CHEMICAL PROPERTIES OF MINESOILS ON A MOUNTAINTOP REMOVAL MINE IN SOUTHERN WEST VIRGINIA[1]

by

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Abstract. Mountaintop removal is a common surface coal mining procedure and has been practiced in West Virginia for more than 30 years. Recently, as the mines are becoming larger and disturbing hundreds to thousands of ha, questions have arisen concerning the long-term use of those lands, and the quality of post-mining soils and drainage. Therefore, a study was initiated to evaluate the properties of soils on a vast reclaimed mountaintop removal mine in southern West Virginia. Minesoils of four different ages (2, 7, 11, and 23 years) and two different slope classes (nearly level and steep) were sampled. Contiguous native soils also were sampled and compared to minesoils. Samples were analyzed for pH, extractable acidity, exchangeable Al and Mn, extractable P, extractable bases, total C, N, and S. Analysis of the data revealed the minesoils in general to be less acidic than the native soils. Total C and N were higher in the surface horizons of native soils compared to minesoils, but minesoils generally had higher C and N in the lower horizons. The higher C with depth may be due to the presence of carbolithic material. Phosphorus was highest in the 2-year-old minesoil, possibly due to the residual effects of fertilization. Exchangeable Al was generally higher in the native soils than the minesoils. Manganese was highest in the surface of the native soils, but dropped below that of minesoils at lower depths. Extractable acidity was highest in the native soils, and base saturation was lowest in the native soils. It appears from our studies that the minesoils developing on this site have potential productivity as good as or better than native soils and that land uses on native soils can be developed on these minesoils.

Additional Key Words: Reclamation, Minesoil Quality, Minesoil Productivity

Introduction

The process of mountaintop removal mining results in reclaimed landscapes that differ from the original landscapes. The mining process adapts the concepts of area mining for use in steeply sloping terrain. As a result, relief is sometimes reduced to that of the lowest economically mineable coal seam and excess spoil is commonly placed in head-of-hollow or valley fills. On most mountaintop sites, much of the overburden is replaced but the topography is less steep and ridges are rounded. The soils developing on these mined and filled areas differ from the original native soils, but they have not been widely evaluated.

One way to view the differences between native soils and minesoils is that native soils have had greater time to weather and develop their own unique set of chemical properties based on climate, aspect, parent material, and organisms. Most of the properties of minesoils are derived either from overburden placement, overburden geology, or by some human interaction, such as compaction or fertilization. Many minesoil chemical properties are site specific, reflecting characteristics of the overburden and reclamation practices of the given area. Minesoil properties are closer to their parent material properties than natural soils are to their parent material properties (Sobek et al., 1978). Minesoils usually have an irregular distribution of carbon with depth. This irregular distribution can be associated with coal and dark shale fragments found throughout the soil as well as mixing of the original soil with depth (Ciolkosz et al., 1985; Pederson and Rogowski, 1978; Smith et al., 1971; Thurman and Sencindiver, 1986). Minesoil pH values have been known to range from as low as 2.9 to as high as 8.2 (Barnhisel and Massey, 1969; Ciolkosz

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et al., 1985; Daniels and Amos, 1981; Johnson and Skousen, 1995; Plass and Vogel, 1973; Sencindiver, 1977; Smith et al., 1971). In some cases minesoil pH values have been reported as being equal to the contiguous native soils (Pederson and Rogowski, 1978; Thurman and Sencindiver, 1986). Phosphorous and N deficiencies have been widely recognized in minesoils throughout the eastern coal region (Barnhisel and Massey, 1969; Smith and Sobek, 1978; Daniels and Amos, 1981). Exchangeable bases in minesoils often reflect the base status of the original pre-mine native soil or overburden strata. Base saturation may vary in minesoils from 1 to 100% (Daniels and Amos, 1981; Ciolkosz et al., 1985; Short et al., 1986; Smith et al., 1971).

Few studies on chemical properties of mountaintop removal minesoils have been conducted. Little information is known about long-term environmental changes on these sites. Therefore, we initiated a study to evaluate chemical and physical properties of minesoils and contiguous native soils to: (1) help evaluate the quality and development of these soils on a reclaimed mountaintop removal coal mine in southern West Virginia, and (2) initiate the development of a minesoil database for mountaintop removal mines. The physical and morphological properties of these soils were discussed in an earlier paper (Thomas et al., 2000). The objective of this study was to document chemical properties of mountaintop removal minesoils and correlate the data to soil quality and development.

Materials and Methods

Study Area

In July 1999, minesoil pits were dug and samples were collected on a mountaintop removal site near Sharples, Logan County, West Virginia. The coal beds mined at this site were within the Kanawha formation, which is composed of approximately 50% sandstone and 50% shale, siltstone, and coal. There are several marine zones found throughout the formation (Cardwell et al., 1968). Most of the soils in the unmined area are moderately deep to very deep Dystrudepts or Hapludults forming in residuum or colluvium. General slope classes of the premined and the mined and reclaimed areas were gently sloping to very steep. However, the general relief of the reclaimed areas is less than the premined landscape. Elevation of the native landscape where samples were collected ranged from 561 to 568 m (1845-1863 ft), and the reclaimed mined land elevations ranged from 442 to 525 m (1450-1720 ft). The average temperature during the summer months is 22.8° C (73° F), and in the winter 1.0° C (34° F). The annual precipitation is 112 cm (44 in), 55% of which falls between April and September. The major vegetation before mining was predominantly forest which consisted of northern red oak (*Quercus rubra*, L.), black oak (*Q. velutina*, Lam.), yellow poplar (*Liriodendron tulipifera*, L.), hickory (*Carya* sp.), scarlet oak (*Q. coccinea*, Muench.), white oak (*Q. alba*, L.), and American beech (*Fagus grandifolia*, Ehrh.) (Wolf, 1994).

Field and Laboratory Studies

Four different ages of reclaimed mined land with two slope classes each were sampled in 1999. These sites were reclaimed in 1976 (23 yrs), 1988 (11 yrs), 1992 (7 yrs), and 1997 (2 yrs). Three replications of each of the minesoil slope classes and age combinations were sampled. One very deep and two moderately deep undisturbed native forest soils representing the major soil series in the county were sampled for comparison. The very deep soil developed in colluvium, and the moderately deep soils developed in residuum. Soil pits approximately 1 m wide x 2 m long x 1+ m deep were excavated at each sampling point. Each pedon was described using standard soil survey procedures (Soil Survey Division Staff, 1993). Bulk samples were collected from every horizon described. The slope classes consisted of one that was steep to very steep and a second that was nearly level to gently sloping. For this paper, all minesoil data for steep and nearly level slope classes for each age class were combined. General trends were evaluated for age classes, but not for slope classes. Fertilization of the 23-year-old minesoil is unknown. However, the 7- and 11-year-old minesoils had 560 kg/ha (500 lbs/acre) of 18-46-0 applied, and the 2-year-old minesoil had 672 kg/ha (600 lbs/acre) of 15-30-15 applied. None of the minesoils were limed. Vegetation on the 2- and 11-year-old minesoils was predominantly grasses and legumes, and the 7-year-old vegetation was a combination of grasses, legumes, and shrubs. The 23-year-old minesoil had predominantly forest cover of a few prominent trees, either planted or volunteer, with a sparse understory of grasses and legumes. Although several tree species were found on the site, the prominent species were black locust (*Robinia pseudoacacia* L.) and red maple (*Acer rubrum* L.) (Skousen et al., 1999)

Each minesoil pedon was classified to the series level by Soil Taxonomy (Soil Survey, 1998). All minesoils in our study fit one of the four following series: Bethesda (loamy-skeletal, mixed, acid, mesic Typic Udorthents), Sewell (loamy-skeletal, mixed, semiactive, acid, mesic Typic Udorthents), Fiveblock (loamy-skeletal, mixed, semiactive, nonacid, mesic Typic Udorthents), or Kaymine (loamy-skeletal, mixed, active, nonacid, mesic Typic Udorthents). The 23-year-old minesoil had two pedons classified as Bethesda, two classified as Fiveblock, and two pedons classified as Sewell. The 11-year-old minesoil had four pedons classified as Fiveblock, one pedon classified as Sewell, and one as Bethesda. The 7-year-old minesoil had three pedons classified as Fiveblock, two classified as Sewell, and one classified as Kaymine. The 2-year-old minesoil had three pedons classified as Fiveblock one classified as Bethesda, one as Sewell, and one as Kaymine.

In the laboratory, pH was measured by a 1:1 soil to water suspension method using a standard pH probe on an Accumet 915 pH meter (Method 8C1, Soil Survey Staff, 1996). Total C, N, and S were determined by using a LECO CNS 2000 analyzer. Extractable bases (Ca, Mg, K, Na) and CEC-7 were determined by ammonium acetate extraction with 1.0 *N* NH_4OAc buffered at pH 7.0 (Method 5A, 5A8, 5A8b, 6N, 6O, 6P, 6Q, Soil Survey Staff, 1996). Base saturation at pH 7.0 was calculated by dividing the sum of the bases by CEC-7 (Method 5C, 5C1, 5C3, 5A3a, Soil Survey Staff, 1996). Extractable Al and Mn were measured by 1 *N* KCl extraction. Again, analysis followed standard soil survey methods, and extracts were analyzed on the Atomic Absorption Spectrophotometer for Al and Mn (Method 6G, 6G9, Soil Survey Staff, 1996). Effective cation exchange capacity (ECEC) was computed by summing NH_4OAc extractable bases noted above and KCl extractable Al (Method 5A3b, Soil Survey Staff, 1996). Extractable acidity was determined by barium chloride triethanolamine extraction (Method 6H5a, Soil Survey Staff, 1996). Cation exchange capacity at pH 8.2 (CEC-8.2) was calculated by adding the extractable acidity to the sum of the bases. Then, base saturation at pH 8.2 was calculated by dividing the sum of the bases by CEC-8.2. Phosphorus was determined by the Bray-1 method and analyzed on a Perkin Elmer Emission Spectrophotometer Plasma 400 (Method 6S3, Soil Survey Staff, 1996).

Results and Discussion

Nitrogen, Phosphorus, Sulfur, and Carbon

In areas of the eastern coal region where acidic minesoils occur, P, N, and water have been reported as being the most common limiting factors of obtaining adequate vegetation cover (Barnhisel, 1977). Previous studies of West Virginia minesoils of different ages, land uses, and parent materials have reported total minesoil N generally ranging from 0.03% to 0.6% with most minesoil horizons having less than 0.3% (Adamo, 1986; Sencindiver, 1977; Vandevender and Sencindiver, 1982). Li (1991) reported 0.06-0.25% N in southwest Virginia minesoils. All soils in this study had less than 0.1% average total N (Fig. 1), and all minesoils had lower values than the native soils, where most N was in the surface horizon (Table 1). Total N tended to increase with age within the minesoils. The 23-year-old minesoil had the highest total N levels, and the 2-year-old minesoil had the lowest (Fig. 1).

Phosphorus is a major limiting nutrient in Appalachian minesoils (Plass and Vogel, 1973). Researchers in West Virginia have reported Bray extractable P levels ranging from very low to moderate in minesoils (Adamo, 1986; Dant, 1984). A similar

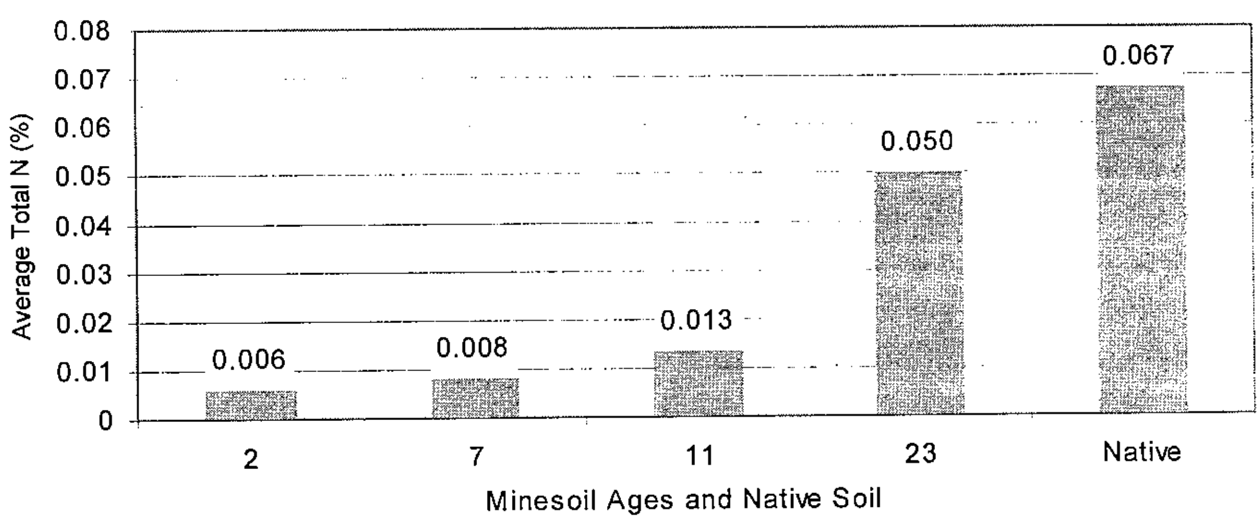

Figure 1. Average Total Nitrogen of all Minesoil and Native Soil Horizons by Age

Table 1. Minesoil and Native Soil Chemical Properties by Year of Reclamation and Average Depth

				Total			Extractable							
Years	Layers*	Depth(cm)	pH	C	N	S	Ca	Mg	Na	K	Al	Acidity	Mn	P
				.......%.........			....................cmol+kg^{-1}........................							mg/kg
23	1	10	4.6	2.9	0.09	0.04	2.8	1.7	0.03	0.14	1.0	8.1	0.12	8.1
	2	29	4.9	2.4	0.04	0.05	2.7	1.9	0.04	0.10	0.8	5.7	0.09	4.3
	3	112	5.0	2.6	0.03	0.06	2.5	2.2	0.00	0.00	0.5	3.9	0.05	3.6
11	1	8	5.3	2.1	0.02	0.04	1.7	0.7	0.00	0.09	0.2	3.9	0.03	11.6
	2	33	5.6	2.4	0.02	0.06	1.6	1.0	0.00	0.10	0.4	3.0	0.03	1.7
	3	91	5.9	2.8	0.01	0.06	2.0	0.8	0.00	0.10	0.1	2.7	0.02	1.9
7	1	8	5.0	3.7	0.02	0.07	1.2	1.1	0.11	0.12	0.8	3.9	0.03	12.6
	2	24	4.9	3.7	0.01	0.10	1.0	1.2	0.04	0.11	0.9	3.9	0.04	6.6
	3	127	5.7	2.3	0.00	0.05	1.3	1.2	0.06	0.07	0.5	1.6	0.02	1.9
2	1	6	5.7	3.9	0.02	0.06	2.7	2.7	0.00	0.20	0.3	3.3	0.06	69.4
	2	15	5.8	2.9	0.00	0.04	2.4	2.6	0.00	0.10	0.3	2.9	0.05	27.7
	3	118	5.6	3.4	0.00	0.06	2.5	2.9	0.00	0.10	0.4	3.7	0.06	3.6
Native	1	7	4.7	7.9	0.25	0.07	5.5	1.0	0.00	0.18	1.7	17.6	0.25	24.7
	2	19	4.7	0.8	0.00	0.03	0.7	0.4	0.00	0.08	2.7	7.1	0.07	2.9
	3	102	4.7	0.3	0.00	0.04	0.9	1.3	0.00	0.10	2.5	5.4	0.02	0.7

*1 = Average of all A,A1,A2,A/E horizons

2 = Average of all AC,BA,Bw,BC horizons

3 = Average of all CB,C/B,C,C1,C2,C3,C4 horizons

range was found in this study as well. The 2-year-old minesoils in our study had higher extractable P values than other minesoils and the native soils (Fig. 2). The higher levels of P in the 2-year-old minesoils are believed to be a residual result of fertilization during revegetation. Phosphorus seemed to be concentrated in

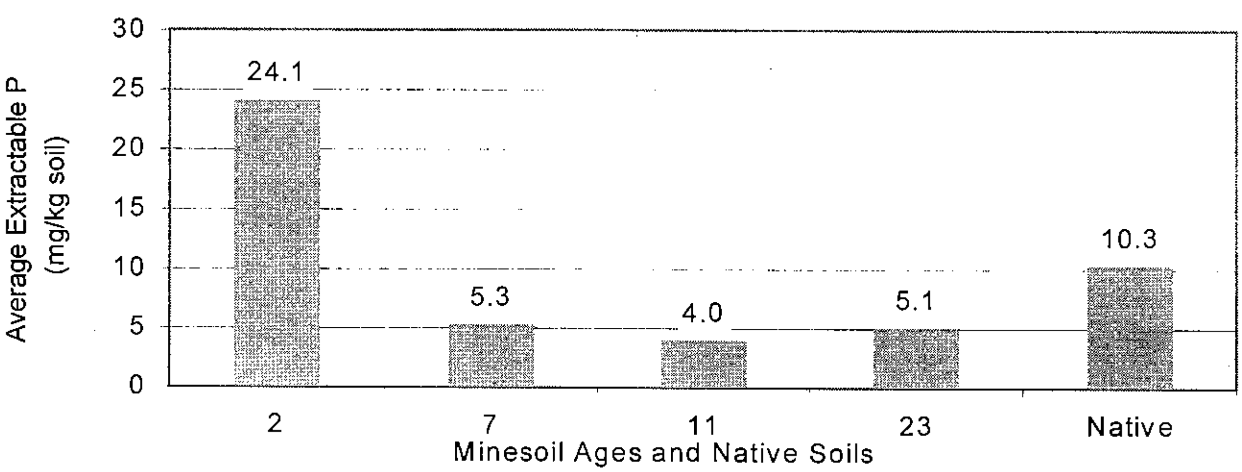

Figure 2: Average Extractable Phophorus of all Minesoil and Native Soil Horizons by Age

the top two horizons of the native soils, and tended to decrease with depth (Table 1). The same trend was indicated in the majority of the minesoils. This trend of decreasing P with depth may be the result of biocycling or root interaction.

Wolf et al. (1990) found S values as high as 0.45% in minesoils located in similar areas of southern West Virginia as those sampled in this study. However, the overburden and coal mined in the area of our study had little or no pyritic material (Barlow and Erwin, 1974). Therefore, S values in the minesoils and native soils were 0.1% or less (Table 1).

Irregular distribution of C with depth is a common trend in minesoils (Ciolkosz et al., 1985; Pederson and Rogowski, 1978; Smith et al., 1971; Thurman and Sencindiver, 1986), and also was demonstrated in these mountaintop removal minesoils. The native soils had the highest total C in the surface with 7.9 % (Fig. 3), and the 11-year-old minesoils had the lowest with 2.1 % total C in the surface. However, total C increased with depth in the 11-year-old minesoil to 2.8% (Table 1). One explanation for the irregular distribution is the presence of carbolithic shale and coal fragments throughout the minesoils. The combustion method used to determine C would likely measure fossil carbon in coal, carbonaceous shale material, and soil organic matter C.

Exchangeable Bases

Of the four bases analyzed in both minesoils and native soils, Ca and Mg were most abundant (Table 1). The Na content was low in the minesoils because Na is typically not found in geologic material of the mined area. Potassium was lower than expected since most parent materials in the area have K-bearing minerals associated with them. Earlier studies of minesoils in southern West Virginia (Skousen et al., 1998; Wolf et al., 1990) reported K levels of 0.3-0.6 $cmol+kg^{-1}$. In our study, the highest K level was 0.1 $cmol+kg^{-1}$ in the 23-year-old soil. The higher levels of K and all other extractable bases, except Na, found in the other studies may be due to higher clay content in those minesoils than the minesoils of this study.

Total extractable bases were highest in the 2-year-old minesoils, and lowest in the native soils (Fig. 4). The higher bases in the 2-year-old minesoil could be the result of several things, i.e. (1) higher bases in the parent material, (2) less uptake by vegetation because of shortness of time, and (3) less leaching because of shortness of time and low rooting. However, the 23-year-old minesoil had higher bases than that of the 7 and 11-year-old minesoils. These higher base values may be the result of an older, tree vegetated site bringing bases to the surface because of deep rooting depths and returning bases to the soil surface through leaf and limb fall. However, the higher bases could be

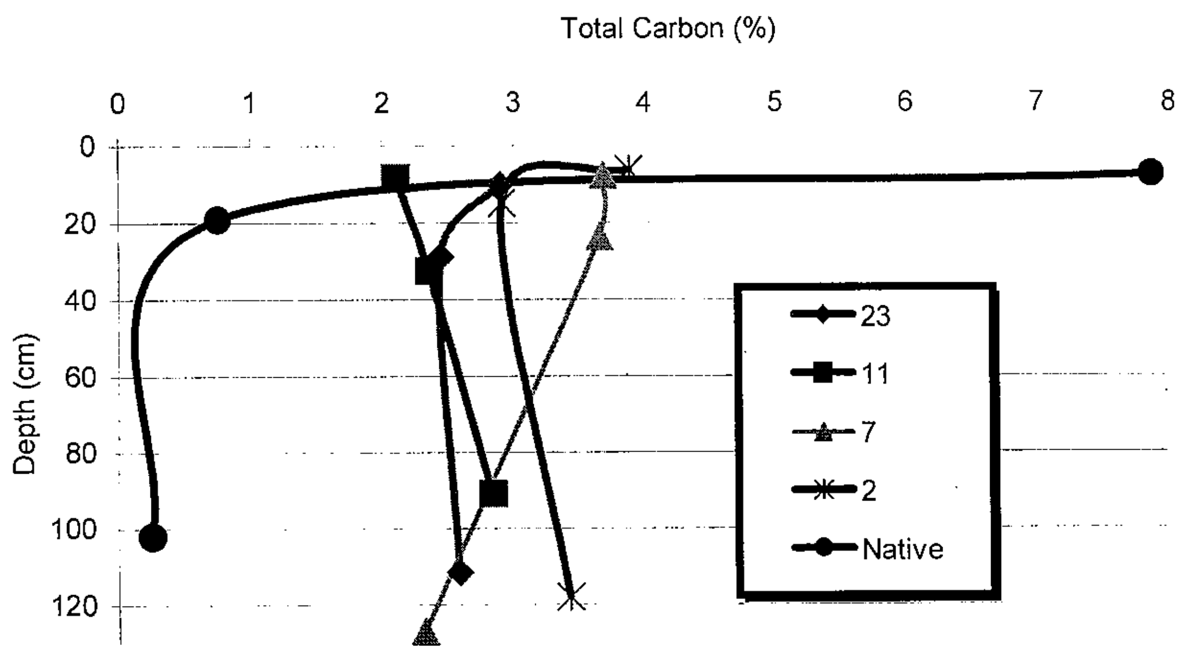

Figure 3. Average Percent Carbon with Depth of Minesoils and Native Soils

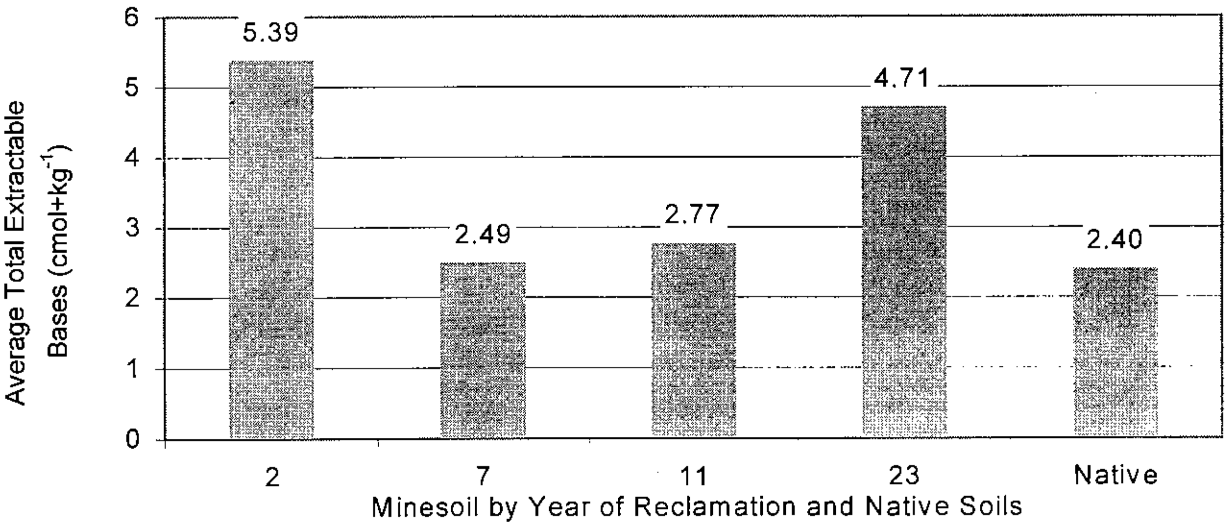

Figure 4. Average Total Extractable Bases of all Minesoil and Native Soil Horizons by Age

Table 2. Minesoil and Native Soil Calculated Chemical Properties by Year of Reclamation and Average Depth

Years	Layers*	Depth (cm)	CEC-7	CEC-8.2	ECEC	Base Sat.-7	Base Sat.-8.2	Al Sat.
			..........cmol+kg^{-1}..........			..........%..........		
23	1	10	9.8	12.9	6.5	48	37	17.5
	2	29	7.3	10.5	5.5	65	45	14.2
	3	112	5.9	8.6	5.2	79	54	10.4
11	1	8	4.9	6.4	2.7	51	39	8.6
	2	33	5.0	6.4	3.3	53	41	11.7
	3	91	4.2	5.5	3.0	68	51	4.2
7	1	8	6.0	6.3	3.3	41	39	24.4
	2	24	4.4	6.3	3.4	55	38	28.0
	3	127	3.7	4.1	3.1	69	63	17.6
2	1	6	6.4	8.8	5.8	87	63	5.5
	2	15	6.6	8.0	5.5	78	64	6.2
	3	118	7.5	9.1	5.8	72	60	7.0
Native	1	7	22.4	24.3	8.3	30	27	20.2
	2	19	7.1	8.2	3.8	16	14	69.9
	3	102	7.3	7.6	4.7	30	29	53.1

*1 = Average of all A,A1,A2,A/E horizons

2 = Average of all AC,BA,Bw,BC horizons

3 = Average of all CB,C/B,C,C1,C2,C3,C4 horizons

an indication that the minesoils are only reflecting the original base status of the premined soil and geology.

Cation exchange capacity in the surface horizons of the native soils was higher than that of the minesoils primarily because organic matter was higher in the native soils (Table 2). Effective cation exchange capacity was higher in the native soils, but base saturation was higher in all minesoils than the native soils.

pH, Exchangeable acidity, Aluminum, and Manganese

In general it has been noted that minesoil pH is influenced by human interactions, such as liming and the placing of alkaline geologic material on the surface during reclamation, and natural interactions, such as leaching caused by rainfall. In our study, minesoil pH tended to decrease with age, and native soils had lower pH values at all depths than the minesoils except for the surface of the 23-year-old minesoil (Table 1).

At low pH, certain elements such as Al and Mn become toxic to plants and may contribute to vegetation failures on minesoils (Berg and Vogel, 1968; Berg and Vogel, 1973; Fleming et al., 1974). Extractable Al was higher at all depths in the native soil, because of its correlation to lower pH values (Table 1). Manganese was twice as high in the surface of the native soil than that of the 23-year-old minesoil. However, the 23-year-old minesoil had higher Mn levels in the lower horizons than that of the native soils, and it had higher levels of Mn than all the other minesoils. Since all soils studied had relatively the same concentrations of Mn then parent material could be playing a role with this chemical property.

Acidity in minesoils can arise from rapid leaching of bases in a humid environment, or the oxidation of pyritic material within the minesoils (Mays and Bengston, 1978). Since total sulfur values are low in these minesoils (Table 1), it is assumed that very little acidity resulted from pyrite oxidation. The average extractable soil acidity was greater in the native soils than the minesoils at all depths (Table 1). The 23-year-old minesoils had the highest extractable acidity of all the minesoils with an average of 5.9 $cmol+kg^{-1}$. The average extractable acidity of all soils tended to decrease with depth except for the 2-year-old minesoil where it increased in the lower horizons.

Summary

This study was initiated to evaluate the properties of minesoils developing on a reclaimed mountaintop removal coal mine in southern West Virginia. Chemical properties of four different-aged minesoils were compared to contiguous native soils. The native soils had higher values than the minesoils for the following properties: total C and N, cation exchange capacity in the surface horizon, exchangeable Al saturation, extractable Mn, and extractable acidity. The minesoils were higher than the native soils for the following properties: total exchangeable bases, pH, and base saturation. Extractable P concentrations were twice as high in the 2-yr-old minesoil as in the native soils, which were twice as high as any other minesoils. The high P levels in the 2-yr-old minesoils were undoubtedly due to fertilization at the time of revegetation. Total N was lower in the minesoils than the native soils. However, the minesoils did show signs of increasing total N levels over time.

The results of these chemical evaluations and results of an earlier study of the morphological and physical properties of these same soils indicate the minesoils will provide adequate rooting depth and plant nutrients for grasses, legumes, and trees. As the minesoils continue to weather and develop over time, they have the potential to become as productive as or better than the original native soil.

Acknowledgements

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