ERODIBILITY OF FLY ASH-TREATED MINESOILS[1]

by

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Abstract. Fly ash, a by-product of coal-fired power plants, has been used successfully in reclaiming adverse mine sites such as abandoned mine lands by improving minesoil chemical and physical properties. But, the fine sand-silt particle size of fly ash may make it more susceptible to detachment and transport by erosive processes. Furthermore, the high content of silt-size particles in fly ash may make it more susceptable to surface crust formation resulting in reduced infiltration and increased surface runoff and erosion.

In the summer of 1989, fly ash/wood waste mixtures were surface applied on two separate mine sites, one with 10% slope and the other 20% slope, in central Preston County, West Virginia. Erosion rates were measured directly using the Linear Erosion/Elevation Measuring Instrument (LEMI). Erosion measurements were taken during the first two growing seasons on both sites.

Erosion values were up to five times greater on the fly ash-treated minesoil than on the minesoil without fly ash cover. Mulching with wood chips reduced fly ash erosion to about one-half the loss of the unmulched plots. Erosion was related to both the amount and type of ground cover. Increased vegetative ground cover resulted in reduced erosion. Mosses and fungi appeared to provide better erosion protection than grass-legume cover.

Additional key words: Mine Land Reclamation, Revegetation, Minesoil Properties.

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Introduction

Drastic land disturbance associated with coal mining is not a new occurrence, but it has become more and more controversial in the last couple of decades with increasing public environmental awareness. Coal mining, with suitable pre-mine planning and adherence to performance standards, does not have to result in degradation of the environment. On the contrary, proper handling and placement of overburden material can result in the development of a soil that is deeper and higher in nutrients than the original soil. Thus, the soil developing on the mined site can be potentially more productive than the original soil.

Prior to the Federal Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87-SMCRA) some mine operators did very little pre-mine planning or segregation of overburden materials during mining. This often left post-mine lands devoid of and/or incapable of supporting vegetation, resulting in severe erosion and sedimentation. Acid mine drainage, resulting from the oxidation of pyritic materials near the soil surface, is also a common problem on many of these mined sites. Many of these sites were abandoned by the coal operators and continue to be sources of ground water and stream pollution today. It is estimated that there are between 32,000 and 40,000 ha of "orphaned" or abandoned mine-lands in West Virginia alone (Kupelian, 1980). Most of these abandoned mine-lands require specialized and often expensive methods of reclamation to improve their adverse chemical and physical properties.

Fly ash or precipitator ash is the powdery residue which remains after the combustion of pulverized coal in electrical power generating plants. The United States is currently producing 80 million tons of coal combustion products annually (Bedick, 1995). Approximately 80% or 64 million tons is fly ash. Currently, only 30% of the fly ash produced is utilized in any form with the remainder being placed in storage or disposal areas (Bedick, 1995). Millions of dollars are being spent annually to dispose of this "waste" product and the costs of disposal are continually increasing. Until recently, cost of disposal in unlined facilities was generally less than $5 per ton of material. Many states now require lined facilities with leachate and groundwater monitoring, and in some cases leachate collection and treatment. As a result, typical costs for disposal in these new landfill facilities run from $10 to $20 per ton (Bedick, 1995). With these rising costs of disposal, alternative uses such as land application may be more economical.

In the last decade, pure unamended fly ash has been successfully used as a topsoil substitute in reclaiming drastically disturbed mine sites in the eastern United States by improving both soil chemical and physical properties (Bhumbla et. al., 1991b; Gorman et. al., 1991). But one problem with fly ash is that its fine sand to silt size particles are very susceptable to detachment and transport by erosive processes (Lehrsch and Baker, 1991). Furthermore, the high content of silt-size particles in fly ash would make it more susceptable to surface crust formation when exposed to raindrop impact. Formation of surface crusts could result in reduced infiltration rates and increased surface runoff and erosion.

Numerous studies have shown that shredded hardwood bark and other wood wastes, when used as mulches, are very effective at controlling erosion on disturbed land surfaces and have even accelerated the establishment of vegetational cover (Dyer and Sencindiver, 1985; Plass, 1978; Vail and Koon, 1980; Wittwer et al., 1980). Holmberg (1983) and Lyle (1987) stated that woodchip mulches, because of better soil contact and less susceptability to movement by wind and water, give much better erosion protection than hay or straw mulches especially on steeper slopes.

In addition to erosion control, wood wastes, when used as a mulch or when mixed into the soil, can have a beneficial effect on a number of soil properties which affect plant growth. When used as a mulch, wood waste, such as shredded hardwood bark, will intercept raindrops and prevent surface crusting of the soil. Bark mulches also break up and slow down the flow of water over the soil surface allowing more time for infiltration to take place. A bark mulch is also very effective in insulating the soil by reducing surface temperature extremes (Cunningham and Wittwer, 1980). By reducing water evaporation from the soil surface, a bark mulch not only helps to retain more available water for plants, but is also thought to aid in the leaching of toxic ions from the soil by reducing wetting-drying cycles (Plass, 1978). Wood waste incorporated into the soil adds organic matter and serves as an energy source for soil microbes. Polysaccharides and other organic by-products of the decomposition of wood wastes are important in developing soil structure and in promoting aggregate stability.

Currently, over 200,000 tons of wood wastes are produced in north-central West Virginia annually. Stricter laws are being enacted concerning the disposal of these wood waste materials in landfills, and alternate uses for this by-product of wood industry are needed. The greater use of wood wastes in mine land reclamation may be one such alternative.

The objective of this research was to determine the erosion rates of a surface applied fly ash/sawdust mixture as affected by percent slope and mulching treatment and compare these to the erosion rates of conventionally prepared minesoils.

Methods

Study Area

Research plots for this study were located near Lenox, Preston County, in north central West Virginia. The major coal beds mined in this area are the Upper Freeport and Bakerstown. The overburden associated with the Upper Freeport Coal is predominantly sandstone with some shale. Overburden associated with the Bakerstown Coal is generally a mixture of limestone, shale and sandstone. Research for this study was performed on two separate sites, one with 10% slope and the other with 20% slope.

10% Slope Site

The 10% slope site was located approximately 1 km southwest of Lenox, West Virginia ($39^0$33'N,$79^0$36'W). The coal bed mined at this site was the Brush Creek Coal. The Brush Creek is located in the geologic column between the Upper Freeport and Bakerstown coals. It is usually too thin to be mined economically, but at this location it was approximately 1.2 meters thick and was mined by a small scale bulldozer-endloader operation. The site was first mined in the early 1970's prior to SMCRA. The overburden on this site was unusually high in pyritic sulfur averaging slightly over 1 percent. The resulting minesoil on this site was extremely acid with a pH of 3. Due to the pyrite content, sustained, successful revegetation could not be established despite repeated previous attempts by the coal operator using conventional methods. This site was typical of many abandoned mine lands in north-central West Virginia. The site was later remined in the early to mid 1980's to remove the remaining coal. By this time very little of the original topsoil was left. Due to the adverse chemical and physical conditions of the overburden, fly ash used as a topsoil substitute appeared to be a practical alternative in revegetating this site.

Experimental plots on the 10% site were established in early June 1989. Plots were 5 meters by 40 meters in size and consisted of three treatment groups replicated three times in a randomized complete block design. Treatment groups consisted of 1) fly ash, with approximately 3 cm of sawdust mixed in, surface applied as a topsoil substitute at a rate of 1000 mT/ha which amounted to a total thickness of 13 to 15 cm; 2) same fly ash/sawdust mixture with the surface addition of coarse wood chip mulch material at a rate of approximately 27 mT/plot; 3) minesoil control plots which also recieved wood chip mulch at the 27 mT/plot 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 has been used extensively in this area for revegetation studies (Bhumbla et. al., 1991a; Gorman et. al., 1991; Keefer et. al., 1979; Saini et. al., 1995) due to its near ideal chemical properties (slightly alkaline pH and low soluble salts). The wood chips and sawdust were obtained from a local sawmill. The wood chip mulching material averaged about 3 to 5 cm in diameter. 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*), birdsfoot trefoil (*Lotus corniculatus*), tall fescue (*Festuca arundinacea*), and orchardgrass (*Dactylis glomerata*) 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. The resulting minesoil on the 10% site was described and classified as loamy-skeletal, mixed, mesic Typic Sulfochrepts in the spring of 1996.

20% Slope Site

The 20% slope site was located approximately 1 km northeast of Lenox ($39^0$34'30"N, $79^0$35'30"W). The coal bed mined at this site was the Upper Freeport. Overburden was mainly sandstone with some shale. Fly ash plots were established in early September 1989. Plot establishment was performed in the same manner as on the 10% site. The resulting minesoil was described and classified as loamy-skeletal, mixed, mesic Typic Dystrochrepts in the spring of 1996.

Erosion Measurement

Erosion rates were measured directly using the Linear Erosion/Elevation Measuring Instrument (LEMI) which was developed by Dr. Terrence Toy at the University of Denver (Toy, 1983). The LEMI is an inexpensive device which measures the vertical elevation change of the soil surface over time. It consists of two carpenter's levels positioned at right angles to each other mounted on an aluminum support base. The support base slips down over the top of steel rods which are installed on the site. The steel rods, which serve as permanent measuring stations, are installed on the site in a straight line along the true slope perpendicular to the contour. The top level is used for sighting or aligning the LEMI devise, while the bottom level has sleeve inserts on each end through which steel measuring pins can be lowered to the soil surface. Ground surface elevation changes are determined by measuring the length of the pin remaining above the bottom level. LEMI operation requires two persons, one to sight and level the instrument while the other measures and records the reading. LEMI measurements can be taken to the nearest 0.5 mm. With the LEMI properly leveled and sighted upslope, erosion measurements will theoretically be taken at the same point on the soil's surface each time. The primary advantage of the LEMI is that its measurements are made on undisturbed soil 25 cm away from the support rod. One potential disadvantage of the LEMI is that it is very sensitive to anything that results in soil surface elevation changes such as organic matter accumulations, freeze-thaw, and wet-dry cycles.

Ten steel rods were installed down the center of each plot for a total of 90 measuring stations per site. With two erosion measurements taken at each station, there were 180 erosion measurement points per site for each measurement date. Erosion measurements were taken three times each year on each site during 1989 and 1990. The erosion measuring dates were generally restricted to the late spring to early fall period to avoid the effects of snow cover and frost action during the colder months. On each site, during the last erosion measuring date, the percent vegetative ground cover was estimated at each erosion measuring point on a 1 to 3 scale (1=0%, 2=50%, 3=100%).

Selected soil physical properties which are related to erodibility were also measured each growing season. Bulk soil samples were used in determining particle density (Blake and Hartge, 1986b), particle size distribution-pipette method (Gee and Bauder, 1986), and aggregate stability (Kemper and Rosenau, 1986). Infiltration rates were determined by using a single ring infiltrometer (Bouwer, 1986; Tricker, 1978). Data sets for physical properties and erosion measurement were performed by analysis of variance using SAS statistical analysis program (SAS Institute Inc., SAS Circle, P.O. Box 8000, Cary, NC 27511-8000).

Results and Disscussion

Physical Properties

Results for the physical properties which are related to erodibility follow. Since the physical properties for both fly ashes and minesoils were similar between the two sites, for brevity, only the physical properties for the 10% site are reported.

Particle Density. Particle density values for the 10% site are shown in Table 1. Fly ash had much lower particle density than minesoil materials. The main implication of lower particle density in fly ash is that it would be more vulnerable to detachment and transport by erosive processes. Particle densities remained essentially unchanged over the two-year study period.

Particle Size Distribution. Fly ash was significantly higher in silt and lower in clay than minesoil (Table 2). Texture of fly ash was silt loam while texture of the minesoil was clay loam. Fly ash was very low in clay (<10%) and very high in silt (>60%). This also suggests a high erosion potential for the fly ash due to a lack of cohesion from the low clay content, and to the high percentage of erodible silt-size particles. Also, approximately 47% of the sand-size fraction in the fly ash was in the very fine sand fraction (<0.05 mm), which has been found by others (Wischmeier and Mannering, 1969) to behave more like silt than sand from an erodibility perspective.

Table 1. Particle density of fly ash and minesoil on 10% site.

TREATMENT	YEAR	PARTICLE DENSITY
		--------Mg/m^3--------
FLY ASH	1989	2.17b
	1991	2.17b
MINESOIL	1989	2.75a
(0-8 cm)	1991	2.74a

means in columns with the same letter are not significantly different at p>.05 level

Table 2. Particle size distribution of fly ash and minesoil on 10% site.

TREATMENT	YEAR	SAND	SILT	CLAY	TEXTURE
		----------	----------%----------	----------	
FLY ASH	1989	30.11a	64.07a	5.82b	SILT LOAM
	1990	28.43a	64.15a	7.42b	SILT LOAM
MINESOIL	1989	23.98b	38.23b	37.79a	CLAY LOAM
(0-8cm)	1990	24.65b	40.02b	35.34a	CLAY LOAM

means with the same letter within columns are not significantly different at p>.05

Aggregate Stability. Initially in the first year (1989) the percent aggregation and water stability values were much higher in the minesoil (Table 3) than in fly ash plots. There was very little if any inherent aggregate stability in the fresh fly ash material. This was largely due to fly ash's particle size distribution in that there was very little clay present to bind particles together. Hodgson and Townsend (1973) found that fly ash, with little clay or organic matter to bind particles together, had intrinsic difficulty in forming stable aggregates and was susceptable to wind and water erosion under unprotected conditions. In the second year (1990), the percent aggregation and water stability values increased in all treatment groups (Table 3). The increase was most dramatic in the fly ash , which had higher percent aggregation and water stability values than the minesoil control. It is interesting to note that most of the fly ash aggregation was in the macroaggregate (2-6.35 mm) range. It has been shown that plant roots, fungal hyphae, and organic matter tend to stabilize in the macroaggregate range while clays tend to stabilize 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 during 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). Aggregate stability of fly ash with the addition of organic matter was approximately three times greater in this study than values obtained from a similar study using pure unamended Albright fly ash (Gorman et. al., 1991).

Table 3. Aggregation and water stability index of fly ash and minesoil on 10% site.

		AGGREGATION			WATER STABILITY INDEX
		2.0-6.35mm	0.5-2mm	TOTAL	
		%			
FLY ASH	1989	0.89d	0.34c	1.23d	1.38d
	1990	53.79a	8.06b	61.91a	73.20a
MINESOIL	1989	9.74c	5.24b	14.98c	21.18c
(0-8cm)	1990	27.70b	12.27a	40.00b	50.02b

means with the same letter within columns are not significantly different at p>.05

Infiltration Rate. Infiltration rates initially were much higher in fly ash than minesoil especially in the mulched fly ash plots (Table4). The difference in infiltration between mulched and unmulched fly ash plots may have been a result of surface crusting in the unmulched plots. Hodgson and Townsend (1973) found that raindrop impact on the unprotected silt size particles of fly ash formed an impermeable surface seal which impeded air and water movement into the soil. There was a large degree of variability in infiltration rates for fly ash from one sampling point to another. This variability was largely due to the poor mixing of the fly ash and sawdust on this site. Infiltration rates were much greater when a sampling point was located on or near a pocket of sawdust than when it was located on pure fly ash. The addition of organic matter (sawdust) greatly improved fly ash infiltration rates since fly ash infiltration values in this study were more than seven times greater than those found in the unamended pure Albright fly ash (Gorman et. al., 1991). By the third year (1991), fly ash infiltration rates had decreased to near the level of the minesoil. Infiltation rates of fly ash with and without mulch were not significantly different from minesoil in 1991.

Erodibility

10% Site. Immediately following fly ash application on the 10% site, the northcentral West Virginia region experienced a prolonged period of above normal precipitation. Measurable rainfall was recorded for a record 16 consecutive days totalling over 18 cm (>7 inches). Much of the precipitation during this period consisted of high intensity thunderstorms. When the rainfall finally ended, most of the plots on this site had experienced severe erosion, especially the fly ash plots. Rills and small gullies were present on most plots, and much of the wood chip mulch material had been washed off of the mulch-treated fly ash plots.

Table 4. Infiltration rates of fly ash and minesoil on 10% site.

TREATMENT	YEAR	INFILTRATION RATE
		------------cm/min------------
FLY ASH	1989	1.59b
	1991	0.68c
FLY ASH/	1989	2.81a
MULCH	1991	0.31c
MINESOIL	1989	0.93bc
CONTROL	1991	0.21c

means in columns with the same letter are not significantly different at p>.05 level

Minesoil control plots also experienced severe erosion, but much less than the fly ash plots, largely due to the high percentage of rock fragments which acted as a protective mulch. The severe erosion resulted from a combination of raindrop impact and surface runoff from the sloping area above the plots. After this event, a diversion ditch was installed above the site and hay bales were placed around plot boundaries to exclude off-site water. LEMI support rods were installed and initial base-line readings were taken on June 23, 1989. Unfortunately, this was after the severe erosion had taken place, and thus the erosion values reported for this site are for the subsequent period after June 23, 1989.

Cumulative erosion values during the study period (Table 5) show the highly erodible nature of fly ash on this site. There was very little, if any, difference in erosion values between mulched and unmulched fly ash plots, largely due to the loss of mulching material that resulted from the heavy rains at the time of plot establishment. Due to the measuring technique and the presence of bulldozer cleat tracks, there was a high degree of variability in erosion values between plots and between individual measuring points. As a result, treatment means were not statistically different until the second growing season (last two columns). Negative values exhibited in the control plot means are a result of two factors: one being a vegetational effect resulting from organic matter accumulations on the soil surface and the other being the result of frost heaving that raised the soil surface. It is possible that the same processes were simultaneously taking place on the fly ash plots, but the higher erosion rate of the fly ash may have masked these effects. By the end of the study period (about 14-month time span), cumulative erosion values for fly ash were between 4 to 5 times greater than those for minesoil.

Table 5. Cumulative erosion values - 10% site (6/23/89 to 8/30/90).

	EROSION VALUES (cm)				
TREATMENT	8/25/89	10/26/89	5/9/90	7/15/90	8/30/90
FLY ASH	0.130a	0.152a	0.128a	0.516a	0.913a
FLY ASH/MULCH	0.053a	0.033a	0.133a	0.522a	0.778a
CONTROL/MULCH	0.107a	-0.010a	-0.144a	-0.080b	0.193b

*means in columns with the same letter are not significantly different at the p>.05 level

The percent ground cover was highly variable on the 10% site among the fly ash treated plots (Table 6), but averages among treatment groups were fairly consistent. From these vegetative data, fly ash erosion was determined as a function of percent ground cover (Table 7). These values were for the second growing season only (May-Aug. 1990). On this site, there was a definite negative linear relationship between percent ground cover and erosion value (Table 7) with decreases in percent ground cover resulting in increased erosion values. This table emphasizes the importance of vegetative cover in reducing erodibility of fly ash.

Table 6. Percent ground cover - 2nd growing season (1990) 10% site.

TREATMENT	PLOT	COVER	AVG/TREAT.
		%	%
FLY ASH	2	47.5	68.3
FLY ASH	4	62.5	
FLY ASH	7	95.0	
FLY ASH/MULCH	3	62.5	80.8
FLY ASH/MULCH	6	95.0	
FLY ASH/MULCH	8	85.0	
CONTROL/MULCH	1	85.0	80.0
CONTROL/MULCH	5	77.5	
CONTROL/MULCH	9	77.5	

Table 7. Mean erosion values of fly ash as a function of percent ground cover - 10% site - 2nd growing season.

	EROSION VALUE (cm)	
%COVER	ACTUAL MEAN	LEAST SQUARES MEAN
~100%	0.539	0.497
~50%	0.887	0.975
~0%	1.237	1.450

20% Site. LEMI support rods were installed and initial base-line readings were taken on the 20% site on September 15, 1989, within one week of plot establishment. Precipitation during the 1989 fall period was generally low intensity (gentle) rains. As a result, vegetation was established quickly and there was no evidence of rills or gullies on any of the plots. Woodchip mulch material remained in place on all mulched plots, but appeared to be more concentrated in the bottom of the bulldozer cleat tracks. In mid-October of 1989, all of the fly ash plots began exhibiting nitrogen deficiency symptoms (yellow-foliage), possibly as a result of the sawdust mixture. By mid-November, most of the grass/legume vegetation on the fly ash-treated plots had died. The fly ash-treated plots remained essentially devoid of vegetation (<20% ground cover) until after July 1990 when slow release nitrogen fertilizer was applied. The minesoil control plots, on the other hand, remained densely vegetated throughout the entire study period.

First year erosion values were greater on fly ash plots than on minesoil plots (Table 8), especially on unmulched fly ash plots. Erosion values were approximately three times greater on the unmulched fly ash plots than on the mulched fly ash plots during the first eight months of the study. Once again, negative erosion values appeared in the minesoil control group. These negative values were associated with erosion measurements taken either during or directly after the coldest months, suggesting frost action. Frost action was clearly visible during the winter months on both sites. The lack of negative values on the fly ash plots may be a result of higher fly ash erosion rates masking the frost heaving effect.

Table 8. Cumulative erosion values - 20% site (9/15/89 to 9/3/90).

	EROSION VALUES (cm)				
TREATMENT	11/20/89	1/18/90	5/23/90	7/19/90	9/3/90
FLY ASH	0.220a	0.302a	0.377a	0.539a	0.709a
FLY ASH/MULCH	0.077a	0.087b	0.021b	0.152a	0.363a
CONTROL/MULCH	-0.032b	-0.242c	0.013b	0.203a	0.393a

means in columns with the same letter are not significantly different at the .05 level

After the first 8 months, erosion rates decreased in the fly ash plots. This trend is reflected better in the cumulative erosion values for the second growing season (May-Sept. 1990) where erosion values for all treatment groups were essentially the same (Table 9). This suggested that something very different was taking place on this site compared to the 10% site, especially since minesoil control plots were densely vegetated while the fly ash plots still had very little ground cover (Table 10).

Table 9. Cumulative erosion values - 20% site
2nd growing season (5/23/90 to 9/3/90)

TREATMENT	EROSION VALUE (cm) 7/19/90	EROSION VALUE (cm) 9/3/90
FLY ASH	0.163a	0.333a
FLY ASH/MULCH	0.131a	0.342a
CONTROL/MULCH	0.190a	0.381a

means in columns with the same letter are not significantly different at the .05 level

Table 10. Percent ground cover - 2nd growing season (1990) 20% site.

TREATMENT	PLOT	COVER	AVG/TREAT.
		%	%
FLY ASH	4	47.5	42.5
FLY ASH	5	32.5	
FLY ASH	8	47.5	
FLY ASH/MULCH	2	22.5	35.0
FLY ASH/MULCH	3	47.5	
FLY ASH/MULCH	9	35.0	
CONTROL/MULCH	1	100.0	100.0
CONTROL/MULCH	6	100.0	
CONTROL/MULCH	7	100.0	

Again, fly ash erosion values were related to percent ground cover, but on this site the relationship was more quadratic with the presence of any vegetation resulting in low erosion values (Table 11). A comparison of second growing season erosion values on the two sites (Table 12) shows that minesoil erosion values were essentially the same between the two sites, but fly ash erosion values were much less on the 20% site despite steeper slope and lower vegetative cover.

Table 11. Mean erosion values of fly ash as a function of percent ground cover - 20% site - 2nd growing season.

	EROSION VALUE (cm)	
%COVER	ACTUAL MEAN	LEAST SQUARE MEAN
~100%	0.028	0.125
~50%	0.194	0.195
~0%	0.619	0.597

Table 12. Comparison of 2nd growing season cumulative erosion rates (10% site vs 20% site).

	EROSION VALUE (cm)	
TREATMENT	10% SITE	20% SITE
FLY ASH	0.786a	0.333a
FLY ASH/MULCH	0.646a	0.342a
CONTROL/MULCH	0.338b	0.381a

means in columns with the same letter are not significantly different at the .05 level

A closer examination of the 20% site revealed colonization of the fly ash by mosses and algae and fugal hyphae. The mosses were identified as *Funaria hygrometrica* and *Dicranella heteromalla*. Both mosses are common colonizers of disturbed sites. *Funaria hygrometrica* had been cited in two previous studies as a colonizer of fresh fly ash (Hodgson and Townsend, 1973; Barber, 1973). Barber (1973), stated that *F. hygrometrica* effectively binds fly ash particles together to prevent erosion. These lower plant forms seemed to have formed a protective seal over the fly ash surface protecting it from erosive rain impact and surface runoff on this site. When these differences in fly ash erosion were noticed, soil samples were taken from below three different vegetation types (fungal hyphae, moss, and grass/legume) for aggregate stability analysis. The results of the aggregate stability analysis are shown in (Table 13). There were significant differences in both total percent aggregation as well as in the different aggregate size fractions among the three vegetation types. Total percent aggregation was greatest in the fly ash associated with the fungal hyphae, and a large percent of these aggregates were in the macroaggregate (2-6.4mm) size range. Fly ash associated with moss was intermediate in total percent aggregation and like fungal hyphae, most of the moss aggregation was in the macroaggregate size range. Fly ash associated with the grass/legume vegetation had the lowest total percent aggregation and although most of its aggregates were in the macroaggregate size range, it had a much higher proportion in the microaggregate size range than the other two vegetation types.

Table 13. Aggregate stability of fly ash from beneath different vegetation types -Erosion Study - 10% site.

	AGGREGATION		
	2.0-6.35 mm	0.5-2 mm	TOTAL
	-----------------------------%-----------------------------		
GRASS/LEGUME	55.43b	8.37a	63.80c
MOSS	67.55a	4.06b	71.61b
FUNGAL HYPHAE	68.92a	5.34b	74.27a

means in columns with the same letter are not significantly different at p>.05 level

Summary

The results of the erosion study showed that fly ash had a much greater erosion potential than minesoil. Erosion values were up to five times greater with fly ash than minesoil. Mulching effectively reduced fly ash erodibility. Fly ash erosion values on mulched plots were about one-half as much as those on unmulched plots. Fly ash erodibility was highly correlated with vegetative ground cover. Increased vegetative ground cover resulted in reduced erodibility. Fly ash erodibility was also related to the type of ground cover. Lower plants (mosses) and fungi appeared to provide better erosion protection than grass/legume vegetation. The overall conclusion that can be drawn from the erosion study is that fly ash inherently has a high erosion potential due to it's low particle density, silty texture, spherical shape, and low initial aggregation. However, actual erosion rates observed under field conditions will be highly variable depending on a number of factors such as amount of rainfall, rainfall intensity, percent slope, length of slope, infiltration rates, mulching, and amount and type of vegetative ground cover. Although additions of fly ash can greatly improve both chemical and physical properties of mined lands, use of fly ash may require more careful planning and management practices due to its erosion potential. Thus, use of fly ash as a topsoil substitute may require more moderate slope factors (length of slope and slope gradient) than are possible with many minesoils, as well as the use of management practices that will protect the soil surface from raindrop impact, such as promoting rapid vegetation establishment and the liberal use of mulches.

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