REVEGETATION STRATEGIES FOR COAL REFUSE AREAS

W. Lee Daniels and D. C. Dove

Soil and Environmental Sciences Section
Department of Agronomy
Virginia Polytechnic Institute and State Univ.
Blacksburg, Virginia, 24061.
703-961-7175

ABSTRACT

Current regulations require the establishment of a permanent, self-sustaining vegetative community on coal refuse materials. The development of reclamation practices suitable for establishing vegetation directly on coal wastes is complicated by a number of factors. Chief among these characteristics are extremes in soil pH, high potential acidity, low water retention and high surface temperatures. Practices designed to address each of these troublesome characteristics were used in a field direct seeding study. The addition of straw, mulch and/or a thin (10 cm) soil cover in combination with lime and fertilizer was tested over three growing seasons. While soil cover treatments produced highest dry matter yield in the first year; straw mulch treatments produced comparable yields in the second year. Both Mulch and soil treatments maintained vegetative cover for 3 growing seasons. Physical and chemical changes were observed in coal wastes which suggest that the formation of a "refuse soil" could occur in short period. Several topsoil wedge experiments have also been installed to determine minimum topsoil thicknesses required for effective revegetation. Preliminary results indicate that between 45 to 70 cm of soil cover are required to insure vigorous legume growth over toxic materials. Revegetation strategies for coal waste materials must concentrate on improving water availability, moderating waste pH, and maintaining vegetation through major short-term changes in soil properties.

INTRODUCTION

The reclamation and subsequent establishment of vegetation on coal refuse is difficult but necessary. Current low requires the establishment of a permanent, self-sustaining vegetative community, just as on reclaimed surface mines. The reclamation process for coal waste entails the placement and stabilization of the refuse in either a valley fill or other suitable area. The primary environmental hazards of this process are contamination of surface and groundwaters, sedimentation in nearby watersheds, and property damage from landslides should large slope failures occur. Several, if not all, of these problems can be reduced by the maintenance of a viable plant cover. A vigorous plant community can reduce water and oxygen leaching down into the fill, thereby limiting the production of acidic leachates. The establishment of a permanent cover will also reduce sediment loss and stabilize the fill surface. The establishment of vegetation, however, is complicated by a number of physical, mineralogical and chemical factors.

Problems in Revegetating Coal Wastes

Pyrites are common in coal refuse materials and upon oxidation produce soil and leachate acidity with associated problems. (Carruccio, 1968; van Breemen, 1982). This reserve or potential acidity causes extreme problems in vegetation establishment. As these materials become oxidized, soil pH is depressed, soluble salt concentration in the root zone increases, and heavy metals may reach toxic concentrations. (Bland, 1977; Joost, 1983; Van Breemen, 1982; Wagner, 1982; Williams, 1977). The coal cleaning process itself also affects the physico-chemical behaviour of the waste. Chemical treatments used in coal processing, particularly flotation separation, make the surface of the refuse particles hydrophobic, complicating water retention. Cationic and anionic surfactants, polymer flocculants, fuel oil, and strong bases are all commonly used in coal processing, and little is known about their final concentrations and phytotoxicities in the refuse. It is likely that fresh coal wastes contain a broad spectrum of phytotoxic substances, both naturally occurring and man-made.

Several physical problems associated with coal refuse pile surfaces limit vegetative success as well. Coal refuse is often coarse in texture, with a corresponding low water-holding capacity. Refuse may contain from 47 to 95% coarse (>2mm diameter) fragments depending on length of exposure to weathering (Moulton, 1974). Most refuse materials are also dark and absorb large amounts of solar energy. This energy is then re-radiated in the form of heat. On a warm cloudless day the surface temperature may exceed 160^{o}F (Schramm, 1966; Thompson, 1971). Surface temperatures in this range are lethal to most plants (Maguire, 1955). Legume seedlings are particularly susceptible to heat kill, and their establishment is critical to long-term revegetation success.

The method of placement used in refuse pile construction may also be detrimental to establishment of vegetation. Typically refuse is transferred from the cleaning plant to disposal site by overhead tram, conveyor or overland hauling. Once on site, materials are leveled and compacted to meet regulatory guidelines. If care is not taken when the final layers of refuse are added, the resultant surface is highly compacted. Attempts to vegetate a compacted surface are usually fruitless. Highly compacted surfaces are also prone to ponding water which drown existing plant cover.

A high degree of variability often exists in coal refuse materials within the same disposal area since wastes are usually derived from several different coal seams. Each seam may exhibit very different mineralogical, chemical, physical and morphological properties (Davidson, 1974). This variability makes the development of uniform reclamation strategies difficult. Additional variability is introduced through the weathering process. Because coal refuse materials are primarily fresh unweathered geologic materials which have been subjected to severe physical and chemical treatment during processing, sharp changes in physical and chemical properties are common in short periods of time. Potentially, the pH of refuse materials could drop from 7 to 4 in a single month (Van Breemen, 1982).

Best results in reclamation of coal refuse piles have been achieved by incorporating lime and plant nutrients into a suitable soil cover above the waste (Jastrow, 1977). In many cases this is not possible due to the lack of available soil cover materials, or the expense of transporting soil materials to remote sites. Several workers have suggested that vegetation can be established directly on refuse after amendment with lime and fertilizers (Nickeson, 1984; Joost, 1983). The question remains whether the refuse surface will remain hospitable for plants long enough to establish the viable, self-sustaining plant community required by law (Sutton, 1970). The establishment of a permanent legume component is particularly difficult. Improvement in vegetation establishment on bare refuse has been reported with the addition of very high rates of sewage sludge as well (Jones unpublished; Joost, 1983; Joost, 1987).

Controversy has arisen as to the depth and/or necessity of a soil cover when vegetating coal refuse piles. A soil cover may be essential for the prevention of spontaneous combustion in some high C refuse materials, however. Current state regulatory programs require the establishment of a permanent, self sustaining community that persists for a minimum of five years. Many states require a thick soil cover (>1m) at the final surface to achieve this goal. The increased costs of reclaiming these areas with soil justifies the need for research to determine whether soil is necessary and to what depth. These problems and basic questions form the foundation for several experiments that we are currently conducting. The purpose of this paper is to present preliminary results from several experiments designed to provide basic information about topsoil depth requirements, necessary soil amendments, and overall reclamation strategies for coal refuse. All conclusions and inferences reported in this paper are based on at most 3 years of data, and may not necessarily reflect long term conclusions reached at a later date.

OBJECTIVES

1. Determine if vegetation can be sufficiently established on bare coal refuse and maintained - for an extended period of time.
2. Evaluate several amendments for enhancing vegetation success and longevity, including a thin topsoil substitute cover.
3. Investigate the relationship between topsoil thickness and revegetation success over a range of coal waste materials.
4. Examine changes in physical and chemical characteristics of "refuse soil" over an extended period of time, and relate these characteristics to revegetation success.

MATERIALS AND METHODS

Reclamation of Coal Wastes With Reduced Soil Depth and Other Amendments

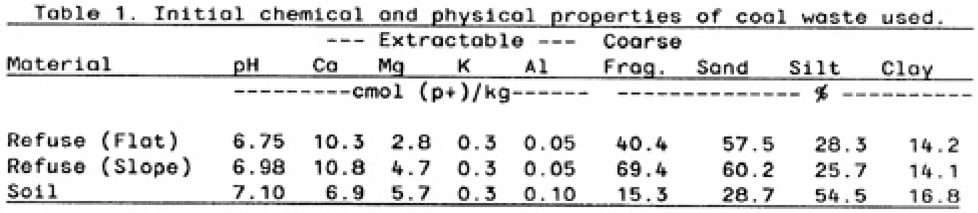
The study site was located in Buchanan County, Virginia at the Harper's Branch Refuse Area of Jewell Smokeless Coal Company. The refuse area is approximately 50 ho in size and formed in a valley fill to a depth of several hundred feet. The actual study area was located on a refuse terrace with a south-facing aspect. Plots were installed on both the flat terrace floor and the adjacent slope (-150). Plots were constructed in spring of 1983 with seeding accomplished in early May. All treatments were applied by hand. Amendments were applied at the following rates where applicable:

Straw mulch	685 kg/ha
Soil	10 cm with lime incorporated
Soil/lime	10 cm with lime at refuse surface

The refuse originated from coal produced in deep mine operations and was a composite of six coal seams all from the Norton formation. Representative samples of refuse and soil were taken prior to plot installation and submitted for commercial laboratory analysis of chemical and physical characteristics (Table 1). The not potential acidity of the fresh material was 47 T/Ac. The cover material consisted of a mixture of native soil and ripped overburden from an adjacent mining cut. We will refer to this material as "soil" in this paper.

Table 1. Initial chemical and physical properties of coal waste used.

		--- Extractable ---				Coarse			
Material	pH	Ca	Mg	K	Al	Frog.	Sand	Silt	Clay
		--------- cmol (p+)/kg ----------					---------- % ----------		
Refuse (Flat)	6.75	10.3	2.8	0.3	0.05	40.4	57.5	28.3	14.2
Refuse (Slope)	6.98	10.8	4.7	0.3	0.05	69.4	60.2	25.7	14.1
Soil	7.10	6.9	5.7	0.3	0.10	15.3	28.7	54.5	16.8



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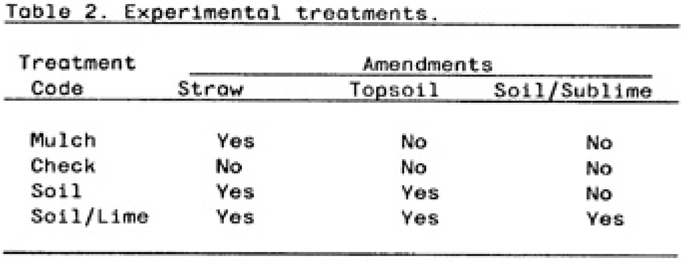
Material	pH	Extractable Ca	Extractable Mg	Extractable K	Extractable Al	Coarse Frag.	Sand	Silt	Clay
	cmol (p+)/kg					%			
Refuse (Flat)	6.75	10.3	2.8	0.3	0.05	40.4	57.5	28.3	14.2
Refuse (Slope)	6.98	10.8	4.7	0.3	0.05	69.4	60.2	25.7	14.1
Soil	7.10	6.9	5.7	0.3	0.10	15.3	28.7	54.5	16.8

Four treatments were selected for use. All treatments were replicated on both slope and flat plots (Table 2). Additionally all plots received a base rate of fertilizer which included 84 kg/ha N, 133 kg/ha Of P205 and 253 kg/ho of K_2O. Lime wa applied over the refuse area at a rate of 27 Mt/ho. A seed mixture of tall fescue, redtop, annual lespedeza, ladino clover and annual ryegrass was used.

Table 2. Experimental treatments.

Treatment Code	Amendments Straw	Topsoil	Soil/Sublime
Mulch	Yes	No	No
Check	No	No	No
Soil	Yes	Yes	No
Soil/Lime	Yes	Yes	Yes



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Treatment Code	Amendments Straw	Topsoil	Soil/Sublime
Mulch	Yes	No	No
Check	No	No	No
Soil	Yes	Yes	No
Soil/Lime	Yes	Yes	Yes

After an establishment period of 90 days, all plots were visually scored for percent total cover and approximate species composition on September 9, 1984. To ascertain plant litter production, total dry matter was collected from each plot on March 28, 1984. Dry matter production was again measured in September 1984 and 1985. Surface soil samples (0-6 cm) were collected at each dry matter harvest and analyzed for of standard soil physical and chemical parameters (USDA-SCS, 1984). Data was analyzed using a randomized complete block design with four replications. Relevant data was examined statistically using the analysis of variance procedure with mean separations by Fisher's protected LSD (SAS, 1982).

Topsoil Wedge Experiments

Three study sites in Wise and Buchanan Counties, Virginia, were located in cooperation with Westmorland, Paramont, and Jewell Smokeless Coal Companies. All wedges were constructed near or on active coal waste disposal areas.

The coal waste materials employed varied from potentially toxic (net potential acidity = 47 T/Ac) at 1 locution (Buchanan), to moderately acid forming at the others. Topsoil materials used were really a mixture of all natural soil horizons above hard rock plus softer underlying overburden that could be cut with a bulldozer. While this is certainly not true "topsoil", it is the material commonly used as soil cover in this region of thin natural soils.

The wedges were constructed so that topsoil depth increased from 0 to 125 cm over a distance of

16 m. (Figure 1) Each wedge was located so that the slope faced south. At the Wise Co. location four wedges were constructed facing each cardinal direction. Lime (27 Mg/ha) was spread at the waste surface under half of each wedge and incorporated with a disc. The wedges were seeded in either the fall of 1984 or the spring of 1985, and received 56 kg N/ha, 224 kg P205/ha, and 168 kg K20/ha in the hydroseeder slurry. The wedges were straw mulched and seeded to redtop, hard fescue, annual ryegrass, cereal rye, weeping lovegrass, birdsfoot trefoil, yellow sweetclover, ladino clover, and kobe lespedeza. Data on survival, ground cover, and dry matter production are taken at 10 cm increments up each wedge at the end of each growing season.

RESULTS

Direct Seeding Experiment

Ground Cover in 1983

Estimation of total vegetation ground cover was highest with soil and soil/lime treatments (Table 3) on the flat plots. When ground cover was separated by plant type (gross vs. legume) the composition varied sharply with treatment. Soil and soil/lime treatments had a higher percentage of legumes present. This contrasted with the mulch and check treatments where grass was dominant. Ground cover was nearly complete on the sloping plots receiving soil and soil/lime treatments. Both the check and mulch treated plots had a low percent ground cover. Legume species dominated in soil and soil/lime plots with grassy species most prominent in the check and mulch plots. Ground cover was similar for both slope and flat plots; as was the relative species composition.

Plant Litter Production in 1983

Plant litter produced during the establishment year often serves as an effective mulching agent in subsequent seasons. For this reason we were particularly interested in the amount of litter produced in each treatment which remained on the plots over the first winter. First year litter production was not consistent across flat and slope plots. On flat plots litter production was highest with the mulch treatment but did not differ appreciably from litter production with soil/lime treatment (Table 4). Lowest levels of litter production were on check and topsoil treated plots.

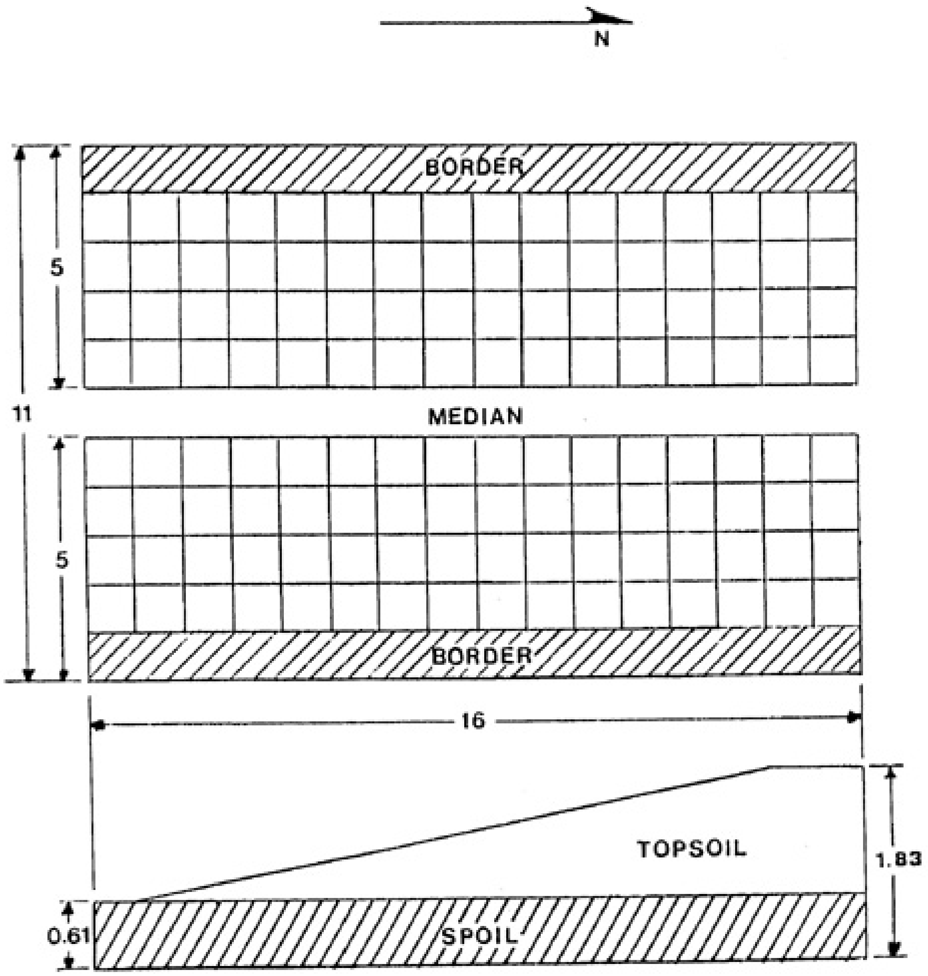
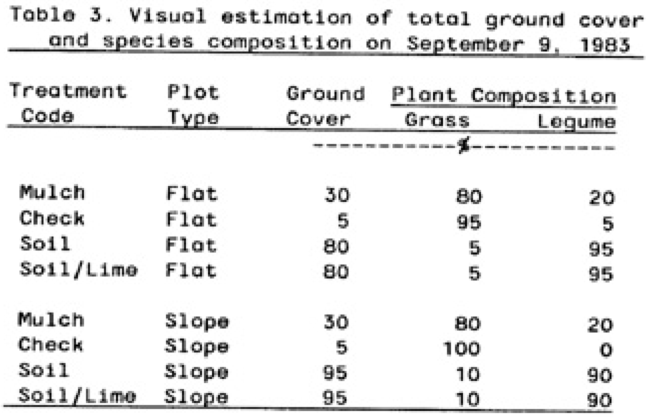


Figure 1. Overall layout and design for topsoil wedge experiments located in three locations in S.W. Virginia.

Table 3. Visual estimation of total ground cover and species composition on September 9, 1983

Treatment Code	Plot Type	Ground Cover	Plant Composition Grass	Legume
		-----------	%	-----------
Mulch	Flat	30	80	20
Check	Flat	5	95	5
Soil	Flat	80	5	95
Soil/Lime	Flat	80	5	95
Mulch	Slope	30	80	20
Check	Slope	5	100	0
Soil	Slope	95	10	90
Soil/Lime	Slope	95	10	90



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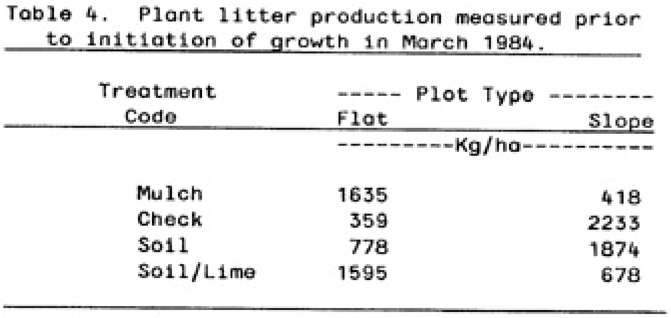
		%	%	%
Mulch	Flat	30	80	20
Check	Flat	5	95	5
Soil	Flat	80	5	95
Soil/Lime	Flat	80	5	95
Mulch	Slope	30	80	20
Check	Slope	5	100	0
Soil	Slope	95	10	90
Soil/Lime	Slope	95	10	90

Table 4. Plant litter production measured prior to initiation of growth in March 1984.

Treatment Code	Plot Type Flat	Plot Type Slope
	Kg/ho	Kg/ho
Mulch	1635	418
Check	359	2233
Soil	778	1874
Soil/Lime	1595	678



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On sloping plots the results were somewhat contradictory to the flat plots. Yields were highest on the check and soil treatments. Lowest production was with the mulch treatments; and soil/lime treated plots were nearly as low.

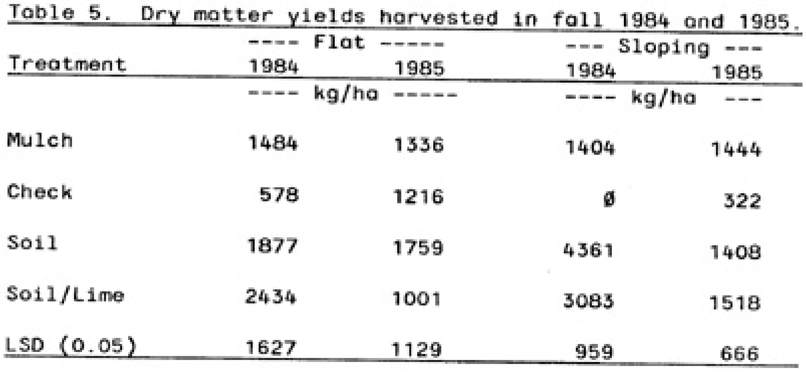
Dry Matter Production in 1984 and 1985

On flat plots dry matter yields in 1984 were highest with soil/lime treatments (Table 5). These yields were significantly higher than check or mulch treated plots. A high degree of variability was observed across all plots as indicated by the high LSD values. In 1985 all treatments produced similar yields. Again variability was high within treatments. Dry matter yields in 1985 were lower than 1984 yields with all treatments except the check plots where yield increased.

Soil/lime treatments produced significantly higher dry matter yields in 1984 on sloping plots (Table 5), than all other treatments. Check plots failed to produce a measurable yield in 1984 and were lowest in 1985 also. Other treatments did not differ significantly. Yields from soil and soil/lime treated plots dropped sharply in 1985 from those observed in 1984 with a 68% and 51% drop in yield respectively. Yields on mulch plots did not change from 1984 to 1985, and on check plots a small but measurable yield increase was observed.

Table 5. Dry matter-Yields harvested in fall 1984 and 1985.

	---- Flat -----		--- Sloping --	
Treatment	1984	1985	1984	1985
	---- kg/ha -----		---- kg/ho ---	
Mulch	1484	1336	1404	1444
Check	578	1216	0	322
Soil	1877	1759	4361	1408
Soil/Lime	2434	1001	3083	1518
LSD (0.05)	1627	1129	959	666



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During 1984, the flat plots were flooded with fine coal slurry from a broken pipeline, which may account for the high variability in production. Remarkably, vegetation continued to grow quite well. In fact, these plots become dominated by annual lespedeza, while legumes failed to survive the second year on any of the sloping plots. Whether or not the failure of legumes on the sloping plots was due to heat kill or lack of innoculation is unknown. The fact that the lespedeza did thrive on the flat plots is encouraging, however.

Soil Physical and Chemical Characteristics

Distinct soil chemical changes were observed after one year (Table 6). The surface pH dropped over 1 unit in all treatments, including the soiled plots. Extractable Ca, K and Al remained fairly constant with time, but Mg increased in all treatments. The drop in pH is probably due to pyrite oxidation and the leaching of free salts. Extractable Al values were higher in the flat plots, while extractable Co and Mg were higher on the slope. Soil acidity (pH) did not appear to be affected by slope position.

Table 6. Refuse soil chemical characteristics in September 1984.

	----------- Flat -----------					---------- Sloping ----------				
Treatment	pH	Co	Mg	K	Al	pH	Ca	Mg	K	Al
		------ cmol/kg --------					------- cmol/kg -------			
Mulch	5.7	9.2	4.7	0.25	0.17	5.7	11.4	5.1	0.22	0.05
Check	5.5	7.8	3.8	0.24	0.25	5.7	9.3	4.7	0.24	0.05
Soil	5.2	8.2	4.1	0.19	2.17	5.4	13.4	6.3	0.25	0.05
Soil/Lime	5.6	10.6	5.4	0.27	0.07	5.9	14.4	5.6	0.25	0.05
LSD (0.05)	1.6	5.6	2.9	0.17	3.29	0.4	15.0	4.9	0.13	0.00

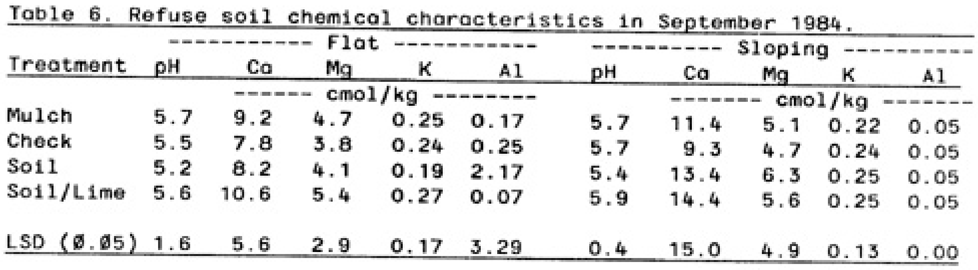


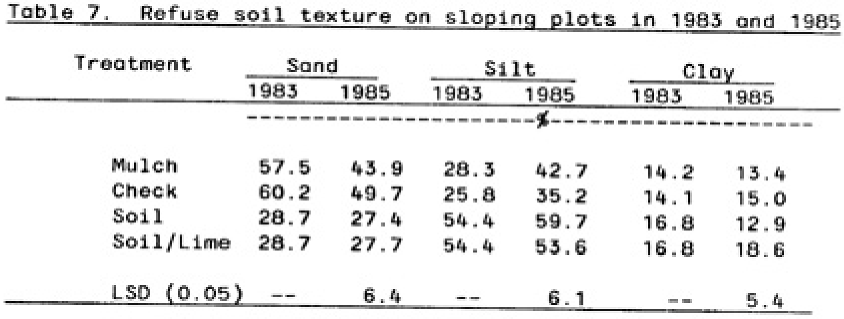
Table 6. Refuse soil chemical characteristics in September 1984.

Treatment	Flat pH	Flat Ca	Flat Mg	Flat K	Flat Al	Sloping pH	Sloping Ca	Sloping Mg	Sloping K	Sloping Al
		cmol/kg					cmol/kg			
Mulch	5.7	9.2	4.7	0.25	0.17	5.7	11.4	5.1	0.22	0.05
Check	5.5	7.8	3.8	0.24	0.25	5.7	9.3	4.7	0.24	0.05
Soil	5.2	8.2	4.1	0.19	2.17	5.4	13.4	6.3	0.25	0.05
Soil/Lime	5.6	10.6	5.4	0.27	0.07	5.9	14.4	5.6	0.25	0.05
LSD (0.05)	1.6	5.6	2.9	0.17	3.29	0.4	15.0	4.9	0.13	0.00

Soil texture changed over the first year of this study reflecting harsh physical weathering at the surface. A drop in percent sand sized (Table 7) particles and an increase in silt size particles occurred in check and mulch plots from 1983 to 1985. Clay content varied somewhat in the first year with an increase in check and soil/lime plots, but a decrease in mulch and soil plots. Plots which received soil or soil/lime had a significantly lower percentage of sand sized particles and higher percentages of silt in 1985. Clay content was significantly higher in soil/lime treated plots only. The soil and soil/lime plots were much lower in sand content because samples were taken from the soil cover layer. Particle size data are not given for the flat plots due to the confounding effects of slurry additions discussed earlier.

Table 7. Refuse soil texture on sloping plots in 1983 and 1985

Treatment	Sand		Silt		Clay	
	1983	1985	1983	1985	1983	1985
Mulch	57.5	43.9	28.3	42.7	14.2	13.4
Check	60.2	49.7	25.8	35.2	14.1	15.0
Soil	28.7	27.4	54.4	59.7	16.8	12.9
Soil/Lime	28.7	27.7	54.4	53.6	16.8	18.6
LSD (0.05)	--	6.4	--	6.1	--	5.4



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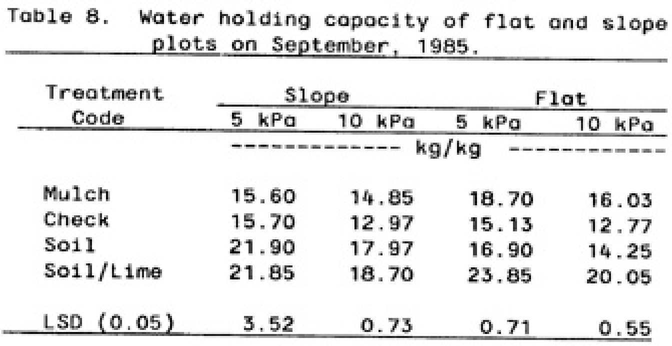
Treatment	Sand		Silt		Clay	
	1983	1985	1983	1985	1983	1985
	%					
Mulch	57.5	43.9	28.3	42.7	14.2	13.4
Check	60.2	49.7	25.8	35.2	14.1	15.0
Soil	28.7	27.4	54.4	59.7	16.8	12.9
Soil/Lime	28.7	27.7	54.4	53.6	16.8	18.6
LSD (0.05)	--	6.4	--	6.1	--	5.4

Water retention was measured at 5 and 10 kPa of pressure to simulate potential water availability to plants under dry soil conditions. At 5 kPa water retention was significantly lower in check and mulch plots than in soil or soil/lime plots (Table 8). Under 10 kPa of pressure all treatments were significantly different on the slope Soil/lime plots retained the highest percentage of water (18.7%) and check plots the lowest (12.9%). On the flat plots, water retention was extremely variable. At 5 kPa all treatments were significantly different. Contrary to the slope plots, mulch plots had greater water retention than topsoil plots. Check and soil/lime plots were lowest and highest in water retention respectively.

Table 8. Water holding capacity of flat and slope Plots on September, 1985.

Treatment	Slope		Flat	
Code	5 kPa	10 kPa	5 kPa	10 kPa

	--------- kg/kg ------------			
Mulch	15.60	14.85	18.70	16.03
Check	15.70	12.97	15.13	12.77
Soil	21.90	17.97	16.90	14.25
Soil/Lime	21.85	18.70	23.85	20.05
LSD-(0.05)	3.52	0.73	0.71	0.55



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	5 kPa	10 kPa	5 kPa	10 kPa
	------------- kg/kg ------------			
Mulch	15.60	14.85	18.70	16.03
Check	15.70	12.97	15.13	12.77
Soil	21.90	17.97	16.90	14.25
Soil/Lime	21.85	18.70	23.85	20.05
LSD (0.05)	3.52	0.73	0.71	0.55

The values given in Table 8 reflect water content in the < 2 mm soil fraction at a given pressure, and not "available water" per se. These values are low compared to even surface mine soil materials, and it must be remembered that these materials are dominated by coarse fragments which hold even less water than the fine fraction tested.

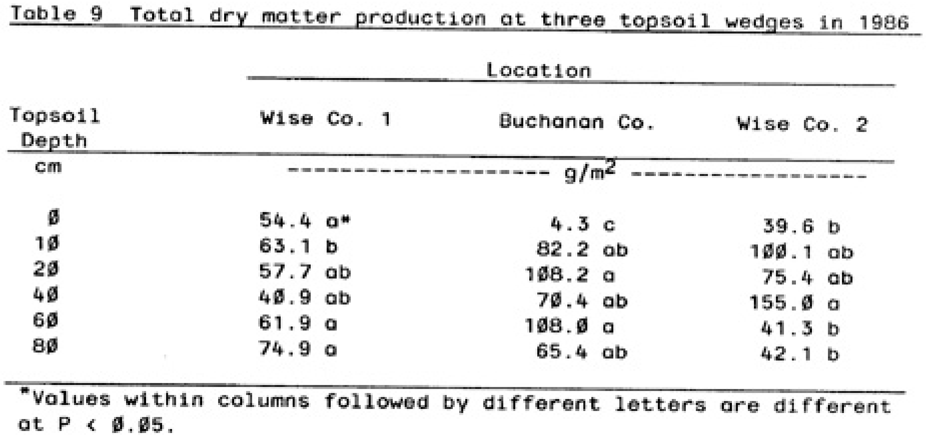
Topsoil Wedge Experiments

At this time these plots are going into their third full year of growth. Data collected to date are of somewhat limited application since this study is long range (5 years) in nature. Establishment was excellent at all sites, even at the very thin depths. Legume survival and growth on the bare waste just below the wedges was minimal. Second year survival and growth was also excellent at all site. While consistent trends of increasing vegetative cover with increasing soil depth are not evident (Table 9) legume growth and vigor below 1811 are limited. To date, no consistent effects of liming at the soil/waste interface have been detected.

Table 9 Total dry matter production at three topsoil wedges in 1986

	Location		
Topsoil Depth cm	Wise Co. 1	Buchanan Co.	Wise Co. 2
	-------------------------g/m^2------------------ ---------		
0	54.4 a*	4.3 c	39.6 b
10	63.1 b	82.2 ab	100.1 ab
20	57.7 ab	108.2 a	75.4 ab
40	40.9 ab	70.4 ab	155.0 a
60	61.9 a	108.0 a	41.3 b
80	74.9 a	65.4 ab	42.1 b

* Values within columns followed by different letters are different at $P < 0.05$.



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20	57.7 ab	108.2 a	75.4 ab
40	40.9 ab	70.4 ab	155.0 a
60	61.9 a	108.0 a	41.3 b
80	74.9 a	65.4 ab	42.1 b

*Values within columns followed by different letters are different at $P < 0.05$.

DISCUSSION

Direct Seeding Experiment

Dry matter yields were highest in topsoiled plots. This was the likely result of better establishment and a higher rate of fertilizer utilization. However in the second growing season yields were similar between soiled and unsoiled plots. In the flat plots this is understandable because in summer 1984 these plots were flooded when a nearby slurry pipeline ruptured negating any treatment effects. This was not the case on the slope site however and a similar leveling of yields was also observed. On both flat and sloping plots initial ground cover was best when soil was added. The addition of soil also increased the establishment of legume species. This may have been related to a better seedbed provided by the soil, or potential phytotoxicity in the bare refuse. The soil used in the cover layer had better water holding ability and reduced surface temperatures. The absence of legumes in bare refuse plots early in 1983 was probably an indication of seedling mortality due to high surface heat. Grass seedlings were more resistant to high temperatures. When small amounts of plant litter accumulated on bare refuse an improvement in dry matter production was observed. Overall best establishment was achieved when the refuse was covered by mulch or soil. This indicates that addition of mulch is essential to plant establishment on bare refuse.

While surface soil pH did drop appreciably during the direct seeding experiment, the drop was not extreme, particularly in light of the high pyritic S content (4.59 %). Apparently the lime additions were effective in slowing the pyrite oxidation rate and neutralizing most of the acidity generated. It is also possible that a large portion the pyritic S was present in large, slowly reactive forms.

The observed decrease in sand sized particles with a concomitant increase in the silt fraction indicates a rapid rate of weathering. If this trend continues, an improvement in water retention and a more suitable media for plant growth could result. Regardless of this fact, water holding in the refuse materials was low, and posed a severe limitation to long-term plant growth. The major advantage of even thin soil covers may simply be improved water holding capacity over droughts, and reduced surface temperatures.

Overall Conclusions

There is little doubt that moisture stress, induced by high coarse fragment contents, salts, and high surface heat is the primary growth limiting factor in fresh coal wastes. As the materials weather, acidity becomes a major problem in some wastes, but can be controlled to a certain extent by liming. Reagents and chemicals used in mineral processing may also severely limit plant growth in fresh wastes, but little is known about their effects. Once the coal wastes weather and leach for several years, they are easier to deal with as a plant growth medium because their properties stabilize. Many of the older abandoned waste piles in the Appalachian region are invaded by native pioneers after this stabilization occurs. Care should be taken not to disturb this fragile surface zone on older piles if at all possible during reclamation.

The use of a reduced soil cover to reclaim coal refuse was successful in these experiments. Even thin layers apparently provide enough water holding capacity, and suitable rooting environment for establishment of both grasses and legumes on harsh wastes. Thicker covers may be necessary for long-term legume vigor, however. When conditions of high surface temperature, and low water supply are present thin topsoiling appears to be the best alternative for establishing a good vegetative cover. Under less stressful conditions the addition of a thick mulch, lime and necessary plant nutrients may permit good plant establishment, particularly if only a grass cover is needed. Revegetation strategies should plan to provide a quick annual cover to rapidly provide shade and natural mulch for perennials. Any plant materials used on coal wastes must be capable of withstanding extreme short and long-term changes in soil conditions.

These studies provide some basic evidence to support the use of a reduced amount of topsoil cover material. Should the use of a soil cover be impractical or impossible, direct seeding of many waste materials can be successful provided a suitable amount of mulch, lime and fertilizer is used. The critical period in achieving successful reclamation of coal refuse appears to be the establishment year, but the plant community must be able to adapt to changing soil conditions as the fresh wastes weather. The importance of overcoming the heat and water holding limitations of bare refuse cannot be overemphasized.

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