Minesoil Properties of 15 Abandoned Mine Land Sites in West Virginia

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ABSTRACT

The characteristics of minesoils on abandoned mine land (AML) often dictate which plant species will invade and establish from nearby undisturbed areas. This study measured physical and chemical minesoil properties on 15 AML sites in northern West Virginia and matched these properties to vegetation cover. Fifteen sites ranging in age from 13 to 35 yr old were selected from three surface-mined coal beds (Pittsburgh, Freeport, and Kittanning). On each site, three 1 m-deep pits were dug and minesoil samples were extracted from two horizons, and vegetation was sampled in three 100-m^2 plots near the pits. Minesoils on Freeport sites had more rock fragments and sand than either Pittsburgh or Kittanning sites. No particle-size changes with depth or age were evident between horizons in any minesoil. Acidity increased and pH decreased with minesoil age on Pittsburgh and Kittanning minesoils due to the oxidation of pyritic materials near the soil surface. A cluster analysis distinguished three minesoil types on these sites. Minesoil type A had low acidity and high CEC. Minesoil type B had high acidity and moderate CEC. Minesoil type C had high rock fragment content, low to moderate acidity, and low CEC. Minesoil type A was completely covered by herbaceous plants and trees, while minesoil types B and C were generally covered by trees. Based on our minesoil analyses and other studies, barren AML sites may not require complete redisturbance for revegetation but may be revegetated by adjacent plant species if surface amendments are applied.

APPROXIMATELY 34 000 ha of mined land in West Virginia were designated as abandoned mine land (AML) in 1977 (USDA-SCS, 1979). Abandoned mine land sites are mining disturbances that were inadequately reclaimed before the passage of the Surface Mining Control and Reclamation Act (SMCRA) on 3 Aug. 1977, and where no company or individual has any reclamation responsibility under state or federal laws. Title IV in SMCRA created a fund to reclaim AML sites by taxing each ton of mined coal. Approximately $3.5 billion were collected from 1977 to 1994. Up to 50% of the tax money from each state can be returned to the state for AML reclamation based on an AML inventory and site eligibility. In spite of the large amount of money generated, Congress realized that the fund would be inadequate to reclaim all AML sites and established a priority system for ranking AML sites for reclamation. In West Virginia alone, $2.5 billion is estimated to reclaim just the Priority 1 and 2 sites, which are sites that pose public health and property hazards. From 1977 to 1992, the West Virginia State AML Program reclaimed about 2200 ha and eliminated 310 of the most dangerous and degraded AML sites. The Office of Surface Mining estimates that only about 6% of West Virginia's AML problems were corrected from 1977 to 1992 (USDI-OSM, 1992). Other Appalachian states are similar in AML problems and disturbed areas reclaimed.

Some AML sites will gradually revegetate in a relatively short time (i.e., 10–20 yr), causing decreased erosion and increased soil development, and may not require AML funding for reclamation. Such sites have fertile minesoils with few physical and chemical properties that limit plant recruitment and growth. Other AML sites with edaphic problems that restrict plant establishment may take much longer (decades to centuries) for natural processes to enable revegetation and stabilization. Abandoned mine land reclamation usually requires burying acid-producing materials with borrowed topsoil for plant establishment and eliminating dangerous conditions and structures on the site.

Minesoils undergo rapid changes in chemical and physical properties as a result of accelerated pedogenic weathering processes (Drury and Nisbet, 1973). These weathering processes act on fresh geologic materials that are not in equilibrium with the surface soil environment (Roberts et al., 1988). The degree to which sites become vegetated naturally may be related to surrounding vegetation (Bramble and Ashley, 1955; Gibson et al., 1985; Skousen et al., 1994), and the quality of the minesoil such as rock fragment content, horizon development, and pH and acidity (Bell and Ungar, 1981; Daniels and Amos, 1981; Schramm, 1966; Smith et al., 1971).

Minesoils in the Eastern Coal Region of the USA generally have high rock fragment content when compared with surrounding native soils (Pedersen et al., 1978; Thurman and Sencindiver, 1986). For example, Pennsylvania minesoils had a rock fragment content of >70% in subsoils and 50% in surface horizons (Ciolkosz et al., 1985). Small rock fragments between 2 and 5 cm were more prevalent in surface horizons than subsurface horizons due to weathering of larger fragments to smaller fragments. Once rock fragments were sieved out, textures of minesoils from 25 to 100 yr old were similar to surrounding native soils (Smith et al., 1971; Thurman and Sencindiver, 1986).

Minesoils have at least two horizons: a distinguishable surface horizon, and a lower horizon having poor structure, no roots, and various sizes of rock fragments. Surface horizons are formed by chemical and physical weathering due to plant roots and sunlight/precipitation, and often contain some organic matter and a high percentage of fine earth material (Sencindiver, 1977). Two minesoils in West Virginia had higher bulk densities and lower porosities than surrounding native soils (Thurman and Sencindiver, 1986), and shallow compacted layers that restricted water, air, and root penetration were found in Virginia minesoils (Daniels and Amos, 1981).

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Abbreviations: AML, abandoned mine land; SMCRA, Surface Mining Control and Reclamation Act; WRD, water retention difference; POR, total porosity; CEC, cation exchange capacity; BS, base saturation; NP, neutralization potential; EC, electrical conductivity.

Minesoil pH of pyritic spoils increased from <5.0 to 6.0 over time on Indiana and Kentucky sites (Davidson et al., 1988; Schrock and Munsee, 1985), and acid-producing Pennsylvania minesoils eventually achieved similar pH values as native soils (Pedersen et al., 1978). Horbaczewski and Van Ryn (1988) discovered with lignite spoils of 0.5% pyritic S a gradual shift in pH with depth as minesoils aged in Texas. A minesoil pH >5.0 was found below 4 m, whereas a pH <4.0 was found near the surface. A corresponding transition of higher sulfate S near the surface to higher pyritic S at deeper levels was evident, indicating the pH shift was due to oxidation of pyrite and the creation of acidity and sulfate. Pyrite oxidation in acid sandstones caused mineral weathering in West Virginia minesoils because sulfuric acid produced from pyrite oxidation attacked primary and secondary minerals, thereby releasing Al, Fe, and Mg (Singh et al., 1982). Weathering, leaching, and vegetation establishment on Illinois minesoils from pyritic shale overburden neutralized acidic surface soils but not acidic subsoils (Lindsay and Nawrot, 1981). In this case, excavation and regrading during AML reclamation could expose buried acid-producing materials, thereby releasing large quantities of acid and creating a worse problem than was present before reclamation.

Poor physical properties of minesoils (i.e., depth, particle-size distribution, and bulk density) generally are more difficult to ameliorate than soil chemical problems because correcting physical characteristics requires mechanical manipulation at great cost. Poor chemical properties such as acidity, salts, and infertility, which are detrimental to plant growth, can be corrected in the root zone by adding lime and/or fertilizers (Bennett et al., 1976; Vogel, 1975). Physical and chemical properties of AML minesoils should be considered when assessing a site's potential for AML reclamation. In designing AML reclamation of a site, planners could benefit from knowing that a site has the potential to revegetate itself naturally with no redisturbance, or whether it may introduce greater pollution and liability upon redisturbance by exposing buried pyritic materials.

This study measured minesoil physical and chemical properties on 15 AML sites ranging in age from 13 to 35 yr from three acid-producing coal beds in northern West Virginia. Data were analyzed to evaluate relationships between minesoil properties with mine site age, minesoil depth, and vegetation characteristics of the site. This information may help reclamation planners in developing cost-effective approaches for reclaiming AML sites.

METHODS

Site Selection

Fifteen AML sites in northern West Virginia were sampled from 1989 to 1990. The AML inventory of the West Virginia Division of Environmental Protection was used as the source of available AML sites. The inventory of sites was reduced to those with south- to west-facing highwall aspects to control microclimatic variation (Hicks and Frank, 1984). Geologic maps were used to identify the coal bed mined on each site. Five sites each from the Pittsburgh, Freeport, and Kittanning coal beds were randomly selected (Fig. 1). These three coals were chosen because they represent about one-third of the coal mined in the state. Furthermore, these coal beds account for about 8000 ha of disturbed land in West Virginia, and are known for their potential to produce acid minesoils and barren landscapes. The date of site abandonment was determined by interviews with the landowner or adjacent landowners, and also by extracting tree cores of the largest trees. Each site was named by the letter of the coal bed mined and its age (e.g., P30 is a Pittsburgh site mined 30 yr ago). The 15 AML sites we selected ranged in age from 13 to 35 yr old.

Soil Sampling and Analyses

Three points on each site were located by placing a grid over a map of each site and randomly selecting plots by a computer random coordinate generator. Soil pits were dug at these points to a depth of 1 m. Minesoils were described and classified according to standard methods (Soil Survey Staff, 1975). Soil samples were collected from two soil horizons. The upper surface horizon was distinguished by fine textures and granular structure due to plant roots, and thicknesses ranged from 5 to 15 cm. Lower horizons that were sampled were located between 50 and 100 cm in depth, and were generally skeletal or fragmental with disoriented rock fragments, had few roots, and had massive or no structure.

Particle-size distribution was determined by weighing rock fragments in the following categories: >1.9 cm (large), 0.6 to 1.9 cm (medium), and 2 mm to 0.6 cm (small). Texture was determined on the <2 mm fraction by the pipette method (Sobek et al., 1978). Samples containing visible organic matter in the upper horizon were pretreated with hydrogen peroxide.

Bulk density, porosity, and moisture retention difference were analyzed only in the upper horizon soil material of each pit. Bulk density was determined by the core method (Sobek et al., 1978) using an Uhland soil sampler and included rock fragments. Water retention characteristics were determined on the <2 mm fraction by measuring the percent moisture retained at 1500 and 33 kPa on a pressure plate. Water retention difference (WRD) was calculated as the difference in soil moisture percentage between 33 and 1500 kPa. These moisture differences were adjusted for bulk density and volume of fine earth material (Soil Survey Staff, 1984). Total porosity (POR) was determined from bulk density measurements and an assumed particle density of 2.65 Mg/m^3 (Sobek et al., 1978).

Chemical analyses were conducted on soil samples from both horizons. Soil pH was measured with a Fisher Scientific Accumet pH meter on a 1:1 soil/water paste (Sobek et al., 1978). Exchangeable bases (Ca, Mg, Na, and K) were extracted by 1 *M* ammonium acetate at pH 7.0 (Soil Survey Staff, 1984) followed by analysis with a Perkin Elmer model 403 atomic absorption spectrophotometer. Electrical conductivity (EC) was measured with a YSI Conductivity Bridge on a 1:2 soil/water paste (Sobek et al., 1978). Exchangeable acidity was determined by 1 *M* KCl extraction followed by NaOH titration to pH 7.0 using a Fisher Scientific computer-aided titrimeter (Soil Survey Staff, 1984). Cation exchange capacity (CEC) was determined by summing exchangeable bases plus exchangeable acidity. Base saturation (BS) was calculated by the number of cation exchange sites occupied by exchangeable bases divided by CEC.

The soil samples were ground with a mortar and pestle to pass through a 60 mesh (270 μm) sieve for conducting neutralization potential and S fractionation. Neutralization potential (NP) was obtained by treating a <60 mesh sample with a known excess of standardized hydrochloric acid and then

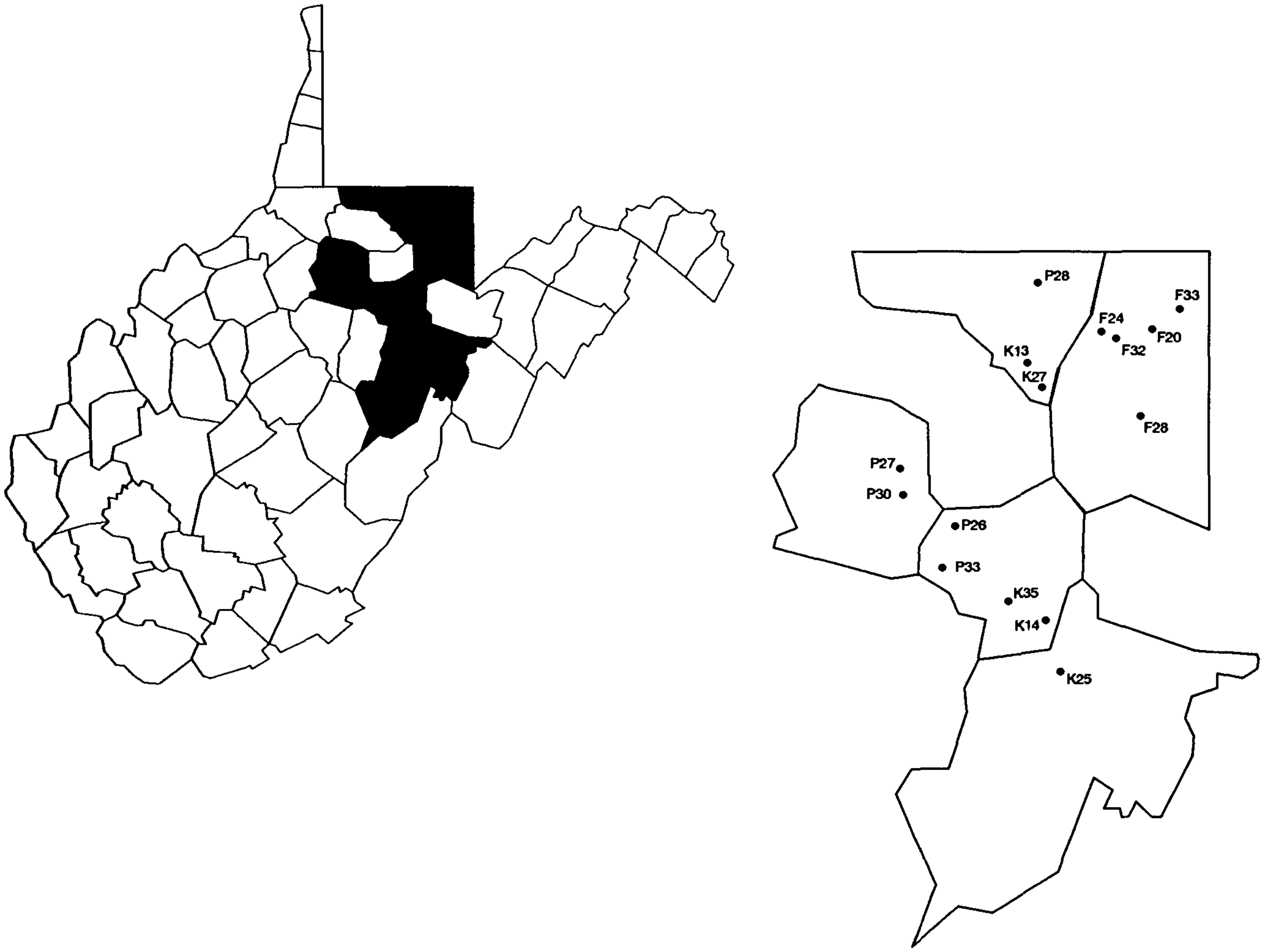

Fig. 1. Location of 15 abandoned mine land sites in northern West Virginia. The first letter of the site designates the coal bed (P = Pittsburgh, F = Freeport, K = Kittanning) and the number refers to the age or time since disturbance.

heating to ensure that the reaction was complete. Next, the amount of unconsumed acid was determined by titration with standard sodium hydroxide using a Fisher Scientific computer-aided titrimeter.

Another <60 mesh soil sample was separated into three subsamples for total S determination and S fractionation by the method of Sobek et al. (1978) to determine pyritic, organic, and sulfate forms. Sulfate S was extracted using 4.8 M HCl, pyritic S was leached using 2 M HNO_3, and organic S was the S form left after the former two leachings.

Results for each soil test were analyzed by ANOVA to determine significant differences ($P < 0.05$) among sites within each coal bed for the same soil horizon. Significant differences were also determined between horizons of the same site. Significant differences for upper horizons among sites were separated by the Student Newman Keul's multiple comparison procedure (SAS Inst., 1985).

Vegetation Sampling

Vegetation was sampled by locating the northeast corner of a 10 m by 10 m plot at each soil pit. All trees in the 100 m^2 plot were identified by species and their canopy cover measured by the line intercept method on the southern side of each plot. Canopy cover for each species was recorded in cm/1000 cm and summed to determine total canopy cover. Next, these totals were converted to percent by dividing by 10. A value of 0% indicates no canopy cover, 100% reflects complete canopy cover, and values >100% signifies an overlapping canopy. Herbaceous cover was estimated in three 1-m^2 plots randomly located within each 100-m^2 plot using a modified Daubenmire cover class technique (Skousen et al., 1988). Results of cover values for trees and herbaceous plants were analyzed by ANOVA to determine significant difference ($P < 0.05$) among sites within each coal bed. When differences were found, the cover values were separated among sites within coal beds by the Student Newman Keul's multiple comparison test (SAS Inst., 1985).

Clustering

To detect complex patterns of similarity among the 15 sites, a cluster analysis based on soils was performed using Ward's minimum variance method (Ward, 1963). In clustering, each observation (a soil pit) begins by itself. Similar observations are joined to form clusters, which are then joined with other similar clusters to form larger clusters. This process continues until only one cluster remains (SAS Inst., 1985). The clusters were then printed as a dendrogram with each soil pit as the roots (Johnson, 1967).

RESULTS AND DISCUSSION

Rock Fragments and Sand, Silt, and Clay

Freeport minesoils had more large (>1.9 cm) rock fragments (31-67%) and less fine earth (<2 mm) than either Pittsburgh or Kittanning minesoils (0-41% large fragments) (Table 1). Similarly, the percentage of sand was greater in Freeport minesoils (36-67%) than Kittanning (16-38%) and Pittsburgh minesoils (14-52%). Freeport and Kittanning coal beds both have sandstones immediately overlying the coal (Mahoning and Lower Freeport sandstones, respectively). As a result, minesoils resulting from mining these two coal beds should have large amounts of sandstone rock fragments and sand. Reger and Teets (1918) stated the Lower Freeport sandstone is very irregular and is known as a *soft* sandstone. On the other hand, the Mahoning Sandstone is much more resistant to weathering and is quarried extensively in northern West Virginia. Since the soft Lower Freeport sandstone overlies the Kittanning coal, Kittanning minesoils showed lower amounts of large rock fragments and greater amounts of medium and small (<1.9 cm-2 mm) fragments than Freeport sites.

Sencindiver (1977) and Ciolkosz et al. (1985) reported that surface layers of most minesoils have smaller amounts of rock fragments than deeper horizons. They attributed this phenomenon to more active chemical and physical weathering at the surface. This phenomenon was observed on about half of our sites throughout the three coal beds (Table 1, astericks denote differences between upper and lower horizons). Five (P26, P28, P30, K13, and K25) of the 15 sites had a significantly lower amount of large and medium rock fragments in upper horizons compared with lower horizons.

The P28 site (a Pittsburgh site) had similar sand content to those exhibited by Freeport sites. This site, located in Monongalia County (Fig. 1), had considerably more sandstone in the overburden than other Pittsburgh sites. The other four sites were located over 65 km south of Monongalia County in Harrison, Barbour, and Upshur Counties. In Monongalia County only, the Upper Pittsburgh sandstone overlies the Pittsburgh coal because sand was deposited by a meandering river after the coal was laid down (Donaldson et al., 1979). Hennen and Reger (1913) found the Upper Pittsburgh sandstone easily decomposed into sand upon exposure. Greater amounts of sandstone in the P28 overburden resulted in the development of a very different minesoil than other Pittsburgh sites. This site had a sandy clay loam texture compared with silt loam textures for the other Pittsburgh sites.

No changes in sand, silt, or clay content with depth

Table 1. Physical properties of upper (U) and lower (L) (>0.5 m depth) horizons on 15 AML sites in northern West Virginia. First letter of the site designates the coal bed (P = Pittsburgh, F = Freeport, and K = Kittanning) and the number refers to the age or time since disturbance.

Sites (coal bed and age)		Particle-size distribution†						Bulk density	Total porosity	Water retention difference
		Rock Fragments								
		Large	Medium	Small	Sand	Silt	Clay			
		%						Mg m^{-3}	%	g kg^{-1}
P26	U	0a‡	18ab*	40a	21b	63a	17d	1.7a	47c	6.1a
	L	0	42	34	21	58	21			
P27	U	4a	27a	39a	14b	47a	38a	1.4b	48c	3.8a
	L	0	39	33	17	52	30			
P28	U	6a*	13ab	20ab	49a	29b	22c	1.2b	61b	2.8a
	L	41	11	17	52	33	15			
P30	U	3a*	7b	18b	18b	51a	31b	1.1b	73a	2.8a
	L	22	13	22	32	40	29			
P33	U	0a	24ab	32ab	18b	59a	23c	1.4b	52c	3.3a
	L	6	32	33	16	57	27			
F20	U	56a	9a	7a	51a	33a	16a	1.3a	66a	1.4b
	L	56	10	7	49	28	23			
F24	U	35a	16a	18a	50a	31a	18a	1.5a	51a	2.0b
	L	58	7	10	36	36	28			
F28	U	42a	11a	8a	67a	20b	12a	1.6a	48a	8.9a
	L	67	7	6	58	24	18			
F32	U	31a	12a	15a	47a	34a	19a	1.5a	48a	5.8ab
	L	51	15	12	62	20	18			
F33	U	67a	14a	10a	53a	30a	17a	0.8b	76a	0.4b
	L	61	12	10	62	24	13			
K13	U	0a*	23a	44a	16a*	59a	25a	1.5a	56a	4.0a
	L	22	34	27	31	43	25			
K14	U	0a	17a	42a	18a	55a	27a	1.6a	49a	4.1a
	L	0	27	40	16	54	30			
K25	U	0a	16a*	30ab	37a	44a	18a	1.4a	51a	6.0a
	L	0	41	25	38	41	20			
K27	U	10a	23a	24b*	28a	44a	28a	1.7a	37a	4.8a
	L	14	30	28	29	46	25			
K35	U	14a	24a	26b*	38a	41a	21a	1.5a	47a	2.5a
	L	19	31	35	38	39	23			

* Significant difference at $P < 0.05$ between upper and lower horizon values.

† Percentages in rock fragment categories (large = >1.9 cm, medium = 1.9-0.6 cm, small = 0.6 cm-2 mm) were on total soil volume, while sand, silt, and clay percentages were based on 100% of the total material <2 mm.

‡ Upper horizon values within columns for the same coal bed with the same letter are not significantly different at $P < 0.05$.

were found for any coal bed (with one exception, K13). Neither bulk density nor percent porosity (POR) in the upper horizons of the three beds correlated highly ($r^2 < 0.35$) with site age (data not shown). The lack of significant change in physical properties with age probably demonstrates that mining and grading techniques were more important to physical properties at this young stage of minesoil development than minesoil genesis processes (Schafer et al., 1980; Smith et al., 1971; Thurman and Sencindiver, 1986). Water retention difference was significantly different among upper horizons only on the Freeport sites, largely due to the F33 site, which had a very high percentage of large rock fragments.

Chemical Properties

The P28 site had very high exchangeable acidity and low pH, while the P33 site also showed acidic conditions compared with the other three Pittsburgh sites (Table 2). A linear trend of increasing exchangeable acidity and decreasing pH with age seemed apparent in upper horizons of Freeport and Kittanning sites. However, acidity increased significantly with age only on Kittanning sites. Exchangeable acidity and pH between horizons on most of the sites showed no measureable differences (only P26 and F24 were significantly different between horizons). This was probably due to a similar mixture of materials in the top 1 m of these minesoils resulting from overburden mixing during mining operations.

We expected to observe leaching of bases to deeper levels as sites aged as reported by other studies on weathering of acid minesoils (Down, 1975; Rich and Obenshain, 1955; Singh et al., 1982). Basic cations and base saturation did tend to decline with age on Pittsburgh and Kittanning sites but not in Freeport sites (Table 2).

Only a few differences were noted in total S and forms of S in upper horizons of Pittsburgh and Freeport sites, and no differences on Kittanning sites (Table 3). Total S was generally highest on Pittsburgh sites, followed by Kittanning, then Freeport, and no significant differences in S values between horizons were found.

VonDemfange and Warner (1975) used pyritic S content to indicate pyrite oxidation in Alabama minesoils and found pyrite oxidation occurred above 0.6 m in depth. On our 15 sites, pyritic S increases with depth were not evident (Table 3). These minesoil horizons, however, had varying levels of total S, which may have masked significant differences. Therefore, values for pyritic, sulfate, and organic forms of S were divided by total S and multiplied by 100% to calculate relative S forms. The result of this evaluation showed three Pittsburgh and two Kittanning sites with lower pyritic S in upper horizons than in lower horizons (Table 3). Freeport sites exhibited no evidence of increasing pyritic S with minesoil depth. The reason for a lack of pyritic S response may be due to rock fragments, which allowed infiltration of water and air exchange to deeper depths, thereby

Table 2. Chemical properties of upper (U) and lower (L) (>0.5 m depth) horizons on 15 AML sites in northern West Virginia. First letter of site name refers to the coal bed and the number refers to the age or time since disturbance (CEC is cation exchange capacity, BS is base saturation, and EC is electrical conductivity).

Sites (coal bed and age)		pH	Exchange acid	Ca	Mg	CEC	BS	EC
			cmol$_c$/kg				%	dS/m
P26	U	6.2a†*	0.3b	14a	3a	18a	97a	0.5a
	L	7.9	0.1	13	3	16	99	0.1
P27	U	6.9a	0.1b	19a	3a	22a	100a	0.6a
	L	7.1	0.0	44	4	48	100	1.6
P28	U	3.3b	11.3a	1b	1b	13a	11b	0.5a
	L	3.3	9.5	2	1	13	35	1.1
P30	U	6.6a	4.3ab	18a	4a	27a	88a	0.3a
	L	6.5	3.2	23	4	30	91	0.7
P33	U	4.4b	5.2ab	2b	1b	9a	47b	0.2a
	L	4.7	7.6	3	2	13	42	0.1
F20	U	4.2a	3.9a	1a	1a	6a	35a	0.2a
	L	4.6	8.3	1	1	9	10	0.1
F24	U	5.2a*	1.9a	9a	2a	16a	55a	0.1a
	L	3.9	5.9	1	1	2	56	0.3
F28	U	3.8a	6.7a	1a	1a	8a	13a	0.2a
	L	3.5	3.4	1	1	4	35	0.1
F32	U	3.9a	8.4a	1a	1a	10a	15a	0.1a
	L	4.3	6.6	12	1	19	35	0.5
F33	U	3.9a	8.9a	1a	1a	10a	11a	0.1a
	L	3.7	6.4	1	1	7	38	0.2
K13	U	5.3a	0.8b	11a	2a	14a	92a	0.4a
	L	5.5	1.9	8	2	12	83	0.7
K14	U	5.3a	3.2b	9a	3a	15a	74ab	0.4a
	L	5.2	0.2	5	3	9	97	0.7
K25	U	4.3a	7.8ab	2b	1a	10a	30ab	0.1b
	L	4.1	7.1	1	1	9	22	0.3
K27	U	4.1a	9.9ab	1b	1a	12a	18b	0.3a
	L	4.2	8.7	2	2	12	34	0.7
K35	U	3.8a	13.1a	1b	1a	14a	3b	0.1b
	L	3.6	14.4	1	1	16	9	0.2

* Significant difference at $P < 0.05$ between upper and lower horizon values.

† Upper horizon values within columns for the same coal bed with the same letter are not significantly different at $P < 0.05$.

Table 3. Sulfur (total, pyritic, and sulfate S) and neutralization potential values of upper (U) and lower (L) (>0.5 m depth) horizons on 15 AML sites in northern West Virginia. First letter of the site name refers to the coal bed and the number refers to the age or time since disturbance.

Sites		Total S	Pyritic S	Sulfate S	Relative Pyritic S	Relative Sulfate S	Neutralization potential
		%					CaCO$_3$ Equivalent, g kg^{-1}
P26	U	0.29ab†	0.07a	0.00a	23a*	0a	2.6a*
	L	0.58	0.32	0.00	49	0	7.2
P27	U	0.52a	0.00a	0.03a	0a*	5a*	3.4a
	L	0.97	0.34	0.23	31	29	8.7
P28	U	0.21ab	0.01a	0.06a	3a	28a*	−1.1a
	L	0.42	0.02	0.16	4	51	−2.0
P30	U	0.30ab	0.05a	0.04a	13a	16a	15.2a
	L	0.19	0.03	0.00	22	3	3.9
P33	U	0.09b	0.01a	0.02a	16a*	21a	2.1a
	L	0.06	0.02	0.01	40	6	1.7
F20	U	0.02b	0.01a	0.01b	20a	6a*	−0.1ab
	L	0.06	0.01	0.01	6	28	−0.6
F24	U	0.10b	0.01a	0.03b	2a	27a*	0.3a
	L	0.12	0.01	0.00	2	0	4.0
F28	U	0.06b	0.01a	0.03b	21a	32a	−0.4ab
	L	0.05	0.00	0.01	0	19	−0.1
F32	U	0.21a	0.03a	0.09a	12a	41a	−1.2b
	L	0.10	0.02	0.04	15	35	−0.1
F33	U	0.08b	0.03a	0.02b	37a	27a	−0.2ab
	L	0.06	0.02	0.01	37	17	0.4
K13	U	0.11a	0.00a	0.02a	0a	20a	2.9a
	L	0.14	0.01	0.01	6	8	4.0
K14	U	0.10a	0.01a	0.01a	13a	5a	2.1a
	L	0.10	0.02	0.01	15	14	2.2
K25	U	0.17a	0.01a	0.03a	8a*	16a	−1.6b
	L	0.26	0.08	0.02	23	5	−0.9
K27	U	0.10a	0.01a	0.01a	8a*	8a	0.1ab
	L	0.16	0.03	0.03	27	9	0.0
K35	U	0.17a	0.01a	0.01a	1a	6a	−0.1ab
	L	0.22	0.00	0.01	0	7	0.0

* Significant difference at $P < 0.05$ between upper and lower horizon values.

† Upper horizon values within columns for the same coal bed with the same letter are not significantly different at $P < 0.05$.

increasing oxidation at greater depths. Overburden mixing and compaction during mining may also be involved.

Sulfate can be used as an indicator of pyrite oxidation since it is a product of this reaction, but sulfate is soluble and may leach. Therefore, sulfate should be found in greater amounts at lower depths on older sites (Horbaczewski and Van Ryn, 1988). Only three sites (P27, P28, and F20) showed a significant relationship (Table 3).

Soil Cluster

The cluster analysis of the minesoil data (Fig. 2) produced two distinct clusters (semipartial $r^2 = 0.46$, the dendrogram's highest value). The small cluster was named minesoil Type A, and the larger cluster was then divided into two smaller clusters (semipartial $r^2 = 0.15$), which were named minesoil Types B and C.

Minesoil Type A (Table 4) was the most suitable minesoil type for plant growth with low exchangeable acidity, high BS, pH 5.0 to 7.4, high CEC, and high total S. Minesoil Type B was the most variable minesoil type with high exchangeable acidity, very low to moderate BS, pH 3.0 to 5.0, moderate CEC, moderate total S, and low relative pyrite. Minesoil C had low to moderate exchangeable acidity, low BS, pH 4.0 to 4.6, low CEC, low <2 mm, and low total S.

The minesoil types were largely differentiated by their parent material, as was also found in a study on minesoils by Tyner and Smith (1945). Freeport sites were exclusively found in minesoil Type C and were excluded from minesoil Type A. Pittsburgh, Kittanning, and Freeport sites were all found in Type B, while Pittsburgh and the youngest Kittanning sites were grouped in Type A. However, mining techniques and/or placement of specific overburden materials on the surface can dissipate differences in parent materials and cause similar minesoil properties. Evidence of this can be seen by looking at type B, which included all three parent material types.

Vegetation Characteristics

Total tree cover was significantly different among sites within the Pittsburgh and Kittanning coal beds (Table 5). Kittanning sites had the lowest total tree cover (avg. of 33%), while Freeport sites had the highest (avg. of 145%). Total herbaceous cover was significantly different among sites among all three coal beds. The P30 site had no tree cover and was dominated by grasses, while the F24, K13, and K14 sites had >75% herbaceous cover. The number of tree species varied across our sites. Red maple (*Acer rubrum* L.), black birch (*Betula lenta* L.), and other prominent tree species with their canopy cover values are given in Table 5 to give an idea of the major tree species found.

The P26, P27, and P30 sites all had minesoil pH >6.0 (Table 2), whereas the F24, K13, and K14 sites had pH >5.0. These sites with pH >5.0 had low acidity (<6 cmol$_c$/kg), high Ca (>9 cmol$_c$/kg), and >50% BS. The

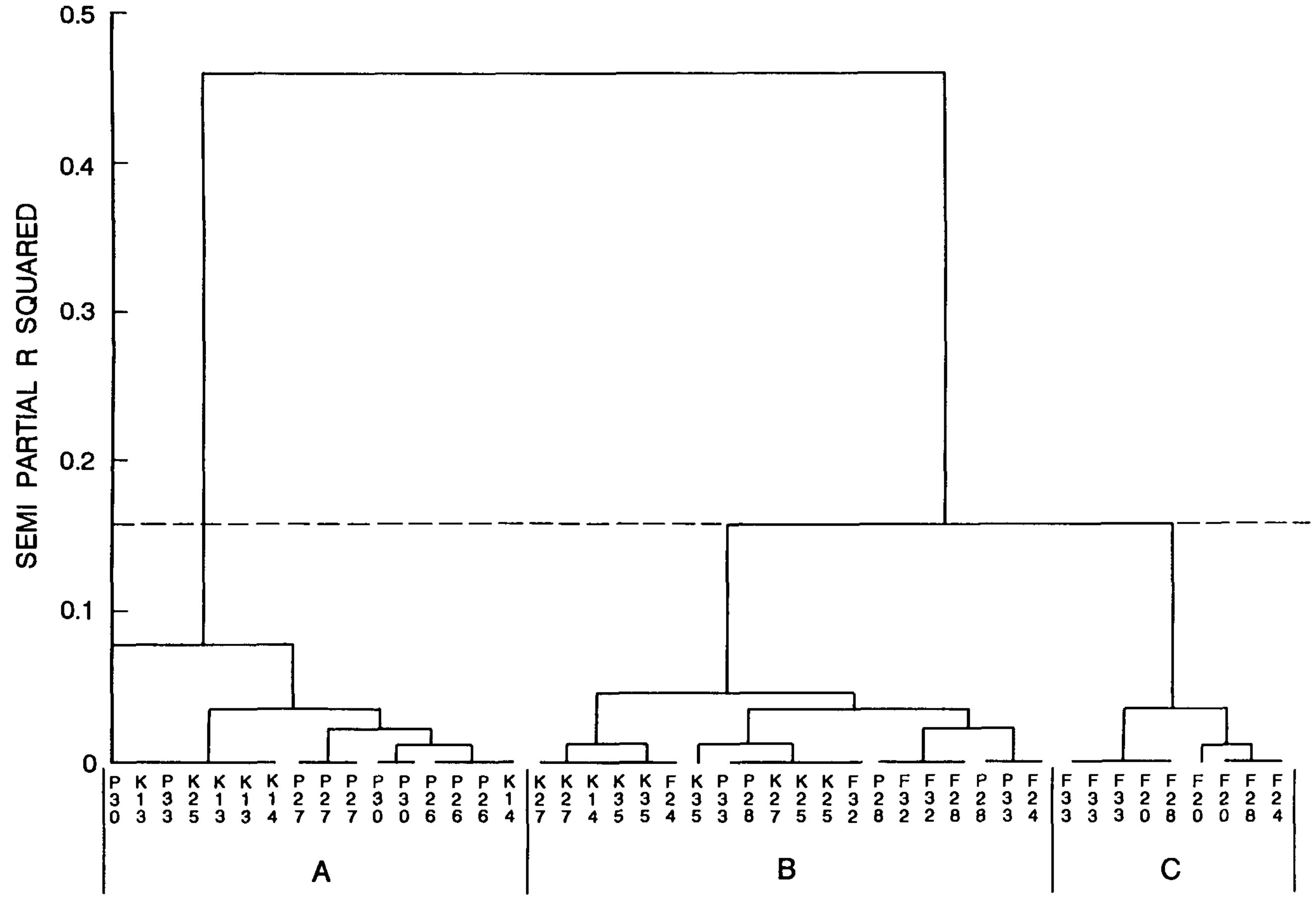

Fig. 2. Cluster dendrogram of minesoil pits on 15 AML sites (3 pits per site for 45 total pits) in West Virginia. The cluster analysis used all chemical and physical properties from each pit. The first letter of each site designates the coal bed and the number refers to the age.

high pH and low acidity is reflected in the amount of herbaceous cover on these sites (avg. 72%, range 26–93%). Tree cover averaged 37% on these same sites (range 0–117%). Conversely, sites with pH <5.0 and high acidity had total herbaceous cover ranging from 1 to 33% (avg. 11%) and tree cover varying from 27 to 214% (avg. 111%). Clearly, the minesoil's pH and acidity dramatically influenced the composition of the plant community.

Reclamation Implications and Conclusions

Abandoned mine land reclamation is expensive when complete regrading of the site is necessary to reduce steep slopes, and when topsoil is imported from another site. With traditional AML reclamation, plants already established on the site (commonly trees) are bulldozed and, after grading and topsoiling with borrowed soil, herbaceous plants are seeded to control erosion. Also, revegetation of the topsoil borrow area is necessary.

All of the 15 AML sites we studied were vegetated to some degree. Five sites with pH >5.0 were predominantly covered by herbaceous plants, whereas the other 10 were covered in various amounts and with varying combinations of 29 tree species. Our minesoil analyses and clustering showed that sites with minesoil Type A require no chemical amendments to improve the pH of the soil (Table 4) and have been naturally revegetated by herbaceous plants and trees. These sites also show

Table 4. Cluster summary of soil variables.

			Soil variables†										
Cluster	Pits per coal	Sites	Acid	BS	pH	CEC	<2mm	Sand	Silt	Clay	TotS	RPyr	RSulf
			cmol$_c$/kg	%		cmol$_c$/kg	%						
A	P-10 K-6	P26, P27, P30, P33 K13, K14, K25	0–2	70–100	5–7.4	10–30	25–55	10–25	40–65	10–40	0.10–0.60	0–30	0–45
B	K-9 F-6 P-5	K14, K25, K27, K35 F24, F28, F32 P28, P33	5–17	0–60	3–5	6–17	20–60	15–50	30–55	15–30	0.10–0.25	0–15	0–50
C	F-9	F20, F24, F28, F33	1–10	6–30	4–4.6	5–10	13–40	45–70	20–30	10–20	0.02–0.10	0–30	0–45

† Acid = exchangeable acidity, BS = base saturation, CEC = cation exchange capacity, <2mm = less than 2-mm soil fraction, TotS = total sulfur, RPyr = relative pyritic S, and RSulf = relative sulfate S.

Table 5. Vegetation characteristics of 15 AML sites in northern West Virginia. First letter of the site refers to the coal bed and the number refers to the age or time since disturbance.

Site (coal bed and age)	Total tree cover	Total herbaceous cover	Number of tree species	Canopy cover of trees†		
				Red maple	Black birch	Other tree species
	%	%		%	%	%
P26	117a*	26b	10	0	0	Sycamore = 43, Slip elm = 45
P27	17ab	61a	12	2	0	Redbud = 8
P28	84a	1b	14	21	24	Aspen = 25
P30	0b	82a	4	0	0	
P33	115a	33b	7	54	0	Cherry = 12, Tuliptree = 28
F20	214a	4b	15	54	99	Locust = 34
F24	90a	93a	8	0	0	Aspen = 51, Locust = 28
F28	143a	2b	10	34	66	Locust = 26
F32	97a	12b	5	5	9	Locust = 47, Cherry = 37
F33	183a	6b	12	16	1	Cherry = 87, Hrcls club = 47
K13	0b	93a	2	0	0	
K14	0b	77a	4	0	0	
K25	27ab	30b	9	2	4	Cherry = 15
K27	70a	5b	9	20	33	Locust = 8
K33	70a	4b	14	15	13	Pin oak = 12, Cherry = 11

* Values within columns for the same coal bed with the same letter are not significantly different at $P < 0.05$.

† Sycamore (*Platanus occidentalis* L.), slippery elm (*Ulmus rubra* Muhl.), redbud (*Cercis canadensis* L.), aspen (*Populus grandidentata* Michx.), cherry (*Prunus serotina* Ehrh.), tuliptree (*Liriodendron tulipfera* L.), black locust (*Robinia pseudo-acacia* L.), Hercules club (*Aralia spinosa* L.), pin oak (*Quercus palustris* Muenchh.), red maple (*Acer rubrum* L.), and black birch (*Betula lenta* L.).

low amounts of rock fragments (Table 1), which could negatively influence bulk density and water holding capacity.

Minesoil Type C (all Freeport sites) generally had low pH and high amounts of rock fragments making them best suited for revegetation with trees. The fact that these sites have almost complete tree canopy cover attests to their suitability for tree recruitment and forest development. Reclaiming such sites by AML reclamation by regrading and topsoiling is unnecessary and adding lime or fertilizer would probably show minimal effects on tree growth.

Some areas on minesoil Types B and C had either small or extensive unvegetated areas. Barren AML sites (those where no public health or safety hazards exist) may be prepared for invasion by adjacent plant species if small amounts of lime and/or fertilizer are applied and if some mulch is used to enhance water relations and soil temperatures (Hedin and Hedin, 1990; Keeney, 1980). This reclamation technique may not work on all AML sites, but a few AML dollars spent in applying some amendments may significantly improve the potential for natural invasion and establishment of surrounding plant species on AML sites. Many barren AML sites that otherwise might require many years for a suitable soil material to naturally develop onsite would revegetate quickly without costly engineering designs, extensive regrading, and topsoiling.

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