual	30	31.22	1.041		

LSD Analysis

Factor	Identity	Mean pH
Treatment 7	Depth 1	7.39 c
	Depth 2	5.31 b
	Depth 3	2.92 a
	Depth 4	3.16 a

Table 28. Analysis of variance and least significant difference of Spring, 1986 pH data by depth (P=0.05).

Depth 1 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	2.528	1.264		
Treatments	6	130.9	21.82	56.21	0.000
Residual	54	20.96	.3882		

LSD Analysis

Factor	Identity	Mean pH
Depth 1	Treatment 1	3.00 A
	Treatment 2	7.31 C
	Treatment 3	7.38 C
	Treatment 4	7.05 CB
	Treatment 5	6.99 CB
	Treatment 6	6.48 B
	Treatment 7	7.06 CB

Table 28. Continued.

Depth 2 pH

ANOVA

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	25.65	12.82		
Treatments	6	62.20	10.37	5.035	.57E-03
Residual	54	111.2	2.059		

LSD Analysis

Factor	Identity	Mean pH
Depth 2	Treatment 1	2.81 A
	Treatment 2	4.63 B
	Treatment 3	6.13 C
	Treatment 4	3.63 AB
	Treatment 5	4.91 CB
	Treatment 6	3.99 AB
	Treatment 7	3.73 AB

Depth 3

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	2.155	1.078		
Treatments	6	29.55	4.925	7.226	0.000
Residual	54	36.81	.6816		

LSD Analysis

Factor	Identity	Mean pH
Depth 3	Treatment 1	2.84 A
	Treatment 2	3.21 AB
	Treatment 3	3.75 B
	Treatment 4	3.01 AB
	Treatment 5	5.00 C
	Treatment 6	3.03 AB
	Treatment 7	3.54 AB

Depth 4 pH

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	1.535	.7675		
Treatments	6	8.945	1.491	1.502	.1946
Residual	54	53.61	.9928		

LSD Analysis

Factor	Identity	Mean pH
Depth 4	Treatment 1	3.24 AB
	Treatment 2	3.51 AB
	Treatment 3	3.98 B
	Treatment 4	3.09 AB
	Treatment 5	3.23 AB
	Treatment 6	2.77 A
	Treatment 7	2.87 A

Table 29. Analysis of variance and least significant difference of Spring, 1986 pH data by treatment (P=0.05).

Treatment 1 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	9.477	4.739		
Depths	3	1.071	.3571	.8192	.4961
Residual	30	13.08	.4359		

LSD Analysis

Factor	Identity	Mean pH
Treatment 1	Depth 1	3.00 a
	Depth 2	2.81 a
	Depth 3	2.84 a
	Depth 4	3.24 a

Treatment 2 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	3.837	1.918		
Depths	3	94.07	31.36	24.41	0.000
Residual	30	38.53	1.284		

LSD Analysis

Factor	Identity	Mean pH
Treatment 2	Depth 1	7.31 c
	Depth 2	4.63 b
	Depth 3	3.21 a
	Depth 4	3.51 a

Treatment 3 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	12.77	6.383		
Depths	3	82.43	27.48	23.98	0.000
Residual	30	34.38	1.146		

LSD Analysis

Factor	Identity	Mean pH
Treatment 3	Depth 1	7.38 c
	Depth 2	6.13 b
	Depth 3	3.75 a
	Depth 4	3.98 a

Table 29. Continued.

Treatment 4 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	1.567	.7835		
Depths	3	100.1	33.36	109.0	0.000
Residual	30	9.180	.3060		

LSD Analysis

Factor	Identity	Mean pH
Treatment 4	Depth 1	7.05 c
	Depth 2	3.63 b
	Depth 3	3.01 a

Treatment 5 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	26.47	13.23		
Depths	3	63.78	21.26	18.23	0.000
Residual	30	34.99	1.166		

LSD Analysis

Factor	Identity	Mean pH
Treatment 5	Depth 1	6.99 c
	Depth 2	4.91 b
	Depth 3	5.00 b
	Depth 4	3.23 a

Treatment 6 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.8780	.4390		
Depths	3	77.19	25.73	17.57	0.000
Residual	30	43.92	1.464		

LSD Analysis

Factor	Identity	Mean pH
Treatment 6	Depth 1	6.48 c
	Depth 2	3.99 b
	Depth 3	3.03 ab
	Depth 4	2.77 a

Table 29. Continued.

Treatment 7 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	6.009	3.005		
Depths	3	94.81	31.60	49.00	0.000
Residual	30	19.35	.6449		

LSD Analysis

Factor	Identity	Mean pH
Treatment 7	Depth 1	7.06 c
	Depth 2	3.73 b
	Depth 3	3.54 ab
	Depth 4	2.83 a

Table 30. Analysis of variance and least significant difference of Fall 1986 pH data by depth (P=0.05).

Depth 1 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.9533	.4767		
Treatments	6	160.9	26.82	146.2	0.000
Residual	54	9.906	.1834		

LSD Analysis

Factor	Identity	Mean pH
Depth 1	Treatment 1	2.77 A
	Treatment 2	7.59 D
	Treatment 3	7.43 CD
	Treatment 4	7.29 CBD
	Treatment 5	6.93 B
	Treatment 6	7.04 CB
	Treatment 7	7.49 D

Table 30. Continued.

Depth 2 pH

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	6.811	3.405		
Treatments	6	85.96	14.33	5.922	0.000
Residual	54	130.6	2.419		

LSD Analysis		
Factor	Identity	Mean pH
Depth 2	Treatment 1	2.28 A
	Treatment 2	5.27 B
	Treatment 3	4.72 B
	Treatment 4	4.13 AB
	Treatment 5	4.70 B
	Treatment 6	4.83 B
	Treatment 7	6.98 C

Depth 3 pH

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	1.371	.6857		
Treatments	6	8.522	1.420	5.895	0.000
Residual	54	13.01	.2410		

LSD Analysis		
Factor	Identity	Mean pH
Depth 3	Treatment 1	2.82 A
	Treatment 2	3.02 A
	Treatment 3	3.53 BC
	Treatment 4	3.22 AB
	Treatment 5	3.74 C
	Treatment 6	3.56 BC
	Treatment 7	3.92 C

Depth 4 pH

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	1.758	.8788		
Treatments	6	3.359	.5598	2.851	.17E-01
Residual	54	10.60	.1964		

LSD Analysis		
Factor	Identity	Mean pH
Depth 4	Treatment 1	2.96 A
	Treatment 2	2.78 A
	Treatment 3	3.39 BC
	Treatment 4	3.14 ABC
	Treatment 5	3.54 C
	Treatment 6	3.12 ABC
	Treatment 7	3.09 AB

Table 31. Analysis of variance and least significant difference of Fall 1986 pH by treatment (P=0.05).

Treatment 1 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	4.466	2.233		
Depths	3	.2142	.72E-01	1.318	.2862
Residual	30	1.624	.54E-01		

LSD Analysis

Factor	Identity	Mean pH
Treatment 1	Depth 1	2.77 a
	Depth 2	2.78 a
	Depth 3	2.82 a
	Depth 4	2.96 a

Treatment 2 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.69E-01	.35E-01		
Depths	3	136.0	45.32	34.39	0.000
Residual	30	39.54	1.318		

LSD Analysis

Factor	Identity	Mean pH
Treatment 2	Depth 1	7.59 c
	Depth 2	5.27 b
	Depth 3	3.02 a
	Depth 4	2.78 a

Treatment 3 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	4.886	2.443		
Depths	3	94.89	31.63	47.47	0.000
Residual	30	19.99	.6662		

LSD Analysis

Factor	Identity	Mean pH
Treatment 3	Depth 1	7.43 c
	Depth 2	4.72 b
	Depth 3	3.52 a
	Depth 4	3.39 a

Table 31. Continued.

Treatment 4 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	1.328	.6640		
Depths	3	102.6	34.20	69.84	0.000
Residual	30	14.69	.4897		

LSD Analysis

Factor	Identity	Mean pH
Treatment 4	Depth 1	7.29 c
	Depth 2	4.13 b
	Depth 3	3.22 a
	Depth 4	3.14 a

Treatment 5 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	1.039	.5194		
Depths	3	65.41	21.80	22.11	0.000
Residual	30	29.59	.9862		

LSD Analysis

Factor	Identity	Mean pH
Treatment 5	Depth 1	6.93 c
	Depth 2	4.72 b
	Depth 3	3.74 a
	Depth 4	3.54 a

Treatment 6 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	9.282	4.641		
Depths	3	83.40	27.80	25.84	0.000
Residual	30	32.27	1.076		

LSD Analysis

Factor	Identity	Mean pH
Treatment 6	Depth 1	7.04 c
	Depth 2	4.83 b
	Depth 3	3.56 a
	Depth 4	3.12 a

Table 31. Continued.

Treatment 7 pH

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	1.518	.7590		
Depths	3	129.2	43.08	87.53	0.000
Residual	30	14.77	.4922		

LSD Analysis

Factor	Identity	Mean pH
Treatment 7	Depth 1	7.49 c
	Depth 2	6.98 b
	Depth 3	3.92 a
	Depth 4	3.09 a

Table 32. Analysis of variance and least significant difference of Germination density, total (P=0.05).

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	9.166	4.583		
Treatments	6	164.3	27.39	71.21	0.000
Categories	3	1171.	390.4	1015.	0.000
Treat x Cat	18	117.0	6.502	16.90	0.000
Residual	2910	1119.	.3827		

LSD Analysis

Factor	Identity	Total Mean Density
Treatments	1	64.1 A
	2	116.8 C
	3	140.1 C
	4	87.3 B
	5	64.2 A
	6	222.8 D
	7	305.7 E

Table 33. Analysis of variance and least significant difference of Germination density by category (P=0.05).

Seeded grass

ANOV

Source_	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	11.44	5.721		
Treatments	6	208.6	34.77	31.12	0.000
Residual	726	811.2	1.117		

LSD Analysis

Factor	Identity	Mean Density
Seeded grass	Treatment 1	63.0 A
	Treatment 2	102.3 BC
	Treatment 3	127.0 C
	Treatment 4	77.7 AB
	Treatment 5	56.0 A
	Treatment 6	164.5 D
	Treatment 7	252.3 E

Seeded forb

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.9225	.4612		
Treatments	6	60.45	10.07	32.68	0.000
Residual	726	223.8	.3083		

LSD Analysis

Factor	Identity	Mean Density
Seeded forb	Treatment 1	1.0 A
	Treatment 2	12.7 B
	Treatment 3	10.3 B
	Treatment 4	7.7 B
	Treatment 5	7.7 B
	Treatment 6	40.2 C
	Treatment 7	43.3 C

Table 33. Continued.

Non-seeded forb

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.3808	.1904		
Treatments	6	2.182	.3637	7.215	0.000
Residual	726	36.60	.50E-01		

LSD Analysis		
Factor	Identity	Mean Density
Non-seeded forb	Treatment 1	0.1 A
	Treatment 2	1.8 AB
	Treatment 3	2.8 BC
	Treatment 4	1.9 AB
	Treatment 5	0.5 A
	Treatment 6	5.7 D
	Treatment 7	4.8 D

Non-seeded shrub

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	2.258	1.129		
Treatments	6	10.10	1.648	29.14	0.000
Residual	726	41.96	.58E-01		

LSD Analysis		
Factor	Identity	Mean Density
Non-seeded shrub	Treatment 1	0.0 A
	Treatment 2	0.0 A
	Treatment 3	0.0 A
	Treatment 4	0.0 A
	Treatment 5	0.0 A
	Treatment 6	5.3 B
	Treatment 7	12.4 C

Table 34. Analysis of variance and least significant difference of Germination density by treatment (P=0.05).

Treatment 1

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	6.871	3.435		
Categories	3	91.60	30.53	123.3	0.000
Residual	414	102.5	.2477		

LSD Analysis

Factor	Identity	Mean Density
Treatment 1	Seeded grass	63.0 b
	Seeded forb	1.0 a
	Non-seeded forb	0.0 a
	Non-seeded shrub	0.0 a

Treatment 2

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	10.94	5.471		
Categories	3	155.0	51.66	161.0	0.000
Residual	414	132.8	.3208		

LSD Analysis

Factor	Identity	Mean Density
Treatment 2	Seeded grass	102.3 c
	Seeded forb	12.7 b
	Non-seeded forb	1.8 a
	Non-seeded shrub	0.0 a

Treatment 3

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.2385	.1192		
Categories	3	206.8	68.92	181.8	0.000
Residual	414	157.0	.3791		

LSD Analysis

Factor	Identity	Mean Density
Treatment 3	Seeded grass	127.0 c
	Seeded forb	10.3 b
	Non-seeded forb	2.8 a
	Non-seeded shrub	0.0 a

Table 34. Continued.

Treatment 4

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	9.779	4.890		
Categories	3	109.1	36.36	124.0	0.000
Residual	414	121.4	.2933		

LSD Analysis

Factor	Identity	Mean Density
Treatment 4	Seeded grass	77.7 c
	Seeded forb	7.7 b
	Non-seeded forb	1.9 a
	Non-seeded shrub	0.0 a

Treatment 5

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	2.674	1.337		
Categories	3	70.92	23.64	121.9	0.000
Residual	414	80.27	.1939		

LSD Analysis

Factor	Identity	Mean Density
Treatment 5	Seeded grass	56.0 c
	Seeded forb	7.7 b
	Non-seeded forb	0.5 a
	Non-seeded shrub	0.0 a

Treatment 6

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	8.901	4.450		
Categories	3	223.3	74.43	133.1	0.000
Residual	414	231.5	.5593		

LSD Analysis

Factor	Identity	Mean Density
Treatment 6	Seeded grass	164.5 c
	Seeded forb	40.2 b
	Non-seeded forb	5.7 a
	Non-seeded shrub	12.4 a

Table 34. Continued.

Treatment 7

Source	D.F.	S.S.	M.S.	F-value	P-value
		ANOV			
Blocks	2	6.768	3.384		
Categories	3	431.7	143.9	232.0	0.000
Residual	414	256.8	.6204		

LSD Analysis

Factor	Identity	Mean Density
Treatment 7	Seeded grass	252.3 c
	Seeded forb	43.3 b
	Non-seeded forb	4.8 a
	Non-seeded shrub	5.3 a

Table 35. Analysis of variance and least significant difference of Percent Canopy Cover, total, 1985 (P=0.05).

Source	D.F.	S.S.	M.S.	F-value	P-value
		ANOV			
Blocks	2	.8460	.4230		
Treatments	6	50.28	8.380	144.4	0.000
Categories	3	71.70	23.90	411.8	0.000
Treat x Cat	18	12.23	.6796	11.71	0.000
Residual	1146	66.51	.58E-01		

LSD Analysis

Factor	Identity	Total Percent Cover
Treatments	1	0.6 A
	2	4.1 C
	3	1.5 AB
	4	2.8 B
	5	2.9 B
	6	18.4 D
	7	19.9 D

Table 36. Analysis of variance and least significant difference of Percent Canopy Cover by category, 1985 (P=0.05).

Seeded grass

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	1.565	.7826		
Treatments	6	36.99	6.164	74.89	0.000
Residual	285	23.46	.82E-01		

LSD Analysis

Factor	Identity	Mean Cover
Seeded grass	Treatment 1	0.6 A
	Treatment 2	3.9 D
	Treatment 3	1.5 B
	Treatment 4	2.6 C
	Treatment 5	2.2 CB
	Treatment 6	15.8 E
	Treatment 7	13.9 E

Seeded forb

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.1065	.53E-01		
Treatments	6	6.385	1.064	65.28	0.000
Residual	285	4.646	.16E-01		

LSD Analysis

Factor	Identity	Mean Cover
Seeded forb	Treatment 1	0.0 A
	Treatment 2	0.0 A
	Treatment 3	0.0 A
	Treatment 4	0.2 A
	Treatment 5	0.7 A
	Treatment 6	0.9 B
	Treatment 7	1.4 C

Table 36. Continued.

Non-seeded forb

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.82E-01	.41E-01		
Treatments	6	15.27	2.544	27.50	0.000
Residual	285	26.37	.93E-01		

LSD Analysis		
Factor	Identity	Mean Cover
Non-seeded forb	Treatment 1	0.0 A
	Treatment 2	0.2 A
	Treatment 3	0.0 A
	Treatment 4	0.0 A
	Treatment 5	0.0 A
	Treatment 6	2.2 B
	Treatment 7	2.4 B

Non-seeded shrub

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.6848	.3424		
Treatments	6	3.873	.6456	17.62	0.000
Residual	285	10.44	.37E-01		

LSD Analysis		
Factor	Identity	Mean Cover
Non-seeded shrub	Treatment 1	0.0 A
	Treatment 2	0.0 A
	Treatment 3	0.0 A
	Treatment 4	0.0 A
	Treatment 5	0.0 A
	Treatment 6	1.0 B
	Treatment 7	0.7 B

Table 37. Analysis of variance and least significant difference of Percent Canopy Cover by treatment, 1985 (P=0.05).

Treatment 1

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.1242	.62E-01		
Categories	3	1.421	.4736	23.31	0.000
Residual	162	3.291	.20E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 1	Seeded grass	0.6 b
	Seeded forb	0.0 a
	Non-seeded forb	0.0 a
	Non-seeded shrub	0.0 a

Treatment 2

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.7783	.3891		
Categories	3	13.57	4.522	100.8	0.000
Residual	162	7.267	.45E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 2	Seeded grass	3.9 b
	Seeded forb	0.0 a
	Non-seeded forb	0.2 a
	Non-seeded shrub	0.0 a

Treatment 3

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.28E-02	.14E-02		
Categories	3	4.972	1.657	109.3	0.000
Residual	162	2.456	.15E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 3	Seeded grass	1.5 b
	Seeded forb	0.0 a
	Non-seeded forb	0.0 a
	Non-seeded shrub	0.0 a

Table 37. Continued.

Treatment 4

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.2285	.1142		
Categories	3	9.466	3.155	109.0	0.000
Residual	162	4.688	.29E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 4	Seeded grass	2.6 b
	Seeded forb	0.2 a
	Non-seeded forb	0.0 a
	Non-seeded shrub	0.0 a

Treatment 5

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.2061	.1031		
Categories	3	7.673	2.558	97.02	0.000
Residual	162	4.271	.26E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 5	Seeded grass	2.2 b
	Seeded forb	0.7 a
	Non-seeded forb	0.0 a
	Non-seeded shrub	0.0 a

Treatment 6

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	1.766	.8828		
Categories	3	25.28	8.427	70.60	0.000
Residual	162	19.34	.1194		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 6	Seeded grass	15.8 c
	Seeded forb	0.9 a
	Non-seeded forb	2.0 b
	Non-seeded shrub	1.0 a

Table 37. Continued.

Treatment 7

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.7585	.3793		
Categories	3	21.55	7.184	52.46	0.000
Residual	162	22.18	.1369		

LSD Analysis

Factor	Identity	Mean Density
Treatment 7	Seeded grass	13.9 c
	Seeded forb	1.4 ab
	Non-seeded forb	2.4 a
	Non-seeded shrub	0.7 a

Table 38. Analysis of variance and least significant difference of Percent Canopy Cover, total, 1986 (P=0.05).

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.2256	.1128		
Treatments	6	65.79	10.97	190.7	0.000
Categories	3	166.9	55.65	968.0	0.000
Treat x Cat	18	33.94	1.886	32.80	0.000
Residual	1146	65.88	.57E-01		

LSD Analysis

Factor	Identity	Total Mean Cover
Treatments	1	0.0 A
	2	11.0 C
	3	5.1 B
	4	8.4 C
	5	10.6 C
	6	40.0 D
	7	45.5 D

Table 39. Analysis of variance and least significant difference of Percent Canopy Cover by category 1986 (P=0.05).

Seeded grass

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.2218	.1109		
Treatments	6	74.15	12.36	133.5	0.000
Residual	285	26.38	.93E-01		

LSD Analysis		
Factor	Identity	Mean Cover
Seeded grass	Treatment 1	0.0 A
	Treatment 2	10.8 C
	Treatment 3	4.7 B
	Treatment 4	8.0 C
	Treatment 5	10.3 C
	Treatment 6	35.7 D
	Treatment 7	40.7 D

Seeded forb

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.59E-01	.29E-01		
Treatments	6	12.11	2.019	56.56	0.000
Residual	285	10.17	.36E-01		

LSD Analysis		
Factor	Identity	Mean Cover
Seeded forb	Treatment 1	0.0 A
	Treatment 2	0.0 A
	Treatment 3	0.1 A
	Treatment 4	0.1 A
	Treatment 5	0.1 A
	Treatment 6	1.5 B
	Treatment 7	2.2 C

Table 39. Continued.

Non-seeded forb

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.2196	.1098		
Treatments	6	5.792	.9653	16.65	0.000
Residual	285	16.53	.58E-01		

LSD Analysis		
Factor	Identity	Mean Cover
Non-seeded forb	Treatment 1	0.0 A
	Treatment 2	0.1 A
	Treatment 3	0.2 A
	Treatment 4	0.1 A
	Treatment 5	0.1 A
	Treatment 6	1.3 B
	Treatment 7	1.2 B

Non-seeded grass

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.24E-01	.1192E-01		
Treatments	6	7.679	1.280	29.17	0.000
Residual	285	12.51	.44E-01		

LSD Analysis		
Factor	Identity	Mean Cover
Non-seeded shrub	Treatment 1	0.0 A
	Treatment 2	0.1 A
	Treatment 3	0.1 A
	Treatment 4	0.2 A
	Treatment 5	0.1 A
	Treatment 6	1.5 B
	Treatment 7	1.3 B

Table 40. Analysis of variance and least significant difference of Percent Canopy Cover by treatment, 1986 (P=0.05).

Treatment 1

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.13E-16	.68E-17		
Categories	3	.26E-18	.86E-19		
Residual	162	0.000	0.000		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 1	Seeded grass	0.0 a
	Seeded forb	0.0 a
	Non-seeded forb	0.0 a
	Non-seeded grass	0.0 a

Treatment 2

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.1267	.63E-01		
Categories	3	34.12	11.37	223.5	0.000
Residual	162	8.244	.51E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 2	Seeded grass	10.8 b
	Seeded forb	0.0 a
	Non-seeded forb	0.1 a
	Non-seeded grass	0.1 a

Treatment 3

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.2417	.1209		
Categories	3	16.50	5.501	106.3	0.000
Residual	162	8.383	.52E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 3	Seeded grass	4.7 b
	Seeded forb	0.1 a
	Non-seeded forb	0.2 a
	Non-seeded grass	0.1 a

Table 40. Continued.

Treatment 4

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.99E-01	.47E-01		
Categories	3	25.98	8.660	134.6	0.000
Residual	162	10.42	.64E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 4	Seeded grass	8.0 b
	Seeded forb	0.1 a
	Non-seeded forb	0.1 a
	Non-seeded grass	0.2 a

Treatment 5

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.26E-01	.13E-01		
Categories	3	33.40	11.13	419.8	0.000
Residual	162	4.297	.27E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 5	Seeded grass	10.3 b
	Seeded forb	0.1 a
	Non-seeded forb	0.1 a
	Non-seeded grass	0.1 a

Treatment 6

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	1.190	.5952		
Categories	3	43.80	14.60	163.4	0.000
Residual	162	14.47	.89E-01		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 6	Seeded grass	35.7 b
	Seeded forb	1.5 a
	Non-seeded forb	1.3 a
	Non-seeded grass	1.5 a

Table 40. Continued.

Treatment 7

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.1271	.64E-01		
Categories	3	47.08	15.69	137.6	0.000
Residual	162	18.48	.1141		

LSD Analysis

Factor	Identity	Mean Cover
Treatment 7	Seeded grass	40.7 c
	Seeded forb	2.2 b
	Non-seeded forb	1.2 a
	Non-seeded grass	1.5 a

Table 41. Analysis of variance and least significant difference of Biomass Production (kg/ha), total, 1985 (P=0.05).

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.1113	.56E-01		
Treatments	6	7.983	1.331	83.90	0.000
Categories	3	1.513	.5043	31.80	0.000
Treat x Cat	18	1.628	.90E-01	5.705	0.000
Residual	390	6.185	.16E-01		

LSD Analysis

Factor	Identity	Total Mean Production
Treatments	1	0.9 A
	2	2.5 A
	3	1.0 A
	4	1.6 A
	5	1.8 A
	6	34.8 B
	7	45.1 C

Table 42. Analysis of variance and least significant difference of Biomass Production (kg/ha) by category, 1985 (P=0.05).

Seeded grass

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.63E-01	.32E-01		
Treatments	6	4.747	.7912	88.26	0.000
Residual	96	.8606	.90E-02		

LSD Analysis

Factor	Identity	Mean Production
Seeded grass	Treatment 1	0.6 A
	Treatment 2	2.3 B
	Treatment 3	1.0 AB
	Treatment 4	1.6 AB
	Treatment 5	1.7 AB
	Treatment 6	13.2 C
	Treatment 7	25.9 D

Seeded forb

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.54E-02	.27E-02		
Treatments	6	.43342	.72E-01	19.31	0.000
Residual	96	.3590	.37E-02		

LSD Analysis

Factor	Identity	Mean Production
Seeded forb	Treatment 1	0.1 A
	Treatment 2	0.1 A
	Treatment 3	0.0 A
	Treatment 4	0.1 A
	Treatment 5	0.1 A
	Treatment 6	2.3 B
	Treatment 7	3.7 C

Table 42. Continued.

Non-seeded forb

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.85E-01	.42E-01		
Treatments	6	2.991	.4985	14.98	0.000
Residual	96	3.195	.33E-01		

LSD Analysis		
Factor	Identity	Mean Production
Non-seeded forb	Treatment 1	0.2 A
	Treatment 2	0.1 A
	Treatment 3	0.0 A
	Treatment 4	0.0 A
	Treatment 5	0.0 A
	Treatment 6	13.5 B
	Treatment 7	8.3 B

Non-seeded shrub

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.1374	.69E-01		
Treatments	6	1.440	.2400	14.48	0.000
Residual	96	1.591	.17E-01		

LSD Analysis		
Factor	Identity	Mean Production
Non-seeded shrub	Treatment 1	0.0 A
	Treatment 2	0.0 A
	Treatment 3	0.0 A
	Treatment 4	0.0 A
	Treatment 5	0.0 A
	Treatment 6	5.8 B
	Treatment 7	7.2 B

Table 43. Analysis of variance and least significant difference of Biomass Production (kg/ha) by treatment, 1985 (P=0.05).

Treatment 1

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.92E-02	.46E-02		
Categories	3	.12E-01	.40E-02	4.539	.68E-01
Residual	54	.47E-01	.87E-03		

LSD Analysis

Factor	Identity	Mean Production
Treatment 1	Seeded grass	0.6 b
	Seeded forb	0.1 a
	Non-seeded forb	0.2 a
	Non-seeded shrub	0.0 a

Treatment 2

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.66E-02	.33E-02		
Categories	3	.1326	.44E-01	67.50	0.000
Residual	54	.35E-01	.65E-03		

LSD Analysis

Factor	Identity	Mean Production
Treatment 2	Seeded grass	2.3 b
	Seeded forb	0.1 a
	Non-seeded forb	0.1 a
	Non-seeded shrub	0.0 a

Treatment 3

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.45E-03	.22E-03		
Categories	3	.30E-01	.98E-02	26.36	0.000
Residual	54	.20E-01	.37E-03		

LSD Analysis

Factor	Identity	Mean Production
Treatment 3	Seeded grass	1.0 b
	Seeded forb	0.0 a
	Non-seeded forb	0.0 a
	Non-seeded shrub	0.0 a

Table 43. Continued.

Treatment 4

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.10E-01	.51E-02		
Categories	3	.71E-01	.24E-01	14.05	0.000
Residual		54	.91E-01		.17E-02

LSD Analysis

Factor	Identity	Mean Production
Treatment 4	Seeded grass	1.6 b
	Seeded forb	0.1 a
	Non-seeded forb	0.1 a
	Non-seeded shrub	0.0 a

Treatment 5

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.31E-02	.15E-02		
Categories	3	.79E-01	.26E-01	29.78	0.000
Residual	54	.48E-01	.88E-03		

LSD Analysis

Factor	Identity	Mean Production
Treatment 5	Seeded grass	1.7 b
	Seeded forb	0.1 a
	Non-seeded forb	0.0 a
	Non-seeded shrub	0.0 a

Treatment 6

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.2352	.1176		
Categories	3	1.077	.3592	6.273	.13E-02
Residual	54	3.092	.57E-01		

LSD Analysis

Factor	Identity	Mean Production
Treatment 6	Seeded grass	13.2 b
	Seeded forb	2.3 a
	Non-seeded forb	13.5 b
	Non-seeded shrub	5.8 a

Table 43. Continued.

Treatment 7

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.1649	.82E-01		
Categories	3	1.740	.5801	12.36	0.000
Residual	54	2.534	.47E-01		

LSD Analysis

Factor	Identity	Mean Production
Treatment 7	Seeded grass	25.9 b
	Seeded forb	3.7 a
	Non-seeded forb	8.3 a
	Non-seeded shrub	7.2 a

Table 44. Analysis of variance and least significant difference of Biomass Production (kg/ha), total, 1986 (P=0.05).

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.82E-01	.41E-01		
Treatments	6	25.65	4.276	94.34	0.000
Categories	3	73.88	24.63	543.4	0.000
Treat x Cat	18	22.59	1.255	27.69	0.000
Residual	390	17.68	.45E-01		

LSD Analysis

Factor	Identity	Total Mean Production
Treatments	1	0.0 A
	2	182.6 D
	3	18.0 B
	4	61.1 C
	5	133.7 D
	6	458.7 E
	7	537.0 E

Table 45. Analysis of variance and least significant difference of Biomass Production (kg/ha) by category, 1986 (P=0.05).

Seeded grass

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.54E-02	.27E-02		
Treatments	6	39.43	6.572	59.22	0.000
Residual	96	10.65	.1110		

LSD Analysis

Factor	Identity	Mean Production
Seeded grass	Treatment 1	0.0 A
	Treatment 2	181.6 D
	Treatment 3	15.5 B
	Treatment 4	60.4 C
	Treatment 5	132.5 D
	Treatment 6	429.4 E
	Treatment 7	501.3 E

Seeded forb

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.59E-01	.29E-01		
Treatments	6	2.175	.3624	19.47	0.000
Residual	96	1.787	.19E-01		

LSD Analysis

Factor	Identity	Mean Production
Seeded forb	Treatment 1	0.0 A
	Treatment 2	0.1 A
	Treatment 3	0.3 A
	Treatment 4	0.0 A
	Treatment 5	0.0 A
	Treatment 6	4.0 B
	Treatment 7	12.4 C

Table 45. Continued.

Non-seeded forb

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.1046	.52E-01		
Treatments	6	1.286	.2143	6.78	0.000
Residual	96	3.035	.32E-01		

LSD Analysis		
Factor	Identity	Mean Production
Non-seeded forb	Treatment 1	0.0 A
	Treatment 2	0.5 AB
	Treatment 3	2.2 AB
	Treatment 4	0.7 AB
	Treatment 5	0.8 AB
	Treatment 6	9.7 C
	Treatment 7	3.3 B

Non-seeded grass

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.41E-01	.20E-01		
Treatments	6	5.347	.8911	41.27	0.000
Residual	96	2.073	.22E-01		

LSD Analysis		
Factor	Identity	Mean Production
Non-seeded grass	Treatment 1	0.0 A
	Treatment 2	0.4 A
	Treatment 3	0.0 A
	Treatment 4	0.0 A
	Treatment 5	0.4 A
	Treatment 6	15.6 B
	Treatment 7	20.0 B

Table 46. Analysis of variance and least significant difference of Biomass Production (kg/ha) by treatment, 1986 (P=0.05).

Treatment 1

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.32E-16	.16E-16		
Categories	3	.92E-19	.31E-19		
Residual	54	0.000	0.000		

LSD Analysis

Factor	Identity	Mean Production
Treatment 1	Seeded grass	0.0 a
	Seeded forb	0.0 a
	Non-seeded forb	0.0 a
	Non-seeded grass	0.0 a

Treatment 2

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.1089	.54E-01		
Categories	3	20.72	6.906	210.3	0.000
Residual	54	1.773	.33E-01		

LSD Analysis

Factor	Identity	Mean Production
Treatment 2	Seeded grass	181.6 b
	Seeded forb	0.1 a
	Non-seeded forb	0.5 a
	Non-seeded grass	0.4 a

Treatment 3

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.50E-01	.25E-01		
Categories	3	2.171	.7238	12.76	0.000
Residual	54	3.063	.57E-01		

LSD Analysis

Factor	Identity	Mean Production
Treatment 3	Seeded grass	15.5 b
	Seeded forb	0.3 a
	Non-seeded forb	2.0 a
	Non-seeded grass	0.0 a

Table 46. Continued.

Treatment 4

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.68E-01	.34E-01		
Categories	3	9.524	3.175	60.65	0.000
Residual	54	2.826	.52E-01		

LSD Analysis

Factor	Identity	Mean Production
Treatment 4	Seeded grass	60.4 b
	Seeded forb	0.0 a
	Non-seeded forb	0.1 a
	Non-seeded grass	0.0 a

Treatment 5

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.1987	.99E-01		
Categories	3	16.80	5.600	101.1	0.000
Residual	54	2.990	.55E-01		

LSD Analysis

Factor	Identity	Mean Production
Treatment 5	Seeded grass	132.5 b
	Seeded forb	0.0 a
	Non-seeded forb	0.8 a
	Non-seeded grass	0.4 a

Treatment 6

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.3876	.1938		
Categories	3	22.89	7.628	173.5	0.000
Residual	54	2.374	.44E-01		

LSD Analysis

Factor	Identity	Mean Production
Treatment 6	Seeded grass	429.4 c
	Seeded forb	4.0 a
	Non-seeded forb	9.7 b
	Non-seeded grass	15.6 b

Table 46. Continued.

Treatment 7

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Blocks	2	.1943	.97E-01		
Categories	3	24.37	8.123	117.8	0.000
Residual	54	3.723	.69E-01		

LSD Analysis

Factor	Identity	Mean Production
Treatment 7	Seeded grass	501.3 c
	Seeded forb	12.4 b
	Non-seeded forb	3.3 a
	Non-seeded grass	20.0 b

Table 47. Analysis of variance and least significant difference of Rooting Depth (P=0.05).

Source	D.F.	ANOV S.S.	M.S.	F-value	P-value
Replications	2	27.44	13.72		
Treatments	5	5047.	1009.	18.81	0.000
Residual	10	536.6	53.66		

LSD Analysis

Factor	Identity	Mean Temperature
Rooting depth	Treatment 2	34.33 A
	Treatment 3	32.67 A
	Treatment 4	32.00 A
	Treatment 5	75.00 B
	Treatment 6	42.67 A
	Treatment 7	64.00 B

Table 48. Analysis of variance and least significant difference of Root Abundance by depth for the coversoil treatments.

15 cm coversoil

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Treatments	4	5.40	1.35	5.49	0.000
Error	10	2.46	0.25		

LSD Analysis

Factor	Identity	Mean Abundance
Depth	0-10 cm	1.9 b
	10-15 cm	2.4 c
	0-10 cm	2.8 c
	10-20 cm	2.4 c
	20-35 cm	1.1 a

30 cm coversoil

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Treatments	5	3.98	0.80	6.19	0.000
Error	12	1.54	0.13		

LSD Analysis

Factor	Identity	Mean Abundance
Depth	0-15 cm	2.0 a
	15-25 cm	2.2 a
	25-30 cm	2.3 a
	0-10 cm	3.1 b
	10-20 cm	3.2 b
	20-35 cm	2.9 b

Table 49. Analysis of variance and least significant difference of Root Abundance by size (P=0.05).

Very Fine Roots

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.6663	.3332		
Treatments	6	2.760	.5521	2.135	.1438
Residual	10	2.586	.2586		

LSD Analysis

Factor	Identity	Mean Number
Very Fine	Treatment 2	2.6 B
	Treatment 3	1.8 AB
	Treatment 4	1.9 AB
	Treatment 5	2.5 AB
	Treatment 6	1.6 A
	Treatment 7	2.5 AB

Fine Roots

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.6274	.3137		
Treatments	5	1.192	.2384	1.683	.2257
Residual	10	1.417	.1417		

LSD Analysis

Factor	Identity	Mean Number
Fine	Treatment 2	2.4 A
	Treatment 3	1.8 A
	Treatment 4	1.9 A
	Treatment 5	2.3 A
	Treatment 6	1.8 A
	Treatment 7	2.3 A

Table 49. Continued.

Medium Roots

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.20E-02	.10E-02		
Treatments	5	1.260	.2519	1.991	.1655
Residual	10	1.265	.1265		

LSD Analysis

Factor	Identity	Mean Number
Medium	Treatment 2	1.6 AB
	Treatment 3	1.5 AB
	Treatment 4	1.7 AB
	Treatment 5	1.8 AB
	Treatment 6	1.3 A
	Treatment 7	2.1 B

Coarse Roots

ANOV

Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	.3090	.1545		
Treatments	5	.9764	.1953	.6931	.6418
Residual	10	2.818	.2818		

LSD Analysis

Factor	Identity	Mean Number
Coarse	Treatment 2	1.4 A
	Treatment 3	1.5 A
	Treatment 4	2.0 A
	Treatment 5	1.7 A
	Treatment 6	1.3 A
	Treatment 7	1.4 A

Table 50. Analysis of variance and least significant difference of Temperature by depth (P=0.05).

1 Centimeter Depth

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Treatments	5	423.9	84.79	1.104	.3691
Residual	54	4146.	76.79		

LSD Analysis		
Factor	Identity	Mean Temperature
1 cm depth	Treatment 1	30.25 AB
	Treatment 2	30.45 AB
	Treatment 3	32.00 AB
	Treatment 4	34.70 B
	Treatment 6	29.00 AB
	Treatment 7	26.00 A

10 Centimeter Depth

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Treatments	5	113.6	22.72	.3591	.8744
Residual	54	3416.	63.27		

LSD Analysis		
Factor	Identity	Mean Temperature
10 cm depth	Treatment 1	20.70 A
	Treatment 2	20.40 A
	Treatment 3	23.55 A
	Treatment 4	22.70 A
	Treatment 6	20.40 A
	Treatment 7	19.76 A

25 Centimeter Depth

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Treatments	5	8.447	1.689	.30E-01	.9986
Residual	54	3016.	55.85		

LSD Analysis		
Factor	Identity	Mean Temperature
25 cm depth	Treatment 1	18.87 A
	Treatment 2	18.45 A
	Treatment 3	18.17 A
	Treatment 4	18.60 A
	Treatment 6	17.90 A
	Treatment 7	17.82 A

Table 50. Continued.

50 Centimeter Depth

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Treatments	5	10.91	2.181	.40E-01	.9979
Residual	54	2927.	54.20		

LSD Analysis		
Factor	Identity	Mean Temperature
50 cm depth	Treatment 1	18.22 A
	Treatment 2	17.30 A
	Treatment 3	17.40 A
	Treatment 4	17.80 A
	Treatment 6	16.85 A
	Treatment 7	17.40 A

Table 51. Analysis of variance and least significant difference of Surface Temperature (P=0.05).

1985

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	4.333	2.167		
Treatments	6	347.7	57.94	3.519	.85E-02
Residual	33	543.4	16.47		

LSD Analysis		
Factor	Identity	Mean Temperature
1985	Treatment 1	47.3 B
	Treatment 2	47.1 B
	Treatment 3	47.0 B
	Treatment 4	47.2 B
	Treatment 5	47.3 B
	Treatment 6	41.6 A
	Treatment 7	40.2 A

1986

ANOV					
Source	D.F.	S.S.	M.S.	F-value	P-value
Blocks	2	11.03	5.514		
Treatments	6	1654.	275.6	8.908	0.000
Residual	33	2970	30.94		

LSD Analysis		
Factor	Identity	Mean Temperature
1986	Treatment 1	38.2 C
	Treatment 2	33.9 B
	Treatment 3	35.6 CB
	Treatment 4	35.5 CB
	Treatment 5	33.8 B
	Treatment 6	27.4 A
	Treatment 7	26.9 A