INFLUENCE OF LIMING AND TOPSOIL THICKNESS ON VEGETATIVE GROWTH AND LEACHATE QUALITY OF ACIDIC COAL REFUSE[1]

by

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Abstract. Coal waste materials inhibit direct vegetation establishment due to adverse physical and chemical properties, particularly low water retention and high potential acidity. The Moss #1 coal refuse pile is located in Dickenson County, Virginia, and was idled in the late 1980's with little topsoil resource available for final closure. The refuse was acidic (Total-S = 0.38%; pH = 3.6), black, high (70%) in coarse fragments, and had a low water holding capacity (4.5% in < 2.0 mm fraction). A small plot experiment was established on the refuse pile to evaluate the influence of liming rates (50% and 100% of lime req.) and topsoil thickness (15, 30 and 60 cm) on vegetative growth and leachate quality. Liming and topsoil amendment increased the surface soil pH from < 4.0 to > 6.0 over a two-year period, which resulted in greater vegetative cover and biomass than the control plots. All topsoil treatments resulted in greater vegetative cover and biomass than plots treated with lime only due to improved surface soil physical and chemical properties. A topsoil treatment of 60 cm gave the thickest vegetative cover and biomass yield. Such a treatment, however, would be cost-prohibitive at this location. Application of 27 Mg ha^{-1} of lime to the refuse surface along with 15 cm of topsoil produced acceptable two-year vegetative cover and biomass, and appeared to be the optimal treatment for this particular situation. Both liming and topsoil had no affect on leachate pH and the electrical conductivity in leachates collected below the plots. This suggests that surface revegetation will have little effect on the quality of water draining through the pile, so long term water treatment requirements may not be reduced by successfully revegetating the pile surface.

Additional Key Words: potential acidity, sulfidic materials, revegetation, water quality.

Introduction

Coal refuse is composed primarily of coarse rock waste separated from coal by physical screening and flotation processes at a preparation plant. The rock waste is composed of carbonaceous shale, mudstone, sandstone and a minor amount of low grade coal. Reclamation of coal refuse is difficult due to acidity, toxicity, nutrient deficiency and poor physical properties of the coal refuse (Stewart and Daniels 1992). Pyrites are frequently concentrated into coal refuse during coal preparation, and most coal refuse is acid-forming to some extent. concentrated into coal refuse during coal preparation, Acid generation from pyrite oxidation in coal refuse is common in Virginia coal refuse disposal environments (Daniels et al. 1989).

The acidity produced by active pyrite oxidation adversely influences the behavior of nutrient elements and heavy metals in soil solution (Pulford and Duncan 1978; Pulford et al. 1978). It is clear that controlling acid generation is one of the key issues for the successful revegetation of coal waste and the protection of local water quality. Considerable research has been conducted on the kinetics and inhibition of pyrite oxidation in coal refuse. Backes et al. (1986) suggested that by maintaining bulk refuse pH high enough (at least >4) to precipitate iron and inhibit the activity of *Thiobacillus ferrooxidans*, the rate of acid release could be controlled. The most common way to raise pH and control pyrite oxidation is the application of alkaline materials, most typically ground agricultural limestone. Little is known about the cumulative effects of refuse surface revegetation efforts on within-pile leachate quality, although we hypothesized that revegetation should (1) decrease net leachate volumes due to evapotranspiration

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effects and (2) that accumulating organic matter and microbial activity in the surface layer could reduce leachate oxygen levels, thereby reducing the direct (by O_2) pyrite oxidation pathway.

Pulford and Duncan (1978) and Pulford et al. (1978) found that the levels of extractable Co, Ni, Cu and Zn in pyritic coal waste were directly determined by pH and manganese oxide content. As far as plant macronutrients were concerned, N was deficient, and the levels of available K and Ca were influenced by the acidity of the leachates. They concluded that plant nutrition problems could not be solved simply by the periodic application of fertilizers since the aim of reclamation should be to establish self-supporting vegetation that requires little attention after the first few years. Therefore, they suggested that future research should focus on how to increase coal waste's ability to hold nutrients and to supply them in a form available for plants. Stewart and Daniels (1992) indicated that low water holding capacity is the most important physical factor limiting plant growth on coal refuse piles in Southwest Virginia. The size consist of coal refuse is typically very coarse, with more than 50% of the mass being >2 mm fragments. Low soil organic matter and coarse texture in mine soils and coal waste materials result in low infiltration rates and water holding capacity, which in turn leads to periods of plant stress during the summer. (Pedersen et al. 1980; Rimmer 1982).

As discussed above, the key for successful reclamation of coal refuse is to improve both its chemical and physical properties, thereby making it suitable for plant establishment and sustained growth. To improve these adverse conditions, both liming and topsoil additions have been commonly used. The topsoil depth requirement for revegetation of toxic coal mining spoils has been reported to vary from 0 to 150 cm, depending on the quality of topsoil and spoil, plant species requirements, reclamation practices and climatic factors, such as precipitation. Usually, plant biomass has been reported to increase linearly with increasing topsoil depth (Redente and Hargis 1985; Gildon and Rimmer 1993; Pulford et al. 1978; McGinnies and Nicholas 1980; Barth and Martin 1984; Angel and Feagley 1987ab; Ebelhar et al. 1982; Ammons et al. 1991) over a wide range of phytotoxic mine spoil and coal waste materials. Topsoil addition, however, is costly and may not be practical in many locations, particularly at older installations where topsoil resources were not segregated and stored. Therefore, this field experiment was established to evaluate several different approaches to cost-effectively revegetate acidic coal waste. The specific objectives of this study were:

1. To determine if direct revegetation is possible at two different liming rates.

2. To evaluate the influence of topsoil cover thickness on the revegetation of the coal refuse materials.

3. To measure the effect of revegetation on the quantity and quality of leachates under a variety of reclamation treatments.

4. To compare locally available topsoiling materials to a hydrocarbon contaminated soil that was available on-site for revegetation purposes.

Materials and Methods

Plot Construction and Treatment

The Moss #1 coal refuse disposal area was operated by Clinchfield Coal Co. in Dickenson County, Virginia, for approximately forty years through the late 1980's. At that time, the pile was idled and the company was required to develop a final closure plan. Because the original operations at the site significantly pre-dated the Surface Mining Control and Reclamation Act of 1977, topsoil and/or topsoil substitute materials were not segregated and stored properly for final closure purposes. Therefore, the only way to return topsoil to this large (100 ha) coal refuse surface would be to actually strip up spoils from adjacent surface mining areas and/or blast local suitable rock strata into topsoil substitutes. For this reason, the company (with concurrence from the state regulator) decided to investigate the potential for direct seeding vs. the possibility of using reduced (< 1 m) cover soil thicknesses. The site also generated significant acid mine drainage discharge to surface waters from a combination of sources, and the company was interested in determining what the net effect of surface revegetation might be on long-term water treatment demands. The adjacent preparation plant site also contained a significant volume of two differing natural soil materials that had been hydrocarbon contaminated and subsequently partially remediated via windrowing and turning. One proposed final disposition for these materials was to use them as capping material for the refuse pile, so we included them in several treatments.

In early 1992 we surveyed the site and determined that the average pH of the exposed and weathered refuse surface was < 4.0 with an estimated potential acidity (via H_2O_2 oxidation; Barnhisel and Harrison, 1976) of 27 Mg calcium carbonate equivalence per 1000 Mg refuse. The experimental area (60 m by 72 m) was located on a gently sloping portion of the refuse pile. This experiment was arranged as a randomized complete block design with nine treatments and four replications. Each plot was 3 m by 9 m with a 5 m alley between plots.

The treatments were applied as follows:

1. Control without revegetation (*C*).

2. Control with revegetation (*CV*).

3. Lime at 50% potential acidity as determined by H_2O_2 method (*Hlime*: 13.5 Mg lime ha^{-1}, or 36.4 kg lime $plot^{-1}$)

4. Lime at 100% potential acidity as determined by H_2O_2 method (*Lime*: 27 Mg lime ha^{-1}, or 72.8 kg lime $plot^{-1}$)

5. Fifteen centimeters of topsoil over lime (*T15*).

6. Thirty centimeters of topsoil over lime (*T30*).

7. Sixty centimeters of topsoil over lime (*T60*).

8. Hydrocarbon contaminated soil #1 - 30 centimeters (*H1*) over lime.

9. Hydrocarbon contaminated soil #2 - 30 centimeters (*H2*) over lime.

On October 14, 1992, the field experiment plots were laid out and bulk sampled for baseline lab analyses. On October 26-28, 1992, zero tension lysimeters were installed in 12 designated plots. Each lysimeter consisted of a 0.60 m length of smooth bore 0.24 m diameter ABS plastic pipe with a fitted endcap. The design and installation of this type of lysimeter is described in detail by Stewart (1996). A 5-cm thick layer of coarse sand was placed into the bottom of each lysimeter to serve as a reservoir, and the lysimeter was backfilled with the excavated refuse. This configuration left the top of the lysimeter about 20 cm below the refuse surface and final leachate collection depth of approximately 75 cm. The surface excavation was then filled with refuse and the lime was applied and chisel-plowed into the refuse on designated plots. In treatments 5 through 9, agricultural lime was added at 100% of the determined potential acidity (27 Mg ha^{-1}). Burying the lysimeter 20 cm beneath the ground allowed tillage of the treatment into the surface of the refuse, and ensured that we were sampling only waters that percolated down through the treated plot area. The tube from the collection bucket was brought to the surface after the tillage was complete.

On November 16-19, 1992, local "topsoil" and two hydrocarbon contaminated soils were applied as specified in the experimental design with a backhoe. The local topsoil was a mixture of native B, C, Cr horizons and "rippable spoil" removed from a nearby road cut. On November 22, 1992, the entire plot area was seeded by Clinchfield with winter rye (*Secale cereale L.*) plus 450 kg ha^{-1} 16-27-14 fertilizer followed by straw-mulching at a rate of 2000 kg ha^{-1} the following day. On April 8, 1993, the plots were hydroseeded with a grass/legume species mixture (Table 1). Fertilizer was again added at a rate of 100 kg N ha^{-1}, 180 kg P_2O_5 ha^{-1}, and 40 kg K_2O ha^{-1} as 34-0-0, 0-46-0, and 0-0-62, respectively.

Table 1. Seed mix used at Moss #1 experiment.

Variety	Latin name	rate (kg ha^{-1})
German millet	*Panicum sp.*	16.8
Tall fescue	*Festuca arundinacea Schreber*	22.4
Annual ryegrass	*Lolium multiflorum*	16.8
Redtop	*Agrostis alba*	3.4
Annual ryegrass	*Lolium multiflorum*	16.8
Weeping lovegrass	*Eragrotis curvula*	3.4
Ladino clover	*Trifolium repens*	2.2
Kobe lespedeza	*Lespedeza striata*	11.2
Birdsfoot trefoil	*Lotus corniculatus*	11.2
Yellow sweetclover	*Melilotus officinalis*	2.2

<u>Sampling and Laboratory Analyses</u>

<u>Soil/refuse and standing biomass.</u> Composite refuse samples were taken at random from the surface 15 cm at each plot before treatments were applied. The local topsoil and the hydrocarbon contaminated soil used were also sampled. Vegetation performance under each treatment was evaluated by estimating the percentage ground cover (with a point frame), the species composition, and the vigor (color and disease rating) of growth in spring, summer, and fall. Standing biomass samples were taken from each plot in the fall of 1993 and 1994 by hand clipping to ground level within two 0.3 m by 0.3 m randomly assigned quadrats.

Plant tissue was oven-dried at 65°C for 48 hours and weighed to determine the dry weight yield. Soil samples were excavated beneath the biomass sample quadrats to a 0-15 cm depth with a shovel. Soil samples were air-dried and passed through a 2-mm sieve to separate coarse fragments. All analyses were performed on the fine (< 2-mm) fraction. Soil samples were analyzed for pH, conductance, and water retention. Soil pH was determined in a 1:1 soil:water slurry with a glass-calomel electrode pH meter. Specific conductivity of the leachates was determined with a conductance meter. Water holding capacity at various pressure potentials was determined in pressure cells with remolded samples on porous ceramic plates.

Leachates. Leachates were pumped up from each lysimeter with a vacuum pump at monthly intervals. The volume extracted from each lysimeter was recorded and the pH was measured on-site. A subsample was taken into a 250-ml plastic bottle for laboratory analyses. In the laboratory, conductance was measured with a conductivity meter and the samples were then acidified with HNO_3 to preserve them for later chemical analyses. Turbid samples were filtered through a #42 filter paper before conductance was measured. The leachate samples were analyzed for Al, Cu, Fe, Mn, S, Zn, and Ca by ICPES and/or AA spectroscopy.

Results and Discussion

Effect of Treatments on Surface Soil Acidity

The original refuse pH in the plots ranged from 3.62 to 3.88 (Table 2), indicating the presence of free acid from oxidation of pyrite. The original refuse Total-S content varied from 0.30% to 0.39%, with no differences among plots (Table 2). We estimated that 27 Mg of lime per ha (depth of 0.15 m) would be required to neutralize the potential acidity. The liming rates applied in this experiment were based on this assumed stoichiometric acid-base balance, and we used the H_2O_2 oxidation technique specified earlier to estimate reactive pyrite.

Statistical analysis of the soil data revealed that without lime or topsoil additions, there was no difference in surface soil pH between 1992 and 1993 (Table 2). The application of lime and topsoil increased the 0-15 cm soil pH from < 4.0 to > 6.0. It is important to point out that in the control and lime treated plots, this soil sample was taken from the refuse surface, while in the topsoil plots the applied soil materials were being sampled. The pH increased to 6.32, 7.28, 7.99, 7.97, 7.91, and 7.74 for the HLime, Lime, T15, T30, H1, and H2 treatments respectively, all of which were significantly elevated above those of the controls (Table 2). Plots receiving the half rate of lime (HLime) were significantly lower in pH than plots receiving the full rate, but still achieved an acceptable pH level for plant growth. These treatment effects were expected due to the liming rates utilized and the high pH of the topsoiling material used. Liming effects in acid-forming materials are often ephemeral, however, and we would expect the HLime plots to decline in pH more rapidly over time than those receiving the full estimated lime rate.

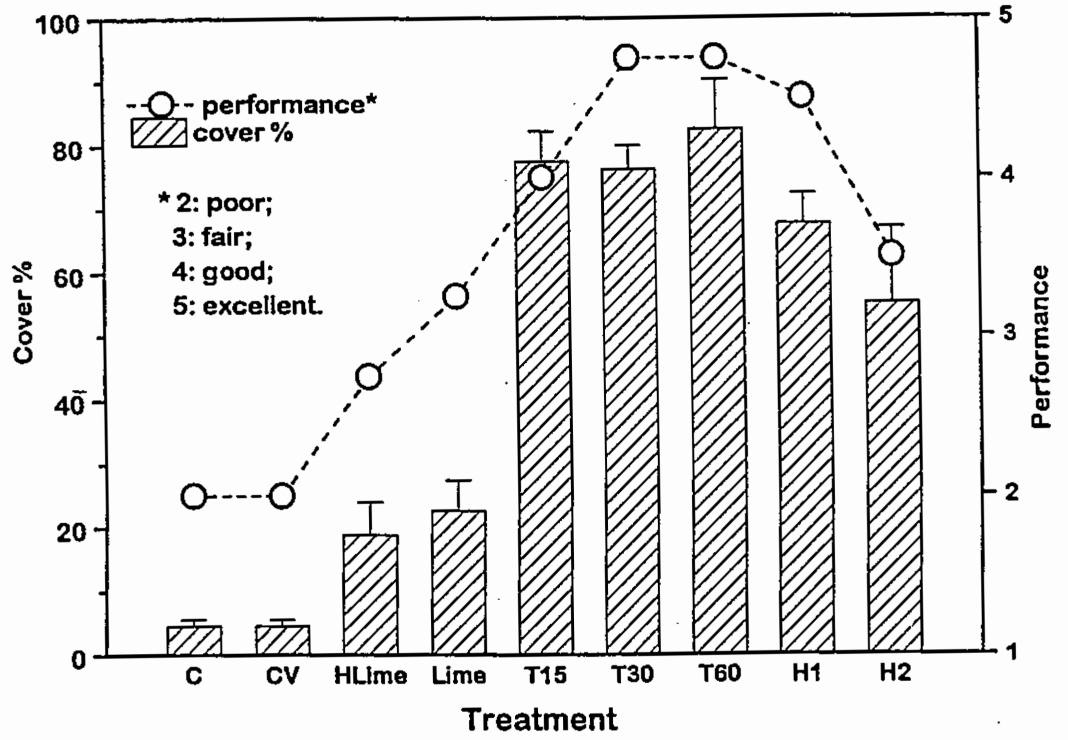
Effect of Treatments on Vegetation

Both lime additions and topsoiling buffered the surface soil pH above 6.0 and therefore led to more favorable conditions for vegetative growth. The winter rye seeded in the late fall of 1992 provided a quick plant cover to prevent erosion and runoff and provided a stubble-mulch for the following spring-seeded perennials. The winter rye was evaluated on May 6, 1993 (Fig.1), and the data indicated that lime and topsoil treatments resulted in higher percentage vegetative cover and more vigorous growth. On the control treatments, the

Table 2. Total-S, soil pH and standing biomass by treatment.

Treatment[†]	S content[‡] (%)	pH		Standing Biomass (kg ha^{-1})	
		1992[‡]	1993	1993	1994
C	0.31 ab[§]	3.88 a	3.95 a	36 a	458 a
CV	0.39 b	3.67 a	3.94 a	316 a	1178 ab
HLime	0.37 ab	3.66 a	6.32 b	1040 ab	2021 bcd
Lime	0.35 ab	3.74 a	7.28 c	1139 b	1762 abc
T15	0.35 ab	3.75 a	7.99 c	1402 b	3110 cd
T30	0.30 a	3.83 a	7.97 c	1402 b	4768 e
T60	0.33 ab	3.83 a	7.91 c	2619 c	5435 e
H1	0.34 ab	3.69 a	7.35 c	1650 b	3378 d
H2	0.35 ab	3.62 a	7.74 c	1465 b	2601 cd

Figure 1. Winter rye cover % and performance evaluation.
(Spring, 1993)



C: control; CV: control with vegetation; HLime: 13.5 ton lime/ha;
Lime: 27 tons lime/ha; T15: 15-cm topsoil; T30: 30-cm topsoil;
T60: 60-cm topsoil; H1: hydrocarbon soil #1; H2: hydrocarbon soil #2.

*Field survey on May 6, 1993, and Values shown are means (n=4) with standard errors.

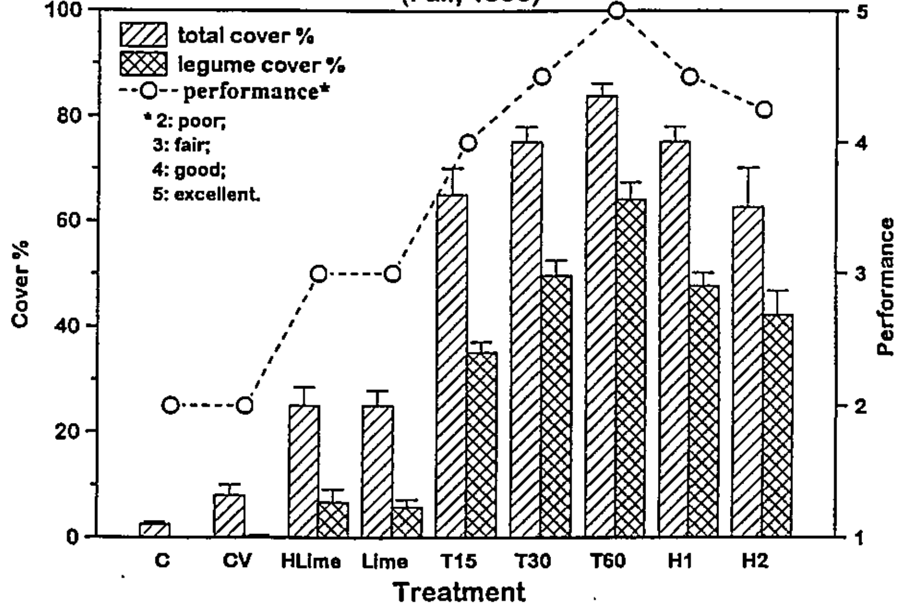
vegetation grew poorly and the cover was < 5%. Lime treatment alone improved the vegetation growth and produced about 20% cover. Topsoil treatments resulted in excellent rye growth and thicker covers (55% - 82%). Rye growth was slightly inhibited in the hydrocarbon soil plots compared with the regular topsoil.

The winter rye cover crop matured in June and matted down, and was successfully overseeded into a mixed grass/legume stand. This perennial stand was evaluated on Oct. 5, 1993, with similar overall cover results to the pure rye stands (Fig. 2). It is also important to note that there was no difference in fall biomass yield between the hydrocarbon soil plots and their comparable 30-cm topsoiled plots. The lime and topsoil treatments not only improved the general performance of vegetation and cover percentage, but also increased the legume component and its growth. There were no legume species in control plots, while about 5% of the plot area was covered with legume species in the limed treatments. The legume species became dominant in all topsoil treatments, however, presumably due to a combined effect of the higher soil pH and other improved soil conditions such as water holding capacity, temperature, etc.. Linear regression coefficients (r) were 0.705, 0.806, 0.783, 0.843, 0.762 and 0.856 for the relationship between pH versus standing biomass, winter rye cover %, winter rye vigor, mixture (grass/legume) cover %, legume cover %, and total vigor, respectively. These relationships indicate that the inherently low pH of the refuse was an important factor limiting vegetation establishment, but the standing biomass and legume data do indicate an added benefit of topsoil and increasing thickness over bare refuse in the first year. In 1993, total biomass yield on topsoil or lime treated plots was 3 to 8 times greater than that on the control plots (Table 2). Obviously, the raw refuse is a fairly harsh material for plant growth and needs to be modified for successful reclamation.

Second year (1994) trends of biomass yield and vegetation performance were similar to those of 1993. The plant cover percentage increased on all plots, and the biomass yields of most treatments were double those of 1993 (Table 2 and Fig. 3). The lowest yield was observed on the control treatment, and the highest yield was produced on the 60-cm topsoil plots. Total biomass production increased with increasing topsoil thickness, which was consistent with the results from other studies (McGinnies and Nicholas 1980; Barth and Martin 1984;

Figure 2. Vegetation cover % and performance evaluation.

(Fall, 1993)

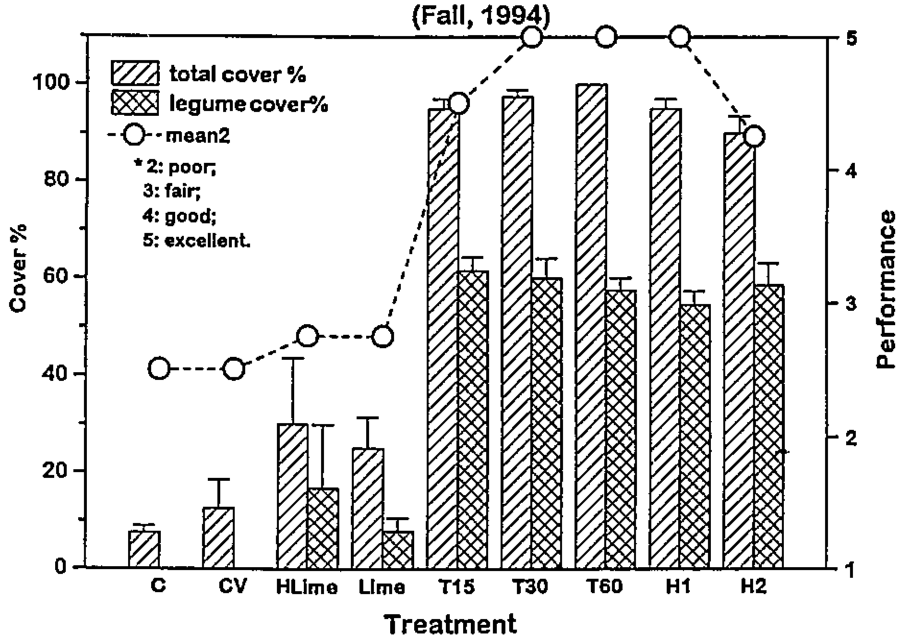


C: control; CV: control with vegetation; HLime: 13.5 ton lime/ha;
Lime: 27 tons lime/ha; T15: 15-cm topsoil; T30: 30-cm topsoil;
T60: 60-cm topsoil; H1: hydrocarbon soil #1; H2: hydrocarbon soil #2.

*Field survey on Oct. 5, 1993, and Values shown are means (n=4) with standard errors.

Figure 3. Vegetation cover % and performance evaluation

(Fall, 1994)



C: control; CV: control with vegetation; HLime: 13.5 ton lime/ha;
Lime: 27 tons lime/ha; T15: 15-cm topsoil; T30: 30-cm topsoil;
T60: 60-cm topsoil; H1: hydrocarbon soil #1; H2: hydrocarbon soil #2.

*Field survey on Oct. 21, 1994, and Values shown are means (n=4) with standard errors.

Power et al. 1981). Both the hydrocarbon soil (30-cm) and the 15-cm topsoil fell within one group that ranged from 2600 to 3400 kg ha^{-1}. The yield on the hydrocarbon soil (30-cm) was lower than that the 30 cm regular topsoil (Table 2), indicating that the hydrocarbon soil somewhat inhibited vegetative growth.

There was a little overall difference observed between October 1993 and 1994 in vegetation performance response to the treatments (Figs. 2 and 3). The vegetation performance was qualitatively rated as "excellent" on the 60-cm topsoil, 30-cm topsoil, and hydrocarbon soil #1 (30-cm) plots. The performance was rated as "good" on the 15-cm topsoil and hydrocarbon soil #2 plots. The poorest performance was on the control plots, while the vegetation on the limed refuse plots in 1994 was just a little better than that of control plots. Vegetation grew vigorously on all topsoiled treatments, including the hydrocarbon soil, and 2/3 of the cover were legumes. The vegetation cover on the limed refuse plots was approximately 25%, and about half of that was legume species. The control plots were covered with grass only, and the cover percentage was < 15%.

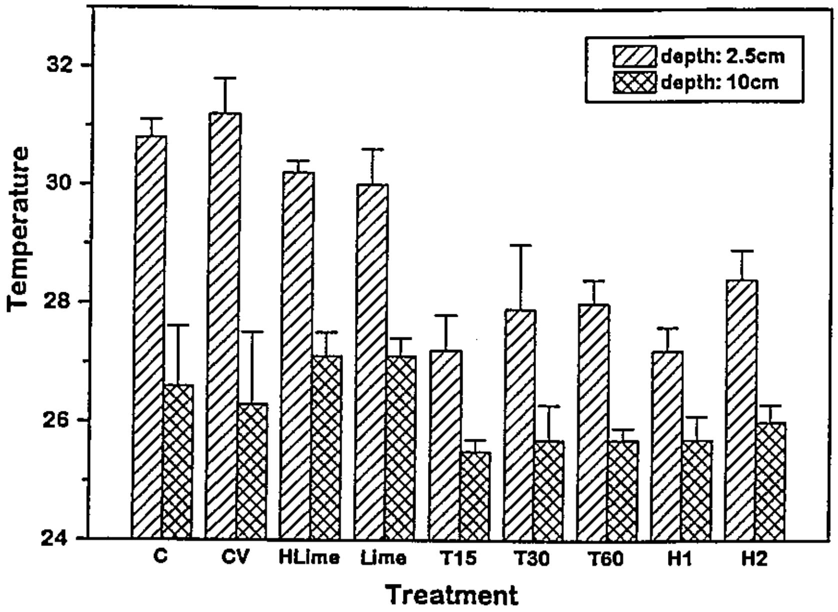
The vegetation results from the second year indicate that both topsoil and liming increased the legume growth via increased soil pH and secondary effects on nutrient availability and metal toxicity. As mentioned earlier, however, potential acidity is only one of the obstacles in the revegetation of coal refuse. Besides improving pH, topsoil provides other functions that lime alone does not, such as higher levels of nutrient retention and supply, higher water holding capacity and lower summer surface temperature. Other studies have shown that the surface temperature of dark mine spoils or coal waste can reach 45 - 75°C in summer (Deely and Borden 1973; Lee et al. 1975). Field temperature measurements at Moss #1 showed that the topsoil treatments effectively decreased surface temperature at a depth of 2.5 cm (Fig. 4). Soil temperature was also probably affected by the vegetation cover, the soil color and water content. The soil moisture vs. potential curves indicated that the topsoil did improve the bulk surface soil water holding capacity while the liming did not (Fig. 5). The coal refuse at Moss #1 tends to be highly compacted, which in combination with its poor aggregation, led to observed waterlogging and ponding in winter and drought in summer. Plant water stress was readily observable on the control and limed plots in June 1993, and only minor amounts of leachate were collected from each lysimeter in that month (Fig. 6).

Treatment Effects on Leachate Quality

Variation in monthly volume of leachate from each treatment is given in Figure 6. The volume of leachate from each lysimeter was affected by both treatment-related factors and certain unrelated factors. The treatment-related factors included infiltration and evaporation governed by the surface soil texture, the organic matter content and the structure of soil, and also by evapotranspiration as governed by vegetative cover and the soil surface temperature. The main unrelated factor was microtopography. For example, we observed that higher volumes of leachate were collected from a lysimeter that was near a depression that would fill with stormwater, which would then continuously infiltrate the nearest lysimeter long after the storm passed. At this location, we could only be sure that the leachate volume corresponded with precipitation.

The pH of leachates from all lysimeters fluctuated between 3.1 and 4.5 after July 1993 (Fig.7). These are relatively low values given the lime and topsoil surface treatments employed. This observation is consistent with that of Gitt and Dollhopf (1991) who found that incorporating lime into refuse made no significant change in leachate pH beyond their 20-cm depth of incorporation. Leachate pH was profoundly influenced by the leachate volume or total mass of flow. The lower the volume of collected leachate, the lower the leachate pH (Figs. 6 and 7). Dry soil conditions retard the rate of water percolation and lead to better soil aeration and higher redox potential. These conditions in turn lead to a longer reaction time between water and the refuse, a higher rate of pyrite oxidation, and a subsequently lower leachate pH. The sulphate concentration of the leachates fluctuated with time and high sulphate levels corresponded well to low pH (Figs. 7 and 8). As expected, at low pH the leachate also had a high electrical conductance (Fig. 9). Aluminum, Fe, Mn, Cu, Zn and Cu concentrations in leachate rose and fell with pH (Figs. 10 - 14) due to its direct solubility control (Rimmer 1982; McGinnies and Nicholas 1980; Barth and Martin 1984), while Ca appeared unaffected by pH or treatment (Fig. 15). The order of solubility measured in terms of leachate concentration was S > Ca > Al > Mn > Zn > Fe > Cu. There did seem to be a higher concentration of metals observed under the vegetated control and hydrocarbon soil #1 plots, but this was presumably due to the pH solubility control effects.

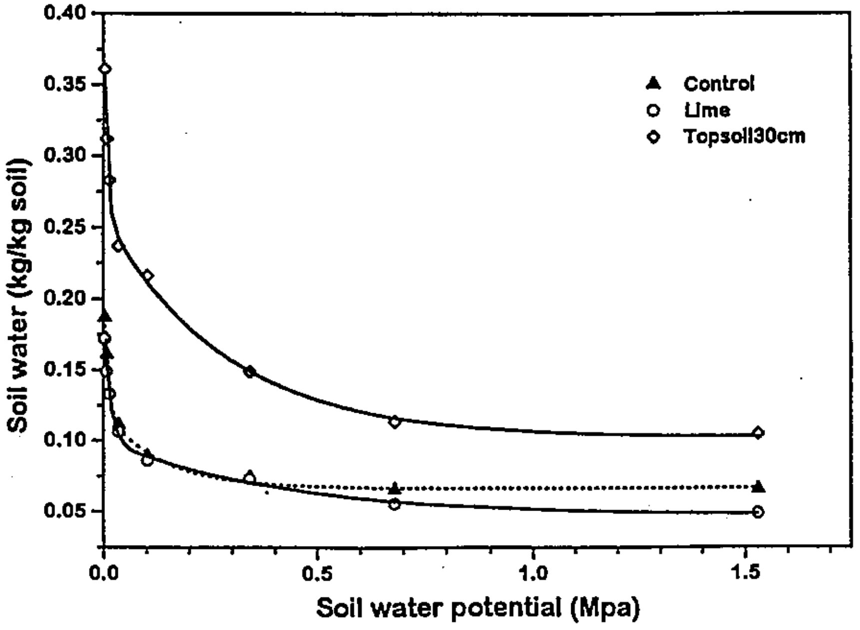
Figure 4. Soil temperature at Moss #1.



C: control; CV: control with vegetation; HLime: 13.5 ton lime/ha;
Lime: 27 tons lime/ha; T15: 15-cm topsoil; T30: 30-cm topsoil;
T60: 60-cm topsoil; H1: hydrocarbon soil #1; H2: hydrocarbon soil #2.

Temperature measured on July 21,1994, and values shown are means (n = 4) with standard errors.

Figure 5. Soil moisture potential curves.



Available soil water is that held between 0.1 and 1.5 Mpa.

Figure 6. Leachate volume at Moss #1.

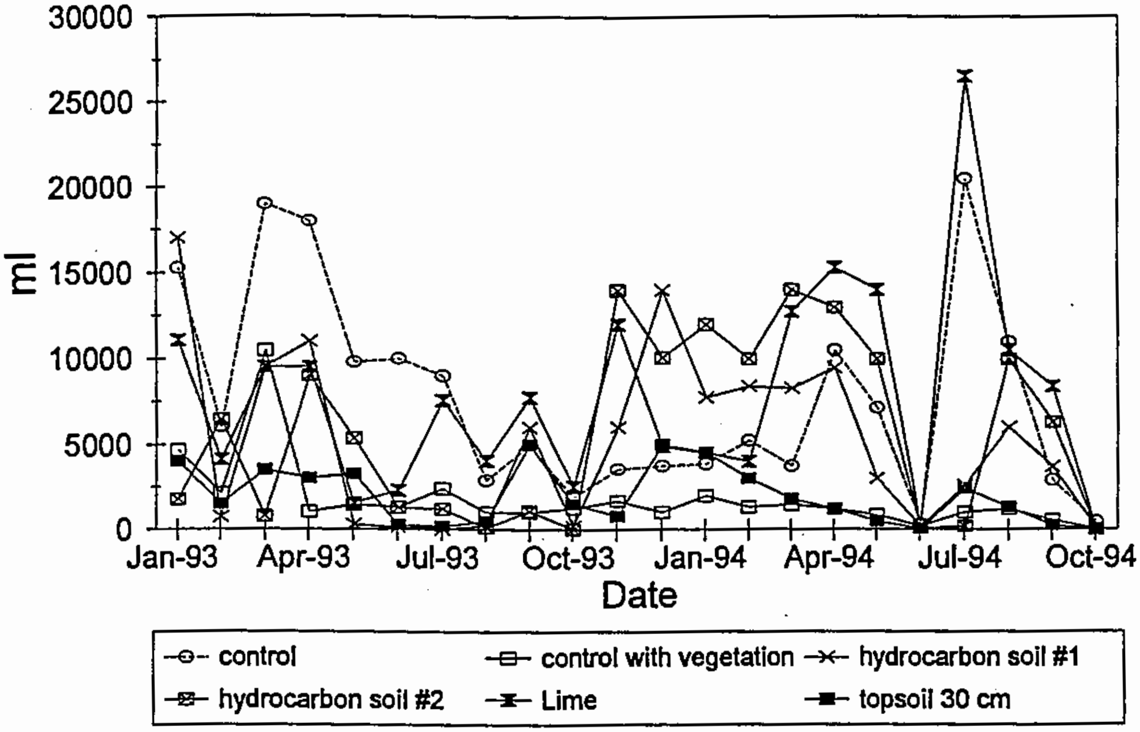


Figure 7. Leachate pH at Moss #1.

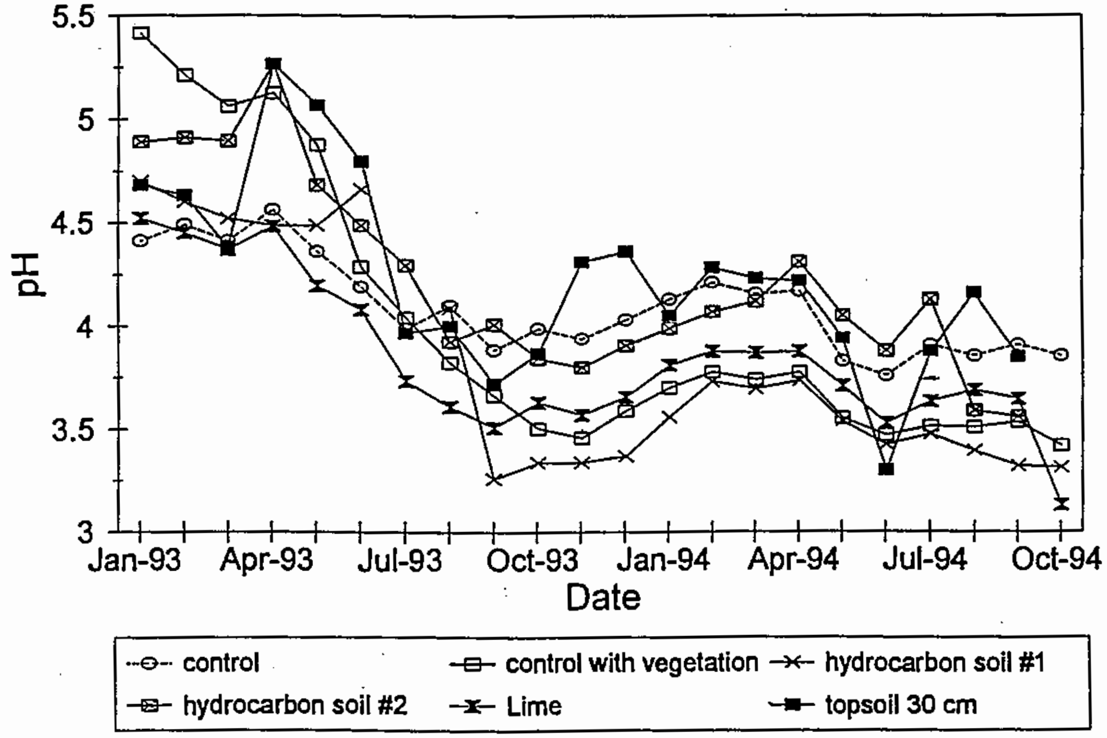


Figure 8. Leachate S at Moss #1.

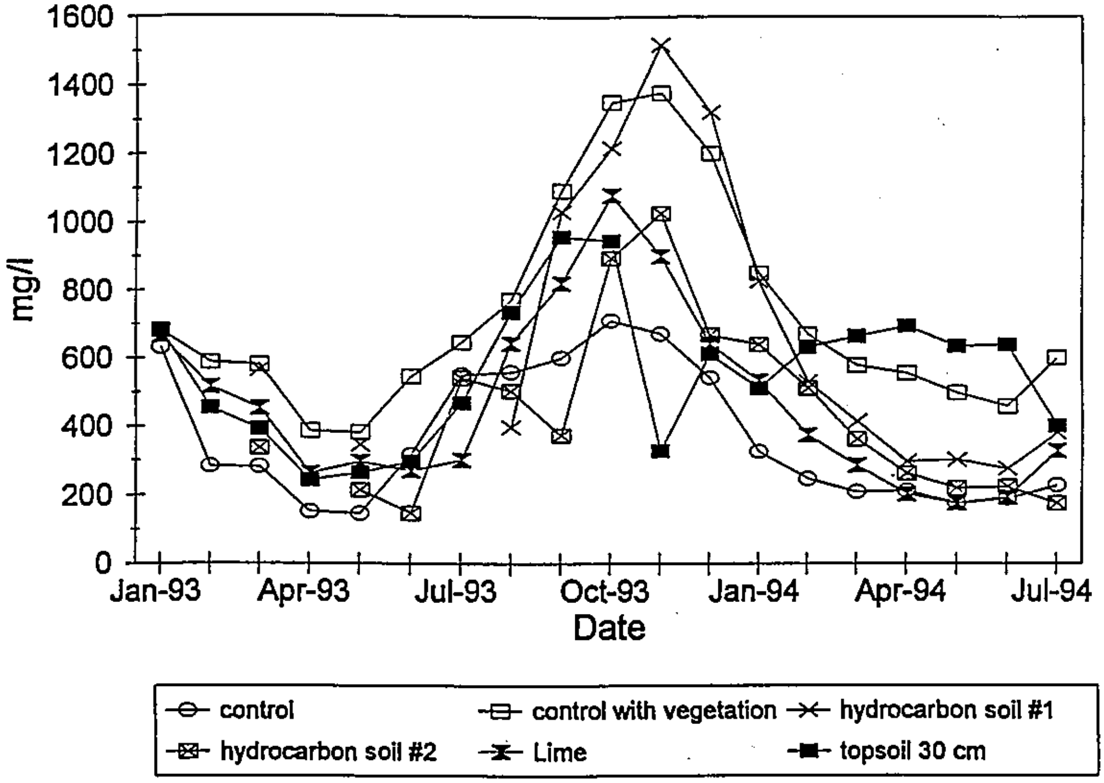


Figure 9. Leachate EC at Moss #1.

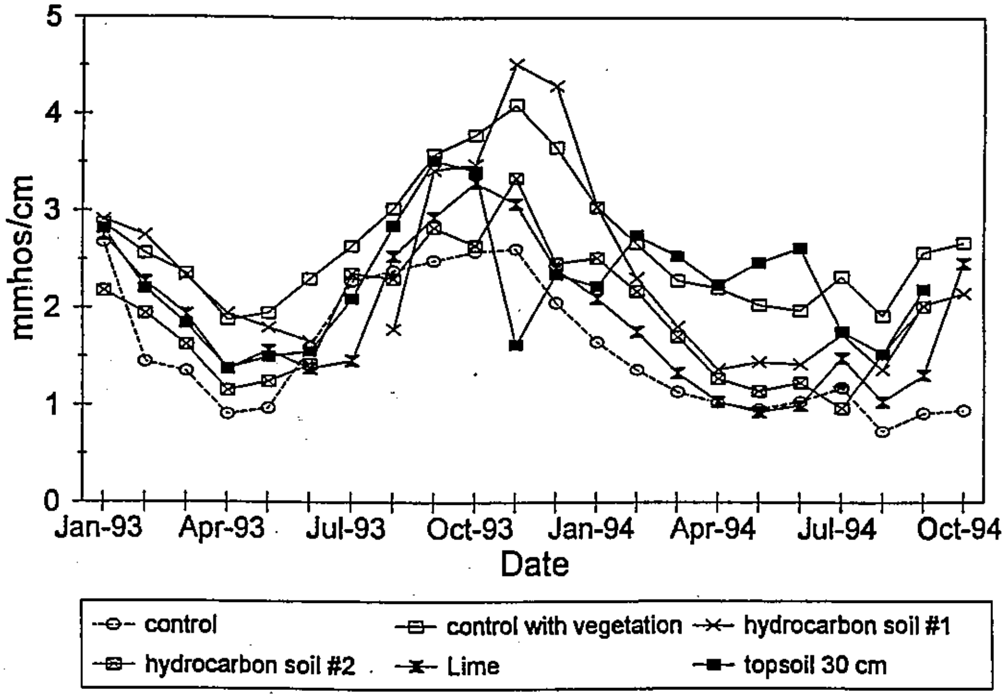


Figure 10. Leachate Al at Moss #1.

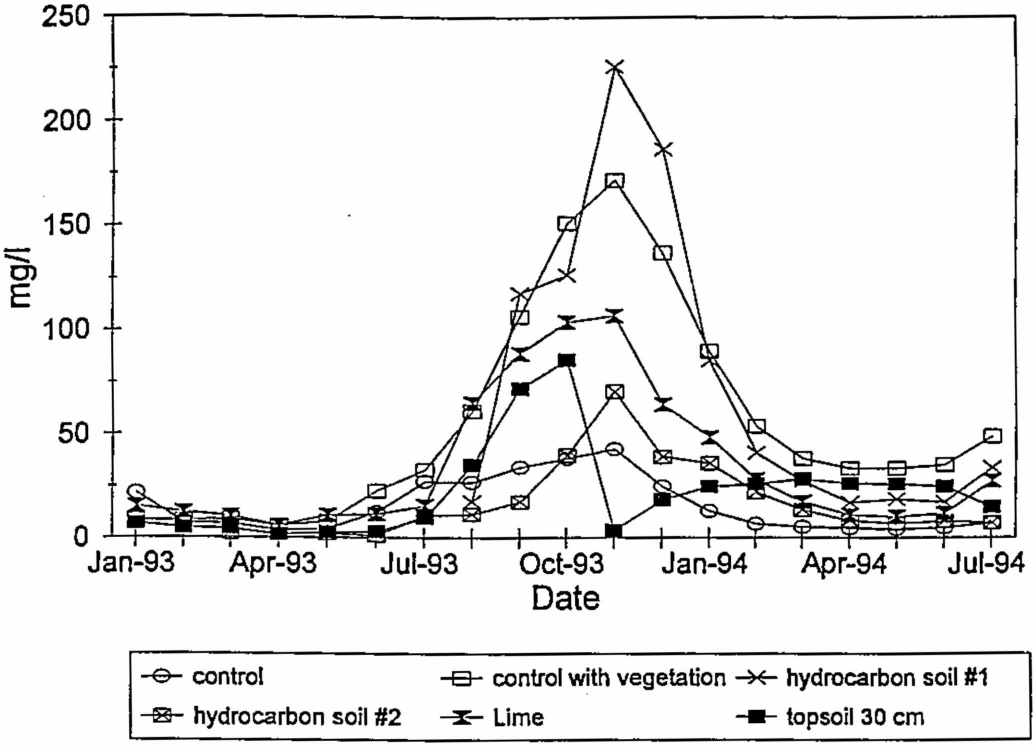


Figure 11. Leachate Fe at Moss #1.

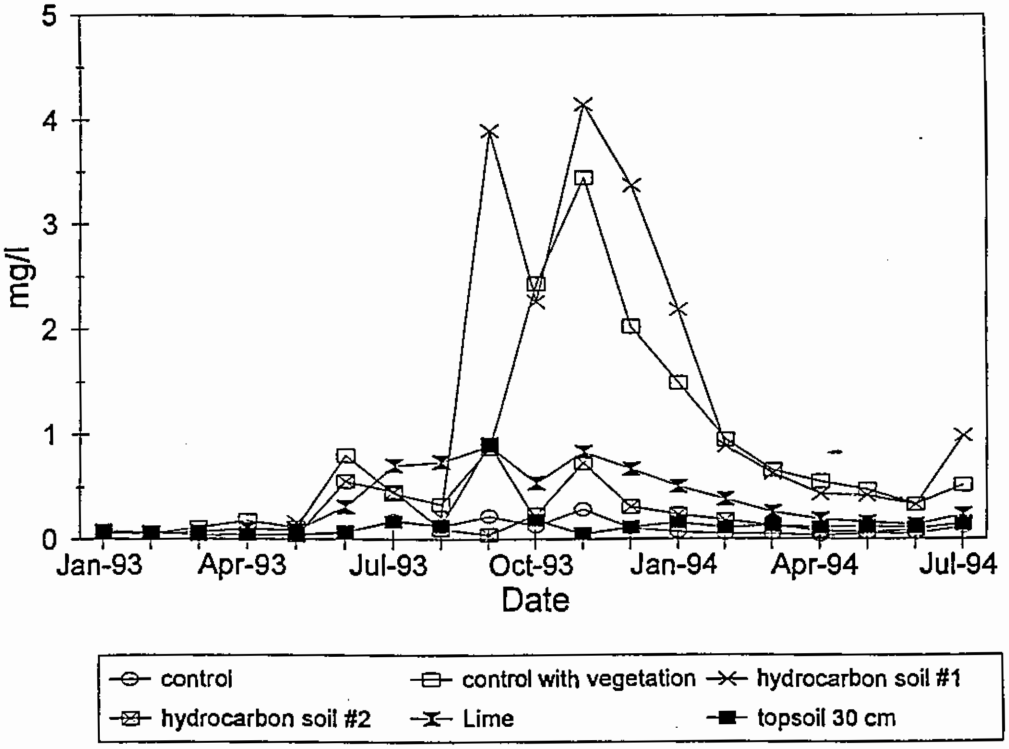


Figure 12. Leachate Mn at Moss #1.

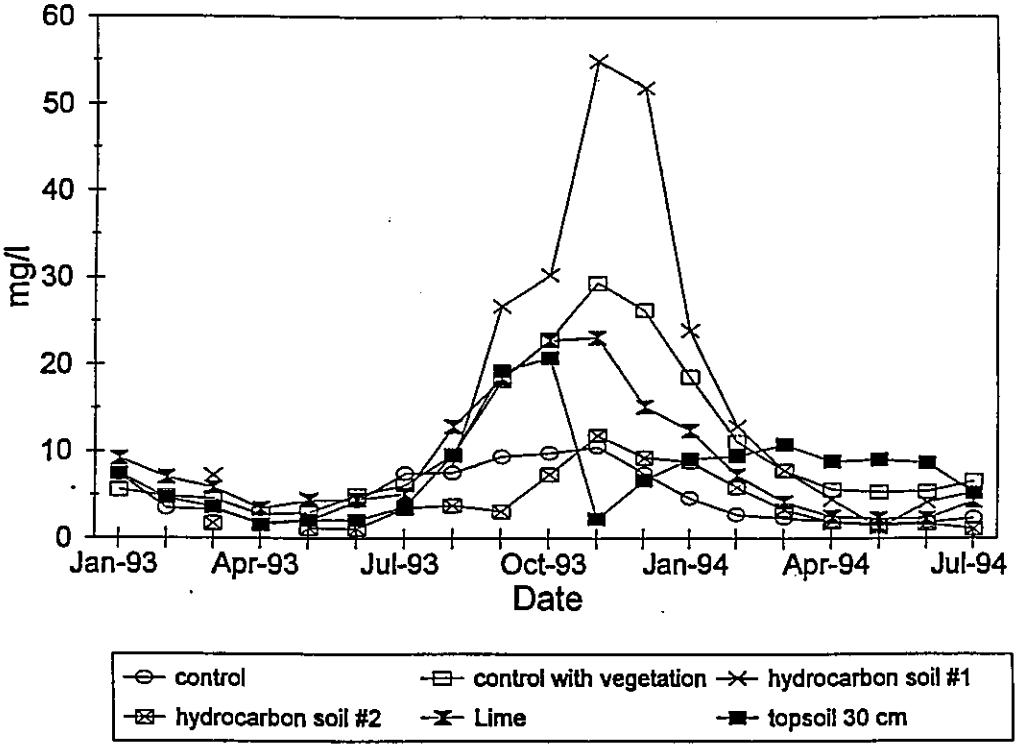


Figure 13. Leachate Cu at Moss #1.

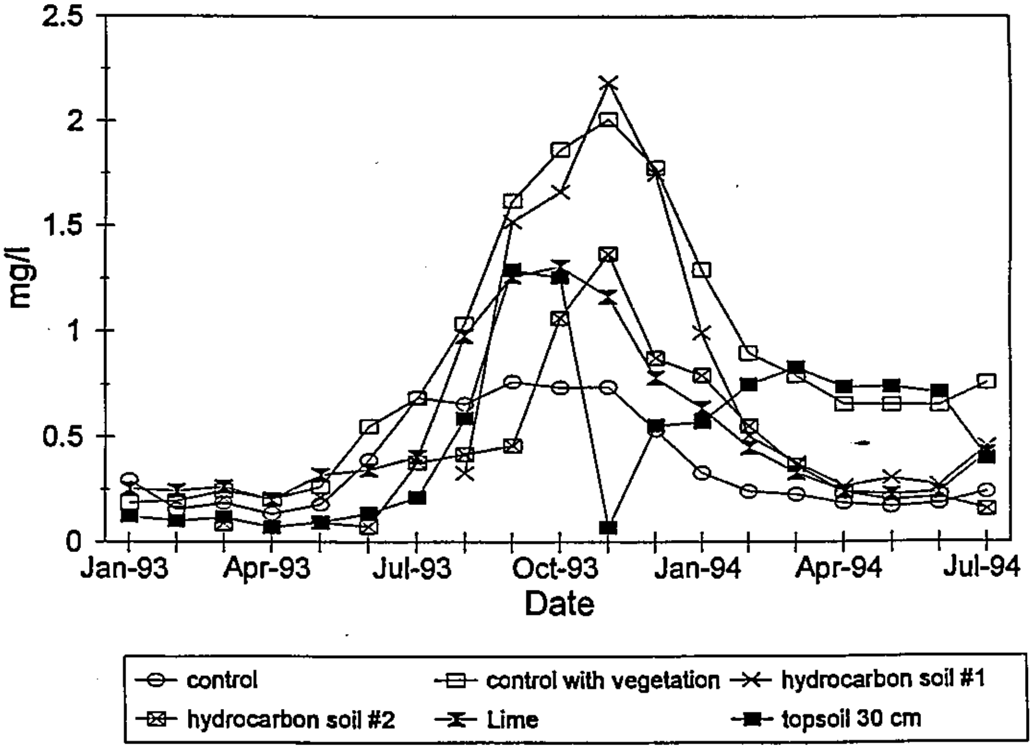


Figure 14. Leachate Zn at Moss #1.

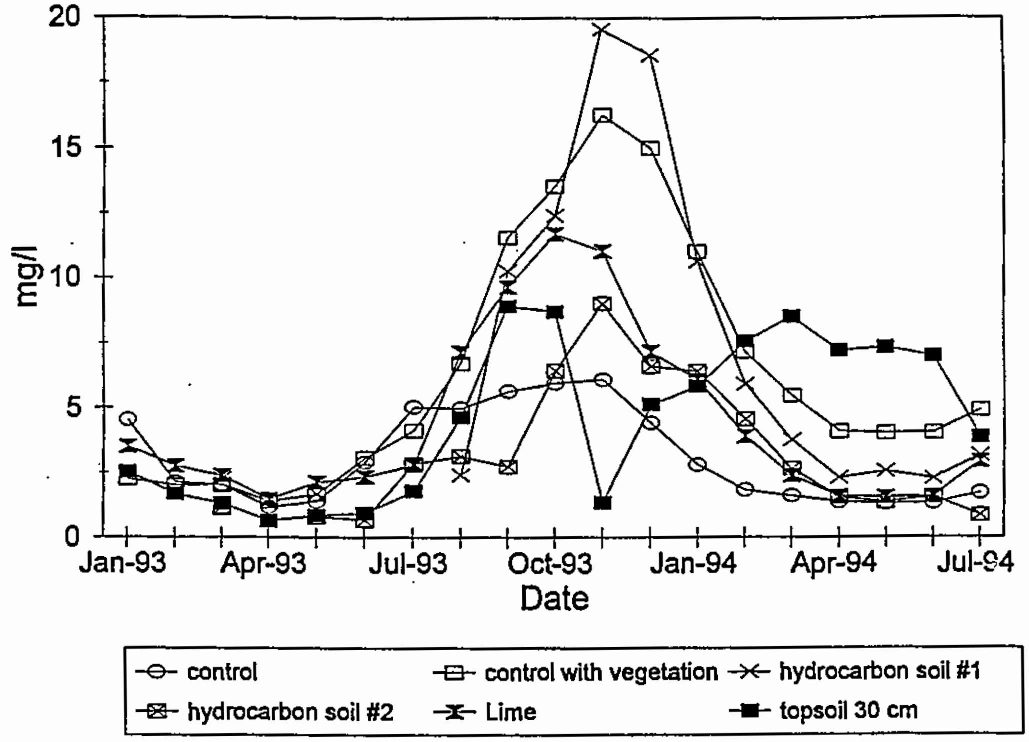
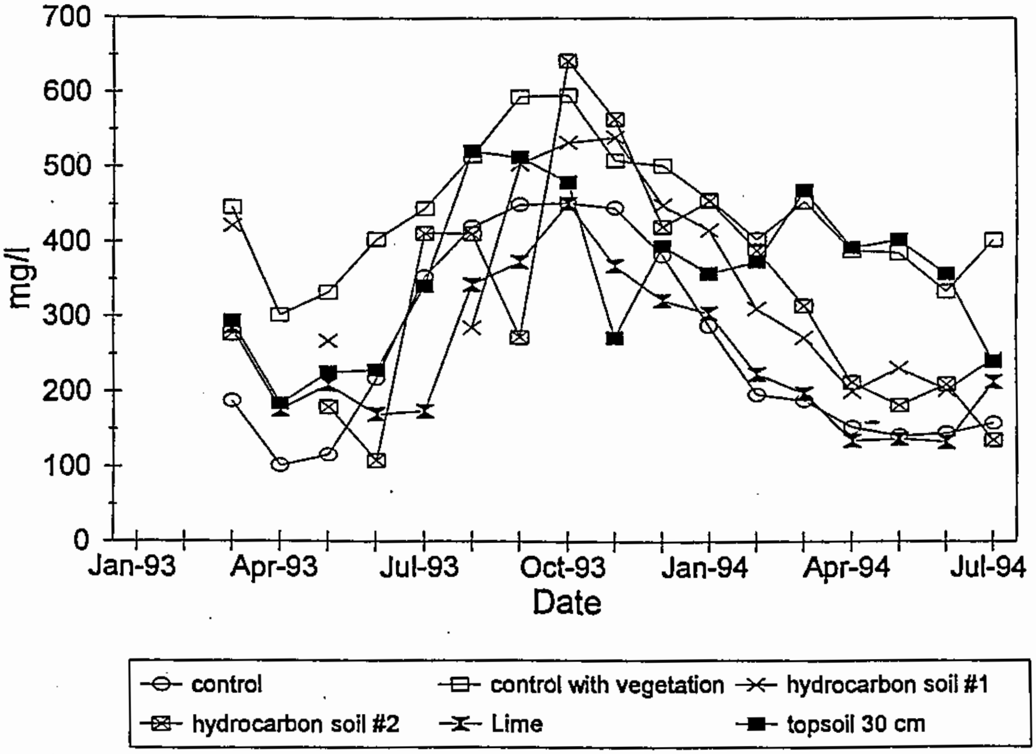


Figure 15. Leachate Ca at Moss #1.



None of the applied treatments had any statistically significant effect on leachate pH or conductance. The lime requirement did an excellent job of neutralizing surface soil pH (Table 2). However, as water moved down through the acidic refuse below the lime-treated zone, its alkalinity was rapidly consumed, and its pH approached that of the unamended refuse. The steady decline in overall pH under all of the treatments with time (Fig. 7) appears to indicate that surface treatments will only have an ephemeral effect on the quality of deeper waters in (or discharging from) the fill.

Summary and Conclusions

Liming the refuse and covering it with a thin lift of topsoil was the best combined treatment observed in this experiment. This treatment combination increased the surface soil pH from < 4.0 to > 6.0, which resulted in a higher cover % and standing biomass over both years. The lime-only direct-seeding treatments were lower in cover and yield than those employing topsoil, presumably due to poor physical and chemical properties, such as low nutrient content, low water holding capacity, and thermal loading characteristics of the bare refuse. The vegetation itself would be expected to improve surface soil conditions over time for these direct-seeded treatments, but the stands we observed at the end of two full seasons were still substandard. Overall, the 60-cm topsoil cover led to the best revegetation results over the two growing seasons, but this could be a very costly alternative for the entire pile. Liming at 27 Mg ha^{-1} along with 15 cm of topsoil produced reasonable two-year plant cover which we believe will proliferate with time to fully stabilize the surface. These results are similar to several other studies that we have conducted on similar materials in the Virginia coalfields (Daniels et al. 1989). The use of the hydrocarbon contaminated soil as a cover material was acceptable, but was less effective than native soil materials.

None of the treatments employed (liming or topsoil covers) appeared to have any consistent affect on leachate pH and conductance. It is possible that leachate chemistry effects could be time-lagged and related to long-term soil organic matter accumulation and oxygen consumption in the surface soil layers associated with microbial activity and organic matter turnover. These phenomena might not have had enough time to become apparent over the two years studied. The volume of pyrite deeper in the pile along leachate flow paths is very large in comparison with the limited amount of buffering achieved by the surface treatments, however, so even complete pile revegetation should not be expected to influence the quality of discharge waters at this site.

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