STABILIZATION OF STEEP COAL WASTE BANKS WITH A SLUDGE-FLY ASH AMENDMENT[1]

by

William E. Sopper[2]

Abstract. The current method used to stabilize steep coal waste banks involves top soiling followed by hydroseeding. This often requires the transportation of large volumes of overburden material from an active mine to the abandoned coal waste bank. This is a costly operation and often only fairly successful. This study was conducted to evaluate the use of a sludge-fly ash mixture as a substitute for top soiling. A sludge-fly ash mixture (2S:1FA) was applied to three experimental plots on a steep (75%) abandoned coal waste bank. The sludge application rate was 65 dry Mg/ha. The plots were hydroseeded with a mixture of grasses and legumes and then seedlings of six tree species were planted. Three year measurements of vegetation growth responses indicated that vegetation establishment was better on the sludge-fly ash amended plots than on the control plots which were treated with lime and fertilizer.

Introduction

Abandoned coal refuse banks dot the landscape throughout the northern Appalachian region in the United States. Mining of coal brings to the surface enormous amounts of black, shaley, acidic refuse material which was traditionally deposited in high conical-shaped banks. Thousands of hectares of such material, produced by over a century of mining, were left unreclaimed prior to the federal reclamation act of 1977. Most of these banks have remained barren and defy revegetation by natural processes. Side slopes of these banks are usually very steep and highly susceptible to severe erosion. The refuse material is black in color resulting in extremely high surface temperatures during the summer growing season. The material is low in nutrients, has a low holding water capacity, and generally has a pH lower than optimum for plant growth. The refuse banks are not only unsightly and unstable but also pose a threat to health and safety. They are a constant source of dust during the summer which often coats nearby houses and aggravates the health problems of persons with asthma, allergies, and other related breathing ailments.

The successful use of municipal sludge as an amendment to facilitate vegetation establishment on abandoned bituminous coal strip mine spoil banks and regraded anthracite coal waste banks has been well documented (Sopper, 1992). However, regrading waste banks is very costly and in many cases space is not available for extensive leveling. Some

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[2]Willam E. Sopper, Professor of Forest Hydrology, School of Forest Resources, Pennsylvania State University, University Park, PA 16802.

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waste banks in Pennsylvania are completely surrounded by houses. Thus, what is needed is a technique to revegetate these steep banks in situ. The main problem is how to vegetate the steep slopes and stabilize them.

One method that has been used is to top soil the slopes with overburden being removed from an active mine. This requires transporting large volumes of material. The material is usually dumped at the top of the slope and then pushed over the edge with a bulldozer. Achieving a uniform cover under such circumstances is almost impossible and all of the coarse material and large rocks in the overburden accumulate at the base of the slope.

In 1988, a study was initiated to investigate the feasibility of using two readily available waste products, municipal sludge and fly ash, as a substitute for top soiling. Previous research had shown that sludge alone tends to crust and becomes somewhat impervious and that the addition of fly ash improves the physical characteristics of the sludge and makes it more friable and more permeable to water (Sopper, 1988).

Method of Study

The study was conducted on an abandoned coal waste bank in eastern Pennsylvania. Six plots were established on the steep bank (75% slope). Each plot is 6 m wide along the top of the bank and 55 m long down the slope to the base of the bank. Three replications were treated with the sludge-fly ash mixture and three replications were treated with lime and fertilizer as a control. Digested dewatered sludge cake and fly ash were obtained from a local wastewater treatment plant and power generating plant and trucked to the site. The two products were mixed on a volume basis consisting of two parts of sludge to one part of fly ash (2S:1FA). The rationale was to apply the mixture at a rate which would provide a suitable depth of medium for seed germination and root establishment and which would contain a sufficient pool of nutrients (N-P-K) to support vegetation growth for at least 3 to 5 years.

In previous research using sludge to revegetate abandoned mine land, it was found that successful revegetation was assured if the sludge was applied at a rate sufficient to supply a minimum of 1000 kg/ha of total nitrogen.

Excelsior matting was installed on the three plots to receive the sludge-fly ash amendment. The mats were 1.2 m wide and 30 m in length. The mats were held in place with wire staples. After installation the excelsior matting was wetted when lime was applied with a hydroseeder. Upon wetting the excelsior matting expands to a depth of approximately 4 cm. The initial pH of the refuse material ranged from 4.0 to 4.5. Lime was applied on all plots at 2800 kg/ha to raise the pH to 7.0.

The sludge-fly ash mixture was applied to the plots with an Estes "Aero-Spreader" truck. This is a commercial vehicle built by Estes Equipment Company specifically designed to spread sludge aerially. The propellor blades can throw sludge a horizontal distance of 50 to 70 m. The "Aero-Spreader" throws the mixture into the expanded excelsior matting which holds it in place. The depth of the mixture was approximately 5 cm. The three control plots were treated with an application of a 10-10-10 fertilizer applied at the rate of 2240 kg/ha with a hydroseeder.

All plots were then hydroseeded with a mixture of grasses and legumes which consisted of K-31 tall fescue (Festuca arundinacea) (22 kg/ha), orchardgrass (Dactylis glomerata) (22 kg/ha), birdsfoot trefoil (Lotus corniculatus) (11 kg/ha), and crownvetch (Coronilla varia) 11 kg/ha). All plots were mulched with straw at 2240 kg/ha and the straw was tacked down by hydroseeding Cellin fiber mulch at 1350 kg/ha. In the spring of 1989, tree seedlings of six species were planted on the plots. Ten seedlings of each species were planted for a total of 60 trees per plot. Species planted were black locust (Robinia pseudoacacia), red oak (Quercus rubra), tree of heaven (Ailanthus altissima), catalpa (Catalpa speciosa), European alder (Alnus glutinosa), and Japanese larch (Larix leptolepis).

Refuse samples were collected at 0-15, 15-30, and 30-60 cm prior to amendment application and at one year intervals and analyzed for pH, N, P, K, Na, Mn, Mg, Al, Fe, Ca, Zn, Cu, Pb, Ni, Cd, Cr, and soluble salts.

At the end of each growing season tree survival and height growth were measured. Ocular estimates of herbaceous percent cover were made using a 50 by 50 cm square placed at intervals of 3 m on a transect line down the center of each plot. Dry matter production samples were collected by clipping all vegetation within a 30 by 30 cm square placed on the same transect line. Foliar sample from each tree species and each of the four grass and legume species was collected for analyses for nutrients and trace metals.

Results

Sludge-Fly Ash Application

The chemical analyses of the sludge and fly ash used on the project is given in Table 1. The sludge was high in nutrients (N and P) and had low trace metal concentrations. The fly ash had a high concentration of Ca and low concentrations of trace metals and boron. Soluble salts were high (258 mmho/cm) but were not expected to be a problem since the concentration was diluted when mixed with the sludge. The amounts of chemical constituents applied in the sludge-fly ash mixture are given in Table 2. The sludge application rate was equivalent to 65 dry Mg/ha. The amounts of trace metals applied in the mixture were well below the allowable maximum amounts recommended by the Pennsylvania Department of Environmental Resources (PDER) for mine land reclamation (Table 2).

Tree Survival and Height Growth

Average tree seedling survival and height growth for all three growing seasons (1989, 1990, and 1991) are given in Tables 3 and 4. Tree seedling survival the first year (1989) was similar on both the control and sludge-fly ash amended plots, except for tree of heaven which had a significantly higher survival rate on the control plots. In 1990 all tree species, except tree of heaven, had a higher survival rate on the control plots, however, only larch survival was statistically significant. By 1991, survival of all tree species were similar except that red oak had a significantly higher survival rate on the control plots and tree of heaven had a significantly higher survival rate on the sludge-fly ash amended plots. The lower survival rates on the amended plots was probably due to the greater competition from the herbaceous vegetation which was greatly stimulated by the sludge-fly ash amendment. There was a large mortality of tree of heaven on the control plots in 1990 and this may have been due to Mn toxicity as discussed later. Average survival of all species combined in 1991 was 74 percent on the control plots and 67 percent on the amended plots.

In 1989, height growth of black locust and tree of heaven were significantly greater on the control plots. However, by 1990 and 1991 only black locust and European alder had significantly greater height growth on the control plots. Tree of heaven was the only species which had a significantly greater height growth on the sludge-fly ash amended plots (1991). The poorer height growth response on the amended plots may again be due to the greater herbaceous vegetation competition. Black locust exhibited the best overall growth response and Japanese larch had the poorest survival and growth response. Black locust, European alder, and catalpa were the species which exhibited the best performance on both the control and sludge-fly ash amended plots.

Tree Foliar Analyses

Average concentrations of macronutrients in the foliage of the tree species for the third growing season (1991) are given in Table 5. Catalpa was the only species which had a significantly higher foliar N concentration on the sludge-fly ash amended plots. There were no significant differences in foliar P concentrations between treatments. Most species had higher foliar K concentrations on the

Table 1. Chemical Analyses of the Sludge and Fly Ash

Constituent	Sludge Concentration	Fly Ash Concentration[1]
	--%--	--mg/kg--
Total P	2.08	--
Bray P	--	20
Total N	4.88	--
NH_4-N	0.79	--
Org-N	4.09	--
Ca	5.76	6000
Mg	0.45	72
Na	0.11	64
K	0.12	222
Al	1.22	105
Fe	1.50	43
B	--	2.7
	--mg/kg--	
Mn	216	2.1
Zn	1243	0.9
Cu	1119	1.3
Pb	187	1.1
Cr	133	78
Ni	61	0.6
Cd	18	0.03
Hg	9.1	--
Solids (%)	17	
pH	8.1	9.4

[1]Concentrations are for available metals.

Table 2. Chemical Analyses of the Sludge-Fly Ash Mixture and the Amounts of Chemical Constituents Applied

Constituent	Concentration	Amount Applied	PDER Maximum
		kg/ha	kg/ha
pH	8.4		
	--%--		
Total P	0.64	1505	
Total N	1.27	2987	
NH_4-N	0.23	541	
Org-N	1.04	2446	
Ca	2.40	5646	
Mg	0.24	564	
Na	0.06	141	
K	0.35	823	
Al	2.47	5809	
Fe	5.61	13195	
	--mg/kg--		
Mn	314	74	
Zn	443	104	280
Cu	357	84	140
Pb	88	20	560
Cr	75	18	560
Ni	73	17	56
Cd	5.3	1.2	5.6
Hg	1.2	0.3	1.7
Solids	43%		

Table 3. Average Tree Seedling Survival

	Control			Sludge-fly ash		
Species	1989	1990	1991	1989	1990	1991
	--%--			--%--		
Black Locust	100	100	100	100	97	97
Red Oak	100	90	83*	97	60	53
European Alder	90	77	73	87	67	57
Catalpa	100	100	100	90	83	83
Tree of Heaven	100*	53	53	87	87*	87*
Japanese Larch	43***	40***	33	27	27	27

*,*** Significant effect at P<0.05 and 0.001, respectively. Comparisons were made between treatments for each species for each year.

Table 4. Average Tree Seedling Height

	Control			Sludge-fly ash		
Species	1989	1990	1991	1989	1990	1991
	-----------------cm-----------------			--------------cm------------		
Black Locust	108**	169**	328***	80	112	225
Red Oak	23	25	41*	23	25	30
European Alder	62	95*	167***	53	64	81
Catalpa	48	69	85	45	61	83
Tree of Heaven	38**	36	46	29	37	78*
Japanese Larch	38	32	102	37	31	77

*, **, *** Significant effect at $p<0.05$, 0.01 and 0.001, respectively.

Table 5. Mean Concentrations of Macronutrients in the Foliage of the Tree Species in 1991

Species	Plot	N	P	K	Ca	Mg
		-----------------------	----------	%	----------	-----------------------
Catalpa	Control	1.49	0.18	1.68	0.35	0.26
	2S:1FA	2.02*	0.14	1.15	0.67	0.20
Alder	Control	2.92*	0.16	0.89	0.49	0.41
	2S:1FA	2.31	0.12	0.80	0.72	0.35
Tree of Heaven	Control	2.10	0.20	1.47	1.11	0.55*
	2S:1FA	3.19	0.22	1.00	2.21*	0.29
Red Oak	Control	2.46	0.18	0.74	0.54	0.38
	2S:1FA	2.36	0.15	0.78	0.73	0.34
Black Locust	Control	3.76	0.17	1.36**	0.39	0.21
	2S:1FA	3.66	0.14	0.96	0.75	0.20
Larch	Control	1.41	0.20	0.91**	0.18	0.13
	2:1FA	1.61	0.20	0.62	0.28**	0.20*

*,** Significant effect at $P<0.05$ and 0.01, respectively.

control plots. Black locust and larch had significantly higher K foliar concentrations. Potassium concentrations in sludge are very low and K was more readily available on the fertilized control plots. Conversely, Ca foliar concentrations were generally higher in the trees growing on the sludge-fly ash amended plots. Both tree of heaven and larch had significantly higher Ca foliar concentrations on the sludge-fly ash amended plots. This was probably due to the fact that the fly ash had a very high concentration of Ca. Foliar Mg concentrations were variable with tree of heaven having a significantly higher foliar concentration in the control trees and larch having a significantly higher concentration in the sludge-fly ash amended trees.

Average foliar concentrations of Mn, Fe, and Al in all tree species in 1991 are given in Table 6. Concentrations of these three elements were generally higher in the foliage of the trees on the sludge-fly ash amended plots. Larch had significantly higher foliar concentration of Mn and Al, red oak had significantly higher foliar concentrations of Fe and Al, and catalpa had significantly higher foliar concentrations of Al on the sludge-fly ash amended plots. All foliar concentrations of Fe were well below the suggested tolerance level. However, alder and red oak both had foliar concentrations of Mn above the suggested tolerance level on both control and sludge-fly ash amended plots. The suggested tolerance levels are not phytotoxic levels but suggest foliar concentration levels at which decreases in growth may be expected (Melsted, 1973). Symptoms of Mn toxicity, leaf margin chlorosis, necrotic spots on the leaves, and leaf puckering were observed on many of the red oak seedlings. The poor height growth of this species might have been due to Mn toxicity.

Average concentrations of trace metals in the foliage of the tree species in 1991 are given in Table 7. Foliar trace metal concentrations were generally higher in tree seedlings growing on the sludge-fly ash amended plots. All foliar trace metal concentrations in all species were below the suggested tolerance level for agronomic crops cited by Melsted (1973). Concentrations of B in all tree species were significantly higher on the sludge-fly ash amended plot. Foliar concentrations of Zn, Pb, and Co were similar between the two sets of plots except for catalpa which had significantly higher foliar concentrations of Co on the control plots.. Tree of heaven, alder, had a significantly higher foliar concentration of Cu on the sludge-fly ash amended plot. Tree of heaven and red oak had a significantly higher concentration of Cd on the sludge-fly ash amended plots. Alder and red oak had a significantly higher concentration of Cr on the sludge-fly ash amended plots.

Table 6. Mean Concentrations of Mn, Fe, and Al in the Foliage of the Tree Species in 1991

Species	Plot	Mn	Fe	Al
		---------mg/kg---------		
Catalpa	Control	37	62	69
	2S:1FA	53	99	132*
Alder	Control	554	243	132
	2S:1FA	506	193	208
Tree of Heaven	Control	167	80	99
	2S:1FA	222	134	136
Red Oak	Control	581	90	61
	2S:1FA	551	272*	140*
Black Locust	Control	145	64	52
	2S:1FA	143	65	70
Larch	Control	177	44	199
	2S:1FA	281*	97	287*
Suggested tolerance level Melsted (1973)		300	750	200

*Significant effect at $P<0.05$.

Herbaceous Vegetation Growth Response

Average percent cover and dry matter production for all three growing seasons (1989, 1990, 1991) are given in Table 8. Both percent cover and dry matter production from the sludge-fly ash amended plots were significantly higher in all three years. By the third year average percent cover was 83.3 percent on the sludge-fly ash amended plot in comparison to 15.2 percent on the control plots. Dry matter production increased each year and peaked at 8145 kg/ha the third year on the sludge-fly ash amended plots in comparison to 1285 kg/ha on the control plots.

Herbaceous Foliar Analyses

Average concentrations of trace metals in the foliage of the herbaceous species are given in Table 9. Trace metal concentrations were, in general, higher in plants growing on the sludge-fly ash amended plots. Trace metal foliar concentrations in all species on both sets of plots were below the suggested tolerance level. In 1991, the third growing season, tall fescue had significantly higher foliar concentrations of Cd and Ni and orchardgrass had higher concentrations of Cu, B, and Cd; and birdsfoot trefoil had significantly higher concentrations of Cu, B, and Pb; and crownvetch had higher concentrations of Cu, B, Pb, and Cd on the sludge-fly ash amended plots. Birdsfoot trefoil was the only species which had higher foliar concentrations of Zn and Ni on the control plots.

Refuse Analyses

Mean concentrations of trace metals in the refuse prior to treatment are given in Table 10. In general, the chemical characteristics of the refuse were quite similar on the three subplots of each treatment and there were no statistically significant differences. Concentrations of trace metals in the refuse three years after treatment are given in Table 11.

Concentrations of trace metals were slightly higher on the sludge-fly ash amended plots.but not statistically significant. Conversely, Cd concentrations in the refuse at the 15-30 cm depth on the control plots was the only trace metal significantly higher than on the sludge-fly ash amended plots. It appears that precipitation has not yet leached many of the constituents from the sludge-fly ash amendment into the refuse.

Conclusions

The results of the study indicate that a mixture of sludge and fly ash can be successfully used as a top soil substitute to facilitate vegetation establishment on steep coal refuse banks. These two waste products are often readily available and can be obtained at little cost. Their use could eliminate the costly transportation of top soil and/or overburden to cover steep refuse banks as is currently being done. The use of this technology to vegetate and stabilize steep coal refuse banks in situ would also eliminate the need for costly regrading such banks to suitable slopes for conventional reclamation.

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Table 7. Mean Concentrations of Trace Metals in the Foliage of the Tree Species in 1991

Species	Plot	Cu	B	Zn	Pb	Cd	Ni	Co	Cr
		mg/kg							
Catalpa	Control	12	20	28	3	0.14	2.8	1.77*	0.54
	2S:1FA	9	40**	20	3	0.21	3.4	1.04	0.53
Alder	Control	17	10	82	3	0.18	17.2	1.14	0.53
	2S:1FA	11	35**	49	4	0.35*	10.5	0.84	1.13***
Tree of Heaven	Control	8	28	19	4	0.11	2.0	1.80	0.55
	2S:1FA	11*	98**	30	4	0.46*	2.4	1.39	0.96
Red Oak	Control	8	17	42	3	0.16	2.3	0.71	0.45
	2S:1FA	10	38**	48	4	0.35*	7.4	0.70	0.90**
Black Locust	Control	12	16	32	2	0.14	10.5	1.01	0.42
	2S:1FA	11	39**	39	3	0.23	12.2	1.07	0.46
Larch	Control	3	8	17	2	0.16	2.9	0.75	0.25
	2S:1FA	5	27***	18	2	0.21	6.0*	0.59	0.95
Suggested tolerance level Melsted (1973)		150	100	300	10	3	50	-	-

*,**,*** Significant effect at P<0.05, 0.01, and 0.001, respectively.

Table 8. Average Percent Cover and Dry Matter Production

	Control			Sludge-fly ash		
	1989	1990	1991	1989	1990	1991
Percent cover (%)	6.9	10.6	15.2	57.3***	62.3***	83.3***
Dry matter (kg/ha) production	799	824	1285	5019***	6029***	8145***

***Significant effect at P<0.01. Comparisons were made between treatments for each year.

Table 9. Mean Concentrations of Trace Metals in the Foliage of the Herbaceous Species in 1991

Species	Plot	Cu	B	Zn	Pb	Cd	Ni	Co	Cr
		---------------------------------mg/kg---------------------------------							
Tall fescue	Control	4	4	26	4	0.17	2.8	2.05	0.85
	2S:1FA	15	9	52	5	0.52*	6.0*	1.10*	1.79
Orchardgrass	Control	4	4	26	5	0.20	2.8	0.77	0.55
	2S:1FA	13**	12*	52	4	0.40*	2.8	1.24	0.81
Birdsfoot trefoil	Control	7	19	107*	4	0.41	16.9*	1.92	0.66
	2S:1FA	14**	74**	54	8**	0.40	9.8	1.72	1.23
Crownvetch	Control	9	9	98	4	0.28	4.9	1.96	0.62
	2S:1FA	15**	47***	89	9**	0.96*	7.2	1.46	0.82
Suggested tolerance level Melsted (1973)		150	100	300	10	3	50	5	2

*,**,*** Significant effect at $P<0.05$, 0.01, and 0.001, respectively.

Table 10. Mean Concentrations of Trace Metals in the Refuse Bank Soil Prior to Treatment

Treatment	Soil depth	Cu	Zn	Pb	Ni	Cd	Cr[1]
	cm	--------------------mg/kg--------------------					
Control	0-15	0.9	0.4	0.3	0.4	0.01	4.2
(Fertilizer)	15-30	1.0	0.3	0.2	0.4	0.01	3.4
	30-60	0.9	0.5	0.3	0.5	0.01	3.6
Amended	0-15	0.9	0.4	0.3	0.4	0.02	3.0
(2S:1FA)	15-30	1.5	0.5	0.6	0.5	0.01	3.2
	30-60	1.7	0.5	0.3	0.5	0.01	3.8

[1] Chromium values are for total metal concentrations.

Table 11. Mean Concentrations of Available Trace Metals in the Refuse Bank Soil Three Years after Treatment

Treatment	Soil Depth	Cu	Zn	Pb	Ni	Cd	Cr[1]	B
	cm				mg/kg			
Control	0-15	1.3	0.7	0.1	0.1	0.02	3.8	0.2
(Fertilizer)	15-30	1.0	0.6	0.1	0.1	0.02*	4.3	0.2
	30-60	1.0	0.6	0.2	0.2	0.01	3.7	0.2
Amended	0-15	2.5	1.7	0.2	0.1	0.03	3.3	0.2
(2S:1FA)	15-30	1.3	0.6	0.1	0.1	0.01	4.2	0.2
	30-60	2.2	1.1	0.1	0.2	0.02	3.6	0.2

[1] Chromium values are for the total metal concentrations

* Significant effect at P<0.05.