REVEGETATION OF STEEP COAL WASTE BANKS USING A SEWAGE SLUDGE-FLY ASH AMENDMENT[1]

by

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Abstract. The current method used to revegetate 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% slope) 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. Two year measurements of vegetation growth responses indicated that vegetation establishment was better on the sludge-fly ash amended plots than on adjacent control plots treated with lime and fertilizer.

Additional key words: Reclamation, trace metals, refuse.

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 waterholding 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 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 and Kerr, 1979; Sopper et al., 1982; Seaker and Sopper, 1983; Seaker and Sopper, 1984). However, regrading waste banks is very costly and in many cases space is not available for extensive leveling. Some waste banks in Pennsylvania are completely surrounded by houses. Thus, what is needed is a technique to revegetate these banks in situ. The main problem is how to vegetate the steep slopes.

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One method that has been used is to topsoil 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 become 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 is being 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). It was proposed 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, we found that successful revegetation was assured if the sludge was applied at a rate sufficient to supply a minimum of 1120 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 depth prior to amendment application and at one year intervals and analyzed for pH, Kjeldahl-N, Bray P, exchangeable K, Ca, and Mg, Fe, Al, Mn, Cu, Zn, Cr, Pb, Co, Cd, and Ni by the Baker Soil Test (Baker and Amacher, 1981).

At the end of the 1989 and 1990 growing seasons 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 samples from each tree species and each of the four grass and legume species were collected and analyzed for N, P, K, Ca, Mg, Mn, and B by plasma emission spectrometry (Baker et al., 1964), Cu, Zn, Cr, Pb, Co, Cd, and Ni by atomic absorption (Jackson, 1958), after dry ashing and digestion.

Results

Sludge-Fly Ash Application

The chemical analyses of the sludge and fly ash used on the project are 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 but were not expected to be a problem since the concentration will be 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 Growth

Average tree seedling survival and height growth are given in Tables 3 and 4. Tree seedling survival in 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. The lower survival rate 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 was 77 percent on the control plots and 70 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 only black locust and European alder had significantly greater height growth on the control plots. 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.

Average concentrations of nutrients in the foliage of the tree species in 1990 are given in Table 5. Concentrations of N and P were generally higher in the foliage of the tree species growing on the sludge-fly ash amended plots. Larch was the only tree species which had significantly higher concentrations of N and P on the sludge-fly ash amended plots. Foliar K concentrations were quite similar for most tree species, except that catalpa and alder had significantly higher foliar K concentrations on the control plots.

Average concentrations of trace metals in the foliage of the tree species in 1990 are given in Table 6. Foliar trace metal concentrations were generally higher in the tree seedlings growing on the sludge-fly ash amended plots. All foliar trace metal concentrations in all species, except red oak, were below the suggested tolerance level for agronomic crops cited by Melsted (1973). The suggested tolerance levels are not phytotoxic levels but suggest foliar concentration levels at which decreases in growth may be expected. Red oak foliar Mn concentrations exceeded the suggested tolerance level in tree seedlings growing in both the control and amended plots. Symptoms of Mn toxicity, leaf margin chlorisis, 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 also be due to Mn toxicity. All species, except catalpa, had significantly higher foliar Cu and Zn concentration on the sludge-fly ash amended plots. Both black locust and larch had significantly higher foliar concentrations of B and Pb on the amended plots. Larch was the only species which had a significantly higher foliar Cd concentration on the amended plots.

Herbaceous Vegetation Growth Responses

Average percent cover and dry matter production are given in Table 7. Both percent cover and dry matter production were significantly higher in both years on the sludge-fly ash amended plots.

Average concentrations of nutrients in the foliage of the herbaceous vegetation in 1990 are given in Table 8. Foliar nutrient concentrations, in general, were higher in plants growing on the sludge-fly ash amended plots. Tall fescue and orchardgrass both had significantly higher foliar N concentrations on the amended plots. Crownvetch and orchardgrass also had significantly higher foliar P concentrations on the amended plots. Crownvetch was the only herbaceous species that had a higher foliar K concentration on the amended plots.

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 amended plots. Trace metal concentrations in all species on both plots were below the suggested tolerance level, except for Mn in orchardgrass. Both crownvetch and orchardgrass had significantly

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	Concen-tration	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

Species	Control 1989	Sludge-Fly Ash 1989	Control 1990	Sludge-Fly Ash 1990
	%	%	%	%
Black Locust	100	100	100	97
Red Oak	100	96	90	60
European Alder	90	87	77	67
Catalpa	100	90	100	83
Tree of Heaven	100*	87	53	87
Japanese Larch	43	27	40***	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 Growth

Species	Control 1989	Sludge-Fly Ash 1989	Control 1990	Sludge-Fly Ash 1990
	cm	cm	cm	cm
Black Locust	108**	80	169**	112
Red Oak	23	23	25	25
European Alder	62	53	95*	65
Catalpa	48	45	69	61
Tree of Heaven	38**	29	37	37
Japanese Larch	38	37	34	31

*,**Significant effect at P<0.05 and 0.01, respectively. Comparisons were made between treatments for each species for each year.

Table 5. Average Concentrations of Nutrients in the Foliage of the Tree Species

Species	Plot	N	P	K
		---------%----------		
Catalpa	Control	1.44	0.16	1.45*
	2S:1FA	2.30	0.15	1.28
Alder	Control	2.20	0.20	1.47*
	2S:1FA	2.11	0.16	1.12
Tree of Heaven	Control	1.57	0.21	1.72
	2S:1FA	2.16	0.23	1.76
Red Oak	Control	1.88	0.27	0.72
	2S:1FA	2.21	0.29	0.83
Black Locust	Control	3.58	0.16	1.38
	2S:1FA	3.64	0.20	1.49
Larch	Control	1.30	0.20	0.78
	2S:1FA	1.68**	0.25*	0.77

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

higher foliar Mn concentrations on the control plots. Birdsfoot trefoil, crownvetch, and tall fescue all had significantly higher foliar concentrations of Cu, Zn, and Pb on the amended plots. Birdsfoot trefoil was the only species which had a significantly higher foliar Cd concentration on the amended plots. Foliar Ni concentrations in birdsfoot trefoil were significantly higher in plants growing on the control plots.

Refuse Analyses

Analyses of refuse samples collected prior to treatment showed that, in general, the chemical characteristics of the refuse were quite similar on the three subplots of each treatment. Analyses of post-treatment samples collected two years after treatment show little change in the chemical status of the refuse in the 0-60 cm depth (Table 10). There were no significant differences in pH, TKN, P, K, Mg, Ca, or total soluble salts in the refuse of both the control and amended plots at all three depths. Phosphorus concentrations increased dramatically on both sets of plots over pre-treatment values. On the control plots P concentration increased from 11.3 to 63.7 mg/kg and on the sludge-fly ash amended plots P increased from 6.0 to 68.5 mg/kg. Average concentrations of Mn, Fe, and Al in the refuse were quite similar on both sets of plots at all three depths (Table 11). Only Fe and Al concentrations were significantly higher at the 30-60 cm depth on the amended plots. Concentrations of trace metals increased slightly on the sludge-fly ash amended plots but only concentrations of Zn at the 0-15 cm depth was significantly higher (Table 12). It appears that precipitation has not yet leached many of the constituents from the sludge-fly ash amendment into the refuse.

Table 6. Average Concentrations of Trace Metals in the Foliage of the Tree Species

Species	Plot	Mn	Cu	B	Zn	Pb	Cd	Ni
		mg/kg						
Catalpa	C	92	10	16	32	2	0.13	6.7**
	2S:1FA	40	9	30	21	4**	0.05	3.2
Alder	C	299*	13	13	40	4	0.15	8.2
	2S:1FA	234	27*	21*	58**	6	0.35	8.6
Tree of Heaven	C	245***	8	27	24	4	0.07	4.6
	2S:1FA	135	12**	61	34*	6	0.07	4.0
Red Oak	C	398	33	8	49	7	0.35	2.7
	2S:1FA	452*	43**	11	56*	9	0.45	3.4
Black Locust	C	34	11	12	20	2	0.11	7.1
	2S:1FA	61	14*	32*	36*	4*	0.03	12.2
Larch	C	212	3	14	14	2	0.26	4.9
	2S:1FA	244*	9*	36*	22*	4*	1.05*	6.8
Suggested Tolerance Level (Melsted, 1973)		300	150	100	300	10	3	50

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

Table 7. Average Percent Cover and Dry Matter Production

	Control 1989	Sludge-Fly Ash 1989	Control 1990	Sludge-Fly Ash 1990
Percent Cover (%)	6.9	57.3***	10.6	62.3***
Dry Matter Production (kg/ha)	799	5019***	824	6029***

***Significant effect at P<0.001

Table 8. Average Concentrations of Nutrients in the Foliage of the Herbaceous Species

Species	Nutrient	Control	2S:1FA
		%	%
Birdsfoot Trefoil	N	3.37	3.62
	P	0.19	0.22
	K	1.14	1.41
Crownvetch	N	2.31	2.47
	P	0.16	0.22*
	K	1.29	1.53*
Tall Fescue	N	1.45	2.76**
	P	0.29	0.31
	K	1.91	1.98
Orchardgrass	N	1.66	2.50***
	P	0.27	0.37*
	K	2.34	2.16

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

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

Species	Plot	Mn	Cu	B	Zn	Pb	Cd	Ni
		---------------------------------mg/kg---------------------------------						
Birdsfoot	C	103	9	17	41	6	0.19	11.5***
Trefoil	2S:1FA	113	14**	67*	53*	10*	0.48*	5.3
Crownvetch	C	96**	7	11	53	4	0.11	4.9
	2S:1FA	86	13**	40	76*	8*	0.56	6.7*
Tall Fescue	C	62	5	5	10	2	0.17	5.6
	2S:1FA	59	12*	9	28**	4**	0.47	4.2
Orchardgrass	C	320**	6	9	31	3	0.19	6.1
	2S:1FA	73	13	8	32	4	0.18	3.5
Suggested Tolerance Level (Melsted, 1973)		300	150	100	300	10	3	50

*,**,***Significant effect at P≤0.05, 0.01, 0.001, respectively

Table 10. Chemical Analyses of the Refuse Two Years After Treatment

Treatment	Refuse Depth	pH	TKN	P	K	Mg	Ca	T.S.S.
	cm		%	mg/kg	------meq/100g-----			mmhos/cm
Control	0-15	5.9	0.45	63.7	0.11	0.9	1.2	0.10
(Fertilizer)	15-30	5.5	0.45	34.5	0.09	0.8	1.0	0.10
	30-60	5.1	0.44	16.0	0.08	0.6	0.8	0.10
Amended	0-15	5.6	0.43	68.5	0.04	0.7	1.8	0.17
(2S:1FA)	15-30	5.0	0.47	15.2	0.04	0.6	1.2	0.13
	30-60	4.6	0.45	7.8	0.03	0.5	0.9	0.10

Table 11. Average Concentrations of Available Mn, Fe, and Al in the Refuse Two Years After Treatment

Treatment	Refuse Depth	Mn	Fe	Al
	cm	--------mg/kg--------		
Control	0-15	1.1	22	15
(Fertilizer)	15-30	1.0	22	18
	30-60	1.7	25	24
Amended	0-15	1.4	32	22
(2S:1FA)	15-30	0.9	37	32
	30-60	2.4	35*	38*

*Significant effect at P<0.05

Table 12. Average Concentrations of Available Trace Metals in the Refuse Two Years After Treatment

Treatment	Refuse Depth	Cu	Zn	Pb	Ni	Cd	Cr[1]
	cm	-----------------------	----------	mg/kg	----------	----------	----------
Control	0-15	1.3	0.4	0.3	0.6	0.02	5.9
(Fertilizer)	15-30	1.6	0.5	0.3	0.5	0.01	5.8
	30-60	2.1	0.6	0.4	0.3	0.08	6.1
Amended	0-15	3.4	2.3*	0.5	0.3	0.04	8.4
(2S:1FA)	15-30	1.5	0.6	0.4	0.3	0.01	5.6
	30-60	1.4	0.6	0.7	0.4	0.02	5.6

[1]Chromium values are for total metal concentrations
*Significant effect at $P < 0.05$

Conclusions

Based on the results to date, it can be concluded that the sludge-fly ash amendment was successful in facilitating the establishment of a herbaceous vegetative cover but adversely affected tree seedling survival and height growth. Monitoring will be continued to evaluate the persistence of the vegetation and the long-term effects of the sludge-fly ash mixture to supply nutrients for plant growth.

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