SOIL DEVELOPMENT ON A MOUNTAINTOP REMOVAL MINE IN SOUTHERN WEST VIRGINIA

by

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Abstract: Mountaintop surface mining for coal has been practiced in West Virginia for over two decades. Only recently has this practice been increasingly scrutinized by the public and regulatory agencies. Increased attention has focused on the environmental impacts of this mining process. Even after reclamation, citizens and regulators have expressed concerns about soil and water quality and post-mining land use. Therefore, a study was initiated to evaluate the quality of soils developing on a reclaimed mountaintop removal mine in southern West Virginia. Minesoils of four different ages (2, 7, 11, and 23 years) and two different slope classes were described and sampled. The slope classes were nearly level to gently sloping and steep to very steep. Contiguous native soils were also described and sampled. All native soils had cambic (Bw) horizons and were classified as Inceptisols. Two of the minesoil profiles had Bw horizons, but only one (23–year–old) was thick enough to be cambic. The minesoil with the cambic horizon was classified as an Inceptisol, while all other minesoils were Entisols. When compared to native soils, the minesoils had much thinner sola (combined thickness of A, AC, Bw and BC horizons). However, all minesoils except those on the two-year-old site had thicker A horizons than the native soils. Seeding of grasses and legumes and extensive root establishment undoubtedly caused the increased thickness of A horizons on minesoils. Aggregate stability tests showed more water-stable aggregates in native than in minesoils, but aggregation of the minesoils increased with age. Surface horizon bulk density tended to be higher in native soils than in minesoils. However, bulk density with depth was similar for all soils. Minesoil pH tended to be between 5 and 6, while native soil pH was between 4 and 5. Electrical conductivity measurements gave low values (<2 dS/m) indicating negligible soluble salts in all soils.

Additional Key Words: reclamation, soil genesis, soil quality

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[1] Paper presented at the 2000 National Meeting of the American Society for Surface Mining and Reclamation, Tampa, Florida, June 11-15, 2000.

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Proceedings America Society of Mining and Reclamation, 2000 pp 546-556
DOI: 10.21000/JASMR00010546

https://doi.org/10.21000/JASMR00010546

Introduction

The process of mountaintop removal mining results in reclaimed landscapes that commonly differ from the original landscapes. Relief has generally been reduced and excess spoil is commonly placed in head-of-hollow or valley fills. The soils developing on these mined and filled areas differ from the original soil, but they have not been widely evaluated.

Minesoils are very young soils developing from mixtures of fragmented rock and fine earth material. The original soil profiles have been disrupted and often partially or totally replaced by earth materials from depths below the original profile. Studies have shown that upon exposure to the surface environment, accelerated weathering may occur and increase soil development (Ciolkosz et al., 1985). This development has been linked to human influences as well as natural processes (Indorante and Jansen, 1984; Schroer, 1978; Smith and Sobek, 1978). Accelerated physical weathering of rocks caused by blasting and movement during both mining and reclamation, and the addition of organic materials during reclamation, increase the rate of soil development (Sencindiver and Ammons, In press).

Smith et al. (1971) studied soil genesis in 70-130 year-old mine sites in West Virginia. They found the minesoils to have deeper root zones, higher bulk densities, and weaker grades of soil structure than native soils. The conclusion drawn from Smith's study and from other studies (Sencindiver and Ammons, In press; Schafer et al., 1980) was that minesoils were superior to native soils in some respects, yet inferior in others.

Few studies on soil development on mountaintop removal sites have been performed. Little information is known about long-term environmental changes on these sites. Therefore, we initiated a study to evaluate the quality of soils developing on a reclaimed mountaintop removal mine in southern West Virginia. The objective of this study was to document soil formation and to correlate minesoil property differences to age.

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). The slope classes consisted of one that was steep to very steep and a second that was nearly level to gently sloping. 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 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)

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 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. Aggregate stability was determined using the wet sieve method developed by Kemper and Rosenau (1986). Soil clods were collected in triplicate from each subsurface horizon, coated with a saran resin, and analyzed for bulk density by a water-displacement method (Soil Survey Staff, 1996). Surface horizons were normally too thin and too friable for clod sampling. Therefore, all surface horizons were sampled using the frame excavation bulk density procedure developed by Dr. Robert Grossman at the USDA-National Soil Survey Laboratory in Lincoln, NE. All bulk density values were corrected for rock fragments and reported as bulk density of the <2 mm fraction. The 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). Electrical conductivity was determined on a 1:2 soil to water suspension by the method presented by Sarrantonio et al. (1996).

Results and Discussion

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.

Horizon Development

Minesoils and native soils are two distinctly different morphological entities.
Native soil morphology is due to thousands, and sometimes tens of thousands, of years of physical and chemical weathering acting upon geologic material. Minesoils also develop through physical and chemical weathering processes, but they are much younger. Minesoils do show signs of pedogenesis but some physical and chemical characteristics are due to human-controlled influences rather than natural factors. These human influences include blasting of rocks into small fragments, compaction due to grading, addition of organic materials, additions of lime and fertilizer, and the seeding of grasses and legumes or the planting of trees.

Processes of soil formation resulted in similar horizon development in each of the native soils (Table 1). All native soils had the following horizons: (1) Oi, leaf and twig litter; (2) A or A/E, dark colored surface mineral horizons with organic matter accumulation; (3) BA, transition horizon between the A and Bw; and (4) Bw, weakly developed major B horizon. The A horizons had weak or moderate granular structure, while the Bw horizons had weak or moderate subangular blocky structure. The Bw horizons classified as cambic, and all three soils classified as Inceptisols (Soil Survey Staff, 1998). All of the minesoils had A horizons (Table 1). Most minesoils had AC horizons, which are transition horizons between the A and C horizons with no B horizon. Structure of the minesoil A horizons was predominantly weak or moderate granular with some subangular blocky. Structure of the AC horizons was predominantly weak subangular blocky with some granular. In general, structure was strongest in the 23-year-old minesoil and weakest in the 2-year-old minesoil.

We described Bw horizons in one 23-year-old and one 7-year-old profile. These horizons had weak subangular blocky structure. Since the structure of the AC and the Bw horizons was similar, the two horizons were separated primarily by color. The AC horizons had colors similar to the A and/or C horizons. The Bw horizons had colors with higher value and/or chroma than the A and C. The Bw in the 23-year-old minesoil was thick

Table 1. Horizons Described in Native Soils and Minesoils.

Horizon Name	Native	1976 (23 yrs)	1988 (11 yrs)	1992 (7 yrs)	1997 (2 yrs)
Oi	3*	6	1	1	6
Oe	-	6	2	2	-
Oa	1	-	-	-	-
A	2	6	6	6	6
A/E	1	-	-	-	-
AC	-	5	4	4	4
BA	3	-	-	-	-
Bw	3	1	-	1	-
BC	2	-	-	-	-
CB	-	-	1	-	-
C/B	-	2	-	4	1
C	1	6	6	5	6
R	2	-	-	-	-
2Cr	-	1	-	-	2
2R	-	1	-	-	-

* Number of pits having each horizon. For native soils, N= 3, for minesoils, N for each year = 6.

enough (at least 15 cm thick) to classify as cambic, but the 7-year-old Bw was too thin (Soil Survey Staff, 1998). Therefore, the older minesoil classified as an Inceptisol, with many similarities to the native soils, while all other minesoils classified as Entisols.

As expected, solum (combined A, AC, Bw and BC horizons) development was considerably greater in native soils than in minesoils (fig. 1). However, minesoil solum thickness tended to increase with age. Average solum development (slope classes combined) per year was 5.9 cm for the 2-year-old site but only 1.3 cm for the 23-year-old site (Table 2). These numbers are very similar to the results of a study reported by Ciolkosz et al. (1985) for nontopsoiled minesoils in western Pennsylvania with slope ranges similar to our study (Table 2). Both our study and the Pennsylvania study indicate that minesoil development is more rapid in the first few years after reclamation. Interestingly, the A horizons of the native soils were thinner than all minesoil A horizons, except the two-year-old site (fig. 2). We think this difference is primarily the result of human activities.

Revegetation techniques normally disturb a 5- to 10-cm layer at the minesoil surface, and include some organic amendment. Also, it is highly probable that the undisturbed sites had been logged in the last 50 to 100 years. If logging had occurred, then the O and A horizons would most likely have been removed, and they have been redeveloping without human influence. For the minesoils, A-horizon thickness tended to increase with age on both slope classes (fig. 2). The actual thicknesses described are very similar to A horizons described in studies on sites mined by methods other than mountaintop removal. Roberts et al. (1988b) found that a 4-cm thick A horizon developed on a nontopsoiled minesoil and a 6-cm thick horizon developed on a topsoiled minesoil in one year. When sewage sludge was added to the minesoil, a 1-yr-old A horizon was 11-12 cm thick.

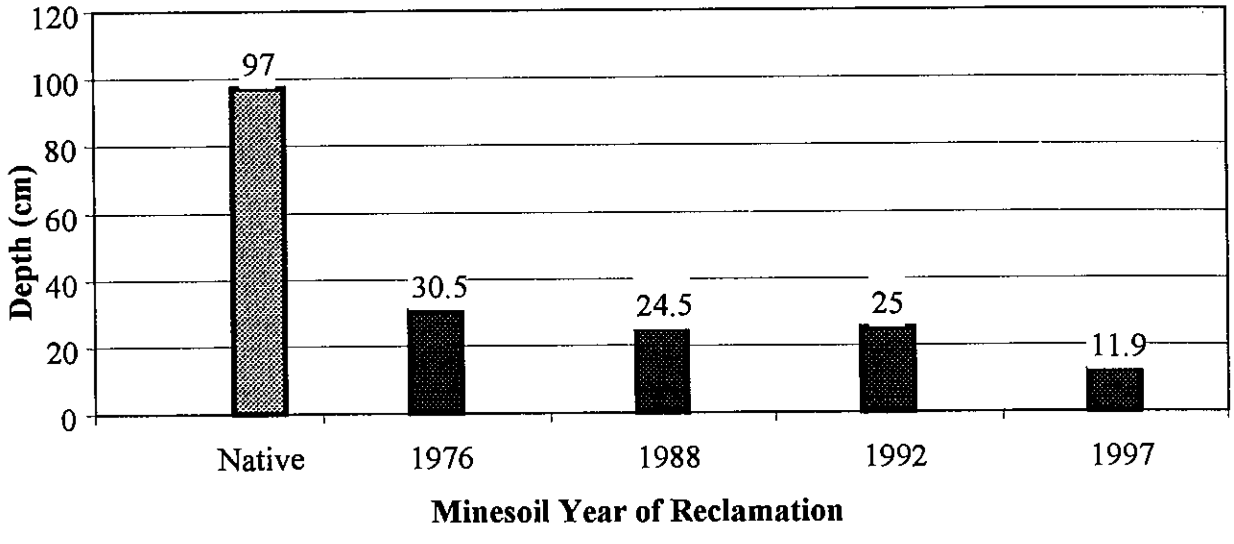

Figure 1: Average Depth of Native Soil and Minesoil Solum Development (A, AC, Bw, BC)

Table 2. Average Depth of Minesoil Horizon Development Per Year.

Year Minesoil Reclaimed	Minesoil Age (Years)	A Horizon (cm)	Solum[#] (cm)	PA Solum[*] (cm)
1976	23	0.5	1.3	2.0
1988	11	0.8	2.2	2.6
1992	7	2.2	3.6	3.2
1997	2	3.1	5.9	8.8

[#] Solum = combined thickness of A, AC, Bw, and BC horizons.

[*] Approximate values from Ciolkosz et al. (1985) for minesoils of equivalent age in Pennsylvania.

Studies of 23 to 29-yr-old minesoils (Ciolkosz et al., 1985; Thurman and Sencindiver, 1986) show that A horizons of 9 to 13 cm thick had developed.

One of the first characteristics recognized when these minesoils were described was the large amount of weakly consolidated fragments of primarily sandstone and shale. The average rock fragment content of all described horizons was approximately 60 %. Roberts et al. (1988a) documented that percent rock fragments in surface horizons

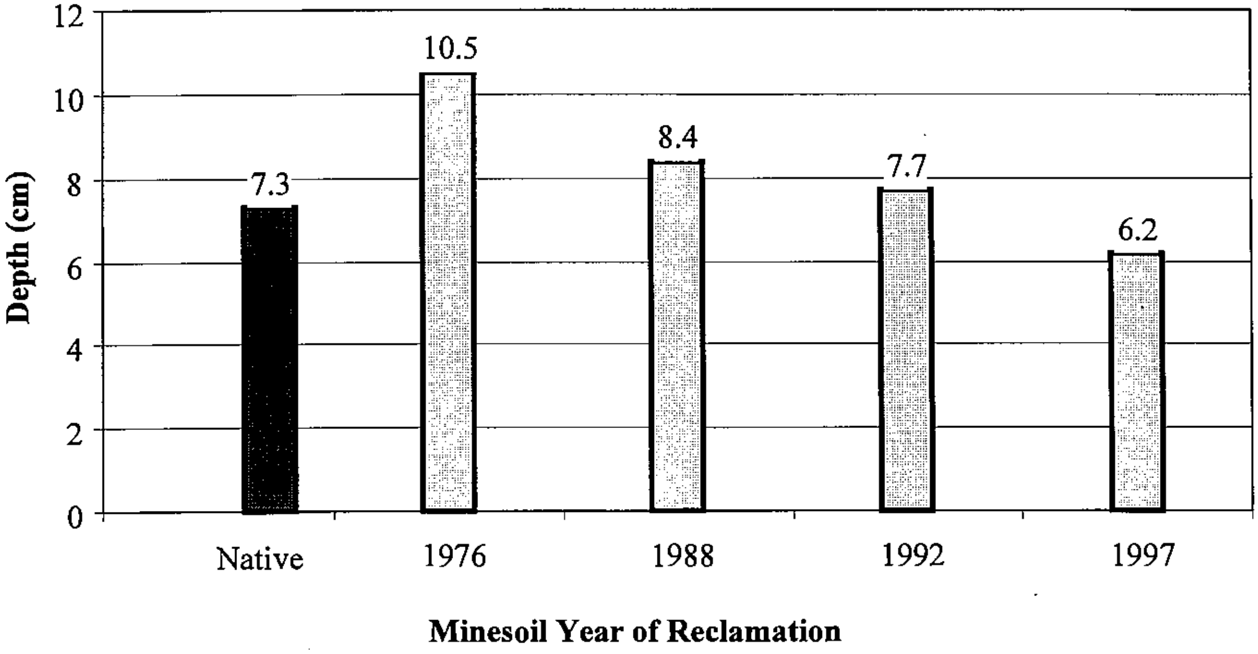

Figure 2: Average Thickness of A Horizon Development

decrease with time. However, this general trend was not documented in our study. Surface rock fragment content in our study varied as follows: 11yrs < 23 yrs < 2 yrs < 7 yrs. The 23-year-old minesoils had higher rock-fragment contents in the C horizons compaired to all other minesoils. Also, the 2-year-old minesoils had fewer rock fragments in their subsoils than any other minesoil. These rock-fragment differences are probably due to differences in reclamation technique rather than weathering.

Aggregate Stability

Soil properties vary in the degree of their vulnerability to external forces. One measure of a soil's vulnerability is aggregate stability (Kemper and Rosenau, 1986), which expresses the resistance of soil structural aggregates to breakdown when subjected to disruptive processes. Freezing and thawing, wetting and drying, additions of organic matter, secretions of microorganisms, earthworm activity, and presence of clay-size particles are some of the factors affecting aggregation in soils. Aggregates generally become more stable over time, and thus total aggregation generally increases, as processes of soil genesis develop soil horizons.

The native soils, with an average of 63.0% in the surface horizon and 62.0% in the subsurface horizon, had higher water-stable aggregation than any of the minesoils (fig. 3). In the minesoils, aggregation increased with age from a low of 12% in the subsurface horizon of the 2-year-old minesoil to a high of 54-56% in the surface horizon of the 11-year-old minesoil and the surface and subsurface horizons of the 23-year-old minesoil. For the 2-, 7-, and 11-year-old minesoils, aggregation of the surface horizon was greater than in the subsurface horizon. These differences can be related to the time of soil development. As these soils age, the aggregation should increase and the two horizons should become more similar as is indicated by the 23-year-old minesoil and the native soil. On a site in northeastern West Virginia, Gorman and Sencindiver (1999) observed water-stable aggregation of 57.8% in the top 8 cm of the minesoil and 51.2% in the 8-16 cm depth in a 9-year-old minesoil. Also, they found that aggregation had increased over time from zero to 9 years.

Bulk Density

Bulk density of the minesoils in the surface horizon was somewhat higher than that of the native soils (fig. 4). Bulk density of the minesoil A horizons ranged from a high of 1.1 Mg/m^3 in the 11-year-old site to a low of 0.87 Mg/m^3 in the 23-year-old site. Bulk density tended to increase with depth in all soils, but the values were similar for minesoils and native soils below the A horizon.

pH and Electrical Conductivity

In general, minesoil pH tended to decrease with age, and native soils had lower pH values at all depths than the minesoils (fig. 5). For all soils, pH tended to increase with depth.

Electrical conductivity (EC) values estimate the salt content of the soils. All soils in our study had electrical conductivity values below 0.3 dS/m (fig. 6). Native soils had higher salt contents in the surface horizon than the minesoils. Salt contents were higher in the surface horizon than in the subsoil for the native soils and all minesoils, except the 2-year-old minesoils. Although the EC values of the 2-year-old minesoils were very low, they were two to three times higher than EC of all other soils at the same depth. It is probable that these

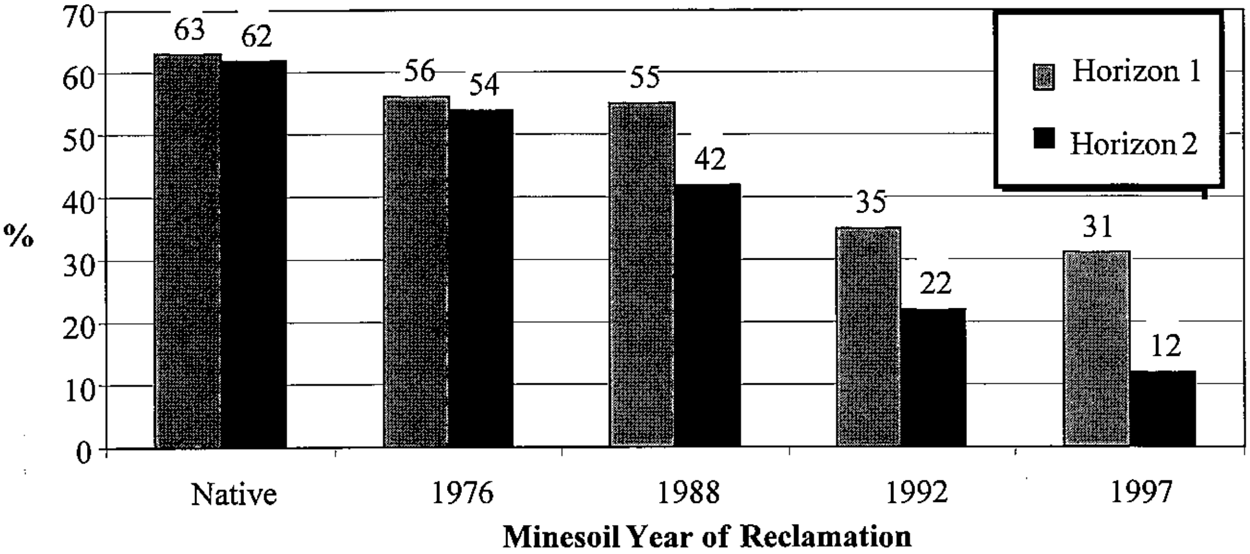

Figure 3: Average Water-Stable Aggregation of the Top Two Horizons

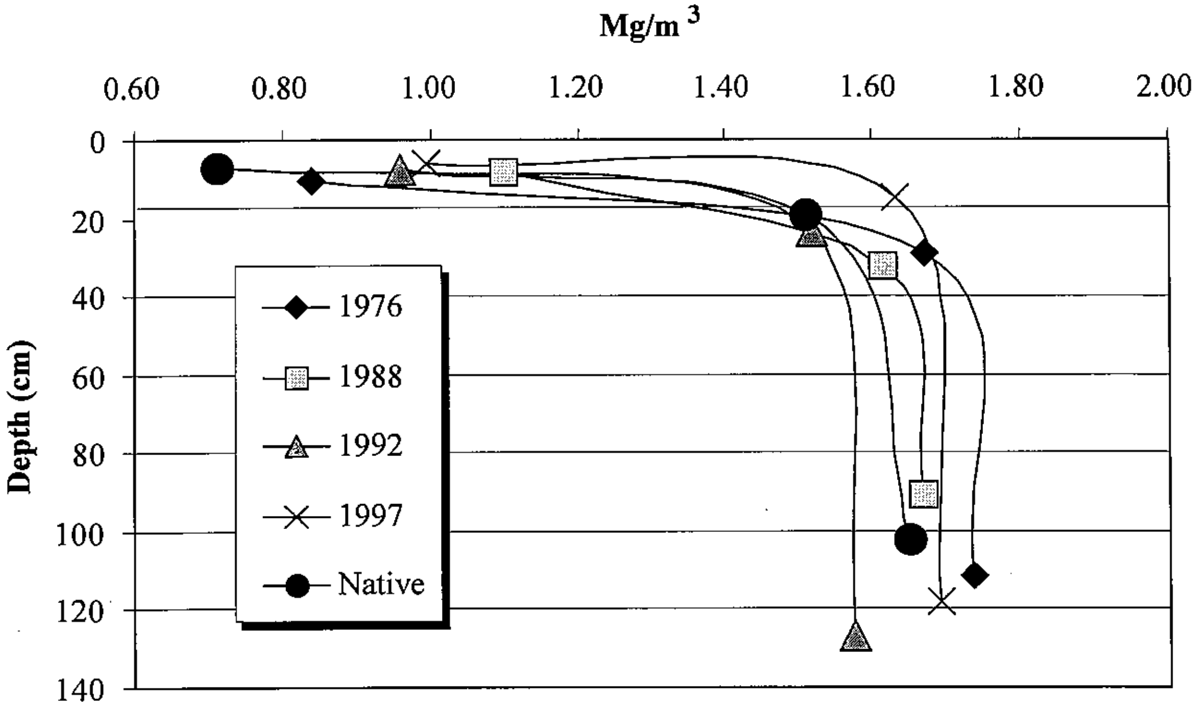

Figure 4: Average Bulk Density (<2mm) with Depth of Minesoils and Native Soils

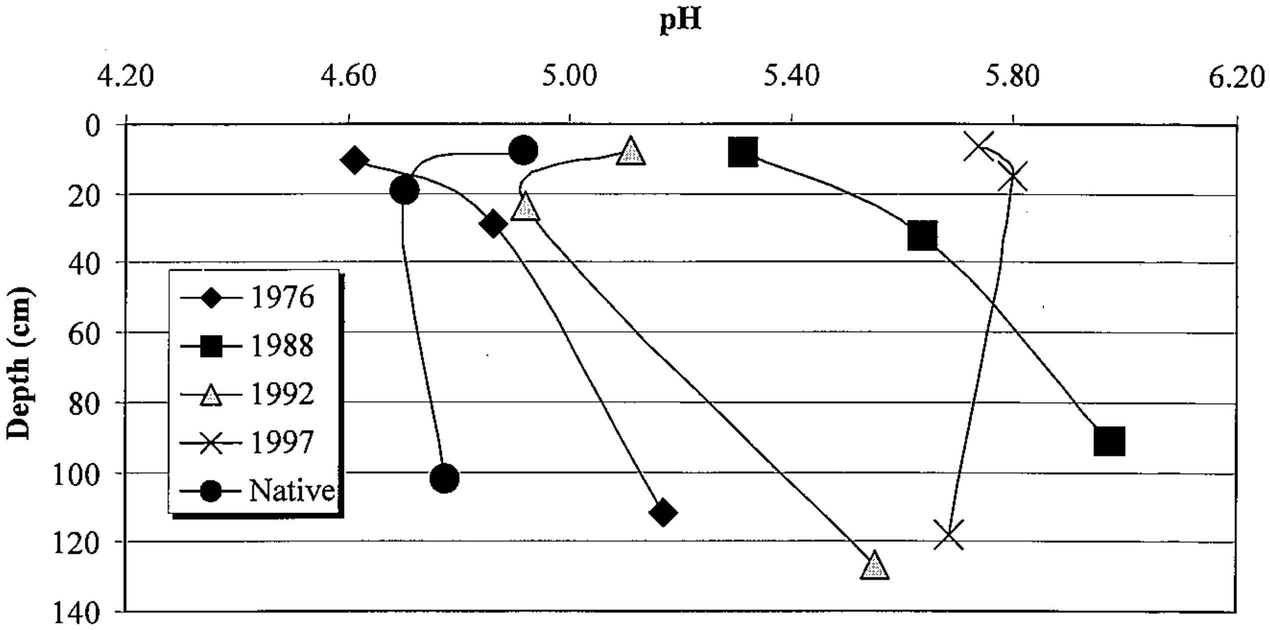

Figure 5: Average pH Values with Depth for Minesoils and Native Soils

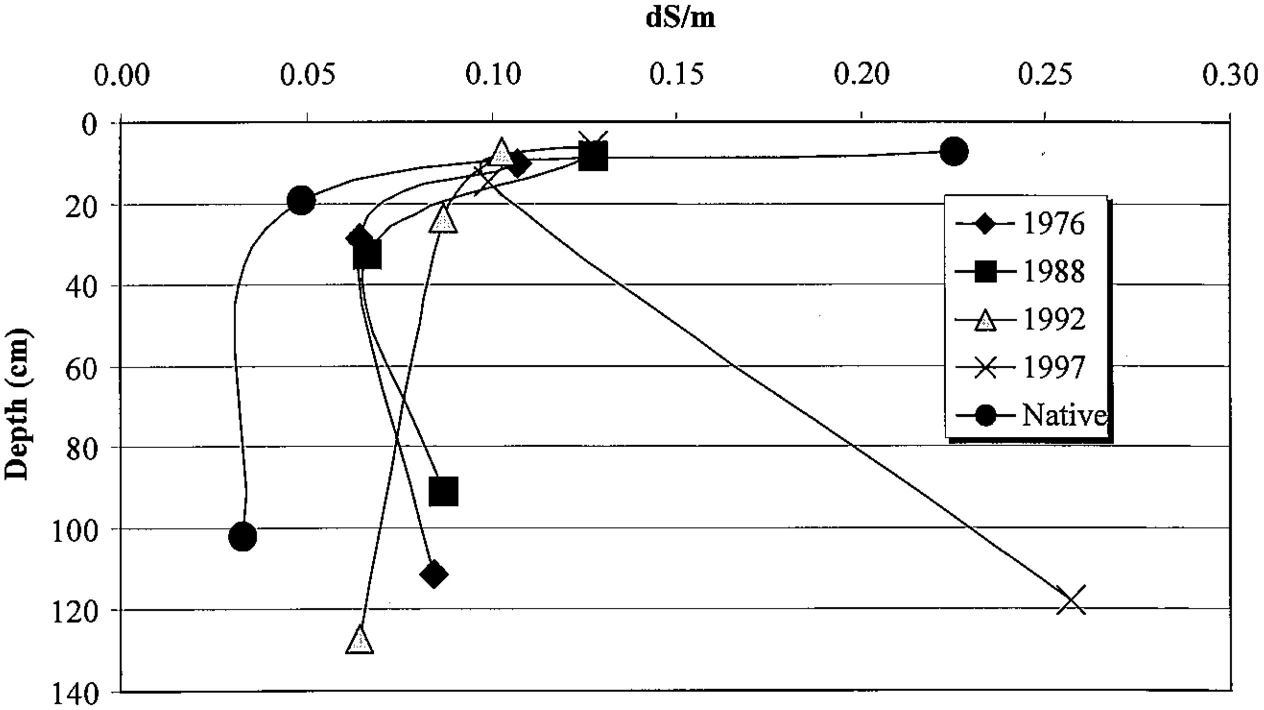

Figure 6: Average Electrical Conductivity with Depth for Minesoils and Native Soils

higher values were simply a result of overburden placement. Salt effects on most plants are negligible at EC values of 0-2 dS/m (Richards, 1954). Some acid minesoils have been observed to have EC values of 4 dS/m or higher in all or part of the profile (Ciolkosz et al., 1985). These high EC values will restrict the yields of most crops.

Summary

Although minesoils in this study are very young compared to native soils of the region, they do show evidence of soil development. The data indicate that soil properties are changing with time, and that the minesoils are becoming better developed with increasing age. Thickness of A horizons, thickness of the solum (A and B horizons), and total aggregation have increased with age in the minesoils. Structure within the solum of some of the older minesoils was similar to comparable depths within the native soils. Minesoil bulk density and electrical conductivity values were comparable to the native soils. Minesoil pH is somewhat higher than native soil pH because of the presence of alkaline shales or other high pH materials being placed at the surface during reclamation.

Acknowledgements

We extend our appreciation to Arch Coal, Inc. and the West Virginia Agricultural and Forestry Experiment Station for providing funding for this study.

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