EVALUATION OF PAPER MILL SLUDGE-FLY ASH MIXTURES AS POTENTIAL AMENDMENTS FOR VEGETATION ESTABLISHMENT ON MINE LAND[1]

by

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Abstract. A greenhouse study was designed to evaluate a mixture of Scott Paper Company sludge and fly ash on the growth responses of selected tree and grass species. The mixture evaluated consisted of 5 parts of fly ash to 3 parts of paper mill sludge (volume basis). Treatments consisted of mixing the 5FA:3S mix with coal refuse and spoil at 50 and 30 percent on a volume basis. The mixtures were placed in quart-size cartons after lime and fertilizer were applied. The containers were seeded with four tree species and two grass species. Control pots with a peat-vermiculite mixture were similarly seeded. Vegetation was grown for 3 months and harvested. Of the four tree species, black locust (Robinia pseudoacacia) had the best height growth in the 30% spoil treatment. Tree of heaven (Ailanthus altissima) had significantly greater height growth in the 50% and 30% refuse pots than in the spoil pots. Shoot biomass of catalpa (Catalpa speciosa) and black locust were not significantly different among the four treatments. Tree of heaven and birch (Betula populifolia shoot biomasses were significantly greater in the 50% refuse pots. Average concentrations of trace metals in the foliage of the tree species were below the tolerance level suggested to cause decreases in growth. For the grass species, tall fescue (Festuca arundinacea) height growth and shoot biomass were the greatest in the 50% refuse pots. Concentrations of all trace metals in the grass species were well below the tolerance level in all treatments. Considering all results, it is recommended that the 50% mixture be used under field conditions.

Additional key words: Reclamation, trace metals, coal waste.

Introduction

Abandoned coal refuse banks and strip mine spoil banks dot the landscape throughout the Appalachian region. Mining of coal brings to the surface enormous amounts of black, shaley, acidic refuse material and overburden. 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. Most of these sites are low in nutrients, have a low waterholding capacity, and generally have a pH lower than optimum for plant growth. The successful use of municipal sludge as

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Table 1. Treatments

Treatment	Application Depth of Amendment	Mixture With Spoil or Refuse (Volume Basis)
	cm	%
1. Control (potting mixture)	-	-
2. 5FA:3S Mixed with Refuse	15.0	50
3. 5FA:3S Mixed with Refuse	7.5	30
4. 5FA:3S Mixed with Spoil	15.0	50
5. 5FA:3S Mixed with Spoil	7.5	30

an amendment to facilitate vegetation establishment on abandoned bituminous coal strip mine spoil banks and regraded anthracite coal refuse banks has been well documented (Seaker and Sopper, 1983; Seaker and Sopper, 1984). However, the use of paper mill sludge and mixtures of paper mill sludge and fly ash have not been as thoroughly investigated.

Scott Paper Company located in Chester, Pennsylvania was planning a modification of their plant to utilize recycled paper. After modification the plant would produce two waste products - paper mill sludge and fly ash. Because of the large volumes to be generated, there was a high interest in using the two products for revegetation of mineland. Therefore, a greenhouse study was designed to evaluate the feasibility of using the mixture of sludge and fly ash as an amendment to facilitate revegetation of coal refuse banks and strip mine spoil banks.

Method of Study

When amendments such as sludge and/or fly ash are applied on mined land, they are usually incorporated into the surface 0-15 cm. This is the primary root development area for seeded vegetation. Therefore, we evaluated a selected mixture of sludge and fly ash applied at various rates to achieve a desirable mixture of the amendment and spoil material in the 0-15 cm depth on a volume basis.

The mixture ratio selected for evaluation was 5 parts of fly ash to 3 parts of paper mill sludge (volume basis), which is the approximate ratio of the expected daily production of the two products. The treatments (Table 1) consisted of mixing the 5FA:3S mix with coal refuse and spoil at 50 and 30 percent on a volume basis. This would equate to incorporating a 15 cm depth of 5FA:3S mix into 15 cm of refuse or spoil for the 50% treatment and 7.5 cm depth into 15 cm for the 30% treatment.

Coal refuse was obtained from the Lehigh Navigation and Coal Company mine at Coaldale, PA. Strip mine spoil was obtained from an abandoned mine site in Somerset County, PA.

Quart-size milk cartons were used as planting containers. The amendment mixtures were mixed with the refuse and spoil as indicated under Treatments and then placed in the planting containers. Prior to filling the containers, agricultural lime was added to the mixture to raise the pH to 7.0 based on the recommendation from the spoil and refuse analyses. Lime application was equivalent to 11 Mg/ha. Fertilizer was also added to the pots equivalent to 448 kg/ha of a 20-20-20 (N-P-K) mix which is commonly used for mine land reclamation in Pennsylvania. The Control containers were filled with a traditional potting mix of peat and vermiculite. There were three replications of each treatment.

Several tree species and grass species were seeded in the containers on August 13, 1990 and watered as needed. The following is the list of species evaluated. No legume species were used because the time period of the study was too short to obtain sufficient legume species growth for analyses.

a. Tree species

	Common Name	Scientific Name
1.	Black Locust	*Robinia pseudoacacia*
2.	Catalpa	*Catalpa speciosa*
3.	Tree of Heaven	*Ailanthus altissima*
4.	Gray Birch	*Betula populifolia*

b. Grass species

	Common Name	Scientific Name
1.	Orchardgrass	*Dactylis glomerata*
2.	K-31 Tall fescue	*Festuca arundinacea*

Tree seedling height growth was recorded at the time of harvest (approximately 11 weeks after seeding). Grass species were harvested several times to prevent seed head formation. Average height growth of the grass species was measured at the time of final harvest. At time of harvest the tree seedlings were removed from the containers and thoroughly washed. Each seedling was cut at the root collar and placed in an oven at 80^{o} C for 48 hrs and then weighed to determine the dry weight of the shoot and root biomass. The grass species were handled in a similar manner. All species were continually monitored for any symptoms of phytotoxicity. All foliage and root biomass from each tree seedling and grass species were oven-dried and ground in a Wiley mill, ashed, and digested for analyses to determine nutrient and trace metal uptake and accumulation. Each sample was analyzed for N, P, K, Ca, Mg, Mn, Fe, Al, B, Cu, Zn, Pb, Cr, Cd, Ni, and Co either by plasma emission spectroscopy or by atomic absorption spectrophotometry.

Results

Fly Ash, Spoil, and Refuse Chemical Characteristics

The chemical characteristics of the fly ash, bituminous spoil, and anthracite refuse used in the study are given in Table 2. The spoil and refuse were collected from mine sites that were extremely acid and were representative of worst case sites in terms of revegetation. The pH of the spoil (pH 4.0) and the refuse (pH 3.9) were very similar. Both had very low concentrations of nutrients and trace metals. The fly ash had a high pH (pH 9.3) and a high concentration of Ca both of which help ameliorate the acid conditions of the spoil and refuse. Boron concentrations in the fly ash, which sometimes can be toxic to vegetation, were extremely low. However, soluble salts were extremely high (2.35 mmhos/cm) considering that values above 1.2 mmhos/cm can be toxic to vegetation.

Sludge and Sludge-Fly Ash Mix Chemical Characteristics

Average concentrations of constituents in the Scott paper sludge and the sludge-fly ash mixture are given in Table 3. The Scott paper sludge is extremely low in macronutrients and has little fertilizer value. It is also low in trace metals, except for zinc. Analyses showed a Zn concentration of 1403 mg/kg. Pennsylvania regulations

Table 2. Average Concentrations of Constituents in the Fly Ash, Bituminous Spoil, and Anthracite Refuse

Constituent	Fly Ash	Spoil	Refuse
pH	9.3	4.0	3.9
	------meq./100g-------		
CEC	17.3	11.2	4.2
	---------mg/kg---------		
K	234	39	19
Mg	204	48	48
Ca	8500	100	360
Bray P	2.5	7.0	3.5
Mn	1.8	4.0	3.0
Fe	14.4	41.7	48.3
Al	41.0	61.0	20.0
Cu	1.3	0.4	0.5
Zn	0.8	0.4	0.4
Na	141.1	13.1	9.2
Pb	1.0	0.2	0.5
Ni	0.7	0.1	0.2
Cd	0.01	0.1	0.03
Cr[1]	49.2	20.7	8.2
B	2.1	--	--
Soluble salts (mmhos/cm)	2.35	0.10	0.17

[1]Chromium values are for total concentrations. Values for all other metals are extractable concentrations.

Table 3. Average Concentrations of Constituents in the Scott Paper Sludge and Sludge-Fly Ash Mixture

Constituent	Sludge	Sludge-Fly Ash Mixture
pH		8.4
	% on a dry weight basis	
Total N	0.18	0.04
Total P	0.04	0.21
Ca	6.94	2.27
Mg	0.11	0.28
Na	0.16	0.15
K	0.01	0.64
Al	1.99	3.43
Fe	0.10	2.57
	----------mg/kg----------	
Mn	37.2	151.3
Zn	1403.4	130.6
Cu	28.7	46.7
Pb	79.1	23.7
Cr	19.3	30.9
Ni	10.7	23.7
Cd	0.1	0.1
Hg	0.1	0.4
Solids (%)	35.1	69.5

on sludge use for mine land reclamation allows a maximum lifetime loading of only 280 kg/ha of zinc. Thus, the maximum application that could be used would be 202 Mg/ha of sludge. However, it should be noted that this zinc constraint is moderated by the dilution effect when the sludge is mixed with fly ash. Average Zn concentration in the sludge-fly ash mixture was only 131 mg/kg.

Tree Seedling Height Growth

Average tree seedling height growth at time of harvest and tree seedling shoot and root biomass are given in Table 4. Height growth of all tree species in control pots were significantly higher than seedlings in the amended refuse and spoil pots. The control values for all portions of the study simply provide a comparison value. The control values represent tree seedling responses growing under optimum conditions. A true control would have been to seed the tree species in pots filled with unamended refuse and spoil. This was not done because, in all probability, seedling mortality would have been great and seedling growth would not have been sufficient for analyses. Height growth of catalpa and birch were not significantly different among the four treatments. Among the four amendment treatments, black locust had the best height growth in the 30S pots and the poorest height growth in the 50R and 50S pots. On the other hand, tree of heaven had significantly higher growth in the 50R and 30R pots than in the spoil pots.

Table 4. Average Tree Seedling Height at Time of Harvest and Shoot and Root Biomass.

Species	Treatment	Average Height	Shoot Biomass	Root Biomass
		cm	g/seedling	g/seedling
Catalpa	C	38.0a[1]	2.91a[1]	2.07a[1]
	50%Refuse	15.4b	0.57b	0.71b
	30%Refuse	15.5b	0.51b	0.69b
	50%Spoil	13.2b	0.49b	0.75b
	30%Spoil	15.7b	0.61b	0.66b
Black Locust	C	34.7a[1]	1.74a[1]	1.54a
	50%Refuse	15.4d	0.78b	0.88b
	30%Refuse	17.1c	0.70b	0.81b
	50%Spoil	14.7d	0.87b	0.95b
	30%Spoil	20.5b	0.97b	1.58a[1]
Tree of Heaven	C	21.7a[1]	3.83a[1]	1.41a[1]
	50%Refuse	10.6b	1.07b	0.67b
	30%Refuse	9.5b	0.56c	0.35c
	50%Spoil	6.5c	0.35c	0.24c
	30%Spoil	7.6c	0.57c	0.32c
Birch	C	23.5a[1]	1.42	0.34
	50%Refuse	5.9b	0.51[2]	0.09[2]
	30%Refuse	5.2b	0.47[2]	0.10[2]
	50%Spoil	4.5b	0.19[2]	0.04[2]
	30%Spoil	4.4b	0.15[2]	0.03[2]

[1]Significant effect at P<0.001 by Duncans Multiple Range Test
[2]Average biomass per pot of all seedlings

Tree Shoot and Root Biomass

Shoot biomass includes the entire above ground biomass (stem and foliage) for a single seedling, except for birch. Birch seedlings were too small to thin to a single seedling per pot. Root and shoot biomass of all seedlings growing in a pot were combined for analyses. Root and shoot biomass of all tree species were significantly greater in the control pots. Shoot biomass of catalpa and black locust were not significantly different among the four treatments. However, tree of heaven root biomass was significantly greater in the 50R pots than in the other three treatments. Among the four treatments, birch had the greatest shoot biomass in the 50R pots. No statistical analyses could be made. Catalpa root biomass was not significantly different among the four treatments. Black locust had the greatest root biomass in the 30S pots. Root biomass was similar in the other three treatments. Tree of heaven root biomass was significantly greater in the 50R pots than in the other three treatments.

Tree Foliar Biomass Analyses

Average concentrations of macronutrients in the foliage of the tree species are given in Table 5. Tree of heaven foliar N, K, and Ca concentrations were not significantly different among the four treatments except for K in the 50%R treatment.

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

Species	Treatment	N	P	K	Ca	Mg
		%				
Tree of Heaven	C	3.95a[4]	0.64a[2]	2.36a[3]	0.72b	0.63a[2]
	50R	3.77ab	0.35b	2.26a	1.13a	0.47b
	30R	3.41ab	0.29c	1.94b	1.25a[3]	0.40c
	50S	3.30b	0.37b	1.78b	1.13a	0.47b
	30S	3.66ab	0.36b	1.86b	1.19a	0.43bc
Catalpa	C	4.36a[2]	0.84a[2]	1.94a	0.52c	0.57a[4]
	50R	3.39b	0.53b	1.79a	0.72b	0.43a
	30R	3.29b	0.47b	1.98a	0.84a	0.38b
	50S	3.34b	0.51b	1.83a	0.77ab	0.41a
	30S	3.44b	0.49b	1.95a	0.86a	0.41a
Black Locust	C	4.11a	2.18a[2]	2.19ab	143d	0.81a[2]
	50R	4.29a	0.36b	1.97c	190c	0.40c
	30R	3.94a	0.43b	2.38a[3]	208c	0.39c
	50S	3.59a	0.32b	2.03bc	244b	0.52b
	30S	4.14a	0.29b	2.04bc	320a[2]	0.38c
Birch [1]	C	3.79	1.03	1.86	0.58	0.64
	50R	3.98	0.47	2.29	0.89	0.40
	30R	4.09	0.48	2.46	1.05	0.40
	50S	4.09	0.51	2.40	1.30	0.54
	30S	4.09	0.51	2.40	1.30	0.54

[1] All foliage combined into one sample for analyses
[2] Significant effect at P<0.001 by Duncans Multiple Range Test
[3] Significant effect at P<0.01 by Duncans Multiple Range Test
[4] Significant effect at P<0.05 by Duncans Multiple Range Test

Foliar P and Mg concentrations were similar for all treatments except 30R which had significantly lower concentrations. Similarly, catalpa foliar concentrations of N, P, and K were not significantly different among the four treatments. Foliar Ca concentrations were similar in all treatments, except 50R, which was significantly lower. Catalpa foliar Mg concentrations were similar in all treatments, except 30R, which was significantly lower. Black locust foliar concentrations of N and P were similar in all four treatments. Foliar K concentrations were similar in all treatments, except 30R, which had significantly higher concentrations. Foliar Ca concentration was significantly higher in the 30S pots. Second highest foliar Ca concentrations were found in the 50S pots. Foliar Ca concentrations were similar and significantly lower in the 50R and 30R pots. Foliar Mg concentrations were similar in all treatments, except 50S, which was significantly higher. Birch foliar concentrations of N, P and K were quite similar in all four treatments. Foliar Mg concentrations were the highest in the spoil pots (50S and 30S). Foliar concentrations of all macronutrients are at levels which would indicate sufficient nutrients were available to support optimum tree seedling growth.

Average concentrations of Mn, Fe, B and Al in the foliage of the tree species are given in Table 6. Foliar concentrations of Mn, Fe, B, and Al were below the suggested tolerance level in all tree species except birch. Birch seedlings in the control pots and in the 30S pots had excessive foliar concentrations of Mn and Al, respectively. The suggested tolerance levels are not phytotoxic levels but suggest foliar concentration levels at which one may expect to get decreases in growth. For some unknown reason the seedlings of all tree species growing in control pots had high foliar concentrations of all four elements.

Foliar Al concentrations in tree of heaven were similar for all four treatments. Foliar Mn was similar in all treatments, except 30R, which had significantly lower concentrations. Foliar Fe and B concentrations were similar for all treatments, except for 50R, which had significantly higher concentrations. Catalpa foliar Fe concentrations were similar for all four treatments. Foliar concentrations of Mn and Al were similar in all treatments, except 30R which had a significantly lower concentration of Mn and 50R which had a significantly lower concentration of Al. Black locust foliar concentrations of Fe and B were similar in all four treatments. Foliar Mn concentrations were similar in all treatments, except 30S, which had significantly higher concentrations. Foliar concentrations of Al were similar in all treatments, except 50S which had significantly higher concentrations.

Average concentrations of trace metals in the foliage of the tree species are given in Table 7. Concentrations of all trace metals in the foliage of all tree species were below the suggested tolerance levels (Melsted, 1973). The suggested tolerance levels are not phytotoxic levels but suggest foliar concentrations at which decreases in growth may be expected. For tree of heaven, concentrations of Cu, Zn, Pb, Ni and Co were significantly different between the refuse and the spoil treatments with higher values generally in the refuse treatments. There were no significant differences in concentrations of Cd and Cr among the four treatments. For catalpa, concentrations of Pb, Cd, Ni, Co, Zn and Cr were significantly different between the refuse and spoil treatments with higher values in the spoil treatments except for Co which were higher in the refuse treatments. There were no significant differences in concentrations of Cu among the four treatments. Concentrations of Zn were

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

Species	Treatment	Mn	Fe	B	Al
		----------	mg/kg	----------	
Tree of Heaven	C	247a[2]	142a[2]	46b	21a
	50R	218ab	108b	56a[2]	28a
	30R	85c	79c	37c	25a
	50S	163b	81c	42bc	21a
	30S	183b	95bc	41c	26a
Catalpa	C	198a[2]	223a[2]	30ab	32ab
	50R	117b	104b	34a[4]	25b
	30R	75c	92b	29ab	30ab
	50S	107b	92b	33a	41a
	30S	115b	115b	28b	43a[4]
Black Locust	C	168a[2]	447a[2]	36a	26b
	50R	47c	64b	37a	23b
	30R	39c	65b	30a	29b
	50S	64bc	65b	34a	65a[3]
	30S	79b	76b	32a	39b
Birch[1]	C	585	342	50	31
	50R	92	111	35	152
	30R	73	165	31	184
	50S	54	187	36	321
	30S	96	715	34	895
Suggested Tolerance Level (Melsted, 1973)		300	750	100	200

[1]All foliage combined into one sample for analyses
[2]Significant effect at $P<0.001$ by Duncans Multiple Range Test
[3]Significant effect at $P<0.01$ by Duncans Multiple Range Test
[4]Significant effect at $P<0.05$ by Duncans Multiple Range Test

similar for all treatments, except for the 50S treatment which had significantly higher concentrations. For black locust, concentrations of Cu, Zn, Ni, Cd, and Co were significantly different between the refuse and spoil treatments with higher values of Cu and Zn in the refuse treatments and higher values of Ni, Cd, and Co in the spoil treatments. There were no significant differences in concentrations of Pb and Cr among the four treatments. No statistical analyses could be made on the birch data, since insufficient growth occurred to provide analyses of individual replications. The results shown are for one composite sample of each treatment. In general, concentrations of Cu and Zn were higher in the refuse treatments and concentrations of Pb, Cd, Ni, Co, and Cr were higher in the spoil treatments.

A comparison of the amendment mixtures in the refuse (50R and 30R) indicates that, in general, both black locust and birch had higher trace metal foliar concentrations in the 30R mixture. Foliar trace metal concentrations in the tree of heaven and catalpa species were highly variable and showed no significant pattern between the two mixtures.

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

Species	Treatment	Cu	Zn	Pb	Cd	Ni	Co	Cr
		mg/kg						
Tree of Heaven	C	19abc	54ab	8a[4]	0.13a	3.1b	1.4c	0.22a
	50R	21a[4]	59a[2]	6b	0.23a	3.7a	1.8a	0.25a
	30R	21a	49b	6b	0.16a	3.9a[2]	1.9a[2]	0.09a
	50S	17c	41c	6b	0.16a	2.9b	1.6b	0.15a
	30S	18bc	36c	7ab	0.11a	3.2b	1.6b	0.11a
Catalpa	C	19a	93a	7ab	0.46a[4]	3.1b	1.3ab	0.30b
	50R	34a	79a	6ab	0.22c	3.1b	1.4ab	0.19b
	30R	19a	70a	6ab	0.27bc	2.6b	1.6a[4]	0.21b
	50S	39a	128b[4]	8a[4]	0.33abc	2.8b	1.3b	0.39b
	30S	16a	77a	5b	0.41ab	4.1a[3]	1.4ab	0.91a[2]
Black Locust	C	12c	98a[3]	13a[2]	0.21c	4.5d	2.2c	0.39a
	50R	17b	76bc	8b	0.24c	5.8c	2.1c	0.10a
	30R	22a[2]	85ab	9b	0.28bc	7.2b	2.8b	0.17a
	50S	15bc	79bc	9b	0.35ab	7.5b	2.8b	0.29a
	30S	14bc	69c	9b	0.41a[3]	8.6a[2]	3.9a[2]	0.68a
Birch	C[1]	23	280	8	0.42	3.5	1.4	0.52
	50R	42	277	8	0.52	5.2	2.3	0.40
	30R	50	285	9	0.54	5.1	2.8	0.60
	50S	37	263	11	0.72	5.9	2.9	0.60
	30S	47	178	10	0.72	9.2	4.1	1.98
Suggested Tolerance Level (Melsted, 1973)		150	300	10	3	50	5	2

[1]All foliage combined into one sample for analyses
[2]Significant effect at $P<0.001$ by Duncans Multiple Range Test
[3]Significant effect at $P<0.01$ by Duncans Multiple Range Test
[4]Significant effect at $P<0.05$ by Duncans Multiple Range Test

A comparison of the amendment mixtures in the spoil (50S and 30S) indicates that, in general, all tree species had higher foliar concentrations of Cu, Zn, and Pb in the 50S pots and higher concentrations of Cd, Ni, Co, and Cr in the 30S pots.

Grass Height Growth

Average height growth and shoot and root biomass for the two grass species are given in Table 8. Tall fescue height growth was the greatest in the 50R pots and the least in the 30S pots. On the other hand, orchardgrass height growth was similar for all treatments, except 30S, which had significantly less height growth.

Grass Shoot and Root Biomass

Root biomass of both grass species were not significantly different among the four treatments. Shoot biomass represents the total dry matter production of the two harvests. There was no significant difference in orchardgrass shoot biomass among the four treatments. However, tall fescue had significantly greater biomass in the 50R and 30S pots than in the other two treatments.

Table 8. Grass species Height Growth and Shoot and Root Biomass at Time of Second Harvest in Pots Amended with Sludge-Fly Ash Mixture.

Species	Treatment	Average Height	Shoot Biomass	Root Biomass
		cm	g/pot	g/pot
Tall Fescue	C	24.3a[1]	4.68a[1]	1.95a
	50R	16.6b	3.61b	2.15a
	30R	10.6d	2.98c	1.86a
	50S	10.8d	3.14c	2.91a
	30S	12.1c	3.53b	2.29a
Orchardgrass	C	26.3a[1]	5.22a[1]	3.38a[1]
	50R	15.7b	2.53b	1.94b
	30R	16.5b	2.16b	1.53b
	50S	16.5b	2.60b	1.61b
	30S	12.9c	2.28b	1.46b

[1]Significant effect at P<0.001 by Duncans Multiple Range Test

Grass Shoot Biomass Analyses

Average concentrations of macronutrients in the foliage of the grass species are given in Table 9. Foliar concentrations of K and Ca were similar for all treatments for both grass species. Tall fescue foliar N and Mg concentrations were the highest in the two refuse treatments and the lowest in the two spoil treatments. Foliar P concentrations were similar in all treatments, except 50R, which had a significantly higher concentration.

The following is the normal range of macronutrients found in grass foliage samples analyzed at the Penn State Merkle Lab. Most of samples analyzed at the Lab are from normal farming operations on land not disturbed by mining.

Table 9. Concentrations of Macronutrients in the Foliage of the Grass Species.

Species	Treatment	N	P	K	Ca	Mg
		%				
Tall Fescue	C	3.79a[1]	1.29a[1]	3.84a[2]	0.37b	0.61a[1]
	50R	2.63b	0.65b	3.45b	0.72a	0.44b
	30R	2.39bc	0.50c	3.26b	0.75a[1]	0.40c
	50S	2.03d	0.44c	3.23b	0.68a	0.36d
	30S	2.11cd	0.50c	3.35b	0.69a	0.35d
Orchardgrass	C	3.65a[1]	1.16a[1]	4.67a[1]	0.29b	0.48a[1]
	50R	2.60bc	0.68b	3.60b	0.75a[2]	0.36b
	30R	2.61bc	0.63bc	3.56b	0.69a	0.31bc
	50S	2.31c	0.50d	3.18b	0.66a	0.31bc
	30S	2.94b	0.54cd	3.32b	0.70a	0.29c

[1]Significant effect at P<0.001 by Duncans Multiple Range Test
[2]Significant effect at P<0.01 by Duncans Multiple Range Text

Element	Concentration Range
	%
N	1.57-2.94
P	0.16-0.30
K	1.07-2.31
Ca	0.29-0.69
Mg	0.10-0.22

Foliar concentrations of all macronutrients are at levels which would indicate sufficient nutrients were available to support optimum growth.

Average Concentrations of Mn, Fe, B and Al in the foliage of the grass species are given in Table 10. Concentrations of Mn, Fe, B, and Al in tall fescue foliage were well below the suggested tolerance levels. Similarly, concentrations of Fe, B, and Al in orchardgrass were well below the suggested tolerance levels. However, Mn concentrations in orchardgrass were slightly above tolerance levels and may have affected plant growth. Orchardgrass had the least height growth and root biomass in the 30S pots where the highest foliar Mn concentrations were also found.

Average concentrations of trace metals in the foliage of the grass species are given in Table 11. Concentrations of all trace metals in both grass species were well below the suggested tolerance levels in all treatments. For tall fescue, there were no significant differences in foliar concentrations of Cu, Zn, Pb, Cr, Ni, and Co among the four treatments. Cadmium was the only element which was significantly higher in the refuse treatments. For orchardgrass, concentrations of Co and Cr were not significantly different among the four treatments. However, foliar concentrations of Cu, Zn, Pb, Cd, and Ni were significantly different between the refuse and spoil treatments with higher values generally found in the refuse treatments.

A comparison of the amendment mixtures in the refuse (50R and 30R) indicates that, in general, both tall fescue and orchardgrass had higher trace metal concentrations in the

Table 10. Concentrations of Mn, Fe, B, and Al in the Foliage of the Grass Species.

Species	Treatment	Mn	Fe	B	Al
		mg/kg			
Tall Fescue	C	387a[1]	65a[2]	21a[1]	14a
	50R	103c	52b	13b	13a
	30R	76d	53b	10b	24a
	50S	130b	51b	12b	28a
	30S	140b	53b	11b	31a
Orchardgrass	C	393a[1]	61ab	17bc	26a
	50R	159b	68a[3]	20b	20a
	30R	157b	64ab	14c	29a
	50S	310a	57b	26a[1]	16a
	30S	316a	68a	16bc	15a
Suggested Tolerance Level (Melsted, 1973)		300	750	100	200

[1]Significant effect at P<0.001 by Duncans Multiple Range Test
[2]Significant effect at P<0.01 by Duncans Multiple Range Test
[3]Significant effect at P<0.05 by Duncans Multiple Range Test

Table 11. Concentrations of Trace Metals in the Foliage of the Grass Species.

Species	Treatment	Cu	Zn	Pb	Cd	Ni	Co	Cr
		mg/kg						
Tall Fescue	C	22a[1]	129a[1]	7a	0.70ab	2.9b	1.8b	0.47a
	50R	10b	46b	6a	0.76a	3.8a[3]	1.8b	0.27a
	30R	8b	39b	6a	0.58b	3.6a	1.8b	0.40a
	50S	8b	38b	6a	0.14c	3.6a	1.9b	0.13a
	30S	8b	35b	6a	0.16c	3.6a	2.0b	0.23a
Orchardgrass	C	20a[1]	118a[1]	7a[3]	0.19a	4.4a[2]	2.0a	0.43a[3]
	50R	10b	68b	7a	0.24a[2]	4.1ab	2.0a	0.26ab
	30R	8bc	48c	6b	0.13b	3.6bc	1.9a	0.21ab
	50S	7c	50c	4c	0.10b	3.5c	1.8a	0.23ab
	30S	10b	49c	4c	0.19a	4.0ab	1.9a	0.06b
Tolerance Level		150	300	10	3	50	5	2

[1]Significant effect at $P<0.001$ by Duncans Multiple Range Test
[2]Significant effect at $P<0.01$ by Duncans Multiple Range Test
[3]Significant effect at $P<0.05$ by Duncans Multiple Range Test

plants growing in the 50R mixture. This is as expected, since these pots contained the largest amounts of the sludge and fly ash which represent the sources of the trace metals. This phenomena was not observed with the two spoil mixtures (50S and 30S). Trace metal concentrations in both grass species were highly variable with no obvious pattern.

Conclusions

Results of the study indicate that the sludge-fly ash mixture could be used successfully to revegetate coal refuse banks and strip mine spoil banks with trees and grasses. There was no clearcut difference between the two application rates (50% and 30% mix by volume). However, it is recommended that the 50% mix be used under field conditions because the greater amount of sludge and fly ash would improve the physical properties of the refuse and spoil making them better growing mediums.

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