REFORESTATION OF A ZINC SMELTER SUPERFUND SITE[1]

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Abstract.--Over 800 ha of forest vegetation have been destroyed on Blue Mountain at Palmerton, PA, primarily by emissions of Zn, Cd, Cu, Pb, and SO_2 from a zinc smelter operating since 1898. In 1982, the site was designated as a "Superfund" site. In 1985, a cooperative research effort was initiated to develop a remedial action program to mitigate the environmental damage. Field plot studies were conducted to determine the feasibility of using mixtures of dewatered municipal sludge and fly ash as amendments to facilitate the establishment of vegetation on the highly contaminated soil. Three mixtures of sludge (S) and fly ash (FA) were evaluated (1S:1FA, 2S:1FA, and 3S:1FA). The amendments were applied to 0.4-ha plots in May 1985. Seedlings of 10 tree species and hybrid poplar cuttings were planted on the plots in 1986 and 1987. Seedling survival was poor in 1986 due to the late planting date, but survival in 1987 was excellent. Species survival ranged from 44 to 91 percent across all treatments. The highest survival rate (80%) for all species was found on the 2S:1FA treatment. Larch and black cherry had the best height growth. Foliar concentrations of Cu, Ni, Cr, Co, and B were generally below the tolerance level for growth suppression in all species on all treatments. Foliar concentrations of Mn, Fe, Al, Zn, Pb, and Cd were all above the tolerance level in most species on all three treatments. However, no phytotoxicity symptoms were observed. Results to date indicate that all three sludge-fly ash mixtures were successful in facilitating tree seedling establishment on the highly contaminated soil.

[1]Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA. The research described in this article has been funded wholly by the U.S. Environmental Protection Agency, Region III; it has not been subjected to Agency review and therefore does not necessarily reflect the view of the Agency, and no official endorsement should be inferred.

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Proceedings America Society of Mining and Reclamation, 1988 pp 68-73

DOI: 10.21000/JASMR88020068

https://doi.org/10.21000/JASMR88020068

INTRODUCTION

In 1900 the north slope of Blue Mountain at the Lehigh Water Gap in the vicinity of Palmerton, PA was a densely forested area of chestnut, white pine, and mixed oak species. Today, it is a barren, devastated, biological desert. Approximately fifty percent of the slope area is strewn with rocks and boulders exposed by severe erosion over the past 50 years which has removed about 30 cm of the original surface soil.

The major cause of denudation was emissions of Zn, Cd, Cu, Pb, and SO_2 from a zinc smelting plant which has been operating in Palmerton since 1898 (Buchauer 1973). In addition, the area was also subjected to extensive logging and frequent fires (Jordan 1975). Natural revegetation has been hampered primarily by the high Zn concentrations in the surface mineral soil and organic detritus material present on the area. Soil nutrients have been washed away, microorganism populations are virtually nonexistent, and the surface soils are droughty with extreme variations in microclimate. As a result the normal balance of vegetation, soil microorganisms, and the recycling of soil nutrients have been severely disrupted by the 50 years of accelerating denudation and erosion.

During the period 1977 to 1983 numerous attempts were made by the Soil Conservation Service to establish vegetation, both herbaceous and trees, on the contaminated soil on Blue Mountain. These attempts used various applications of lime and fertilizer, and species hoped to be tolerant were seeded or planted. Most of these experiments were failures and illustrated dramatically that the Blue Mountain site was too toxic to be revegetated by any conventional techniques.

The Blue Mountain site represents a unique set of reclamation challenges. First of all, the area is totally inaccessible to vehicles because the slopes are covered by rocks, boulders, and undecomposed tree stems. Access would only be possible by bulldozing new roads. The slopes are steep, averaging 30% and ranging from 25 to 100 percent. Most vehicles used to spread lime, fertilizer, or sludge must be able to traverse the site. This is not possible on this site, so that it would be necessary to use a spreading vehicle which could apply the amendments aerially considerable distances (30 to 45m) onto the slopes. Incorporation of the amendments, a usual practice, would also not be possible on this site. And lastly, the surface soil is highly contaminated with trace metals, providing another impediment to vegetation establishment. Background surface soil samples taken downwind of the smelter approximately at midslope on Blue Mountain contained 31,316 ppm of Zn, 5,225 ppm of Pb, and 1,248 ppm of Cd (Shoener et al. 1987). The normal ranges for uncontaminated soils in the United States are 10-300 mg/kg for Zn, 2-200 mg/kg for Pb, and 0.01 to 7.00 mg/kg for Cd (Allaway 1968). A considerable portion of the area is also covered with a layer of black humus detritus that appears to be undecomposed tree bark. Analyses of this material showed equally high concentrations of trace metals --29,475 ppm of Zn, 1,221 ppm of Cd, and 6,237 ppm of Pb. Soil samples taken to a depth of 90 cm indicated that the depth of adverse contamination for Zn (>200 ppm) and Cd (>5 ppm) ranged from 5 to 30 cm. As far as it could be ascertained, reclamation of such a site has never been attempted.

In 1982, the area was placed on the National Priorities List and designated as a "Superfund" site by the U.S. Environmental Protection Agency. Under a consent agreement signed September 25, 1985, a Remedial Investigation/Feasibility Study was initiated to find a remedial action program which would mitigate the environmental damage. Cooperating with the U.S. Environmental Protection Agency were the Department of Public Works, City of Allentown; Pennsylvania Power and Light Company; the Soil Conservation Service, USDA; and the Environmental Resources Research Institute, The Pennsylvania State University (Shoener et al. 1987).

It was quite obvious that attempting to plant or direct seed vegetation on the existing soil surface would be futile since natural revegetation had not occurred over the past 50 years. It is not possible for grass, legume, and tree species to germinate and survive when seeded directly on the highly contaminated soil. Thus, it was concluded that some type of growing medium had to be placed on top of the contaminated soil. Some possibilities were topsoil, peat-vermiculite potting mixtures, and waste products. Economics eliminated the first two possibilities, so attention was focused on local waste products. It was decided to investigate sludge and fly ash because of the potentially large volumes that might be needed. The hypothesis being evaluated is to determine if vegetation germination, survival, and growth can be facilitated by using various mixtures of sludge and fly ash as a growing medium on top of the contaminated soil to provide a nutrient support system for the vegetation until some part of the root system penetrated the highly contaminated surface soil (5 to 30 cm) to reach the uncontaminated subsoil. The assumption is that vegetation survival will be greatly enhanced once the roots reached the normal uncontaminated subsoil.

Since the sludge could not be incorporated, it did not seem feasible to apply sludge alone. Its poor physical characteristics (wetting and drying) when applied on the soil surface without incorporation would not be conducive to seed germination. Thus, the decision was made to use the fly ash in a mixture with sludge to make a more friable product.

Based upon analyses of dewatered digested sludge from the Allentown wastewater treatment plant and fly ash from the Pennsylvania Power and Light generating plant, the decision was made to evaluate three sludge-fly ash mixtures. The mixture ratios (on volume basis) selected for evaluation were 1S:1FA, 2S:1FA, and 3S:1FA.

GREENHOUSE EXPERIMENT

A greenhouse experiment was conducted over the 1985-86 winter period to test the hypothesis. Evaluations were made of the three sludge-fly ash mixtures, and 12 tree species were screened. The 12 tree species were seeded in containers 10 by 10 cm in area and 20 cm in height. Each container was filled with 5 cm of sand in the bottom, followed by 4 cm of contaminated soil from Blue Mountain, and then 10 cm of the various sludge-fly ash mixtures.

The seedlings were grown for 90 days. Measurements were made of height growth, foliar biomass, and root biomass. The latter were also analyzed for nutrients and trace metals. During harvesting, observations were made of root distribution and depth of root penetration. Root systems of most of the tree species developed sufficiently to penetrate through the sludge-fly ash mixture and the contaminated soil into the underlying sand layer. There was no evidence of any roots attempting to avoid entry into the contaminated soil layer. Foliar trace metal concentrations were generally low for all tree species and no phytotoxicity symptoms were observed.

The results of the greenhouse experiments confirmed the feasibility of the proposed remedial action program. Detailed results of these experiments have been reported (Sopper 1987).

FIELD TRIALS

In May 1986 nine 0.4-ha plots were established along a road bulldozed to provide access to the midslope area of Blue Mountain. The plots were located in sets of three for the application of the three sludge-fly ash mixtures. Because of the low potassium content of the sludge, a potassium supplement equivalent to 90 kg/ha was applied to the plots with the lime. Lime was applied at 22 Mg/ha which was double the amount required to raise pH to 7.0 based on a soil analysis. The lime was applied at this higher rate because of the extremely high concentrations of trace metals in the black humus detritus material that sporadically covers large areas. The lime and potash were applied to the plots using an Estes "Aerospreader" truck.

The application rates for the sludge-fly ash mixtures were determined on the basis of previous research results using sludge to revegetate barren strip mine land (Seaker and Sopper, 1984). From that research it was found that successful vegetation establishment was assured if the sludge were applied at a rate sufficient to supply a minimum of 1,120 kg of total nitrogen per hectare. Because of the high N concentration in the Allentown sludge only about 22 Mg/ha would have to be applied to supply 1,120 kg N per hectare. However, this amount would not provide sufficient depth of growing medium to support vegetation. Therefore, it was decided to double the application rate. This application rate would create a large enough pool of nutrients (N and P) to sustain vegetation growth for at least 3 to 5 years.

As a result of the severe erosion, the site is very rocky with fairly large boulders with only a small amount of mineral soil exposed in the interstitial space. A previous survey was made in the vicinity of the field plots to determine the percentage of interstitial space available for vegetation establishment. The average percentage of interstitial space was 53 percent and ranged from 31 to 71 percent. This means that, on the average, only about one-half of each hectare is available for amendment application and vegetation establishment.

Amendment Applications

Typical chemical analyses of the sludge and fly ash used in this project are given in table 1. These are the average values for several composite samples collected as the products were unloaded at the storage area at the base of Blue Mountain. The two amendments were mixed at the storage area with a front-end loader and applied to the plots with an Estes "Aerospreader" truck. The amounts of chemical constituents applied with each mixture is given in table 2. These values were calculated from analyses of samples collected during application of the mixtures to the plots. The amounts of trace metals applied in all mixtures were well below the allowable maximum amounts recommended by the Pennsylvania Department of Environmental Resources for mine land reclamation. The maximum allowable lifetime trace metal loading rates are as follows:

Element	Amounts (kg/ha)
Zn	224
Cu	112
Pb	112
Cr	112
Ni	22
Cd	3

Each field plot was subdivided into five subplots for hydroseeding of five different seed mixtures. All field plots were mulched with CELLIN fiber mulch at an approximate rate to 2,240 kg/ha. Mulch was applied with a hydroseeder. Results of the herbaceous vegetation growth responses are described by Oyler elsewhere in these Proceedings.

Ten species of tree seedlings were then planted on the field plots during the period June 2-5, 1986. Five seedlings of each species except hybrid poplar were

Table 1.--Typical chemical analyses of the sludge and fly ash used on experimental field plots on Blue Mountain, PA.

Constituent	Sludge Concentration[1]	Fly Ash Concentration[1]
	--%--	--mg/kg--
Total P	1.06	70
Total N	3.59	--
NH_4-N	0.45	--
Org-N	3.14	--
Ca	5.10	5240
Mg	0.35	72
Na	0.12	88
K	0.23	211
Al	1.99	23
Fe	2.94	25
B	--	12
	--mg/kg--	
Mn	839	2.5
Zn	1763	15
Cu	747	3.8
Pb	154	1.2
Cr	379	43
Ni	94	0.3
Cd	9	0.2
Hg	1.4	--
Solids (%)	23	--
Soluble Salts (mhos x 10^5)	--	227

[1]The pH was 8.3 for the sludge, and 8.9 for the fly ash.

Table 2.--Sludge-fly ash mixture application rates and amounts of chemical constituents applied per hectare.

Constituent	1S:1FA* (kg/ha)	2S:1FA** (kg/ha)	3S:1FA*** (kg/ha)
Total P	1214	1120	991
Total N	2455	3030	2735
NH_4-N	282	297	314
Org-N	2172	2733	2421
Ca	5419	5466	3563
Mg	620	626	326
Na	197	148	101
K	1157	560	401
Al	9878	4791	3700
Fe	10131	6635	3939
Mn	43	464	26
Zn	100	109	59
Cu	68	83	53
Pb	26	19	16
Cr	46	39	34
Ni	22	18	10
Cd	0.9	0.9	0.8
Hg	0.1	0.1	0.1

1S:1FA*
47 dtS + 235 dtFA
235 wtS + 235 dtFA

2S:1FA**
47 dtS + 117.6 dtFA
235 wtS + 117.6 dtFA

3S:1FA***
47 dtS + 78 dtFA
235 wtS + 78 dtFA

planted on two of the replications of each sludge-fly ash mixture; ten hybrid poplar cuttings were planted on each plot. Tree seedling survival rates in 1986 were poor and were probably due to the late planting date. The seedlings were delivered in April and had to be kept in cold storage until June. As a result, some of the seedlings suffered desiccation, particularly the coniferous species. Early observations two weeks after planting indicated that many of the coniferous species never burst their terminal buds indicating that they were probably dead when planted. Evaluation of the 1986 planting has been reported by Sopper (1987).

In 1987 tree seedlings were again obtained from the Pennsylvania Bureau of Forestry nursery for planting on the field plots. Species planted are shown in table 3. The seedlings were planted during the period May 2-3, 1987. Seven seedlings of each species except hybrid poplar were planted on each field plot; ten cuttings of hybrid poplar were planted on each plot.

RESULTS

Survival and Height Growth

Survival counts and height growth measurements were made on September 10, 1987. Results are given in tables 3 and 4. The

Table 3.--Percentage tree seedling survival by amendment mixture.

Species	1S:1FA	2S:1FA	3S:1FA	All Treatments
White Pine	86	79	86	83
Austrian Pine	79	93	57	76
Virginia Pine	50	50	33	44
Red Pine	36	79	57	57
Larch	86	79	79	81
Black Locust	93	100	65	86
Arnot Bristly L.	64	79	65	69
Alder	72	100	100	91
Black Cherry	93	72	86	84
Sugar Maple	79	72	79	77
Hybrid Poplar	100	75	55	77
All Species	76	80	69	

Table 4.--Tree seedling height growth.

Species	1S:1FA	2S:1FA	3S:1FA	All Treatments
	--cm--			
White Pine	19	15	19	18
Austrian Pine	24	17	20	20
Virginia Pine	14	18	21	17
Red Pine	17	19	17	17
Larch	34	28	58	40
Black Locust	55	49	39	47
Arnot Bristly L.	46	35	46	42
Alder	59	53	46	52
Black Cherry	52	57	61	57
Sugar Maple	34	39	38	37
Hybrid Poplar	34	27	52	38
All Species	35	32	38	

highest rate of survival (80%) for all species was found on the 2S:1FA amendment. Species survival ranged from a low of 44 percent for Virginia pine to 91 percent for European alder. Species with the highest survival rates across all amendments were alder (91%), black locust (86%), black cherry (84%), white pine (83%), larch (81%), and hybrid poplar (77%).

There was little difference in average height growth within a species among the three amendments. Larch had the best height growth (40 cm) of the coniferous species, and black cherry had the best height growth (57 cm) of the hardwood species. The two species which exhibited the most vigorous growth were larch and alder.

Foliar Analyses

Foliar samples were collected on September 10, 1987, from all tree species and analyzed for nutrients (N-P-K), cations (Ca and Mg), and trace metals (Mn, Fe, Al, B, Cu, Zn, Pb, Cd, Ni, Co, and Cr). Nitrogen concentrations in the coniferous species ranged from 1.00 to 1.70 percent and in the hardwood species from 1.34 to 3.34 percent across all amendments. In general, the hardwood species had higher concentrations of nutrients and cations than the coniferous species. The results show a slight trend toward increases in nutrient concentrations with increasing amounts of sludge in the sludge-fly ash mixture. Within a species there was little difference in nutrient and cation concentrations among the three amendment mixtures.

Results of the foliar analyses for trace metal concentrations are given in table 5. Due to limited space, data are presented only for the potentially most toxic elements and selected species. Foliar concentrations of Cu, Ni, Cr, and Co were under the suggested tolerance level for all tree species on all amendments. The suggested tolerance levels are not phytotoxic levels but suggest foliar concentration levels at which one may expect to get decreases in growth (Melsted 1973). Similarly, foliar B concentrations were all below the suggested tolerance level for all tree species on all amendments except for black locust on the 1S:1FA mixture. Foliar Mn concentrations were all below the suggested tolerance level except for white pine on all three amendments and alder on the 2S:1FA mixture. Foliar Pb concentrations exceeded the suggested tolerance level in all species on all amendments. The highest foliar Pb concentration was 140 mg/kg in alder. Lead toxicity should not be a problem since Rolfe (1973) reported that leaf Pb concentrations from 40 to 90 mg/kg did not produce any phytotoxicity symptoms in some of the same species planted on this project. Foliar Cd concentrations equalled or exceeded the suggested tolerance level in all species on all amendments. Hybrid poplar had the highest Cd concentrations while alder and black cherry had the lowest concentrations. In general, within a species there was little difference in foliar trace metal concentrations among the three amendments. No phytotoxicity symptoms were observed on any species.

SUMMARY AND CONCLUSIONS

A field plot study was conducted to evaluate the feasibility of using mixtures of sludge and fly ash as amendments to facilitate the reforestation of a highly contaminated site at a zinc smelter in Palmerton, PA. Three mixtures of sludge (S) and fly ash (FA) were applied to 0.4-ha field plots in May 1986. The mixtures on a volume basis were 1S:1FA, 2S:1FA, and 3S:1FA. Seedlings of 10 tree species were planted in June 1986 and seedlings of 11 tree species were planted in May 1987. Measurements of survival and height growth were made each year. Foliar samples were collected at the end of the growing season for analyses for nutrients and trace metals concentrations. While seedling survival in 1986 was poor, primarily due to the late planting date, survival in 1987 was excellent. Species survival ranged from 44 to 91 percent across all three amendments. The highest survival rate (80%) for all species was found on the 2S:1FA amendment. Within a species there was little difference in average height growth among the three amendments. Larch and black cherry had the best height growth. Foliar concentrations of Cu, Ni, Cr, Co, and B were generally below the suggested tolerance level for growth suppression in all species on all three amendments. Foliar concentrations of Mn, Fe, Al, Zn, Pb, and Cd were all above the suggested tolerance level in most species on all three amendments. However, no phytotoxicity symptoms were observed on any species. Results indicate that all three sludge-fly ash mixtures were successful in facilitating tree seedling establishment on the highly contaminated soil. Monitoring of tree seedling survival and growth will continue for several years. However, while the research will continue, plans are being formulated to continue to apply the sludge-fly ash amendment to additional areas on Blue Mountain. It is anticipated that it will take about five years to revegetate the entire 800 ha.

Table 5.--Effects of sludge-fly ash amendments on selected trace metal concentrations in the foliage of tree seedlings.

Tree Species	Amendment Mixture	Mn	Cu	B	Zn	Pb	Cd	Ni
		mg/kg						
White Pine	1S:1FA	947	14	56	700	40	14	4
	2S:1FA	791	13	47	840	31	6	4
	3S:1FA	732	13	33	604	49	14	4
Larch	1S:1FA	103	7	66	408	34	6	3
	2S:1FA	170	8	84	402	33	5	3
	3S:1FA	159	7	71	450	42	4	3
Black Locust	1S:1FA	103	12	104	870	88	11	6
	2S:1FA	168	12	81	430	59	7	6
	3S:1FA	121	12	72	470	47	12	6
Alder	1S:1FA	154	25	57	1258	140	5	7
	2S:1FA	441	20	58	807	104	4	7
	3S:1FA	164	21	56	2070	76	3	10
Black Cherry	1S:1FA	121	12	29	1033	99	7	5
	2S:1FA	215	11	34	887	84	6	3
	3S:1FA	170	9	28	490	53	4	4
Hybrid Poplar	1S:1FA	106	9	64	1605	34	32	3
	2S:1FA	179	10	34	1650	70	27	4
	3S:1FA	89	10	47	4000	28	66	4
Suggested Tolerance Level		300	150	100	300	10	3	50

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