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

Douglas J. Dollhopf — Chairperson, Graduate Committee

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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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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).

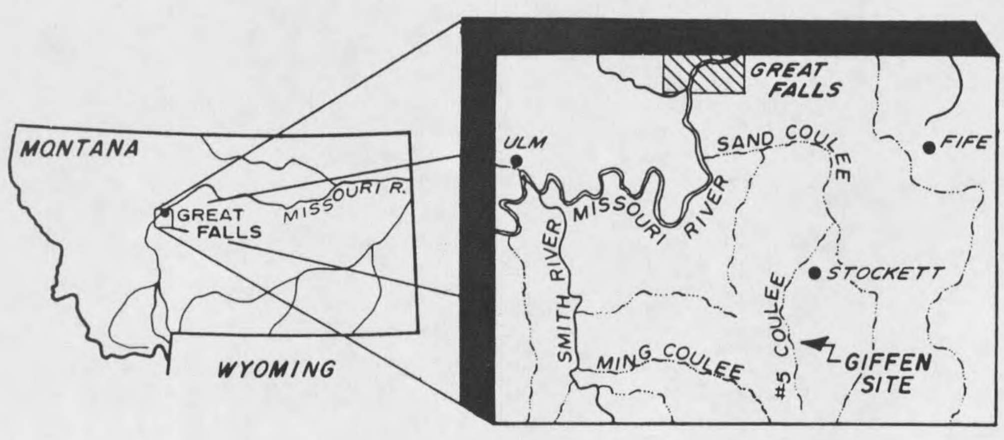

Figure 1. Location of the Giffen site, Stockett, Montana.

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	$CaCO_3$, 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

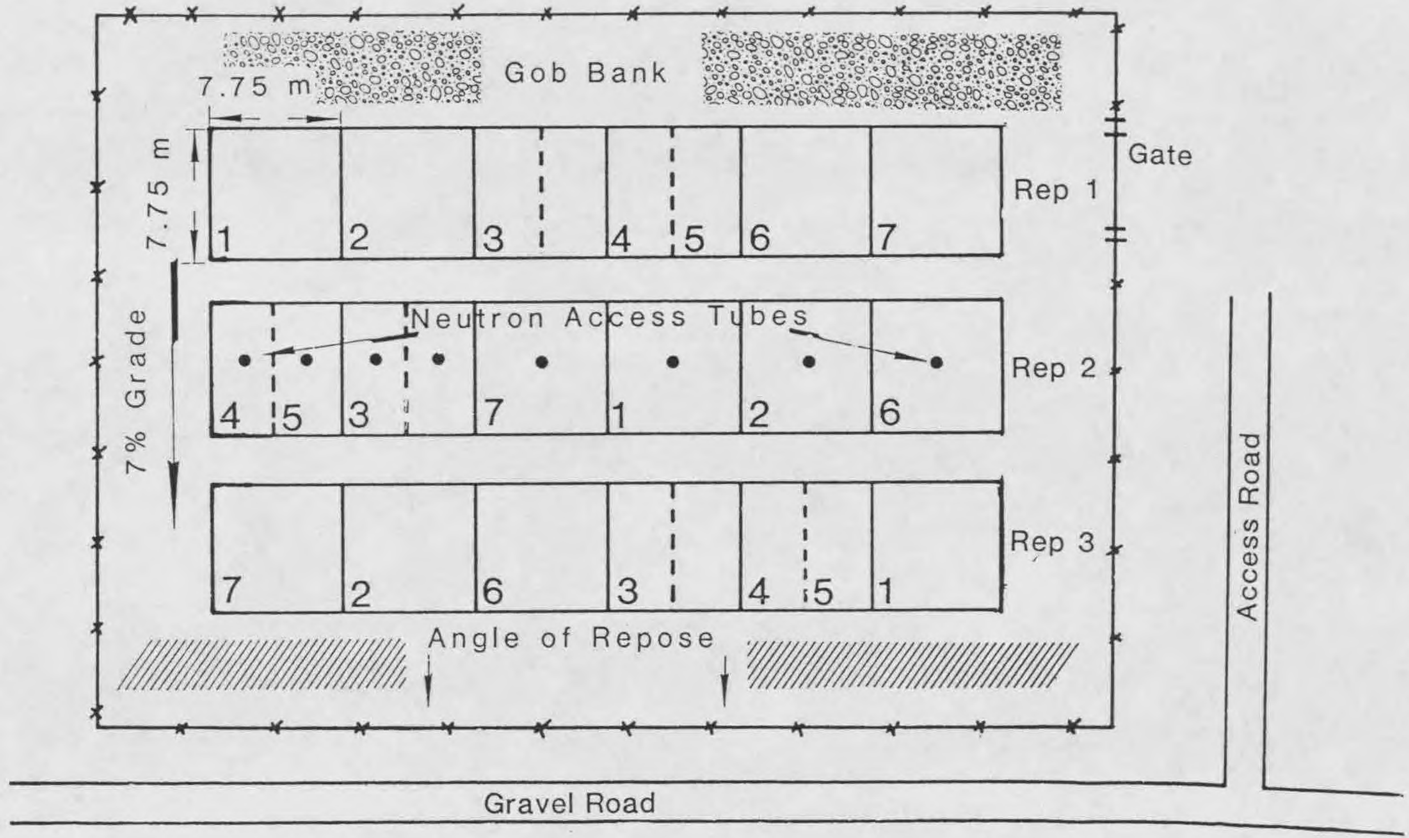

Figure 2. Field plot design implemented at the Giffen site.

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 (≥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