VEGETATING COAL REFUSE WITH A SOIL COVER AND CHEMICAL AMENDMENTS[1]

by

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Abstract. Coal refuse, a waste product of coal cleaning and preparation plants, commonly has a variety of chemical and physical properties which adversely affect establishment of vegetation. The objective of this study was to compare the effects of 0, 7.5, 15, and 30 cm of soil cover in conjunction with chemical treatments of rock phosphate, lime, triple superphosphate, and fly ash on the establishment and growth of grasses and legumes on an active refuse pile in northern West Virginia. Dry matter yields and percent ground cover were measured on each plot for two years. Soil samples were collected at the end of the second growing season from the cover soil surface, from above the refuse/soil interface, and from below the refuse/soil interface of each plot, and analyzed for chemical and physical properties. The fly ash and all lime treatments neutralized the acidity of the refuse without a soil cover, but vegetative yields were low and ground cover was less than 30%. Since the acidity was neutralized, these low yields were probably related to the low water holding capacity of the refuse. Plots with soil cover had greater than 60% ground cover of vegetation for two years regardless of refuse treatment or cover thickness.

Additional Key Words: Minesoil, Reclamation, Topsoil Substitute.

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Introduction

Coal refuse commonly has high levels of pyritic sulfur and associated acidity, high concentrations of soluble salts, low concentrations of plant available nutrients, low water holding capacity, and other properties which adversely affect establishment and growth of vegetation. Coal Refuse Disposal Regulations of the West Virginia Division of Energy (WVDOE) state that at abandonment, all coal refuse shall be covered with a minimum of 120 cm of the best available non-toxic and non-combustible material in a manner that does not impede flow from subdrainage systems. The Director of WVDOE may allow less than 120 cm cover material if the coal company can demonstrate that requirements of Section 4F of the West Virginia Surface Mining Regulations will be met. Section 4F requires the quick establishment of vegetative cover on all disturbed areas to minimize erosion, provide economic benefits, and restore aesthetic appeal.

The process of covering refuse piles with soil is very expensive, and the site from which the soil was removed usually requires some reclamation. It has been hypothesized that it is more economical to treat the refuse and use a thinner soil cover. Common chemical treatments for refuse and acid minesoils have been fly ash, lime and phosphate (either as apatite or triple superphosphate) (Buck and Houston 1988, Ghazi 1984, Bhumbla et al. 1988). The objective of this study was to determine the effects of various thicknesses of soil cover in conjunction with commonly used chemical amendments on establishment and growth of vegetation on coal refuse.

Methods and Materials

A 10- to 12-year old, nearly level portion of a 9-m thick refuse pile in Monongalia County, WV was used for the field experiment. Chemical properties of the untreated, processed coal refuse from the Pittsburgh Coal seam are presented in Table 1. The surface texture of the refuse was channery sandy loam (78% sand, 5% silt, 17% clay). The surface 8 cm had 20% rock fragments by volume increasing to 80% in the lower horizons. Additional site and morphological data are available in Clark (1992).

The following amendments were applied to the refuse and incorporated to a depth of 15 cm by discing. Elemental analyses of fly ash and rock phosphate are presented in Table 2.

1. Control (C) - No additions to refuse before adding soil.

2. Rock Phosphate (RP) - 12.9 Mg ha^{-1}. Amount of rock phosphate needed to saturate all exchange sites to a depth of 15 cm with Ca.

3. Lime (L) - 34.5 Mg ha^{-1}. Amount of agricultural limestone required to raise the pH of the top 15 cm to 6.5 according to West Virginia University Soil Testing Laboratory recommendations.

4. Triple Superphosphate and Lime (SP & L) - 36 kg ha^{-1} P_2O_5 in the form of 0-45-0 fertilizer and 34.5 Mg ha^{-1} agricultural limestone.

5. Fly ash (F) - 761 Mg ha^{-1}. Amount of fly ash (pH 11.0) required to raise the pH of the top 15 cm to 6.0.

Table 1. Chemical Properties of the Refuse and Cover Soil Before Treatment.

Property	Units	Refuse	Soil
pH	-----	2.4	4.9
Elec. Cond.	ds m^{-1}	3.9	0.3
Extr. Bases	$cmol_c\ kg^{-1}$		
Ca		1.2	0.3
Mg		1.3	0.4
K		0.8	0.1
Extr. Acidity	$cmol_c\ kg^{-1}$	10.9	1.7
Extr. Al	$cmol_c\ kg^{-1}$	2.1	0.6
ECEC[1)]	$cmol_c\ kg^{-1}$	5.4	1.4
Extr. Metals	mg g^{-1}		
Fe		1066	134
Mn		4	116
Cu		2.3	3.5
Zn		2.8	1.0
Pyritic S	%	1.45	0.01
NP[2)]	g $CaCO_3$ kg^{-1}	-2.66	9.4
B	mg g^{-1}	11.0	2.3
P	mg g^{-1}	1.4	1.0

1) ECEC = Effective Cation Exchange Capacity
2) NP = Neutralization Potential

Table 2. Total Elemental Analyses of Fly Ash and Rock Phosphate.

Element	Units	Fly Ash	Phosphate
K	%	1.6	0.9
Ca	%	4.8	20.7
Mg	%	0.4	0.5
Al	%	15.1	1.0
Fe	%	11.4	1.2
Zn	mg g^{-1}	110	108
Cu	mg g^{-1}	80	15
Mn	mg g^{-1}	200	227

6. Rock Phosphate and Lime (RP & L) - 302 kg ha^{-1} rock phosphate (30% P_2O_5) and 32.5 Mg ha^{-1} agricultural limestone to raise pH of the top 15 cm to 5.5.

After these treatments where applied, the refuse was covered with soil at thicknesses of 0, 7.5, 15, or 30 cm. Previous efforts by the coal company had indicated that vegetation could be established and maintained on similar refuse with a 30-cm thick soil cover. The company, therefore, wanted to determine if less soil could be used to achieve the required results.

A randomized, split-split plot design with four replications was employed. The main plots were soil thickness and refuse treatment with all combinations of treatments applied in the experiment. A bulldozer removed appropriate depths of refuse so that the surface of all plots was level after the different thicknesses of soil were applied. Amendments were then incorporated into the refuse at the described rates. The soil was applied in 3-m wide strips which were 36 m long. Final plot size was 3 m X 3 m. Chemical properties of the soil used in this study are presented in Table 1. The soil had a clay loam texture (27% sand, 40% silt, 33% clay) and was a mixture of B and C horizons. It fit the definition of weathered topsoil given by Smith (1973), and is commonly called "topsoil" by West Virginia coal company personnel and reclamationists. After adding the soil cover, the entire experimental area, including refuse with no soil cover, was limed with agricultural limestone at 3.14 Mg ha^{-1} and fertilized with 1120 kg ha^{-1} of 10-10-10 fertilizer according to the West Virginia University Soil Testing Laboratory recommendations for the cover soil. After thorough discing, the area was seeded by a hand-held broadcast seeder with several grasses and legumes (Table 3) and mulched with hay at the rate of 4480 kg ha^{-1}. Legume seeds were inoculated with appropriate Rhizobium at twice the normal rate immediately before seeding.

Dry matter yields were determined by hand clipping and percent ground cover was visually estimated from the center section (1.5 m X 1.5 m) of each plot to avoid border effects. These data were collected in July 1988 and 1989. Yield and cover measurements were initially planned for five years, however the coal company covered the plots with additional refuse at the end of the second growing season, terminating any further opportunity for data collection.

Before treatment, samples of soil and refuse were collected and analyzed for the following properties:

A. Chemical Properties

1. 1 <u>M</u> ammonium acetate (pH 7) extractable Ca, Mg, K (Soil Survey Staff 1984)

2. KCl-extractable acidity and Al (Yuan 1959)

3. DTPA-extractable Fe, Mn, Cu, Zn (Lindsay and Norvell 1978)

4. Electrical conductivity (EC) --1:2 soil:water suspension (Soil Survey Staff 1984)

5. Acid-Base Account: pyritic S and neutralization potential (NP) (Sobek et al. 1978)

6. Sodium bicarbonate extractable P (Lim and Jackson 1982)

7. pH--1:1 soil:water suspension (Soil Survey Staff 1984)

8. Boron--saturation extract (Bingham 1982)

B. Physical Properties

1. Texture analysis by pipette method (Soil Survey Staff 1984)

2. Moisture desorption at -33 and -1500 kPa (Soil Survey Staff 1984)

At the end of the experiment (year 2), samples were collected from the soil cover and refuse at three depths as noted below and analyzed for the same chemical properties listed above.

1. Soil surface--0 to 7.5 cm

2. 7.5 cm of soil above the refuse/soil interface

3. 7.5 cm of refuse below the refuse/soil interface.

Results and Discussion

Properties of Refuse with No Soil Cover

Although some significant differences occurred among treatments, data for Ca, Fe, Mn, Cu, Zn, and pyritic S in the refuse were very similar across all treatments where no soil cover was applied. There were no significant differences among treatments for P, Mg, K, or electrical conductivity. These data are not presented in this paper, but they are available in Clark (1992).

Significant differences were observed for most of the properties related to acidity (Table 4). Except for the control plot that had a pH of 3.6 and the rock phosphate plot with a pH of 4.5, all other treatments raised the pH to 6.4 or above. The $CaCO_3$ excess or deficiency values calculated from the acid-base account also showed significant differences among treatments. For the KCl-extractable acidity, however, the control had significantly higher values than any other treatment. Extractable acidity values for all other treatments were very similar.

Properties of Refuse with a Soil Cover

Statistical analyses indicated that soil thickness had no effect on the properties of the refuse. The chemical treatments also had little effect on the chemical properties, except acidity (data not shown but available in Clark 1992). Properties related to acidity were significantly different among treatments (Table 5). The rock phosphate plots, for example, had one of the lowest pH values, one of the highest $CaCO_3$ deficiency values, and the highest KCl-extractable acidity value. These results are understandable since rock phosphate has a low neutralizing capability and these plots received no lime. However, the reasons are not clear for the control plot extractable acidity being no different than any of the plots with lime added.

Properties of the Cover Soil

Properties of the soil surface layer (0 - 7.5 cm) were very similar after two years regardless of soil thickness (Clark 1992) suggesting that, in this time frame, acid salts had not moved upward from the refuse to the soil surface. Evidently,

Table 3. Plant Species Used for Revegetation of Plots.

Species Seeded	Rate kg ha^{-1}	Amount/ acre
Ky-31 Tall Fescue (*Festuca arundinacea* Schreb.)	33.6	30 lb
Perennial Ryegrass (*Lolium perenne* L.)	11.2	10 lb
Birdsfoot Trefoil (*Lotus corniculatus* L.)	11.2	10 lb
Yellow Blossom Sweetclover (*Melilotus officinalis* Lam.)	11.2	10 lb
Red Top (*Agrostis alba* L.)	3.36	3 lb
Rye Grain (*Secale cereale* L.)	31.4	1/2 bu

Table 4. Properties Related to Acidity of Refuse With No Soil Cover Two Years After Treatment.

Treatment[1)]	pH	$CaCO_3$ Equiv.[2)] g kg^{-1}	KCl-Extr. Acidity $cmol_c$ kg^{-1}
C	3.6 c[3)]	-33.1 a	1.2 a
RP	4.5 b	-32.8 a	0.4 b
F	6.4 a	18.6 b	0.2 b
L	6.4 a	22.8 c	0.5 b
SP & L	6.7 a	35.3 d	0.2 b
RP & L	6.7 a	58.5 e	0.2 b

1) Chemical Treatments to the refuse:
C - Control
L- Lime
F - Fly ash
SP & L - Triple superphosphate & lime
RP - Rock Phosphate
RP & L - Rock Phosphate and lime

2) $CaCO_3$ equivalent calculated from acid-base account as the difference between the neutralization potential and the potential acidity. Positive numbers indicate an excess of $CaCO_3$, or a greater neutralization potential than potential acidity. Negative numbers indicate a deficiency of $CaCO_3$, or a greater potential acidity than neutralization potential.

3) Letters following numbers denote significant differences in treatments within a column at 0.05 level of probability by Duncan's Multiple Range Test.

Table 5. Properties Related to Acidity of Refuse With a Soil Cover Two Years After Treatment.

Treatment[1)]	pH	$CaCO_3$ Equiv.[2)] g kg^{-1}	KCl-Extr. Acidity $cmol_c$ kg^{-1}
C	3.8 c[3)]	-42.0 bc	0.7 c
RP	3.6 c	-47.0 ab	4.4 a
F	4.3 b	-56.4 a	2.4 b
L	4.8 a	-32.1 c	1.0 c
SP & L	4.8 a	-48.9 ab	0.9 c
RP & L	4.2 b	-52.7 ab	0.8 c

1) Chemical Treatments to the refuse:
C - Control
L - Lime
F - Fly ash
SP & L - Triple superphosphate & lime
RP - Rock Phosphate
RP & L - Rock Phosphate and lime

2) $CaCO_3$ equivalent calculated from acid-base account as the difference between the neutralization potential and the potential acidity. Negative numbers indicate a deficiency of $CaCO_3$, or a greater potential acidity than neutralization potential.

3) Letters following numbers denote significant differences in treatments within a column at 0.05 level of probability by Duncan's Multiple Range Test.

the initial surface application of lime and fertilizer was still controlling the chemical properties of the soil. Refuse properties and treatments had very little, if any, effect on the surface layer of the soil after two years (Table 6). After two years, most of the properties, except maybe EC and extractable Fe, of the soil layer (7.5 cm) immediately above the refuse/soil interface (Table 7) were very similar to the soil properties before treatment (Table 1). The elevated EC and Fe indicate that acid salts may have begun to move upward from the refuse into the untreated lower layer of the cover soil.

Vegetation Yield and Ground Cover of Plots With No Soil Cover

After two years, the plots without a soil cover treated with triple superphosphate plus lime produced greater yields and ground cover than the control or the rock phosphate treatment (Table 8). Yields and ground cover for other treatments were not significantly different. None of the treatments produced ground cover above 28%. It is evident that lime and P together produced higher (but not always significant) amounts of forage and reduced the acidity of the refuse.

Although chemical treatment seemed to control the acidity of the refuse (Table 4), vegetation yields and ground cover were much lower on the bare refuse than on the cover soil (Figures 1 and 2). These low yields are related to the low water holding capacity of the refuse. Water retention difference (WRD), an estimate of water holding capacity, was determined as the difference between the water retention at -33 kPa and -1500 kPa. Water retention difference for the refuse was 3%, whereas the WRD for the cover soil was 10%. These results are similar to results of other studies on refuse in the Appalachian region (Stewart and Daniels 1992).

Vegetation Yield and Ground Cover of Plots With a Soil Cover

Dry matter yields of vegetation increased with greater thicknesses of topsoil from 7.5 to 30 cm regardless of refuse treatment (Figure 1). Chemical properties of the soil surface layers were not significantly different resulting in no differences in yields within soil thicknesses. Vegetation collected at the end of the first growing season consisted primarily of annual rye. Tall fescue, yellow sweetclover and birdsfoot trefoil were the main components of the vegetation in the second growing season. The difference of these species to annual rye in growth habits and potential biomass production explains the dramatic decrease in dry matter yield from 1988 to 1989.

Ground cover on plots with a soil cover was similar for both years (Figure 2). Percent ground cover increased over three-fold from 0 cm soil to 7.5 cm soil, but little to no relationship existed between percent ground cover and increasing soil thickness from 7.5 cm to 30 cm.

Growth of vegetation on the plots with soil cover probably was related more to the surface application of fertilizer and limestone than to the refuse treatments since the refuse treatments showed no effect on cover soil properties. In fact, fine roots were found to proliferate throughout the cover soil regardless of soil thickness, but roots did not enter the refuse on any plot.

Table 6. Chemical Properties of the Cover Soil (0-7.5 cm) Two years After Treatment.

Property	Units	Range[1)]	Mean[1)]
pH	-----	6.3- 6.8	6.5
Elec. Cond.	ds m^{-1}	1.2- 1.4	1.3
NP[2)] ($CaCO_3$)	g kg^{-1}	13.8-25.6	18.6
Extr. Bases	$cmol_c$ kg^{-1}		
Ca		0.5- 1.8	1.0
Mg		0.3- 0.4	0.4
K		0.2- 1.6	0.5
Extr. Acidity	$cmol_c$ kg^{-1}	0.1- 0.8	0.3
Extr. Al	$cmol_c$ kg^{-1}	0.1- 0.5	0.2
Extr. Metals	mg g^{-1}		
Fe		82 - 198	141
Mn		63 - 138	106
B	mg g^{-1}	1.3- 4.7	2.6
P	mg g^{-1}	0.6- 1.6	1.1

1) Range and mean of all plots with soil cover.
2) NP = Neutralization Potential

Table 7. Chemical Properties of the Cover Soil Layer (7.5 cm) Immediately Above the Refuse/Soil Interface.

Property	Units	Range[1)]	Mean[1)]
pH	-----	4.1- 5.8	4.8
Elec. Cond.	ds m^{-1}	1.3- 1.6	1.5
NP[2)] ($CaCO_3$)	g kg^{-1}	5.6-14.3	9.1
Extr. Bases	$cmol_c$ kg^{-1}		
Ca		0.5- 0.8	0.6
Mg		0.2- 0.4	0.3
K		0.2- 0.7	0.4
Extr. Acidity	$cmol_c$ kg^{-1}	0.2- 2.0	1.3
Extr. Al	$cmol_c$ kg^{-1}	0.1- 2.3	1.3
Extr. Metals	mg g^{-1}		
Fe		164 - 351	256
Mn		93 - 116	107
B	mg g^{-1}	1.7- 3.2	2.4
P	mg g^{-1}	0.7- 1.6	1.0

1) Range and mean of all plots with soil cover.
2) NP = Neutralization Potential

Table 8. Dry Matter Yields and Ground Cover For Plots with No Soil Cover (Average of Two Years).

Treatment[1)]	Yields ($g\ m^{-2}$)	Ground Cover (%)
SP & L	56.4 a[2)]	28 a
RP & L	45.0 ab	20 ab
F	36.1 ab	18 abc
L	32.0 ab	24 ab
RP	21.0 b	12 bc
C	19.0 b	7 c

1) Chemical Treatments to the refuse:
- C - Control
- L - Lime
- F - Fly ash
- SP & L - Triple Superphosphate & lime
- RP - Rock Phosphate
- RP & L - Rock Phosphate and lime

2) Letters following numbers denote significant differences in treatments within a column at 0.05 level of probability by Duncan's Multiple Range Test.

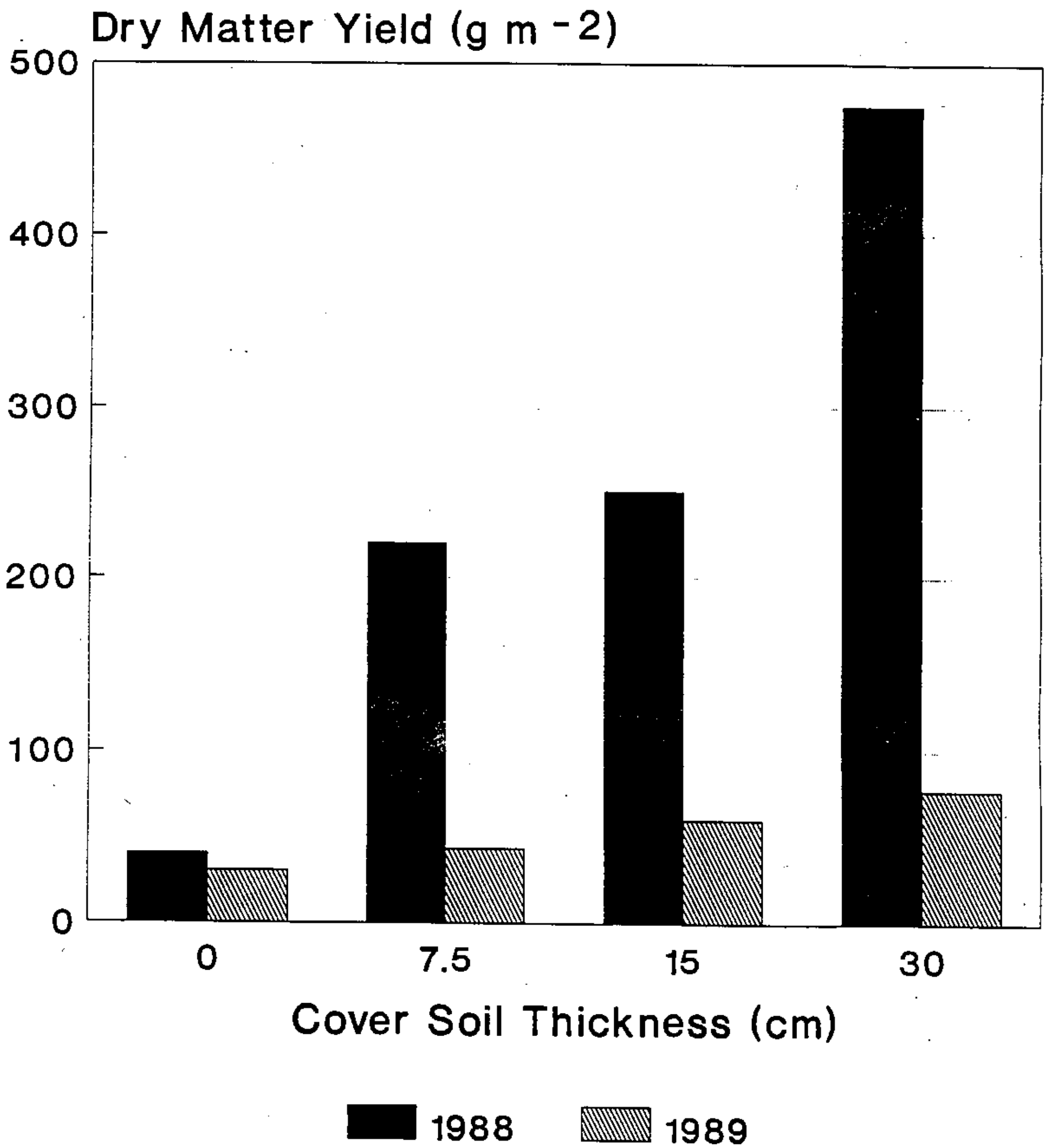

Figure 1. Dry Matter Yield vs. Cover Soil Thickness.

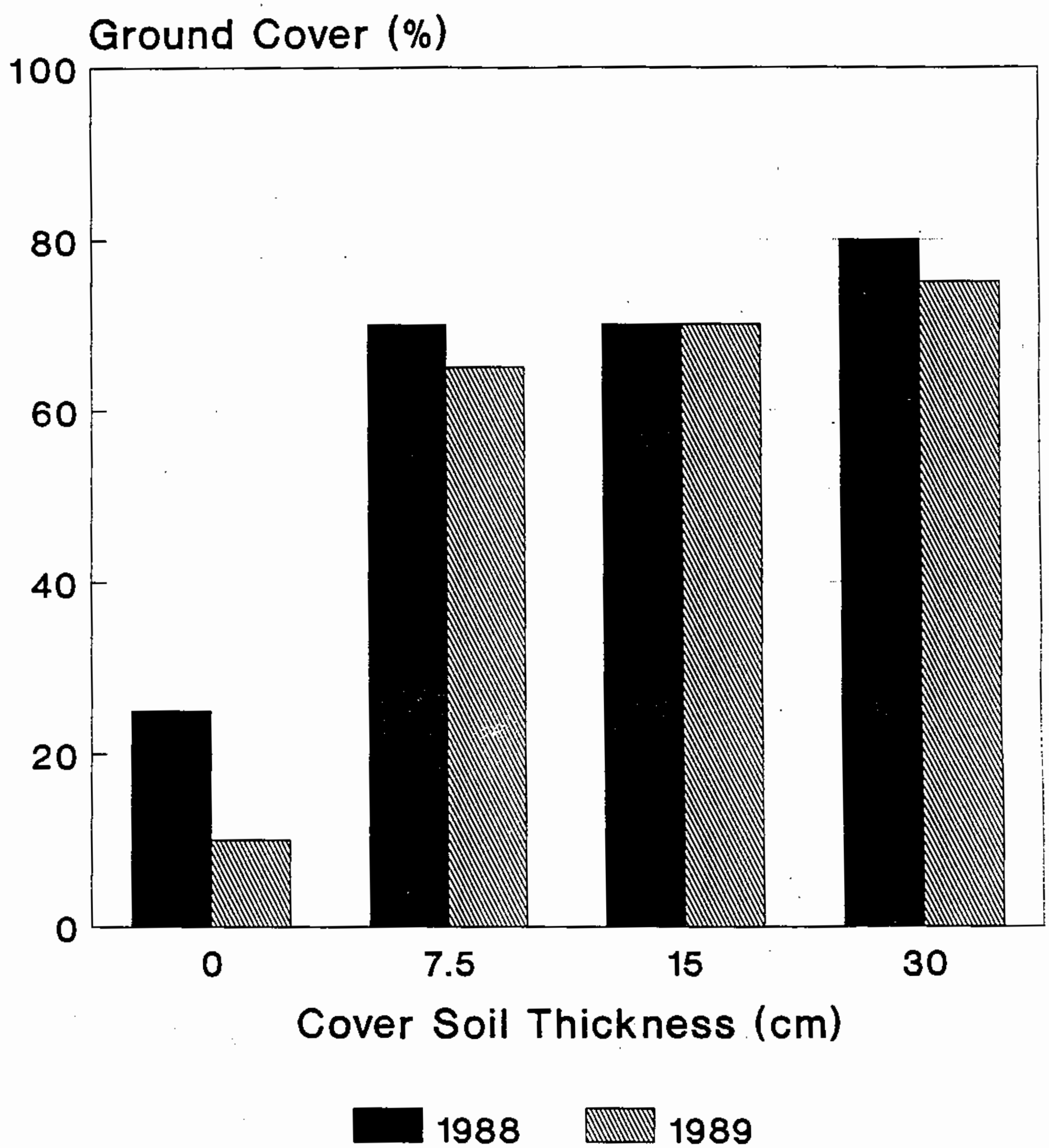

Figure 2. Percent Ground Cover vs. Cover Soil Thickness

Summary

Various chemical treatments and cover soil thicknesses were evaluated for their effects on vegetation establishment and growth on pyritic coal refuse in northern West Virginia. Although some of the treatments did neutralize refuse acidity, vegetation was poorly established on the bare refuse plots, and ground cover was not above 28% for any treatment. Lack of vegetation may be related to the low water holding capacity of the refuse. Percent ground cover increased over three-fold from no soil cover to 7.5 cm of soil, but increased soil thickness did not significantly increase the percent ground cover.

The refuse with 7.5 cm of soil cover had sufficient growth of vegetation to attain greater than 60% ground cover after two years. Plant growth and productivity on the cover soil was neither affected by any of the chemical treatments to the refuse, nor did roots penetrate any of the amended or nonamended refuse. Increasing the length of time for monitoring these treatments would undoubtedly give greater insights to the length of time the different thicknesses of cover soil could support plant growth. Regrettably, this was not possible due to the destruction of the plots after the second year.

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