# SOIL COVER AND ALKALINE AMENDMENT ALTERNATIVES FOR COAL SLURRY IMPOUNDMENTS[1]

By

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Abstract. Current reclamation regulations require a 4 ft soil cap prior to vegetation establishment for inactive coal slurry disposal areas. Research demonstrations implemented by Southern Illinois University at Carbondale (SIU-C) in the late 1970s and 1980s identified alternatives that have included both upland and wetland habitat establishment without the use of soil cover. SIU-C research has emphasized neutralization amendment and direct seeding. To evaluate effect of soil depth on vegetation, Consolidation Coal Company (CONSOL) implemented in the fall of 1980 a demonstration of cover depths (0, 1, 2, and 4 ft) within a 60 acre inactive coal slurry disposal area in Perry County, Illinois. Vegetation sampling (species and density) of 4 herbaceous cover mixes (legume/grass, warm and cool season) was conducted in 1982, 1983, 1984, and 1989 to evaluate cover depth and plant performance. Cover soil, amended refuse, and unamended refuse samples were sampled in 1989 to evaluate long-term effects of cover depth on pyrite oxidation.

The warm season grass mix (little bluestem, Indian grass, side-oats gramma, switchgrass) provided significantly greater cover (82%) after 9 years in the direct seeded plots (0 soil cover) than any of the cool season mixes. Greater cover depths (1, 2, and 4 ft) did not have a significant effect on warm season grass cover. Warm season grass cover generally increased after 9 years, while cool season grass mixes generally declined in the 0 ft and 1 ft depths. No significant difference was found in vegetative cover (all mixes ≥ 83%) for 2 ft or 4 ft cover depths. Soil cover depth had no effect on refuse acidification below soil caps as limestone amendment (@ 100 tons/acre) was sufficient to maintain alkaline conditions (pH 6.4-7.2) in the amended refuse zone (0-9 in). Results of this reclamation demonstration identify the importance of alkaline amendments prior to soil covering of inactive slurry and the value of warm season grass establishment for maintenance of adequate cover (> 80%) for direct seeded refuse without soil.
Additional Key Words: tailings, coal slurry reclamation

## Introduction

Slurry disposal areas containing fine coal-processing wastes are characterized by the Federal Office of Surface Mining as potentially acid-producing, due to the presence of pyritic materials.

Current regulations require 4 ft of soil or other material as final cover on those slurry impoundments not capable of supporting vegetation. Implementation of this requirement is often expensive and extremely difficult, due to inavailability of cover and surface instability. Factors such as coal preparation and slurry disposal processes, coal seam and overburden geology, impoundment morphology, embankment integrity, and age render site conditions, both within and between impoundments, highly variable (Nawrot and Yaich 1982). Consequently,

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reclamation alternatives can also vary, ranging from wetland to upland habitats established on soil covered (1 to 4 ft depths) or directly vegetated (no soil cover, with and without limestone amendment) slurry (Nawrot 1986).

Reclamation alternatives using variable soil cover depths and direct vegetation (with limestone amendment) techniques have been evaluated for both coarse and fine refuse at several sites in Illinois (Deane 1968). A 1 ft soil covering was found to be no less effective than a 2 ft or 3 ft cover in preventing acid runoff from coarse refuse (Kosowski 1973). Brundage (1974) detected no difference in vigor of vegetation growing on soil coverings ranging from 9 in to 4 ft on coarse refuse. Small scale experimental plots have evaluated vegetation establishment on limed, fertilized, and mulched coarse refuse piles without soil cover. Czapowskyj et al (1968) reported that when revegetating coal breaker refuse, lime was essential, mulch was beneficial, and fertilizer had little effect on the success of crownvetch (Coronilla varia). Shetron and Duffek (1970) examined growth and survival of 5 grass, 2 legume, and 3 tree species on 0.1-acre iron mine tailing test plots. They found legume-grass mixtures provided 100% cover during the first growing season when fertilized 3 times; however, they did not evaluate long-term vegetative success. Sorrel (1974) reported that direct seeding of 1 legume and 2 grass species was successful after one month. Barthauer et al (1971) established vegetation directly on acidic refuse material amended with lime, fertilizer, and mulch. Vegetative cover was improved when lime was thoroughly mixed with refuse material; however, long-term success was not determined.

To evaluate long-term vegetative success, this study evaluated vegetation and soil characteristics of an inactive slurry impoundment that had received both no-soil and soil cover (1, 2, and 4 ft) treatments. This paper documents selected soil and vegetative data from the initial no-soil treatments of 1975 and cover depth treatments initiated in 1980. Vegetation evaluations conducted in 1982, 1983, 1984, and 1989; and soil analysis results from 1989 are included, and are also briefly summarized in this paper.

## Study Area

The Pyramid Mine study area is located on an abandoned coal refuse area approximately 1.8 mi south of Pinckneyville, Perry County, Illinois (T6S, R3W, Sec. 1 and 2). The refuse area is associated with the abandoned coal-processing area of Pyramid Coal Corporation. Pyramid Mine opened in 1928 as a surface mining operation extracting the Illinois No. 6 coal seam at a depth of 25 to 50 ft. The first modern coal-washing preparation plant at a surface mine east of the Mississippi River was constructed in 1934 at the Pyramid Mine. Average daily production in 1954 was recorded at 8,000 tons. Disposal of coal refuse from 1930-1954 resulted in a 60 acre slurry impoundment encompassed by surface mine spoils and a coarse refuse (gob) embankment.

Initial attempts (prior to 1975) to control fugitive dust from the refuse area with sprinkler irrigation and chemical binders failed to provide an acceptable degree of control. Consequently, in 1975, limestone amendment and direct seeding of the slurry surface (@ 15 tons/acre) and the interior gob embankment was initiated. Direct seeding of the coarse and fine refuse was successful in controlling the fugitive dust by vegetatively stabilizing the previously acidic (gob pH 1.8-3.2; slurry pH 3.5-4.8) refuse (Smout 1977). Annual augmentation of agricultural limestone through 1977 to the slurry surface maintained alkaline conditions capable of supporting warm season grasses (weeping lovegrass Eragrostis curvula and switchgrass Panicum virgatum). Modification (alkalinity and fertility increases) of the slurry surface also enhanced invasion and colonization by early successional species such as foxtail (Setaria spp.), crabgrass (Digitaria sanguinalis), and sumac (Rhus copalina).

Although direct seeding (no soil cover) of aged and weathered slurry at the Pyramid site had application for other pre-law sites, alternative cover depths (less than 4 ft) had not been evaluated under field conditions. Therefore, 3 experimental plots were established on the Pyramid slurry impoundment in the fall of 1980 to determine the effect of soil cover depth on soil and vegetation characteristics (see Figure 1). Slurry surfaces were

Table 1. Pyramid Mine slurry reclamation demonstration. Test plot vegetation species mixes.

| Mix | Species | Seeding Rate (pounds/acre) |
|---|---|---|
| A | Alfalfa (*Medicago sativa*) | 15 |
| | Orchardgrass (*Dactylis glomerata*) | 10 |
| B | Weeping lovegrass (*Ergrostis curvula*) | 5 |
| | Tall fescue (*Festuca arundinacea*) | 18 |
| | Sericea lespedeza (*Lespedeza cuneata*) | 15 |
| | Birdsfoot trefoil (*Lotus corniculatus*) | 12 |
| C | Little bluestem (*Andropogon scoparius*) | 12 |
| | Indian grass (*Sorgastrum nutans*) | 12 |
| | Side-oats gramma (*Bouteloua curtipendula*) | 12 |
| | Blackwell switchgrass (*Panicum virgatum*) | 12 |
| D | Tall fescue (*Festuca arundinacea*) | 20 |
| | Korean lespedeza (*Lespedeza stipulacea*) | 15 |

amended with agricultural limestone at a rate of 100 tons/acre before soil covering. Prior to limestone application, previously treated surface materials were removed to expose unamended slurry. After scarification of the slurry surface, soil from nearby spoilbank borrow areas was used to cover adjacent quarters ("subplots" 50 ft x 50 ft) of each plot location. Soil depths included 4 ft, 2 ft, 1 ft, and 0 ft.

Each subplot was approximately 0.05 acre and was separated from adjacent subplots by a buffer zone and a vegetative drainage channel to prevent surface water flow between plots. Subplots were divided into 4 subunits for evaluation of 4 herbaceous cover mixes (see Table 1). Vegetative cover mixes included warm season and cool season grasses and legumes.

## Methods

### Vegetation

To determine long-term success of vegetative cover mixes, vegetation sampling of experimental plots was conducted during the growing season (June through August) during 1982, 1983, 1984, and 1989. The most recent vegetation sampling, conducted on 23 and 24 July 1989, was designed to determine the effects of soil cover depths over refuse and to evaluate the performance of 4 grass-legume seed mixes. Grids were established within each test subplot and x-y coordinates were randomly chosen to select sampling locations. A 30-point pin frame was used to evaluate vegetative cover and species composition (Chapman 1976).

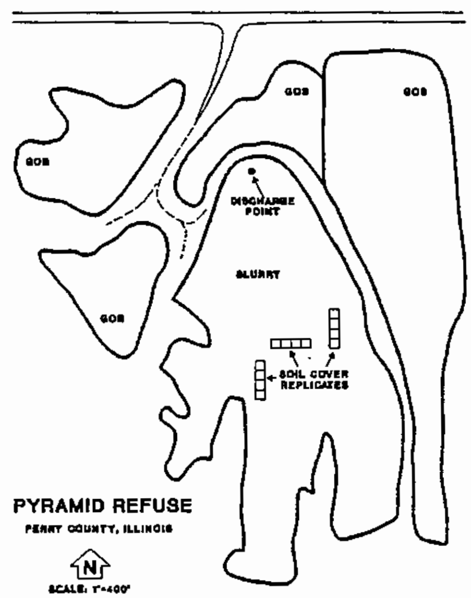


Figure 1. Pyramid Mine slurry reclamation demonstration. 1980 soil cover plot location map.

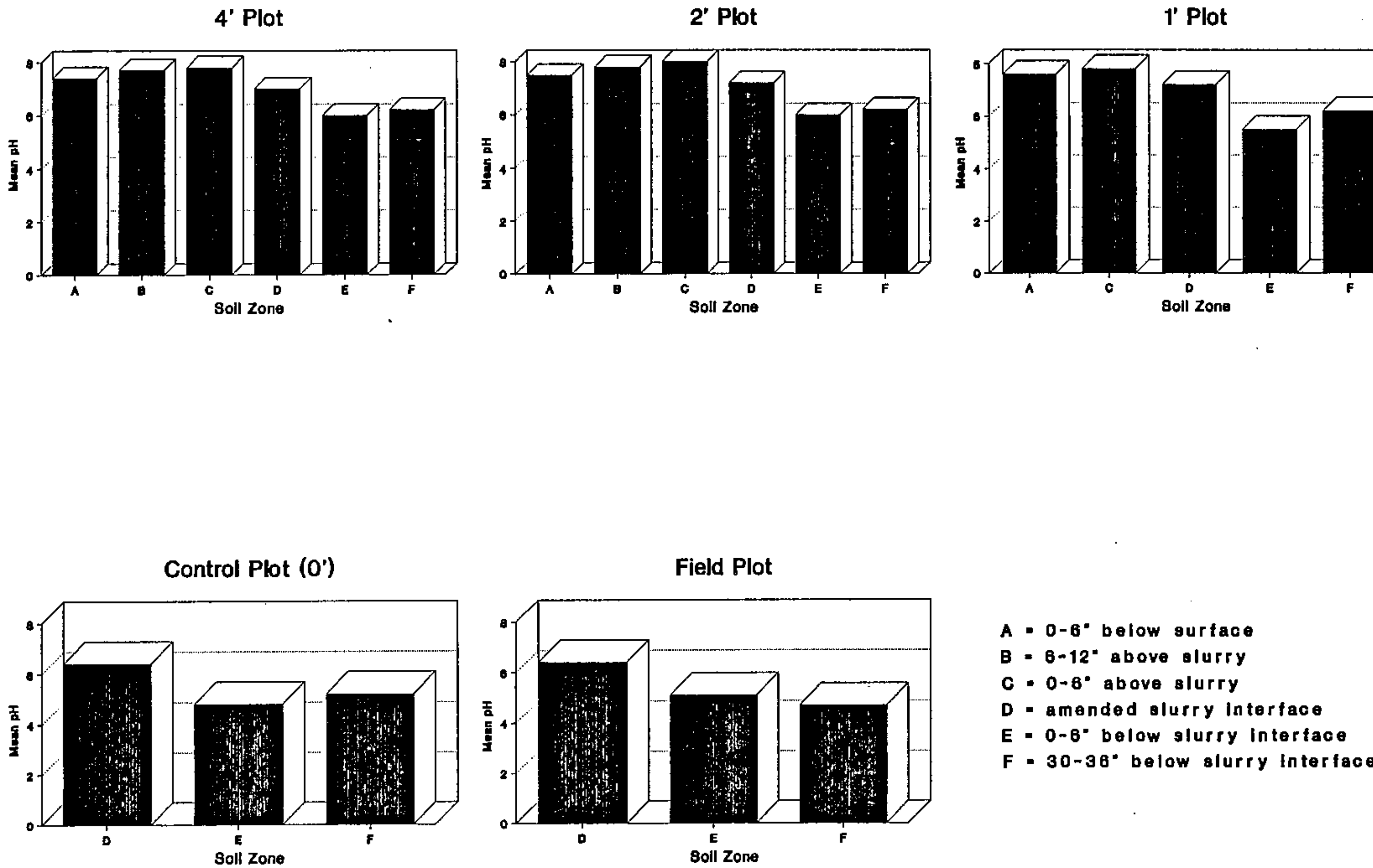


Figure 2. Pyramid Mine slurry reclamation demonstration. Immediate acidity (pH) values for soil cover and slurry cores associated with the 1980 soil cover (0, 1, 2, 4 ft) plots, and the 1975 no-soil field demonstration project.

Table 2. Pyramid Mine slurry reclamation demonstration. Pre-reclamation slurry characteristics mean values (n=32). Samples collected 22 July 1980.

| Depth (in) | Soil pH | Buffer pH | P1 (lb/ac) | P2 (lb/ac) | Potassium (lb/ac) | Magnesium (lb/ac) | Calcium (lb/ac) | Zinc (ppm) |
|---|---|---|---|---|---|---|---|---|
| 0-6 | 5.1 | 6.2 | 36.1 | 51 | 83 | 89 | 7,965 | 4 |
| 7-12 | 4.1 | 5.7 | 5.5 | 10 | 83 | 76 | 16,002 | 7 |
| 13-18 | 4.0 | 6.0 | 3.4 | 11 | 79 | 93 | 21,092 | 6 |

| Manganese (ppm) | Boron (ppm) | Copper (ppm) | Iron (ppm) | CEC (meg/100g) | Soluble Salts (mmhos/cm) | Potential Acidity (tons $CaCO_3$ eq/1000 t) | Total Sulfur (%) |
|---|---|---|---|---|---|---|---|
| 15 | 1.0 | 4.2 | 83 | 28 | 14.6 | 115 | 1.94 |
| 27 | 1.2 | 2.4 | 96 | 46 | 22.3 | 117 | 2.88 |
| 26 | 1.3 | 2.7 | 112 | 54 | 30.6 | 114 | 3.48 |

## Soil

Slurry was sampled at 3 depths (0-6 in; 7-12 in; and 13-18 in) on 22 July 1980, prior to limestone amendment. Soil sampling was also conducted in September 1989 to document the effects of soil cover depths on chemical characteristics of both soil cover and refuse. Two sampling locations were randomly selected within each soil cover subplot, and 8 additional sampling stations were established in the directly vegetated slurry adjacent to soil cover study plots. A Giddings probe was used to determine actual soil cover depths and to extract soil/slurry cores for analyses. Soil cores were sectioned into 6 in segments and assigned the following designations: A = 0-6 in below surface; B = 6-12 in above soil-refuse interface; C = 0-6 in above soil-refuse interface; D = amended soil-refuse interface; E = 0-6 in below soil-refuse interface; and F = 30-36 in below refuse interface.

Core sections from the 1989 sampling were prepared and forwarded to A & L Laboratories (Memphis, Tennessee) for analyses of pH, sulfur, zinc, manganese, iron, copper, boron, aluminum, pyritic sulfur, neutralization potential, organic matter, P1, P2, potassium, magnesium, calcium, sodium, cation exchange capacity, soluble salts, and base saturation of potassium, magnesium, calcium, and sodium. Scope of analyses was limited for some parameters due to cost. This paper summarizes acid-base balance analyses.

## Results and Discussion

### Soil

Prior to the 1980 soil cover demonstration, substrates of the 60 acre inactive slurry site had previously been analyzed to determine immediate acidity, potential acidity, and phytotoxicity characteristics. Surface (0-6 in), intermediate (7-12 in), and deep (13-18 in) sample (n=32 for each depth) sets included 2 locations within each of the 4 treatments (depth) for each of the 3 replicates. The primary emphasis of the July 1980 substrate sampling was to determine agricultural limestone amendment rates based on potential acidity values (see Table 2).

Immediate acidity values identified a moderately buffered (due to previous limestone amendment) surface slurry profile ($\bar{x}$ pH = 5.1) above an unamended, acidified ($\bar{x}$ pH = 3.8) subsurface ($\geq$ 7 in). Residual limestone amendment from prior applications (@ 15 tons/acre in 1975, and 1976; and 3 tons/acre in 1977) had provided sufficient neutralization potential to maintain scattered (~ 40 - 70% cover) stands of vegetation. However, residual potential acidity values ($\bar{x}$ = 115 tons $CaCO_3$ eq/1000 tons) indicated the need for additional limestone amendment (@ 100 tons/acre) prior to plot preparation. Therefore, a 100 ton/acre application rate was identified for the 1980 soil-covering plot establishment, as the previously weathered and amended surface was to be removed prior to limestone amendment and soil covering.

Table 3. Pyramid Mine slurry reclamation demonstration. Soil/slurry acid-base characteristics after 9 years of limestone and soil cover treatment. Mean values (n=6) for cores collected September 1989.

| Variable | Core[1] | Soil Cover Plots (Depth = in) 4 | 2 | 1 | No Soil Cover 0' Control | Field |
|---|---|---|---|---|---|---|
| pH | A | 7.4 | 7.5 | 7.6 | - | - |
| | B | 7.7 | 7.8 | - | - | - |
| | C | 7.8 | 8.0 | 7.8 | - | - |
| | D | 7.0 | 7.2 | 7.2 | 6.4 | 6.4 |
| | E | 6.0 | 6.0 | 5.5 | 4.8 | 5.1 |
| | F | 6.2 | 6.2 | 6.2 | 5.2 | 4.7 |
| Pyritic Sulfur (%) | D | 0.65 | 0.22 | 0.19 | 0.09 | 0.13 |
| | E | 1.15 | 0.42 | 0.26 | 0.11 | 0.29 |
| | F | 1.51 | 2.31 | 1.33 | 1.06 | 0.68 |
| Neutralization Potential (t $CaCO_3$ eq/ 1000 t) | D | 217.5 | 269.4 | 245.3 | 174.3 | 64.5 |
| | E | 123.7 | 69.1 | 30.4 | 29.8 | 33.8 |
| | F | 75.32 | 118.9 | 87.5 | 42.1 | - |

1. A=0-6" below surface; B=6-12" above slurry interface; C=0-6" above slurry interface; D=alkaline amended slurry interface; E=0-6" below slurry interface; F=30-36" below slurry interface.

Slurry sampling of the soil-covered test plots was primarily intended to evaluate effects of cover depths on inhibition of pyrite oxidation and the minimization of upward acid diffusion. In general, increased soil cover depth contributed to inhibition of pyrite oxidation rates in the slurry surface (@ 0-12 in) (see Table 3 and Figure 2). However, oxidation did occur regardless of cover depth, as indicated by greater pyritic sulfur levels in the subsurface zone of each soil cover (4 ft, 2 ft, and 1 ft) control (0 ft cover for 8 years) or field (0 ft soil for 15 years) plot (see Table 3). The 4 ft soil cover plot provided the greatest inhibition to pyrite oxidation. Pyritic sulfur values (0.6%) in the surface slurry zone (0-6 in) beneath the 4 ft soil cover were 2- to 3-fold greater than the 1, or 2 ft cover plot values. However, the absolute difference in potential acidity that resulted from a greater rate of pyrite oxidation, which occurred under the shallow cover plots, was of very little practical importance (approximately 12 tons $CaCO_3$ eq/1000 tons) as all the plots experienced pyritic oxidation that eventually contributed to residual potential acidity values of less than 20 tons $CaCO_3$ eq/1000 tons in the surface zone. Pyritic sulfur data illustrated that oxidation is not precluded by soil covering. Although some inhibitory effects do occur, much more than a 4 ft soil cover would be necessary to achieve a near permanent elimination of pyrite oxidation beneath soil-capped refuse areas.

Pyrite oxidation in the no-soil cover treatments reflected rates that were not inhibited by soil cover. Pyrite oxidation and subsequent depletion in the surface (0-6 in) profiles of the no-soil cover treatments resulted in residual pyritic sulfur values of less than 0.14%. Deeper slurry profiles (e.g., cores E and F) within the no-soil cover treatments also exhibited reduced pyrite oxidation with depth (see Table 3 and Figure 2). Absolute differences in pyritic sulfur values associated with soil cover or no-soil cover treatments were greatest in the slurry zone (Core E) directly below the amended zone (Core D). At the 30 to 36 in slurry depth (Core F) residual pyrite values were in the 0.7 to 1.0% range, indicating again that cover depth (in this case, slurry not soil) has a moderating effect on pyrite oxidation. Pyritic sulfur values in deep (30-36 in) samples did not show significant variance that could be positively correlated with soil depth.

With only minor differences in pyrite oxidation attributable to soil cover depth, it is apparent that neutralization of acidic soils resulting from pyrite oxidation is the more important aspect of acid-refuse reclamation. Prior to the 1980 plot preparation, freshly exposed slurry received a 100 ton/acre limestone

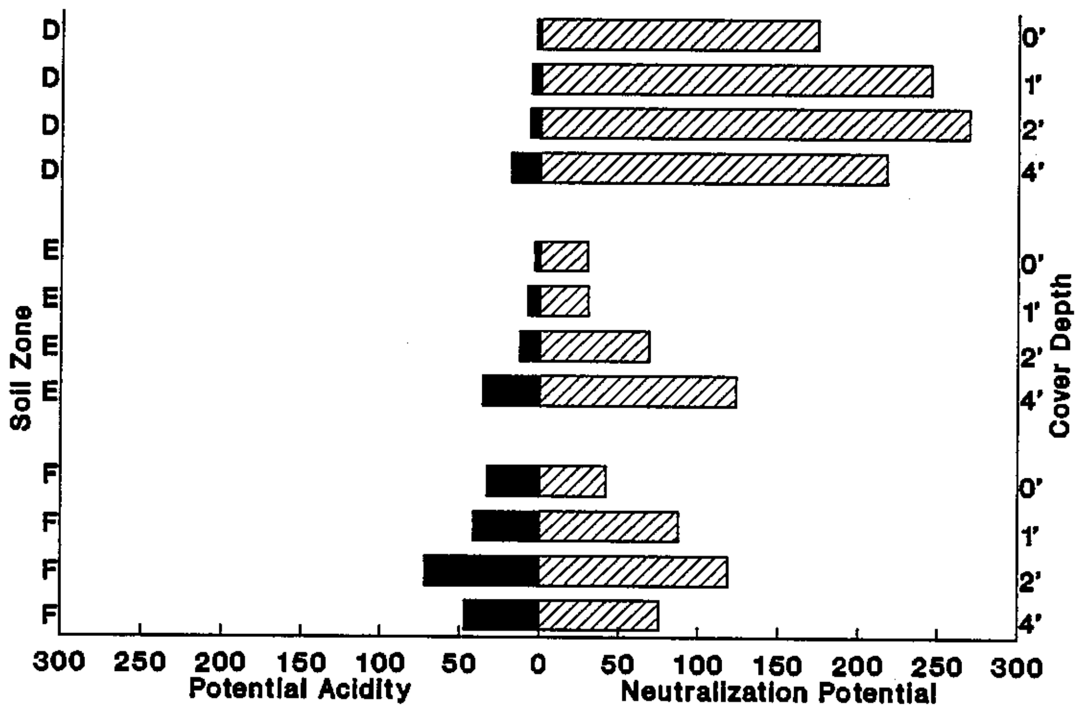


Figure 3. Pyramid Mine slurry reclamation demonstration. Acid-base balance analyses (n=6) for alkaline amended (D) and unamended slurry sample cores collected September 1989 at 0-6" below the amended slurry interface (E), and 30-36" below the amended slurry interface (F) of 3 soil covers (1', 2', and 4') and 1 control (0') soil.

amendment. Limestone amendment prior to soil covering proved to be beneficial in the amelioration of the effects of pyritic oxidation in both the soil cover and the no-soil cover plots. As previously discussed, pyrite continued to oxidize following soil covering. However, due to the presence of an alkaline-amended zone, both the soil cover immediately above slurry (Core C) and the amended slurry (Core D) have maintained near-neutral pH values (pH 7.0-7.9) in the soil cover plots (see Tables 3 and Figure 2). Favorable immediate acidity values (pH @ 6.4) have also persisted since 1980 in the amended zone (Core D) of the no-soil cover control plots. Long-term maintenance of alkaline conditions is expected to continue in the amended slurry zones of all plots as residual neutralization potential values exceeding 150 tons $CaCO_3$ eq/1000 tons were recorded for the no-soil and soil cover plots (see Table 3 and Figure 3). Residual neutralization potential values in the amended zones (Core D) ranged from a low of 174 tons $CaCO_3$ eq/1000 tons in no-soil cover control plot to a maximum value of 269 tons $CaCO_3$ eq/1000 tons in the 2 ft soil cover plot. The lowest neutralization potential value (65 tons $CaCO_3$ eq/1000 tons) associated with the 15-year-old no-soil field plot reflected unreacted limestone from previous (1975-1977) applications (- 50 tons/acre total). Current (i.e., 1989) samples also showed the additive effects of naturally occurring neutralization potential (i.e., naturally present in slurry prior to limestone amendment) and the treatment limestone application. Collectively, naturally occurring neutralization potential (@ - 100 tons $CaCO_3$ eq/1000 tons) and the 1980 limestone amendment (@ - 100 tons $CaCO_3$ eq/1000 tons) now contribute a very favorable acid-base equilibrium that can be expected to maintain near-neutral pH values in both the amended slurry zone and the soil cover interface (Core C)).

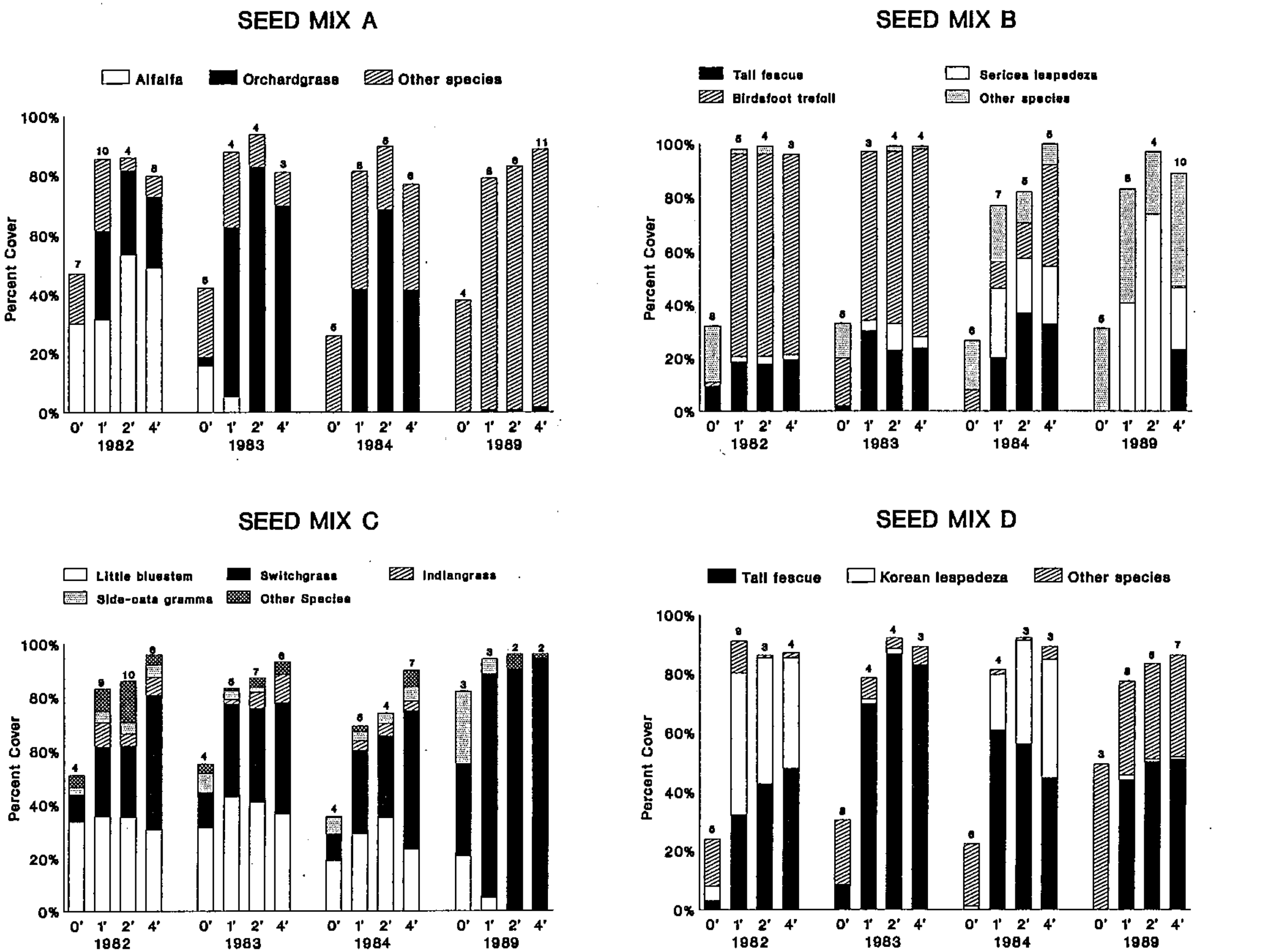


Figure 5. Pyramid Mine slurry reclamation demonstration. Species performance trends for cool season grass-legume and warm season vegetation mixes established on soil cover (1, 2, and 4 ft) and

Table 4. Pyramid Mine slurry reclamation demonstration. Percent canopy cover trends by soil depth and seed mix for sampling periods 1982-1989.

| Seed Mix[1] | Year | Soil Cover Depth 0′ | 1′ | 2′ | 4′ |
|---|---|---|---|---|---|
| A | 1982 | 0.47 | 0.83 | 0.85 | 0.79 |
| | 1983 | 0.38 | 0.88 | 0.94 | 0.81 |
| | 1984 | 0.26 | 0.79 | 0.89 | 0.77 |
| | 1989 | 0.38 | 0.79 | 0.83 | 0.89 |
| B | 1982 | 0.32 | 0.97 | 0.98 | 0.96 |
| | 1983 | 0.33 | 0.97 | 0.99 | 0.99 |
| | 1984 | 0.26 | 0.77 | 0.82 | 0.99 |
| | 1989 | 0.31 | 0.83 | 0.97 | 0.89 |
| C | 1982 | 0.51 | 0.83 | 0.86 | 0.96 |
| | 1983 | 0.55 | 0.84 | 0.87 | 0.96 |
| | 1984 | 0.37 | 0.69 | 0.76 | 0.89 |
| | 1989 | 0.82 | 0.94 | 0.96 | 0.96 |
| D | 1982 | 0.24 | 0.90 | 0.87 | 0.87 |
| | 1983 | 0.30 | 0.79 | 0.92 | 0.89 |
| | 1984 | 0.22 | 0.81 | 0.92 | 0.89 |
| | 1989 | 0.49 | 0.77 | 0.83 | 0.86 |

1. A = alfalfa, orchard grass
   B = weeping lovegreass, tall fescue, sericea lespedeza, birdsfoot trefoil
   C = little bluestem, indian grass, side-oats gramma, switchgrass
   D = tall fescue, Korean lespedeza

## Vegetation

Soil cover of potentially acid-producing refuse provides a substrate for vegetation establishment and a physical barrier above the refuse. Longevity and vigor of vegetation establishment in soil covers may be affected by plant/soil relationships that include: depth of cover, acidification of the soil/refuse interface, and adaptation of the vegetative species mix to long-term seasonal and edaphic conditions.

Soil depth and species mix contributed to some trends in vegetative cover during the 4 sampling periods (1982, 1983, 1984, and 1989) of the study (see Table 4 and Figure 4). Slight decreases in vegetative cover during 1982 through 1989 were observed for all of the species mixes except the native warm season grass mix (Mix C). The slight decline observed in vegetative cover of the domestic species mixes (Mixes A, B, and D) during the 9 years after plot establishment was not unexpected for the soil cover plots. These cool season species cover decreases reflected the normal decline in vigor following the termination of fertility maintenance programs after 1984.

Although all species mixes occurring on the no-soil plots provided significantly less cover (22 to 55%) during the first 4 seasons following seeding, percent cover of the native warm season grass mix had increased to 82% by 1989 (see Figure 4). Increased density of the warm season grass mix was primarily due to the contribution of switchgrass. Switchgrass had become dominant in all of the test plots (0 ft, 1 ft, 2 ft, and 4 ft cover) producing a monoculture in the deeper (2 ft, 4 ft) soil cover plots (see Figure 5). However, in shallower soils (1 ft and no-soil cover), little bluestem and side-oats gramma also contributed to vegetative diversity in the plots seeded with the warm season grass mix.

By 1989, diversity of warm season species was minimal, except in the no-soil cover plot. Soil cover plots

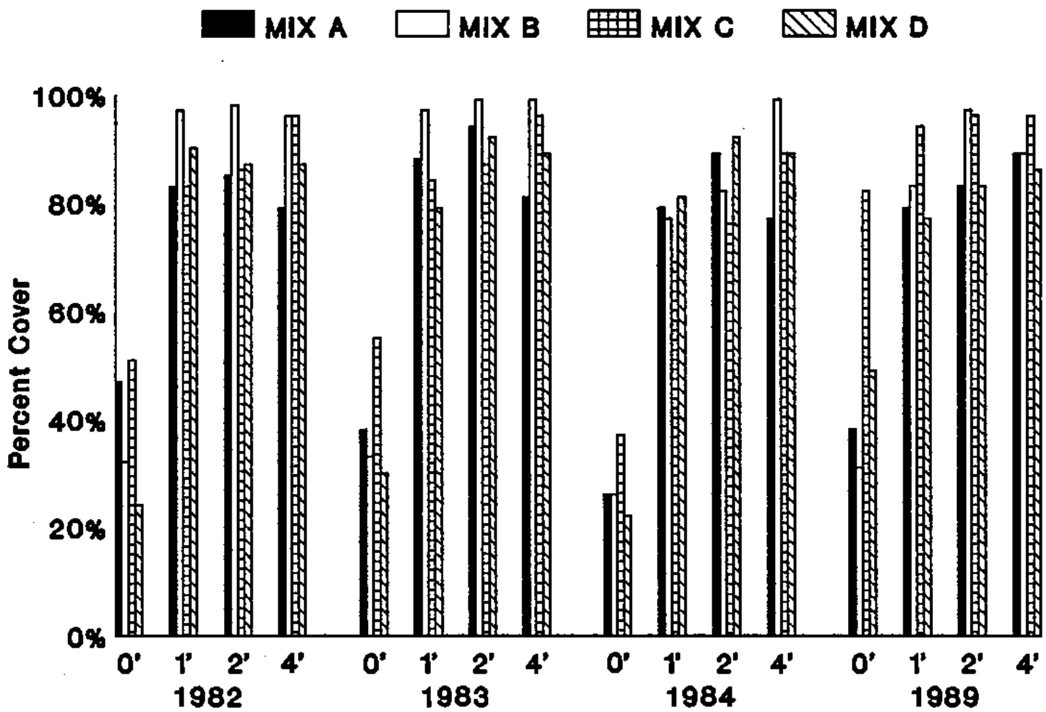


Figure 4. Pyramid Mine slurry reclamation demonstration. Vegetation cover trends for grass-legume (Mix A, B, and D) and warm season (Mix C) mixes established on soil cover (1, 2, and 4 ft) and no-soil (0 ft) test plots.

Cover depth did not significantly effect the rate of neutralization potential decrease in the amended zone. Even in the no-soil cover control plots, neutralization potential values remained greater than 150 tons $CaCO_3$ eq/1000 tons after more than 9 years following the initial limestone application (@ 100 tons/acre). Only the intermediate slurry profile (i.e., Core E) illustrated any trends of decreased neutralization potential values due to weathering. In the intermediate zone (~ 7-12 in below the slurry surface) neutralization values ranged from 30 to 120 tons $CaCO_3$ eq/1000 tons. In contrast, the deeper slurry profile (i.e., Core F @ 30-36 in below the slurry surface) was characterized by neutralization values that were often 2 times greater than corresponding values for the shallower (7-12 in) zones within both the soil cover (2 ft and 1 ft) and no-soil control plots (see Table 3).

In summary, soil cover did not prevent pyrite oxidation, although there was a slight indication that the 4 ft depth inhibited the pyrite oxidatiorate. However, the total decrease in pyrite oxidation rates under 4 ft soil cover compared to no-soil cover did not represent a meaningful reduction (0.5% difference) in pyritic sulfur values after 9 years. Limestone amendment did correct pre-treatment (i.e., 1975) acidic conditions (pH 3.5 - 4.8) and has maintained near-neutral conditions (pH 6.4-7.2) in amended slurry of both the soil cover and no-soil cover plots. Limestone amendment also maintained near-neutral conditions (pH - 7.8) in the soil segment of the soil/refuse interface. Establishment of an alkaline-amended refuse zone prior to soil covering is recognized as an integral part of refuse reclamation, as the maintenance of a favorable acid-base equilibrium in the upper zone of the refuse profile is a more critical aspect of acid refuse reclamation than depth of soil cover (Nawrot and Warburton 1987, Warburton et al 1987). Inability to prevent oxygen and water infiltration in soil covered refuse areas necessitates that alkaline amendment is included as part, or all, of any acid refuse reclamation project.

(except the native warm season grasses) gradually exhibited greater species diversity after the vigor and abundance of the domestic grass-legume species declined. Invasion by herbaceous and woody species was greatest on the 4 ft soil cover plot that had initially been seeded by the least-competitive domestic species mix (Mix A - alfalfa, orchardgrass). Typical invading species included sweet clover (Melilotus spp.), multiflora rose (Rosa multiflora), poison ivy (Toxicodendron radicans), and Russian olive (Elaeagnus angustifolia). This shift in vegetative species equilibrium illustrates the importance of selecting species that are compatible with site conditions and reclamation goals. After post-reclamation site maintenance is terminated, it is imperative that a vegetative cover mix be adapted to eventual declines in fertility and possible moisture stress.

Moisture stress can be a critical factor affecting vegetation establishment of soil-covered refuse if the soil/refuse interface has not been adequately amended to prevent upward acid diffusion. Soil-cover contamination through acidification from the buried refuse can reduce soil cover effectiveness by as much as 50 percent. A 2 ft soil cover could become no more effective for plant establishment and root penetration than a 1 ft depth if the lower 1 ft of soil cover becomes acidified.

## Conclusions

Vegetative performance in this study illustrated that even a 1 ft, 2 ft, or 4 ft soil cover on limestone amended slurry can provide acceptable long-term vegetative cover (> 75%). Inclusion of warm season grass species (especially switchgrass) can guard against moisture stress and nutrient deficiencies. Limestone amendment (with or without soil covering) will ensure that a favorable acid-base equilibrium has been established in the surface slurry zone. Without soil cover, limestone-amendment treatment plots seeded with native warm season grasses, also provided greater than 80 percent vegetative cover more than 9 years after reclamation. Slurry reclamation can be accomplished with less than 4 ft of cover, if the critical aspects of alkaline amendment and species suitability are addressed as part of the reclamation plan. Long-term plant-soil relationship can only be documented through field demonstrations that are allowed to respond to the variability of climate, the effects of aging and weathering of soils, and the successional trends of adapted plant materials. Field demonstrations provide a valuable opportunity for the "test-of-time". Ironically, this field demonstration no longer exists. Test plots and the adjacent direct-seeded slurry area were reclaimed with soil cover during the summer of 1990.

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