CHANGES IN MINESOIL PHYSICAL PROPERTIES OVER A NINE-YEAR PERIOD[1]

by

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Abstract: Soil development on reclaimed Appalachian surface mined lands is often dominated by weathering of "fresh" lithic overburden material due to thinness of native topsoil in this region. In 1989, a study was initiated in northcentral West Virginia to examine changes in physical properties over time in relation to minesoil development. Physical properties were examined on conventionally reclaimed minesoil plots dominated by lithic overburden, and on plots where a fly ash/wood waste mixture was used as a topsoil substitute. Changes in particle-size distribution, bulk density, total porosity, and aggregation occurred during the nine-year period as a result of pedogenesis. The minesoil exhibited reduced bulk density, increased total porosity, increased aggregation, and shifts in particle-size distribution as a result of weathering over time. Changes were more pronounced in surface horizons than in the subsoil. The fly ash topsoil substitute also showed increased aggregation over time but little change in particle-size distribution, bulk density, and total porosity. This study shows that minesoils developing from lithic overburden materials may experience rapid changes in physical properties as a result of pedogenesis.

Additional Key Words: fly ash, reclamation

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INTRODUCTION

Large land areas in the Appalachian region have been disturbed by coal surface mining. There are over 100,000 hectares of surface mined land in West Virginia alone. Due to the thinness of native topsoil in this region, most minesoils are dominated by "fresh" lithic overburden material from both the oxidized and reduced geologic zones. This "fresh" lithic material is not in physical or chemical equilibrium with the surface soil environment. Furthermore, the blasting process used in overburden removal breaks up and pulverizes formerly consolidated rock into smaller fragments, many < 2 mm, greatly increasing the surface area available for physiochemical and biochemical weathering reactions. As a result, young minesoils often exhibit accelerated pedogenic development (Daniels and Amos, 1981; Ciolkosz et al., 1985; Roberts et al., 1988a; Haering et al., 1993; Johnson and Skousen, 1995).

Many hectares of abandoned mine lands (AML) that were surface mined prior to passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) (Public Law 95-87) also are present in this region. Due to lack of regulation and improper handling and placement of overburden materials, many of these pre-SMCRA sites were inadequately reclaimed. Some of these sites remain largely unvegetated due to acidity resulting from pyrite oxidation. A number of studies have shown that fly ash, used as a topsoil substitute, has been successful in reclaiming adverse mine sites by improving both chemical and physical properties of the soil (Bhumbla et al., 1991; Gorman et al., 1991). Fly ash, a by-product of coal combustion differs markedly, both physically and chemically, from natural soil materials.

Numerous investigators have examined the genesis of minesoil properties at various ages of development (Daniels and Amos, 1981; Bussler et al., 1984; Ciolkosz et al., 1985; Thurman and Sencindiver, 1986; Thomas and Jansen, 1985; Roberts et al., 1988a), but information is more limited concerning long-term minesoil genesis using controlled, fixed experimental plots. Information is completely lacking concerning weathering and pedogenic development of fly ash used as a topsoil substitute in mine land reclamation.

The objective of this study was to examine changes in soil physical properties over time in relation to pedogenic development in minesoils and in fly ash used as a topsoil substitute in mine land reclamation.

METHODS

Experimental plots were established in September 1989 on a surface mined site approximately 1 km northeast of Lenox, Preston County, West Virginia ($39^0$34'30"N, $79^0$35'30"W). The coal bed mined at this site was the Upper Freeport (Allegheny formation, Pennsylvania system). Overburden was mainly sandstone with some shale.

Blasted overburden was removed using a small dragline. After removal of the coal, overburden was replaced and regraded using bulldozers. The resulting minesoil was dominated by the blasted and pulverized overburden material. Experimental plots were 5 m by 40 m in size and consisted of three treatment groups replicated three times in a randomized complete block design. Treatment groups consisted of: 1) an 80:20 (volumetric) fly ash:sawdust mixture surface applied as a topsoil substitute at a rate of 3000 Mg/ha, which amounted to a total thickness of 8 to 15 cm; 2) the same fly ash/sawdust mixture at the same rate, but with the surface addition of coarse wood chip mulch material at a rate of approximately 1350 Mg/ha; and 3) minesoil control plots which also received wood chip mulch at the 1350 Mg/ha rate. The fly ash used in this study was obtained from the Albright power station, which was approximately 8 km from the study site. Albright fly ash (nonhardening Class F ash) has been used extensively in this area for revegetation studies (Keefer et al., 1979; Bhumbla et al., 1991; Gorman et al., 1991; Saini et al., 1995) due to its favorable chemical properties (slightly alkaline pH and low soluble salts). The wood chips and sawdust were obtained from a local sawmill. Sawdust was incorporated into the fly ash layer to supply organic matter that fly ash lacks. Sawdust was also used because it is a major wood industry waste product in this region and safe disposal and utilization is becoming a growing concern due to stricter environmental regulations. The fly ash/sawdust mixture was spread on the plots by bulldozer and wood chip mulch was applied using a mulch blower. All plots were seeded with a standard grass/legume mix consisting of alfalfa (*Medicago sativa* L.), birdsfoot trefoil (*Lotus corniculatus* L.), tall fescue (*Festuca arundinacea* Schreb.), and orchardgrass (*Dactylis glomerata* L.) and topdressed with 10-10-10 fertilizer at a rate of 260 kg/ha. Minesoil control plots received, in addition to fertilizer, lime at a rate of 0.82 mT/ha, which was the amount required to neutralize acidity in the upper 15 cm.

Soil samples were taken at two depths. On fly ash plots, samples were taken from the surface 0-8 cm of the fly ash layer and from the top 8 cm of the minesoil immediately below the fly ash. On minesoil control plots, samples were taken at 0-8 cm depth and at 8-16 cm depth.

Soil physical properties were determined from bulk soil samples, undisturbed soil clods, and undisturbed soil cores (7.62 cm x 7.62 cm). Bulk soil samples were used in determining particle size distribution by the pipette method (Gee and Bauder, 1986) and aggregate stability (Kemper and Rosenau, 1986). The average particle density of 2.2 Mg/m^3 was used to calculate the settling velocity of fly ash particles for pipette analysis. Undisturbed soil clods were used to determine bulk density and total porosity using a non-polar liquid method (Sobek et al., 1978). Bulk density and total porosity for the surface 0-8 cm of both fly ash and minesoil were determined from undisturbed soil cores in 1998 since intact soil clods could not be taken due to strong aggregation in the surface horizons. Soil samples were taken at three separate undisturbed locations on each experimental plot for a total of 27 samples for each sampling depth. Data sets were analyzed by analysis of variance using SAS statistical analysis program (SAS Institute Inc., SAS Circle, P.O. Box 8000, Cary, NC 27511-8000).

RESULTS AND DISCUSSION

Aggregation. In the first year (1989) the percent aggregation and water stability index were much higher in the minesoil than in fly ash treated plots (Table 1). There is essentially very little if any inherent aggregate stability in the fresh fly ash material. This is largely due to the little amount of clay present in fly ash to bind particles together (Table 3). Hodgson and Townsend (1973) found that fly ash has intrinsic difficulty in forming stable aggregates due to little clay or organic matter to bind particles together and is susceptible to wind and water erosion under unprotected conditions. The minesoil control plots showed very similar aggregation and water stability index between the two depths during the first year. This lack of difference between the two depths is what would be expected with fresh material that has not yet experienced the forces of pedogenesis. In the second year (1990), the percent aggregation and water stability index increased in all treatments and depths (Table 1). The increase was most dramatic in the fly ash, which had higher percent aggregation and water stability index than the minesoil control. It is interesting to note that most of the fly ash aggregation was in the larger macroaggregate (2-6.35 mm) range. It has been shown that plant roots, fungal hyphae, and organic matter tend to stabilize aggregates in the larger macroaggregate range while clays tend to stabilize aggregates more in the microaggregate range (Tisdall and Oades, 1982; Reichert and Norton, 1994). Since the fly ash had very little clay, the dramatic increase in aggregation the second year can be attributed to biological processes. Fly ash aggregation likely resulted from a combination of plant root effects (physical binding and root exudates), fungal hyphae, and microbial products of decomposition of organic matter (sawdust). The minesoil also had a higher percentage of its aggregates in the macroaggregate range but not as disproportionately as the fly ash. Percent aggregation and water stability index decreased in the fly ash from the second (1990) to the third (1991) year (Table 1), but values for fly ash were still higher than those of the minesoil control. Decreases in fly ash aggregate stability from the second to third year corresponded with changes in the type of vegetative ground cover (mosses/fungi to grass/legume) during this period (Gorman et al., 1997). By the ninth year (1998), fly ash's water stability index had decreased even more and was now lower than the water stability index for the minesoil surface layer. Also by the ninth year (1998) there had been a shift in aggregate size stabilized with most aggregates stabilized falling in the microaggregate range. Percent aggregation and water stability index increased progressively at each sampling depth in the minesoil control plots from 1989 to 1998 (Table 1). By the third year, percent aggregation and water stability index were significantly greater in the surface 0-8 cm depth of the minesoil than in the 8-16 cm depth. Again the majority of the aggregation in the 0-8 cm depth was in the macroaggregate size range. This is most likely reflecting the greater influence of plant roots and organic matter decomposition on aggregation at the 0-8 cm depth at this early stage of development. By the ninth year (1998), the majority of water stable aggregates in the minesoil surface layer had shifted to the microaggregate range similar to the shift that occurred in the fly ash during this same time period. Aggregation and water stability index for minesoil under fly ash were similar to those for the minesoil control at the 8-16 cm depth for the first three years (1989-1991) due to lack of root penetration. Very few roots from vegetation growing in the fly ash layer entered the underlying minesoil even after nine years. This corresponds with the small changes in aggregation in the minesoil beneath the fly ash.

Table 1. Water stable aggregation of minesoil and fly ash.

		AGGREGATION			WATER STABILITY
TREATMENT	YEAR	2.0-6.35mm	0.5-2mm	TOTAL	INDEX
		----------------	%	----------------	
FLY ASH (0-8 cm)	1989	0.42h*	0.17g	0.59g	0.64g
	1990	79.12a	2.39g	81.50a	89.64a
	1991	68.18b	5.10ef	73.31b	77.58b
	1998	10.26fg	52.20a	62.46b	66.46c
CONTROL (0-8cm)	1989	4.09g	9.26de	13.35f	17.13f
	1990	18.36de	11.72d	30.08de	38.31d
	1991	42.74c	6.52ef	49.26c	66.70c
	1998	8.15g	49.66a	57.81b	78.02b
CONTROL (8-16cm)	1989	5.09g	13.86cd	18.95f	24.52ef
	1990	10.61fg	14.61c	25.21e	30.96e
	1991	15.25ef	16.33c	31.57d	40.09d
	1998	11.04fg	40.24b	51.28c	66.90c
MINESOIL UNDER FLY ASH (first 8 cm)	1989	7.45g	7.17de	14.62f	18.81f
	1990	11.82fg	12.19d	24.01e	30.23e
	1991	14.93ef	17.01c	31.94d	42.18d
	1998	10.39fg	26.26c	36.65d	49.46d

*Means in columns with the same letter are not significantly different at $p>0.05$ level

The largest increase in minesoil aggregation at the 8-16 cm depth occurred during the later years of the study (1991-1998) as plant rooting and structure development progressed deeper into the minesoil profile.

Bulk Density and Total Porosity. Bulk density was significantly lower and total porosity significantly greater in fly ash than minesoil throughout the study period (Table 2). Surprisingly, while soil structure was forming in the fly ash layer during the nine year period, bulk density and total porosity values did not significantly change. In the surface 0-8 cm of the minesoil, both the total and <2 mm bulk densities decreased significantly in each of the years sampled. Decreases in bulk density at the 0-8 cm depth were most pronounced during the first three years (1991-1998). This is probably a result of a combination of mineral weathering, freeze-thaw, and vegetational effects, and corresponds with the rapid changes in aggregation that occurred at this depth during the same period. Correspondingly, total porosity showed a dramatic increase in the 0-8 cm depth during the same period. Bulk density and total porosity in minesoil at the 8-16 cm depth did not change until the later years of the study (1991-1998) similar to changes in aggregation occurring during this period. Bulk density and

Table 2. Bulk density and total porosity of minesoil and fly ash.

TREATMENT	YEAR	BULK DENSITY	<2mm BULK DENSITY	TOTAL POROSITY
		------------Mg/m^3------------		%
FLY ASH (0-8 cm)	1989†	0.75f*	0.71f	66.56a
	1990	0.72f	0.65fg	66.42a
	1991	0.69f	0.61g	68.43a
	1998†	0.72f	0.64fg	67.37a
CONTROL (0-8 cm)	1989	1.87a	1.66a	29.71e
	1990	1.73c	1.53c	33.88d
	1991	1.53d	1.24d	41.92c
	1998†	1.44e	1.13e	45.50b
CONTROL (8-16 cm)	1989	1.91a	1.68a	27.96e
	1990	1.79b	1.59b	32.31d
	1991	1.89a	1.63a	28.38e
	1998	1.73c	1.51c	33.77d
MINESOIL UNDER FLY ASH (first 8 cm)	1989	1.92a	1.68a	27.98e
	1990	1.85a	1.52c	32.70d
	1991	1.86a	1.50c	32.23d
	1998	1.78b	1.52c	31.82d

† Bulk density and total porosity values calculated from undisturbed soil cores since stable clods could not be obtained.

*Means in columns with the same letter are not significantly different at $p>0.05$ level

total porosity values for minesoil under fly ash were similar to values for minesoil control at the 8-16 cm depth.

Particle-size Distribution. Results of particle size analysis showed significant differences between fly ash and minesoil (Table 3). Fly ash was significantly higher in silt and lower in clay than minesoil. Texture of fly ash was silt loam while texture of the minesoil was clay loam. There are some interesting trends in particle size distribution over the nine-year period in both the fly ash and minesoil. Fly ash showed a significant increase in the percentage of sand size particles and decrease in percentage of silt size particles. Fly ash also exhibited shifts in the percentage of clay size particles with increases in clay during the first three years (1989-1991) followed by a dramatic decrease in clay by the ninth year (1998). These shifts in particle size distribution in fly ash are possibly a result of eluvial stripping of fine silt and clay enhanced by the decomposition of acidic organic matter (sawdust). Eluvial stripping of fines was also noticed by Roberts et al. (1988b) when sawdust was used as an organic amendment of minesoil. Minesoil at the 0-8 cm depth also showed evidence of weathering and eluviation. The percentage of clay size particles increased during the first three years (1989-1991) as weakly cemented soil particles weathered. Clays were later eluviated as evidenced by the discontinuous clay films that were found in pores in the upper

Table 3. Particle-size distribution of minesoil and fly ash.

TREATMENT	YEAR	SAND	SILT	CLAY	TEXTURE
			%		
FLY ASH (0-8 cm)	1989	24.98bc*	67.92a	7.10f	SILT LOAM
	1990	27.14b	64.66b	8.20e	SILT LOAM
	1991	29.42b	60.93c	9.65d	SILT LOAM
	1998	34.58a	59.68c	5.75f	SILT LOAM
CONTROL (0-8cm)	1989	36.45a	35.74d	27.81c	CLAY LOAM
	1990	34.87a	34.39d	30.74b	CLAY LOAM
	1991	32.35ab	35.80d	31.85ab	CLAY LOAM
	1998	37.94a	36.63d	25.43c	LOAM
CONTROL (8-16cm)	1989	34.37a	37.07d	28.56c	CLAY LOAM
	1990	33.01ab	36.65d	30.34bc	CLAY LOAM
	1991	29.86b	35.98d	34.16a	CLAY LOAM
	1998	32.73ab	36.30d	30.97b	CLAY LOAM
MINESOIL UNDER FLY ASH (first 8 cm)	1989	36.36a	37.57d	26.07c	CLAY LOAM
	1990	35.27a	35.28d	29.45bc	CLAY LOAM
	1991	33.18ab	35.32d	31.45bc	CLAY LOAM
	1998	32.35ab	40.15d	27.50c	CLAY LOAM

*Means in columns with the same letter are not significantly different at $p>0.05$ level

loam at the 0-8 cm depth (Table 3). There were similar shifts in clay in the minesoil profile (Tables 4). By the ninth year (1998) these shifts in particle size resulted in a textural class change in the minesoil from clay loam to at the 8-16 cm depth, but not as pronounced as they were at the 0-8 cm depth. Whether or not significant eluviation has taken place could not be determined given the arbitrary sampling depths used in this study. There were no changes in particle size distribution in the minesoil under fly ash during the nine-year study period.

CONCLUSIONS

Significant changes occurred for aggregation, bulk density, total porosity, and particle-size distribution as a result of pedogenesis. The minesoil exhibited shifts in particle-size distribution as a result of weathering, reduced bulk density, increased total porosity, and increased aggregation over time. Changes were more pronounced in the surface horizons. The fly ash topsoil substitute exhibited no changes in bulk density or total porosity during the nine year study period. Fly ash did exhibit shifts in aggregation with a rapid increase between the first and second year and a gradual decrease in succeeding years. Fly ash also appeared to exhibit the effects of eluvial stripping, which produced increases in percentages of sand, decreases in silt, and gradual increases followed by a decreases in clay size particles. This study showed that minesoils developing from "fresh" lithic overburden materials may experience rapid changes in physical properties as a result of pedogenesis.

Table 4. Minesoil profile description #1 as described 7/10/98 (9-years after reclamation).

Horizon	Depth (cm)	Description
A1	0-1	dark brown (10YR 3/3) silt loam; worm casts at surface; medium and coarse granular structure; very friable; mildly alkaline; abundant but discontinuous-intermittent.
A2	1-9	dark yellowish brown (10YR 4/4) clay loam; weak medium and moderate coarse subangular blocky structure; friable; common fine roots, higher concentrations found along rock fragment faces; few discontinuous clay films in pores; 10% sandstone fragments; neutral; abrupt smooth boundary.
C/A	9-20	dark yellowish brown (10YR 4/4) channery clay loam; massive; firm; few fine to medium strong brown (7.5YR 5/6) lithochromic mottles; very strongly acid; with distinct pockets of very dark grayish brown (10YR 3/2) silt loam; moderate medium and coarse granular structure; friable; common fine and very fine roots, more numerous around rock fragments; few dincontinuous clay films in pores in the C; 40% sandstone, siltstone, and carbolithic fragments throughout the horizon; neutral; clear wavy boundary.
C1	20-33	dark yellowish brown (10YR 4/4) very channery clay loam; massive; firm; common fine roots; 50% sandstone, siltstone and some carbolithic fragments; extremely acid; clear wavy boundary;
C2	33-45	strong brown (7.5YR 5/6) extremely channery sandy loam; massive; firm; few fine roots; 70% sandstone fragments; extremely acid; clear wavy boundary.
C3	45-90+	mixed colors strong brown (7.5YR 5/6), dark yellowish brown (10YR 4/4), grayish brown (10YR 5/2), and yellowish brown (10YR 5/4), extremely channery sandy loam with pockets of yellowish red (5YR 5/6) silty clay loam; massive; friable; 85% sandstone fragments with many bridging voids up to 10 cm diameter; many dark reddish brown (5YR 3/3) stains on rock fragments; extremely acid.

Soil Classification: loamy-skeletal, mixed, mesic Typic Udorthents

LITERATURE CITED

Bhumbla, D.K., R.N. Singh, and R.F. Keefer. 1991. A model for reclaiming strip mine land using fly ash. Final Report, Allegheny Power Service Corporation. Research and Development Project, RP 87-13. 63 pp.

Bussler, B.H., W.R. Byrnes, P.E. Pope, and W.R. Chaney. 1984. Properties of minesoil reclaimed for forest land use. Soil Sci. Soc. Am. J. 48:178-184.
https://doi.org/10.2136/sssaj1984.03615995004800010033x

Ciolkosz, E.J., R.C. Cronce, R.L. Cunningham, and G.W. Petersen. 1985. Characteristics, genesis, and classification of Pennsylvania minesoils. Soil Sci. 139:232-238.
https://doi.org/10.1097/00010694-198503000-00007

Daniels, W.L. and D.F. Amos. 1981. Mapping, characterization, and genesis of minesoils on a reclamation research area in Wise County Virginia. pp. 261-265. In: Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation. 7-11 Dec. 1981. Univ. of Kentucky, Lexington, KY.

Gee, G.W. and J.W. Bauder 1986. Particle-size Analysis. pp. 383-411. In: Klute, A. (ed.). Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. No. 9, Agronomy. ASA, SSSA, Madison, WI.

Gorman, J.M., J.C. Sencindiver, R.F. Keefer, and R.N. Singh. 1991. Physical properties of fly ash-treated minesoils. pp. 389-402. In: Proc. of the American Society for Surface Mining and Reclamation Conference, Durango, Colorado, May 14-17, 1991.
https://doi.org/10.21000/JASMR91020389

Gorman, J.M., J.C. Sencindiver, D.J. Horvath, R.N. Singh, and R.F. Keefer. 1997. Erodibility of fly ash-treated minesoils. pp. 465-479. In: Proc. of the American Society for Surface Mining and Reclamation Conference, Austin, Texas, May 10-25, 1997.
https://doi.org/10.21000/JASMR97010465

Haering, K.C., W.L. Daniels, and J.A. Roberts. 1993. Changes in minesoil properties resulting from overburden weathering. J. Environ. Qual. 22:194-200.
https://doi.org/10.2134/jeq1993.00472425002200010026x

Hodgson, D.R. and W.N. Townsend. 1973. The amelioration and revegetation of pulverized fuel ash. pp. 247-271. In : R. J. Hutnik and G. Davis (eds.) Ecology and Reclamation of Devastated Land. Vol. 2. Gordon and Breach Sci. Publ. Inc.

Johnson, C.D. and J.G. Skousen. 1995. Minesoil properties of 15 abandoned mine land sites in West Virginia. J. Environ. Qual. 24:635-643.
https://doi.org/10.2134/jeq1995.00472425002400040014x

Keefer, R.F., R.N. Singh, F. Doonan, A.R. Khawaja, and D.J. Horvath. 1979. Application of fly ash and other wastes to minesoils as an aid in revegetation. pp. 840-865. In: Proc. 5th International Ash Utilization Symp. Atlanta, GA, February, 1979. U.S. Dept. of Energy, Morgantown, WV.

Kemper, W.D., and R.C. Rosenau 1986. Aggregate stability and size distribution. pp. 425-442. In: Klute, A. (ed.). Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods. No. 9, Agronomy. ASA, SSSA, Madison, WI.

Reichert, J.M. and L.D. Norton. 1994. Aggregate stability and rain impacted sheet erosion of air-dried and prewetted clayey surface soils under intense rain. Soil Sci. 158:159-169.
https://doi.org/10.1097/00010694-199409000-00001

Roberts, J.A., W.L. Daniels, J.C. Bell, and J.A. Burger. 1988a. Early stages of minesoil genesis in a southwest Virginia spoil lithosequence. Soil Sci. Soc. Am. J. 52:716-723.
https://doi.org/10.2136/sssaj1988.03615995005200030023x

Roberts, J.A., W.L. Daniels, J.C. Bell, and J.A. Burger. 1988b. Early stages of minesoil genesis as affected by topsoiling and organic amendments. Soil Sci. Soc. Am. J. 52:730-738.
https://doi.org/10.2136/sssaj1988.03615995005200030025x

Saini, P., D.K. Bhumbla, R.N. Singh, and R.F. Keefer. 1995. Evaluation of fly ash and fly ash-sewage sludge mixtures as a topsoil substitute for sustainable vegetation on a minesoil. In: Proc. 11th International Symp. on Use and Management of Coal Combustion By-products. Vol. 1:2-1 to 2-11.

Sobek, A.A., W.A. Schuller, J.R. Freeman, and R.M. Smith. 1978. Field and laboratory methods applicable to overburdens and minesoils. Environmental Protection Technical Series. EPA-600/2-78--054. EPA. Cincinnati, OH. 204 pp.

Thomas, D. and I. Jansen. 1985. Soil development in coal mine spoils. J. Soil and Water Conserv. 40:439-442.

Thurman, N.C. and J.C. Sencindiver. 1986. Properties, classification, and interpretations of minesoils at two sites in West Virginia. Soil Sci. Soc. Am. J. 50:181-185.

Tisdall, J.M. and J.M. Oades. 1982. Organic matter and water stable aggregates in soils. J. Soil Sci. 33:141-163.