THE NEW KATHLEEN MINE - SOIL COVERED REFUSE DEMONSTRATION: 20 YEARS LATER

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ABSTRACT. Soil covering of potentially acid producing coarse coal refuse materials has been an accepted reclamation practice for more than 20 years. However, long-term monitoring of demonstration sites has shown that soil covering alone has not always been sufficient to prevent pyrite oxidation. A 40-acre coarse refuse site in Illinois was graded, limed, and vegetated in 1971 as a cooperative project of the US EPA and Consolidation Coal Company. This is one of the oldest soil cover sites in Illinois. Field sampling and monitoring of soils and vegetation was initiated in 1981 to determine effects of soil cover depth (1′, 2′, 3′) on vegetation. Follow-up monitoring in 1989 evaluated vegetation success and acidification of both the refuse soil interface and overlying soil cover.

Ground cover was not affected by depth of soil cover. Cover densities ranged from 82% (3′ cover) to almost 95% for 2′ cover depths during the 1981 sampling. Vegetative cover densities exceeded 90% in 1989 for all soil cover depths. Successful vegetative cover was established without the use of 4′ soil cover. Uppermost surface (0-6") profiles of soil cover areas remained non-acid (pH >5.9) more than 20 years after grading and covering. However, significant upward acid migration and contamination (pH <4.6) of soil cover was recorded in the first 1 foot of cover above the buried refuse. The previously amended refuse (@ 16 tons/acre agricultural limestone) zone had become acutely acid (pH <3.3). Decreased (2x) pyritic sulfur values in the uppermost refuse profile indicated significant pyrite oxidation occurred below soil covers; cover depth differences of 1 foot did not affect the rate of pyrite oxidation. Excess potential acidity has contributed to upward acidification and contamination of the overlying soil cover. Although vegetation cover has been adequate at all soil depths, additional limestone amendment prior to soil covering could have prevented upward acid migration and minimized the potential for acid seep generation.

Additional Key Words: ACID WASTE RECLAMATION

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INTRODUCTION

The Surface Mining Control and Reclamation Act of 1977 (P.L. 95-87) requires toxic coarse refuse materials (gob) be covered with 4 feet of non-toxic soil material to eliminate acid runoff, prevent oxidation of acid-forming materials, and to allow for effective vegetation establishment. Although soil covering accommodates the "cosmetic" reclamation requirement (i.e., a non-acid substrate for vegetation establishment), "chemical" reclamation objectives (i.e., prevention of further pyrite oxidation) may not be adequately addressed. Soil covering without limestone amendment of the upper zone of acid refuse does little to alter the acid-base equilibrium of the buried refuse. Consequently, the effective soil cover depth may be reduced when lower profiles are contaminated by acid refuse or upward migration of acid salts. If sufficient alkaline buffering is not present acid seeps may develop, or existing seeps may reappear after soil covering.

The environmental and economic consequences of pre-law coarse refuse areas has been severe due to water treatment costs of acid seeps and soil cover costs. Conventional (i.e., 4') soil cover costs can range from $16,000 to more than $30,000 per acre for large refuse sites in the midwest. Availability of a convenient soil borrow area may result in higher costs or the undesirable construction of a borrow area on otherwise productive land. Consequently, both environmental and economic incentives exist for soil cover reclamation alternatives. Many coarse refuse reclamation alternatives have been investigated. Alternatives have ranged from direct vegetation establishment practices (Czapowskyj et al. 1968, Barthauer et al. 1971, Smith and Bradshaw 1972, Welsh and Hutnik 1972, Sorrel 1974, Davidson 1974, Nickeson 1984) which evaluated vegetation established directly on refuse that had been neutralized and fertilized, to soil cover demonstrations that used less than 4-foot of soil cover with varying limestone amendment rates (Brundage 1974, Kosowski 1973, Barthauer et al. 1971, Smout and Sobek 1983, Nawrot et al. 1987, Warburton et al. 1987).

In general, early (i.e., 1970's, 1980's) soil cover studies demonstrated that soil cover depths less than 4-foot were capable of preventing acid surface runoff and maintaining adequate vegetative cover. However, many early soil cover demonstration studies did not address long term vegetation success or the effects of time and soil cover depth on pyrite oxidation and upward acid diffusion. Therefore, in 1981 a field study was implemented to evaluate soils and vegetation associated with the 40-acre New Kathleen Mine coarse refuse reclamation demonstration that had been initiated in 1969 (Barthauer et al. 1971, Kosowski 1973). This paper incorporates and summarizes soils and vegetation data collected by Consolidation Coal Company in 1981 and 1982 and CWRL personnel in 1989.

The objective of this study was to evaluate and identify long-term vegetation success and to assess the long-term effect of soil cover depth on pyrite oxidation, upward acid migration, and vegetative cover.

STUDY AREA

The New Kathleen refuse area, in Perry County, Illinois (T6S, R2W, Sec. 36) is located on an abandoned slope mine approximately 5 miles southwest of DuQuoin. The mine was active from 1943-1955 recovering the Herrin No. 6 seam at a depth of about 110 feet. Coal processing waste included a 40-acre coarse coal refuse pile that once stood more than 60 feet and contained approximately 2,000,000 cubic yards of waste material (Barthauer et al. 1971).

In 1970, the U.S. Environmental Protection Agency and Consolidation Coal Company initiated a full scale reclamation demonstration. The New Kathleen gob pile was graded in 1970 to establish three distinct basins, ranging in size from 3.2 to 5.5 acres. Agricultural grade limestone was then applied at a rate of 15.7 tons/acre and the three test plots were covered with soil from a nearby borrow area to intended depths of approximately 3 feet (East plot), 2 feet (Central plot), and 1 foot (West plot), respectively (Smout and Sobek 1983). Actual soil cover depths varied; the Central and West plots both averaged 2 feet of cover.

Vegetative establishment on the soil cover areas included the incorporation of agricultural grade limestone (6 tons/acre) and fertilizer (11-17-23 @ 800 lbs/acre) (Table 1). A grass mixture of perennial rye (37%) and tall fescue (63%) was seeded at a rate of 80 lbs/ac. In Spring 1971, a legume mixture comprised of equal portions of sweet clover, alfalfa, and Korean lespedeza was applied at the rate of 12 lbs/acre. The final vegetative stabilization efforts, including the application of nitrogen at a rate of 300 lbs/acre, were completed in July 1971 (Barthauer et al. 1971).

Following the sale of the New Kathleen site to a private individual in Fall 1971, grazing and haying of the reclaimed area occurred for a few years. Additional impacts of subsequent reclamation activities in 1987 (construction equipment traffic and accidental limestone application on some surface soils) may have contributed to some minor but atypical soil and vegetation relationships identified in the present study.

METHODS

Vegetative Sampling

Vegetation sampling was conducted on the established experimental plots on 21 and 22 July 1989 to determine the effect of soil cover depth (over refuse) on vegetation. Similar to the 1981 and 1982 vegetation analysis techniques, circular sampling quadrants were established near the center of each test plot and 16 randomly-selected sampling locations were located within each quadrat. A 30-point pin frame was then used to evaluate summer vegetative cover and species composition (Chapman 1976).

Soil Sampling

Soil sampling was conducted on the soil cover test plots and underlying refuse during July 1982 and September 1989 to document the effect of soil cover depth on the physical and chemical characteristics of the soil cover and refuse. Circular sampling quadrats were established near the center of each experimental plot and 10 randomly selected sampling locations were located within each quadrat. Each location was sampled using a Giddings probe to determine actual soil cover depth and to remove soil cores for future analyses. Soil cores were then 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 = soil-refuse interface; E = 0-6 in. below soil-refuse interface; and F = 30-36 in. below refuse interface.

Soil core sections were analyzed by A & L Laboratories at Memphis, Tennessee, for pH, pyritic sulfur, neutralization potential, organic matter, P1, P2, potassium, magnesium, calcium, sodium, cation exchange capacity, buffer index, soluble salts, and percent base saturation of potassium, magnesium, calcium, hydrogen, and sodium.

RESULTS AND DISCUSSION

Vegetation

Percent Cover

Vegetative cover was not effected by soil plot depths (i.e., 1′, 2′, 3′). Several factors contributed to this effect. First, the actual measured (1989 data) soil depth of the West plot (1′ by design, 22.2" actual) was not significantly different from that of the Central plot (2′ by design, 27.0" actual). Therefore, cover depth was not considered when comparing the Central and West plot vegetation or soils data. Second, sites were not uniform with respect to drainage and soil moisture. Soils in portions of the West plot basin were often moist, as evidenced by presence of sedges (Carex spp.). Consequently, the west plot supported denser cover than might have been expected (Table 2). In addition, the East plot (3' by design, 39.4" actual) was disturbed (surface compaction) by heavy equipment and remedial reclamation activities during the summer of 1987, adversely impacting and reducing that plot's vegetative cover.

When the Central and West plots were combined in analyses, measured soil depth (i.e., ~2' actual cover depth) did explain a significant proportion of the variance in percent cover ($P < 0.04$). The two shallow (2' cover) plots supported significantly more vegetative cover (95%) than the 3-foot plot (91%, $P < 0.05$). The occurrence of greater vegetative cover on the shallow soil plots is contrary to the expected. Apparently, disturbance of the East plot during 1987 IAMLRC reclamation activities contributed to decreased cover of this plot.

Although it was not possible to ascertain direct soil depth/vegetative cover relationships at New Kathleen, it is important to note that vegetative cover for all three study plots generally increased since 1981 and exceeded 90% at the time of the 1989 study (Figure 1). Vegetation analyses indicated 2-foot soil cover was sufficient to maintain successful grasses and herbaceous cover on the areas covered with less than 3-foot of soil. However, the conspicuous absence of woody species indicated that cover depth (or perhaps herbaceous competition) may have inhibited volunteer establishment of woody species.

Species Composition

The major species present on all three study plots were tall fescue (Festuca arundinacea), lance-leaf ragweed (Ambrosia bidentata) and Korean lespedeza (Lespedeza stipulacea). The West plot (1' design depth) was the most diverse, supporting at least 14 species, and the Central plot was the least diverse, supporting 19 (Table 2). These trends are interesting as both plots had virtually equal mean soil depths. In general, these data illustrated that soil depths did not affect species composition.

Soils

Acid runoff and subsurface seeps from the 40-acre New Kathleen coarse refuse area had been adversely affecting water quality of Walker Creek since the mine was inactivated in 1955. In an effort to abate acid runoff a site characterization study was implemented in 1968. Initial soil analyses characterized the surface refuse zone as acidic (pH <3.0) and generally well-weathered except for exposure of fresh refuse in eroded areas (Barthauer et al. 1971). Surface (0-4") samples collected in 1968 identified pyritic sulfur values characteristic of well-oxidized refuse (pyritic sulfur <0.1%) and unweathered extremely acid-producing refuse (pyritic sulfur >10%) (Table 3). Sulfate sulfur contributed more than 87 percent of total sulfur in well weathered samples, while pyritic sulfur contributed to more than 70 percent of total sulfur in the more acid-producing unweathered samples (Table 3). Carbonaceous refuse and non-carbonaceous shales accounted for 37.8 percent and 27.5 percent, respectively of the coarse refuse materials, while clay materials accounted for the remaining 34.7 percent (Barthauer et al. 1971).

Moderate and worst-case pyritic sulfur sample data would have indicated a need for 90 to more than 300 tons/acre of limestone amendment. To evaluate potential reclamation alternatives, fourteen 0.1 acre test plots were established throughout the coarse refuse pile during 1969 to evaluate effects of limestone, soil cover, fertilizer, sewage sludge application on vegetation establishment and acid runoff abatement (Table 4). Although two of the direct seeded (40 tons/acre limestone, no-soil) plots produced excellent vegetative cover during the first growing season (Fall 1969 through early Summer 1970) final reclamation plans included grading of the entire 40-acre gob pile to establish the three soil cover (1', 2', 3') demonstration areas. Beginning in July 1970 135,000 cubic yards of refuse were graded to reduce slopes to less than 33 percent. After grading, agricultural limestone was applied at 16 tons/acre. Soil cover was applied and amended with 6 tons/acre agricultural limestone. Surface areas were disced, seeded, fertilized and mulched (Table 1).

Monitoring of New Kathleen demonstration area immediately following soil covering emphasized the abatement of acid runoff due to the positive effects of soil covering and vegetation establishment practices. A 91 percent average reduction in acid formation rates was achieved for the three soil cover plots with no significant difference due to cover depth (Kosowski 1973).

To evaluate long-term effectiveness of soil cover depths and vegetation establishment a 10-year follow-up study was initiated in July and August 1982. In addition to vegetation monitoring, soil cores were collected from the three soil cover demonstration areas. A total of 205 soil cores (6" and 12" increments) were collected and analyzed (Table 5). As indicated by low pH values of soil cores (0-6") immediately above the graded and amended refuse, acidification has depleted the 16 tons/acre limestone amendment applied to the graded refuse surface in 1970. Soil pH values had declined to 3.5 and 3.2 in the soil cover immediately above the refuse (Table 5). The previously amended gob (16 tons/acre limestone applied in 1970) was also extremely acid (pH <3.5). Upward migration of acid salts was also detected in the first one foot of soil cover above refuse in all the soil cover areas. Soil cover depths less than 40 inches did not affect pyrite oxidation. All cover treatments experienced upward migration of acid salts as well as continued oxidation of pyrite. Upward acid salt migration was evidenced by elevated levels of iron, zinc and soluble salt values in the soil cover samples above the oxidized refuse. Despite acid contamination of all but the upper one foot of soil cover in the two shallow (25") soil cover plots, vegetation density was not affected. Both shallow (25") soil cover areas supported greater than 95 percent vegetative cover. Despite previous (1982) indications of upward acid migration and some erosion of lower slopes and exposure of previously buried refuse, the original soil cover demonstration areas on the upper terrace of the 40-acre gob pile maintained stable vegetative cover for more than 15 years after soil covering.

Samples of 176 soil cores (6") collected in September 1989 from the three soil cover areas again identified contaminated zones of upward acid migration in all cover areas (Table 6, Figure 2). Acid soil profiles extended to within 6 inches of the surface in all soil cover depths. The shallowest soil cover zone (1′ plot - depth range 13-32") was characterized by average pH values less than 4.5 in the profile from 7 to 12 inches below the surface. Similarly, low pH values were recorded for the 7 to 12" soil cover zone in both the 2 foot (21 to 32" range) and 3 foot (18 to 60" range) cover depth areas. Previously amended (16 tons/agricultural limestone applied in 1971) refuse zones (Table 2, Horizon D) remained extremely acidic (pH <3.3) beneath all three soil cover areas. A slight decrease in acidity was recorded in the deeper refuse profiles (6-36" below the refuse surface) for all soil cover depths. Mean pH values of 4.3 to 5.8 were recorded for coarse refuse profiles 30 to 36 inches below the soil refuse interface.

Decreased acidification of refuse profiles at depths greater than 30 inches reflected a cumulative effect of soil cover and refuse depth rather than soil cover depth alone. Pyritic sulfur values of gob samples analyzed in 1989 were generally low throughout the entire refuse profile compared to samples collected in 1969. Worst case pyritic sulfur sample values occurred in the lower refuse profile (6-36") where levels of 2.7-2.8 percent pyrite were recorded. Pyritic sulfur levels were somewhat greater (2x) in the deeper refuse profiles compared to the 0-6" more readily oxidized refuse surface (Figure 3). Despite indications of reduced pyrite oxidation due to profile depth, there was no discernable effect of soil cover depth on pyrite oxidation.

Neutralization potential values show a much stronger relationship with sample depth. Minimal neutralization potential values (<2 tons/1000 tons $CaCO_3$ eq) occurred in the 0-6" surface refuse profile compared to the deeper refuse profiles (30-36") where residual neutralization potential values ranged from an average of 10 tons/1000 tons $CaCO_3$ eq to more than 90 tons/1000 tons $CaCO_3$ eq (Table 6, Figure 3). Presence of residual neutralization potential at the 30-36" refuse profile as well as less acidic conditions indicated that total depth of refuse burial (of soil cover and overlying refuse) does effect the rate of pyrite oxidation.

Pyrite oxidation was not eliminated at total cover depths of 6 to 7 feet. Maximum pyrite oxidation occurred within the upper 9 inches of the reactive surface (0-24") refuse zone. In the upper zone of active pyrite oxidation, neutralization potential (naturally occurring and limestone amendments) is rapidly depleted. After the exhaustion of neutralization potential, acidification of the refuse occurs resulting in downward infiltration of acid salts, and upward acid migration (due to capillary transport) and contamination of the lower soil cover profiles. Continued pyrite oxidation beneath the soil cover can and will continue in any inadequately amended (with alkaline materials) upper profile of buried refuse. Accumulated acid salts will be flushed from the active surface zone of oxidation and eventually deplete residual neutralization potential in lower refuse profiles. A subsurface acid profile will gradually develop as ferric ions are leached downward and accelerate pyrite oxidation. Without adequate alkaline amendment in the upper refuse profile a net acid groundwater equilibrium will be established that promotes the formation and maintenance of chronic acid seeps. Unfortunately, this acid seep generating mechanism of inadequately amended refuse has been and is often overlooked in refuse reclamation plans.

CONCLUSIONS

The New Kathleen refuse reclamation demonstration was one of the earliest soil cover demonstrations in the Midwest. The age of this project and the follow-up monitoring studies afforded an opportunity to evaluate the effectiveness of soil cover as an acid waste reclamation technique. Many principles can be learned from this "classic" reclamation demonstration.

The initial 1969-1973 (Barthauer et al. 1971, Kosowski 1973) research identified.

1) Less than 4 feet of soil cover (range 22-40") was equally effective in preventing acid runoff.
2) Soil cover depth (range 22-40") did not affect successful (>80%) vegetation establishment,
3) Subsurface acid generation was not affected by depth of soil cover.

Follow-up vegetation and soils monitoring conducted in 1981-1982 and again in 1989 identified.

1) Vegetation establishment could be successfully maintained on less than 4 foot (22-40") of soil cover
2) Soil cover (range 20-40") did not prevent or significantly inhibit pyrite oxidation.
3) Inadequate neutralization amendment in the reactive upper refuse zone resulted in an acid-base imbalance which,
    a) contributed to upward acid migration and contamination of the lower profiles (13-40") of the soil cover, and
    b) contributed to acid seep generation from within the lower profiles of the refuse area.

Many lessons can be learned from the New Kathleen and other older refuse demonstration areas. The importance of chemical (alkaline amendment) reclamation is now better understood and appreciated. The chemical approach for acid waste reclamation does not ignore the value of soil cover as a rooting medium, it merely ensures that the chemical imbalance of buried refuse has been addressed as a component of the reclamation process. The following principles of coarse refuse reclamation represent fundamentals of a reclamation philosophy that emphasizes a successful "chemical" technique (alkaline amendment) rather than a "cosmetic" (soil cover) reclamation approach (Warburton et al. 1987).

1) Pre-reclamation site characterization should include pyritic sulfur analyses from samples in the unoxidized lower refuse profiles, not only the upper weathered zone.

    a) Weathered oxidized samples will underestimate the worst case acid producing potential.

    b) Unweathered samples will more accurately reflect maximum acid producing potential of freshly exposed refuse when grading occurs prior to soil covering.

2) The upper refuse zone should ideally be allowed to partially weather (18-24 months) to ensure that the acute pyrite oxidation phase (due to fine-grained pyrite oxidation) has rendered the refuse surface "treatable".

    a) Limestone (or any suitable alkaline amendment) "treatment" should be based on "worst-case" pyritic sulfur values.

    b) Treatment rates should begin at the absolute minimum level of 31 tons $CaCO_3$ eq/1% pyrite in weathered refuse containing low residual pyrite (e.g., 0.75%) levels.

    c) "Excess" rates (2X-3X) of limestone amendment (@ 62 to 93 tons $CaCO_3$ eq/1% pyrite) should be used as a safety factor when treating only moderately weathered refuse or to account for additional depth of treatment.

3) No amount of alkaline amendment can be considered excessive as alkaline infiltration and flushing are needed to maintain an alkaline environment in the refuse surface.

4) Increase the concentration and solubility of alkaline refuse amendments prior to soil covering to:

    a) protect overlying soil covers from upward acid migration, and

    b) to inhibit the subsurface acid generating mechanism responsible for chronic acid seeps.

5) Less than 4 foot of soil cover (e.g., 2') can support adequate vegetative cover if underlying acid refuse has been adequately amended with limestone and upward migration has been eliminated.

As illustrated by the New Kathleen demonstration project, old refuse piles never die, the pyritic wastes simply keep on aging. No currently required depth (≤4') of soil cover completely eliminates oxygen or water infiltration. Therefore, pyrite oxidation continues and acid seeps occur. Soil covers are acidified and effective rooting depths are reduced. Alkaline amendment and enhancement of upper refuse profiles can establish a favorable acid-base equilibrium and maintain adequate rooting depths. An integrated approach of alkaline amendment (of the refuse surface) and reduced soil cover (e.g., 2') can provide a cost-effective alternative to covering acid refuse when soil cover materials are inadequate or unavailable (Warburton et al. 1987). As alkaline coal combustion by-products become increasingly more expensive to dispose of in landfills, greater use should be made of these materials to construct an enhanced zone of alkaline production in the upper zone of refuse prior to soil covering.

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Table 1. Summary of reclamation treatments of the New Kathleen Mine coarse refuse demonstration areas, July-December 1970.

Area	Treatment			
	Agricultural Limestone Amendments (tons/ac)	Nutrients (lbs/ac N-P-K)	Seed Mixture (lb/ac)	Straw Mulch (tons/ac)
<u>Soil Cover Depth</u>				
1 ft	refuse surface-15 soil surface-6	88-136-184	perennial rye-30 Kentucky fescue-50	1.5
2 ft	refuse surface-15 soil surface-6	88-136-184	perennial rye-30 Kentucky fescue-50	1.5
3 ft	refuse surface-15 soil surface-6	88-136-184	perennial rye-30 Kentucky fescue-50	1.5
Side slopes, 1 ft	refuse surface-15 soil surface-6	88-136-184	perennial rye-30 Kentucky fescue-50	2.5

Table 2. Percent canopy cover and species frequency by study plot for soil covered gob plots at the New Kathleen Mine, July 1989.

Variable	West Plot[1] (1' Design Depth)	Central Plot[1] (2' Design Depth)	East Plot[1] (3' Design Depth)
Percent Cover	96	94	91
Diversity Index[2]	1.33	0.80	1.08
Species Present (#)	14	9	10
tall fescue (*Festuca arundinacea*)	0.62	0.77	0.57
lance-leaf ragweed (*Ambrosia trifida*)	0.13	0.16	<0.01
alfalfa (*Medicago sativa*)	<0.01	0.01	0.33
Korean lespedeza (*Lespedeza stipulacea*)	0.11	0.03	0.03
red clover (*Trifolium pratense*)	0.03	--	0.03
path rush (*Juncus tenuis*)	0.03	<0.01	--
sweet clover spp. (*Melilotus* spp.)	--	0.01	0.02
common ragweed (*Ambrosia artemisiifolia*)	0.02	--	--
sericea lespedeza (*Lespedeza cuneata*)	--	--	0.01
timothy (*Phleum pratense*)	0.01	--	--
sedge spp. (*Carex* spp.)	0.01	--	--
daisy fleabane (*Erigeron strigosus*)	0.01	0.01	--
orchard grass (*Dactylis glomerata*)	--	0.01	<0.01
partridge pea (*Cassia fasciculata*)	--	<0.01	--
field garlic (*Alium vineale*)	<0.01	--	--

Table 2. Continued.

Variable	West Plot[1] (1′ Design Depth)	Central Plot[1] (2′ Design Depth)	East Plot[1] (3′ Design Depth)
croton spp. (_Croton_ spp.)	<0.01	--	--
smooth brome (_Bromus inermis_)	<0.01	--	--
prairie 3-awn (_Aristida oligantha_)	<0.01	--	--
trumpet creeper (_Campsis radicans_)	--	--	<0.01
tall goldenrod (_Solidago canadensis_)	--	--	<0.01

[1] 1989 actual depth data: West Plot = 22.2", Central Plot = 27.0", East Plot = 39.4".

[2] Shannon-Weaver function.

Table 3. New Kathleen Mine coarse refuse demonstration area. Preliminary soil analyses[1] (sulfur forms) June 1968.

	Sulfur (percent)			
Sample #	Total	Sulfate	Pyritic	Organic
1	5.51	4.83	0.029	0.65
2	9.12	3.36	4.08	1.68
3	14.05	3.27	10.60	0.18
4	14.02	2.73	9.78	1.51
5	7.77	3.07	3.70	1.00
6	5.35	3.94	0.72	0.69
7	5.82	5.05	0.078	0.69
Average	8.81	3.75	4.14	0.91

[1] 0-4" surface samples.
From: Barthauer et al. 1971.

Table 4. New Kathleen coarse refuse reclamation demonstration test plots established during 1961 (from Barthauer et al. 1977).

Test Plot No.	Date Installed	Barrier	pH Adjustment		Fertilizer		Grass Seed	
			Type	Rate T/A	Type	Rate Lb/A	Type	Rate Lb/A
1	June 1969	None	Limestone[1]	40	6-24-24	1500	KY fescue Per. rye mix	30 50
2	July 1969	None	Limestone	40	6-24-24	1500	KY fescue Per. rye mix	30 50
3	Sept. 1969	None	Limestone	40	6-24-24	1500	KY fescue Per. rye mix	30 50
4	Sept. 1969	None	Limestone	40	6-24-24	1500	KY fescue Per. rye mix	30 50
5	Sept. 1969	None	Limestone	40	6-24-24	1500	KY fescue Orchard mix	30 50
6	Oct. 1969	Polyethylene membrane plus 4" topsoil	Limestone	2	6-24-24	1000	KY fescue	50
7	Control plot	None	None		None		None	
8	Oct. 1969	4" topsoil	Limestone	2	6-24-24	500	KY fescue Orchard mix	40 30
9	Oct. 1969	12" topsoil	Limestone	2	6-24-24	500	KY fescue Orchard	40 40
10	Oct. 1969	24" topsoil	Limestone	2	6-24-24	500	KY fescue Orchard Lespedeza both sides	40 40 10
11	Oct. 1969	None	Limestone	40	6-24-24	1500	KY fescue Per. rye mix	30 50

Table 4. Continued.

Test Plot No.	Date Installed	Barrier	pH Adjustment		Fertilizer		Grass Seed	
			Type	Rate T/A	Type	Rate Lb/A	Type	Rate Lb/A
12	Oct. 1969	4" dried sewage sludge	None		None		KY fescue Per. rye mix	10 10
13	Oct. 1969	Lime sludge from oil refinery water treatment plant	None		None		None	
14	Oct. 1969	Waste lime-limestone mixture	Code L	90	None		None	

[1] Agricultural limestone used on Test Plots was 48 x 100 mesh.

Table 5. New Kathleen coarse refuse-soil cover plots. Soils and refuse analyses for samples collected 1982.

Soil Cover Design[1] Depth/Sample Depth	n	Soil pH	Buffer pH	Conductivity (mmhos/cm)	Phosphorus		K (ppm)	Mg (ppm)	Ca (ppm)	Na (ppm)	Zn (ppm)	Mn (ppm)	Fe (ppm)	Cu (ppm)
					P_1 (ppm)	P_2 (ppm)								
1′ (25.1″)														
soil														
0-12″	16	5.0	6.4	1.2	4.8	12.3	88.8	577.2	2,515.6	66.6	3.9	57.0	71.4	1.7
13″-24″	13	4.6	6.3	1.8	5.7	14.6	91.3	836.2	2,107.7	161.3	4.0	68.1	61.2	1.7
soil above gob														
0-6″	16	3.5	4.8	2.5	4.8	12.5	66.8	453.8	2,331.2	117.3	9.3	64.9	293.0	1.7
gob														
0-6″	16	3.2	5.0	3.3	13.1	24.9	49.2	219.3	5,774.0	92.9	34.3	38.5	718.4	3.6
2′ (25.0″)														
soil														
0-12″	16	4.9	6.2	0.4	14.8	27.0	109.3	487.8	1,975.0	100.5	4.3	35.2	66.1	2.4
13″-24″	16	4.2	5.6	1.7	9.8	23.6	97.0	632.8	1,706.2	205.9	6.4	69.9	107.2	2.2
soil above gob														
0-6″	16	3.2	4.3	2.5	6.1	19.9	73.0	410.6	2,512.5	128.2	14.2	65.8	413.5	2.5
gob														
0-6″	16	3.1	4.8	3.4	30.6	67.8	93.9	258.4	6,640.6	100.1	39.1	47.4	910.9	6.4
3′ (40.3″)														
soil														
0-12″	16	5.1	6.6	0.2	11.6	23.9	82.1	427.5	1,612.5	78.8	3.1	27.4	43.1	2.1
13″-24″	16	5.1	6.5	0.3	9.9	20.3	75.9	553.1	1,356.2	237.9	2.5	34.4	54.1	2.1
25″-36″	16	4.2	5.9	1.2	8.0	20.3	76.8	498.1	1,234.4	288.8	4.6	80.4	89.4	2.2
soil above gob														
0-6″	16	3.5	5.1	2.3	8.0	24.6	66.6	527.8	1,484.4	214.2	33.4	107.4	290.6	2.8
gob														
0-6″	16	3.3	5.3	3.5	22.4	60.4	61.9	315.9	6,768.8	151.4	53.4	68.2	875.9	5.5

[1] Soil cover design depths included 1′, 2′, and 3′ covers; actual average depth as determined from sample cores is indicated in ( ).

Table 6. Soil cover and coarse refuse characteristics of the New Kathleen Mine study plots, Perry County, Illinois, September 1989.

		East Plot (3' Design Depth)				Central Plot (2' Design Depth)				West Plot (1' Design Depth)			
Variable	Horizon*	N	Mean	Standard Deviation	Range	N	Mean	Standard Deviation	Range	N	Mean	Standard Deviation	Range
Soil Depth (in)	-	10	39.4	11.5	17.5-60.0	10	27.1	4.1	21.0-32.0	10	22.2	5.8	13.0-32.5
pH	A	10	7.92	0.2	7.5-8.2	10	5.94	0.78	4.8-7.4	10	6.77	0.71	5.1-7.5
	B	10	4.59	0.6	3.8-5.7	8	4.16	0.48	3.7-5.0	10	4.48	0.87	3.2-5.9
	C	10	3.81	0.4	3.4-4.9	10	3.36	0.19	3.1-3.7	10	3.51	0.45	2.8-4.4
	D	10	3.28	0.79	2.4-4.9	10	3.22	0.70	2.4-4.8	9	2.81	0.26	2.5-3.2
	E	10	4.14	1.40	2.6-6.2	10	5.02	1.46	3.1-6.7	9	3.41	1.09	2.4-5.8
	F	10	4.29	1.12	2.6-6.5	10	5.78	1.41	3.0-7.0	9	4.35	1.32	2.9-6.0
Pyritic Sulfur (%)	D	10	0.60	0.37	0.03-1.27	10	1.42	0.60	0.87-2.12	10	0.76	0.70	0.07-1.91
	E	10	1.26	0.89	0.10-3.01	10	1.97	0.50	1.17-2.82	10	0.96	0.70	0.03-1.90
	F	9	1.13	0.50	--	10	1.82	0.52	0.71-2.75	9	1.57	0.49	0.90-2.23
Neutralization Potential (T/KT)	D	10	1.96	3.63	0.50-11.90	10	1.42	2.90	0.50-9.70	10	0.50	0	--
	E	10	7.61	11.34	0.50-34.10	10	8.09	8.42	0.50-22.50	10	3.79	6.93	0.50-17.20
	F	9	13.43	28.86	0.50-89.10	10	15.90	9.89	0.50-29.60	9	10.00	20.82	0.50-64.10
Sulfur-Sulfate (ppm)	A	2	32	1.41	31.0-33.0	2	13.0	7.07	8.0-18.0	2	28.5	12.02	20-37
	B	2	977	682	495-1460	1	2410	--	2410-2410	2	5235	1279	4330-6140
	C	2	2040	1103	1260-2820	2	3520	905	2880-4160	2	5640	1866	4320-6960
	D	2	4770	14.14	4760-4780	2	5730	141	5630-5830	2	5920	947	5250-6590
	E	2	5605	629	5160-6050	2	4115	2241	2530-5700	2	6075	756	5540-6610
	F	2	4950	1979	3550-6350	2	3240	2432	1520-4960	2	6670	14.14	6660-6680
Zinc (ppm)	A	2	2.55	1.41	1.80-3.30	2	2.55	0.07	2.50-2.60	2	3.95	0.35	3.7-4.2
	B	2	8.90	6.50	14.30-13.50	1	8.10	--	8.10-8.10	2	8.55	0.63	8.10-9.00
	C	1	22.00	--	--	2	10.35	0.49	10.00-10.70	2	16.95	12.79	7.90-26.00
	D	1	38.00	--	--	2	28.05	23.97	11.10-45.00	2	14.15	15.34	3.30-25.00
	E	2	36.50	23.33	20.00-53.00	2	12.40	5.23	8.70-16.10	2	14.40	16.40	2.80-26.00
	F	2	41.00	4.24	38.00-44.00	2	9.35	9.26	2.80-15.90	2	32.50	4.94	29.00-36.00
Manganese (ppm)	A	2	97.0	0	--	2	28.0	4.2	25.0-35.0	2	72.5	2.1	71.0-74.0
	B	2	65.5	24.7	48.0-53.0	1	56.0	--	--	2	38.5	13.4	29.0-48.0
	C	2	76.5	7.7	69.0-80.0	2	72.0	33.9	48.0-96.0	2	43.0	15.5	32.0-54.0
	D	2	46.0	15.5	35.0-57.0	2	44.0	22.6	28.0-60.0	2	16.5	4.9	13.0-20.0
	E	2	61.5	53.0	24.0-99.0	2	63.5	48.7	29.0-98.0	2	19.5	4.9	16.0-23.0
	F	2	38.5	14.8	28.0-49.0	2	79.5	27.5	60.0-99.0	2	56.5	60.1	14.0-99.0

Table 6. Continued.

		East Plot (3' Design Depth)				Central Plot (2' Design Depth)				West Plot (1' Design Depth)			
Variable	Horizon*	N	Mean	Standard Deviation	Range	N	Mean	Standard Deviation	Range	N	Mean	Standard Deviation	Range
Iron (ppm)	A	2	33.0	33.9	9.0-57.0	2	54.0	1.4	--	2	51.5	0.7	51.0-52.0
	B	2	150.0	28.2	130.0-170.0	1	150.0	--	--	2	250.0	98.9	180.0-320.0
	C	2	260.0	0	69.90-80.0	2	290.0	169.0	170.0-410.0	2	295.0	63.6	250.0-340.0
	D	2	490.0	70.7	440.0-540.0	2	625.0	162.6	510.0-740.0	2	385.0	247.4	210.0-560.0
	E	2	639.5	508.4	280.0-999.0	2	745.0	190.9	610.0-880.0	2	500.0	240.4	330.0-670.0
	F	2	794.0	288.4	590.0-998.0	2	738.0	364.8	480.0-996.0	2	797.5	279.3	600.0-995.0
Boron (ppm)	A	2	0.45	0.07	0.40-0.50	2	0.90	0.14	0.80-1.00	2	0.70	0.14	0.60-0.80
	B	2	0.10	0	--	2	0.15	0.07	0.10-0.20	2	0.25	0.21	0.10-0.40
	C	2	0.15	0.07	0.10-0.20	2	0.15	0.07	0.10-0.20	2	0.25	0.21	0.10-0.40
	D	2	1.65	0.07	1.60-1.70	2	2.70	1.41	1.70-3.70	2	0.90	0.14	0.80-1.00
	E	2	2.05	1.20	1.20-2.90	2	1.95	0.77	1.40-2.50	2	1.65	0.49	1.30-2.00
	F	2	2.60	0.70	2.10-3.10	2	2.60	0.28	2.40-2.80	2	1.80	1.69	0.60-3.00
Aluminum (ppm)	A	2	4.0	1.4	3.0-5.0	2	40.5	33.2	17.0-64.0	2	4.5	0.7	4.0-5.0
	B	2	292.0	250.3	115.0-469.0	2	101.0	--	--	2	179.5	238.2	11.0-348.0
	C	2	473.5	51.6	437.0-510.0	2	497.0	199.4	356.0-638.0	2	341.0	25.4	323.0-359.0
	D	2	260.0	67.8	212.0-308.0	2	327.5	106.7	252.0-403.0	2	171.0	100.4	100.0-242.0
	E	2	48.0	60.8	5.0-91.0	2	175.0	239.0	6.0-344.0	2	151.0	86.2	90.0-212.0
	F	2	8.0	0	--	2	22.0	24.0	5.0-39.0	2	75.0	39.5	47.0-103.0
Organic Matter (%)	A	10	1.20	0.80	0.40-2.90	10	2.30	0.55	1.50-3.00	10	2.96	1.14	1.1-4.6
P_1 (ppm)	A	10	10.0	9.2	1.0-27.0	10	11.4	6.3	3.0-25.0	10	6.8	3.9	2.0-16.0
P_2 (ppm)q	A	10	52.8	35.0	3.0-109.0	10	32.1	32.0	11.0-120.0	10	12.2	4.9	5.0-21.0
Potassium (ppm)	A	10	124.4	15.2	96.0-153.0	10	122.8	13.4	107.0-156.0	10	164.3	41.8	112.0-127.0
Magnesium (ppm)	A	10	525.0	97.6	302.0-650.0	10	470.7	54.4	398.0-571.0	10	309.7	127.1	166.0-520.0
Calcium (ppm)	A	10	2085	196	1780-2400	10	1515	273	1190-2060	10	2277	315	1510-2680
Sodium (ppm)	A	10	55.0	28.6	20.0-97.0	10	50.2	14.4	34.0-72.0	10	24.7	6.2	16.0-35.0
Cation Exchange (meq/100g)	A	10	15.37	0.99	14.0-17.8	10	15.18	2.26	12.60-19.40	10	15.58	0.87	14.4-17.4

Table 6. Continued.

		East Plot (3′ Design Depth)				Central Plot (2′ Design Depth)				West Plot (1′ Design Depth)			
Variable	Horizon*	N	Mean	Standard Deviation	Range	N	Mean	Standard Deviation	Range	N	Mean	Standard Deviation	Range
% Potassium (base saturation)	A	10	2.09	0.31	1.40-2.60	10	2.09	0.21	1.60-2.40	10	2.72	0.76	1.60-4.00
% Magnesium (base saturation)	A	10	28.45	4.82	16.80-32.60	10	50.85	3.51	19.30-30.20	10	16.56	6.64	9.00-27.20
% Calcium (base saturation)	A	10	67.91	5.28	62.70-80.00	10	50.85	10.91	30.60-66.70	10	73.53	11.68	43.40-85.40
% Hydrogen (base saturation)	A	0	--	--	--	9	21.61	13.23	0.50-47.00	6	10.83	13.79	1.50-38.00
% Sodium (base saturation)	A	10	1.55	0.76	0.60-2.70	10	1.44	0.44	0.90-2.30	10	0.69	0.16	0.50-1.00
Soluble Salts (mmhos/cm)	A	5	0.72	0.29	0.40-1.00	10	0.21	0.07	0.10-0.40	10	0.88	0.57	0.40-2.40

*A = 0-6" below surface; B = 6-12" above refuse interface; C = 0-6" above refuse interface; D = refuse interface; E = 0-6" below refuse interface; F = 30-36" below refuse interface.

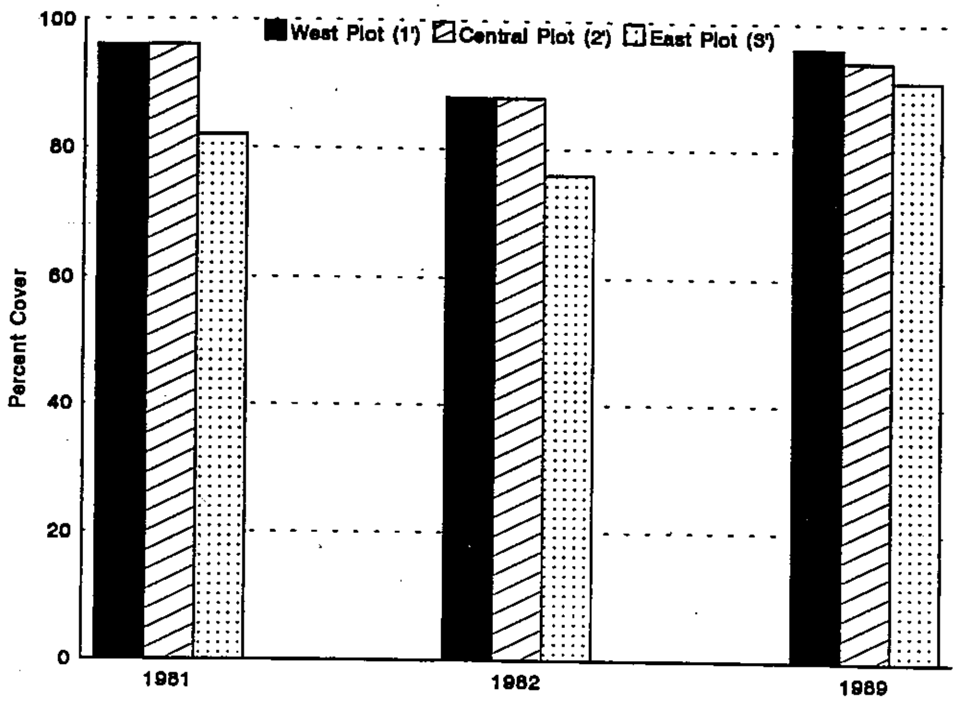

Figure 1. New Kathleen coarse refuse reclamation demonstration. Vegetation density changes (1981, 1982, 1989) following initial vegetation establishment (1971). Actual soil depths: West Plot and Central Plot - 25", East Plot - 40".

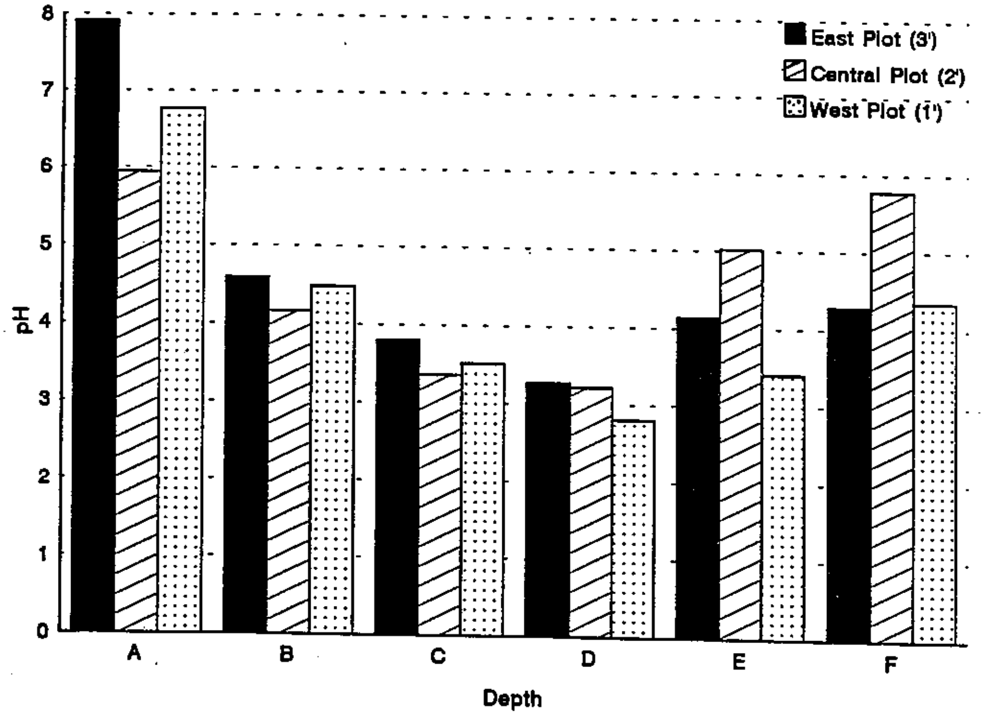

Figure 2. New Kathleen coarse refuse reclamation demonstration. Soil-refuse pH values for soil cores sampled (September 1989) from plots of varying cover depths (A = 0-6" below surface; B = 6-12" above refuse interface; C = 0-6" above refuse interface; D = refuse interface; E = 0-6" below refuse interface; F = 30-36" below refuse interface). Soil depths: West Plot and Central Plot - 25", East Plot - 40".

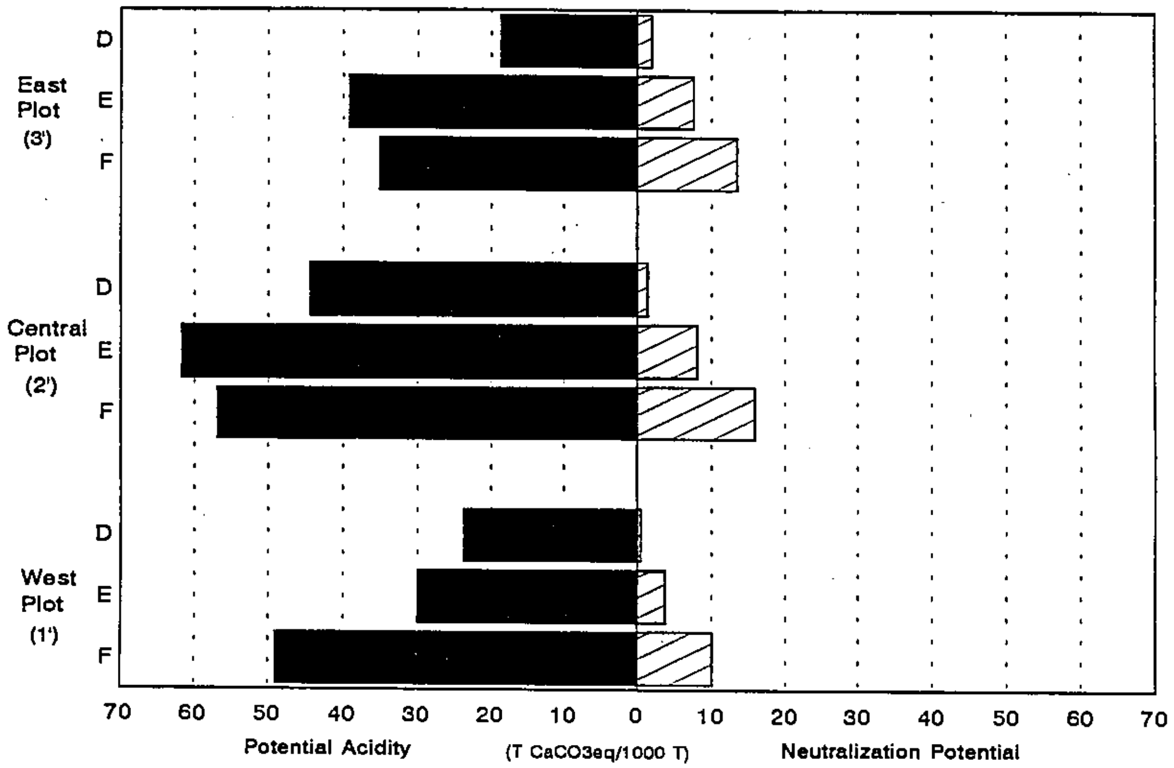

Figure 3. New Kathleen coarse refuse reclamation demonstration. Acid base balance values for refuse cores sampled (September 1989) from plots of varying cover depths (D = refuse interface; E = 0-6" below refuse interface; F = 30-36" below refuse interface). Soil cover depth: West Plot and Central Plot - 25", East Plot 40".