COPPER MINE TAILINGS RECLAMATION NEAR DUCKTOWN, TENNESSEE[1]

by

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Abstract. A century of copper and pyrite mining activities near Ducktown, Tennessee has resulted in several reclamation challenges. One such challenge is the revegetation of mine tailings, a by-product of the milling process for extraction of metals. Revegetation of mine tailings requires extensive chemical analysis to establish a reclamation protocol for future land use. The objectives of this study were to establish soil fertility regimes and apply biosolids to grass/legume mixtures to initiate vegetation on copper mine tailings. Two one-acre test plots were established and monitored over a one-year period. Initial chemical analysis indicated a phosphorous deficiency. Treatment variables included three phosphorous (P) treatments (50, 100, and 200 lb acre^{-1}), four grass/legume mixes (tall fescue, birdsfoot trefoil, kobe, Korean, and sericea lespedeza), and a biosolid and non-biosolid application. Plots were monitored using plant counts and fertility sampling quarterly throughout the year. Fescue responded well on the biosolid treated plots, but the legume population was extremely low. Kobe and Korean did well on the non-biosolid plot and this was related directly to the levels of P treatments. Overall, more vegetative cover (mainly fescue) was found on the biosolid treated plot. Phosphorous was found to be the key for successful establishment of vegetation.

Additional Key Words: anthropogenic, Copper Basin, revegetation, minesoil, biosolids

Introduction

Mining activities can cause severe environmental problems including the loss of vegetation. Over one hundred years, the impact of copper and pyrite mining in southeast Tennessee resulted in widespread denudation of vegetation. While the majority of environmental devastation was caused by massive timber harvesting and primitive separation processes, other environmental problems included the disposal of mine tailings, a mining by-product. Tailings are waste materials generated by the grinding and processing of ores and other materials containing economically retrievable minerals (Hossner and Hons, 1992).

The physical and chemical characteristics of tailings are very diverse. Mine tailings are often deficient in many essential plant nutrients. Copper mine tailings are generally deficient in nitrogen (N) and may lack other essential nutrients including phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) (Hossner and Hons, 1992; Day and Ludeke, 1973; Shetron, 1983). Initial investigations by Branson *et al.* (1999) showed the tailings in the Copper Basin were deficient in P (<.5 mg kg^{-1}).

Day and Ludeke (1980) reported revegetation difficulties in copper mine waste in southwestern United States were associated with deficiencies of essential plant nutrients. Previous research on copper mine tailings has shown that with the amendments of N, P, and K, revegetation attempts have been successful (Gemmell, 1977; Ludeke *et al.*, 1974; Hossner and Hons, 1992).

Acid drainage due to sulfide oxidation may be associated with mine tailings (Hossner and Hans, 1992). Exposure of sulfide-bearing minerals (pyrite, pyrrhotite, chalcopyrite, arsenopyrite, cobaltite) to the atmosphere is a common result of mining. During the mining process, not all pyritic materials are removed from the tailings product, thus they may have high concentrations of sulfide

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materials. When these minerals are exposed, they react with water and oxygen forming sulfuric acid (H_2SO_4) consequently reducing pH, increasing solubility of heavy metals, and limiting the availability of essential plant nutrients in the tailings (Foy, 1974).

Some tailings may contain toxic ions in sufficient concentrations to prevent revegetation. Tailings are known to contain toxic substances and high levels of heavy metals from the original ore and as a by-product of the processing operation (Whitby and Hutchinson, 1974; Lan *et al.*, 1997). Toxic ions may contaminate soils and waters that are adjacent to smelters (Rutherford and Bray, 1979) or tailings through seepage, runoff, and eroded sediments (Johnson and Eaton, 1980).

Tailings are usually devoid of vegetation and lack organic matter (OM) which can result in higher surface temperatures (Lan *et al.* 1997; Shetron, 1983; Hossner and Hons, 1992). Tailings with no vegetative cover can have temperatures of 55° to 65° C (Shetron, 1983). In sand tailings, the absence of OM and a predominance of course-sized particles often result in low water-holding capacity (Tanpibal and Sahunalu, 1989; Miles and Tainton, 1979). These high temperatures and lower water-holding capacity can cause high evapotranspiration rates limiting available water in the growing season (Shetron, 1983). Finer textured tailings usually have a greater water-holding capacity but may have poor structural characteristics from the consolidation and compaction of particles thus limiting water percolation (Hossner and Hons, 1992).

Another common problem associated with bare tailings is wind erosion (Johnson and Eaton, 1980). Wind blown particles can pollute air, chafe vegetation, decrease aesthetics, and create health problems for communities adjacent to the waste site (Hossner and Hons, 1992; O'neil *et al.*, 1998; Day and Ludeke, 1973). Erosion of tailings can also cause sedimentation in stream and river channels (Tanpibal and Sahunalu, 1989).

The application of biosolids from municipal wastewater treatment plants to anthropogenic soils can be advantageous in supplying essential plant nutrients including N, P, K, Ca, and Mg. The effects of a slow release of nutrients common in biosolids provide "residual" fertilization to vegetation (Sopper, 1992). Biosolids may even contribute to stabilization of soil structure and improve infiltration and water holding capacity (Younos *et al.*, 1982; Henry and Brown, 1997). Further, biosolids application may also increase pH, reducing heavy metal runoff. When biosolids were applied to copper tailings in Arizona, plant yield was increased compared to plots receiving only N, P, and K fertilizer treatments (Verma *et al.*, 1977). Sabey *et al.* (1990) reported increased levels of N, P, and K availability on copper mine spoils when municipal sewage sludge was added.

The application of biosolids can sometimes yield unfavorable results such as heavy metal contamination. Heavy metals that may pose problems include zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd), and lead (Pb) (EPA, 1977). On average, vegetation grown on soil receiving biosolids treatments generally have higher concentrations of these metals (Sopper, 1982). Although this may present problems with biosolids applications, heavy metal uptake can vary greatly among types of plants (EPA, 1977).

Past reclamation attempts on these tailings have been met with bleak results. The objectives of this study were to establish soil fertility regimes and apply biosolids to grass/legume mixtures to initiate vegetation on copper mine tailings.

Methods and Materials

Site Location

The study site was located near Ducktown in southeast Tennessee on a copper mine tailings pond. Approximate coordinates for the tailings pond are 35°02' N and 84°21' W on the Isabella Quadrangle (USGS, 1978). The study area is approximately 520 m (1700 ft) above sea level and receives approximately 152 cm (60 in) of precipitation, which is equally distributed throughout the year. Average temperatures range from 21°C (70°F) in the summer to 7°C (44°F) in the winter (NCDC, 2000).

Geology and Soils

Ducktown lies within the Copper Basin. This basin is an intermontane depression caused by bedrock erosion and is surrounded by mountains giving the area a bowl-like feature containing Precambrian aged sandstones, siltstones, and shales

(Moore, 1994). The Copper Basin lies within the rocks of the Copperhill Formation, primarily composed of metagraywackes, metagraywacke conglomerates, and metapelites (USGS, 1993). Soils on the tailings pond have been classified as mixed, mesic Typic Udipsamments (Cook *et al.*, 1999).

Field Methods

Two one-acre plots were measured 91.5 m (300 ft) long by 45.7 m (150 ft) wide. A 9.1 m (30 ft) wide aisle separated the two plots. A silt fence was set along the west, north, and eastern sides to decrease wind erosion (sand blasting). Plots were configured to a randomized block strip plot on biolsolids and grass/legume mixture with a split plot on P applications (Figure 1). Variables on the research plots included 1) phosphorous treatments, 2) grass/legume mixtures, and 3) biosolids/nonbiosolids application.

Various rates of P were amended into the soil so that different amounts could be monitored over time. Rates were 0 lb P acre^{-1} (control), 50 lb P acre^{-1}, 100 lb P acre^{-1}, and 200 lb P acre^{-1} designated as 0, 1, 2, and 3 respectively.

Lime was incorporated on both plots at a rate of 2 tons acre^{-1} to neutralize minimal amounts of acidity. Nitrogen was applied two different times. In September 1998, N was added at 50 lb N acre^{-1} in the form of ammonia nitrate. In March 99, N was added again at 50 lb N acre^{-1} in the form of sulfur-coated urea. Potassium was added in the form of potash at 50 lb K acre^{-1}.

Biosolids were added to the research area on one of the acre plots from the Moccasin Bend Treatment Plant, Chattanooga. The biosolids were applied at a rate of 4 tons acre^{-1} using a manure spreader and incorporated into the upper 6 inches of soil using a tiller. Of the 12 419 kg (27 380 lb) biosolids applied, 28% percent, or 3477 kg (7666 lb) was dry weight. The second one-acre plot did not receive biosolids application. Initial fertility sampling and incorporation of amendments were completed by Sept 1998.

Plant Species. Grass and legumes with high success rates over wide ranges of soil pH were chosen for this experiment. Tall fescue (*Festuca arundinacia* Schreb.), birdsfoot trefoil (*Lotus corniculatus*), sericea lespedeza (*Lespedeza cuneata*), kobe lespedeza (*L. striata*), and Korean lespedeza (*L. stipulacea*) were seeded with rates of 15 lb acre^{-1}, 10 lb acre^{-1}, 30 lb acre^{-1}, 40 lb acre^{-1}, and 25 lb acre^{-1}, respectively. Prior to seeding, seeds were inoculated with either *Rhizobium loti.* (Birdsfoot trefoil) or *Bradyrhizobium sp.* (Kobe, Korean, and sericea lespedeza).

The seeding of the grass/legume mixtures took place at two different times (Sep 1998 and Mar 1999) due to summer and fall drought conditions. Following the September seeding, both plots were mulched with wheat/rye straw (80 bales acre^{-1}).

Sampling. Fertility samples were obtained using a punch probe to 6 inches of soil in an "X" sampling pattern. Initial samples were taken prior to any soil treatments to establish preliminary fertility

Figure 1. Test plot layout.

Non-biosolids					Biosolids			
0	1	2	3	A B	2	0	3	1
1	2	3	0	C D	3	1	2	0
2	0	1	3	B A	0	1	3	2
1	3	0	2	C D	3	2	0	1

Legume/Grass Seed Mixture

A	Birdsfoot trefoil/Tall fescue
B	Sericea lespedeza/Tall fescue
C	Kobe lespedeza/Tall fescue
D	Korean lespedeza/Tall fescue

Phosphorus Amendments

0	0 lb acre^{-1} (Control)
1	50 lb acre^{-1}
2	100 lb acre^{-1}
3	200 lb acre^{-1}

Table 1. Mean acid-base account of test plots prior to soil amendments.

Percent Sulfur (pyritic)	Max acidity form %S $CaCO_3$ Equivalent	Neutralization Potential $CaCO_3$ Equivalent	Max Needed (pH 7)	Excess $CaCO_3$
	--------------------------------tons 1000 tons^{-1} of material			---------------------------
.045	1.41	129.6	0	128.19

characterization. Plots were monitored quarterly throughout the year by simultaneous plant counts and fertility sampling. A 1 ft by 1 ft wooden square was randomly thrown within each subplot to conduct plant counts. Plants inside the square were counted and recorded. Percent vegetative cover was estimated within the square. This sequence was repeated three times. During the final plant count, biomass samples on a 1.625 m^2 (17.5 ft^2) area from each subplot were taken. These clippings were dried and weighed to compare biomass weights. Statistical analysis was performed using the GLM procedure on SAS statistical software (SAS, 1990).

Laboratory Methods

Acid-base accounting was performed on initial samples to estimate potential acidity or alkalinity of the tailings material (Sobek *et al.*, 1978). Plant available P was determined using the sodium bicarbonate extractable P method (Olson *et al.*, 1954). Biosolids data was obtained by total elemental analysis to compare controls and various treatments (Ammons *et al.*, 1995). Total N was measured on all samples to monitor effects of the legumes (Sobek *et al.*, 1978).

Results and Discussion

Pyritic Acidity

Sulfuric acid forms from oxidizing S originating primarily from pyritic S. Mean percent pyritic S over both test plots was minimal (Table 1). There was a high amount of neutralizing bases in the tailings which was in excess of the maximum potential acidity possible from pyritic S. Therefore, there should be little or no potential acid problems in the tailings material. Paste pH on initial fertility samples showed ranges from 6.1 – 6.5.

Plant Responses to Soil Amendments

Scattered vegetation began appearing on both plots one month after initial seeding. Vegetation on the non-biosolids plot was sparser as compared to the biosolids plot. Winter wheat and rye began to appear on both plots resulting from high seed contamination in the straw.

Phosphorus. Initial fertility tests on the research plots showed P was a limiting nutrient with mean concentrations below 0.2 mg kg^{-1} (Table 2). Observations on the study site in November 1998 (2 months after treatment and seeding) revealed definite boundaries outlining P treatments with more vegetative response on plots receiving higher P amendments. In January 1999, vegetation growing on 0 and 1 P treatment plots showed typical purpling of leaves, indicative of P deficiencies.

Plant available P increased correlating to the three different applications of P on both the non-biosolids and biosolids plot (Table 2). When comparing the non-biosolids to biosolids plots, P concentrations were slightly higher on the

Table 2. Mean P concentrations of test plots.

P Treatment	Nonbiosolids	Biosolids
	----------------mg kg^{-1}	-----------
Preamend*	0.167	0.167
Control#	2.05	3.22
1#	3.93	4.53
2#	7.02	8.48
3#	10.64	10.08

*Concentrations before application of lime, biosolids, and soil amendments.

#Concentrations 2 months after soil amendment application biosolids plot indicating the biosolids contained some P. The increase in P concentration on non-biosolids control plots may have resulted from P washed on the plot via water and/or wind.

The final plant count (Oct 1999) revealed plots receiving P treatments had significantly increased in plant population (Table 4). These had plant population increases as much as 2 plants ft^{-2}. This was also noticed during field observations, as plant counts were much lower on control subplots.

Biosolids. Total elemental analysis on the biosolids revealed that heavy metal concentrations were not high enough to be problematic (Table 5). Vegetation was noticeably higher on the biosolids plot compared to the non-biosolids plot throughout the sampling period. Tall fescue and wheat/rye grass composed most of the vegetative cover on the biosolids plot with legume populations being extremely low. The non-biosolids had less grass populations but were higher in legumes. Kobe and Korean lespedeza populations were higher on the non-biosolids plot as compared to sericea lespedeza and birdsfoot trefoil.

Final plant counts (Oct 99) showed vegetative cover was significantly higher on control plots receiving biosolids compared to non-biosolids + P treatments. The biosolids plot had as much 30% higher estimated plant cover over the entire acre (Table 6). Although biomass weights were not significantly affected by treatments ($p>.05$), they were greatly increased when biosolids and biosolids + P treatments where added (Tables 3,7).

Nitrogen. Total N in the tailings prior to amendments was <500 mg kg^{-1}. Nitrogen increased to about 1400 mg kg^{-1} after the addition of biosolids and ammonium nitrate (Table 8). Total N on the non-biosolids plot remained constant (1475 – 1800 mg kg^{-1}) throughout the sampling period while N concentrations on the biosolids plot varied. The higher rate of legume success on the non-biosolids plot may have resulted from the increased nodulation on legume roots. Biosolids application provided available N, possibly causing legumes on the biosolids plot to nodulate at a slower rate. These higher legume populations were able to fix N from the atmosphere, increasing N concentrations in the soil.

The decrease in N concentrations on the biosolids plot may have resulted from legume/grass competition for nutrients supplied by biosolids and fertilizer. The increase in total N on the biosolids plot in the Jun 99 sampling may have resulted from the second N fertilizer application.

Conclusions

1. Potential acidity resulting from pyritic sulfur was not problematic due to the high content of neutralizing bases contained in the tailings.
2. Phosphorus was the primary limiting nutrient in the tailings material preventing the establishment of vegetation.
3. Plant counts were significantly higher when plots were amended with P.
4. Legume populations, namely kobe and Korean lespedeza, were higher on the non-biosolids plot.
5. Biosolids alone and the combination of biosolids and phosphorus application increased plant cover percentages.
6. Plant biomass was significantly increased with the applications of biosolids and P.
7. Non-biosolids plot yielded more legumes which were able to supply more N to the soil.

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Table 3. ANOVA table for final (Oct 1999) plant counts, percent plant cover, and biomass separated by treatment.

	Plant Counts	Percent Cover	Biomass
Source of variation	p value	p value	p value
Plant Mix	NS	NS	NS
Biosolids	NS	NS	NS
Biosolids*Plant Mix	NS	NS	NS
P Treatment	.0001	.0008	NS
Plant Mix*P Treatment	NS	NS	NS
Biosolids*P Treatment	NS	.0001	NS
Biosolids*Plant Mix*P Treatment	NS	NS	NS

NS, nonsignificant at the .05 probability level.

Table 4. LS means for final (Oct 99) plant counts affected by P treatment. (N=576, SE=.783, p<.001)

P Treatment	LSMEAN
Control	2.38a*
1	4.13b
2	4.42b
3	4.44b

*Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 5. Total elemental analysis on biosolids

Element	Concentration mg kg^{-1}
N	600
P	12 840
K	1 142
Ca	229 120
Cd	2
Cu	197
Ni	159
Pb	72
Zn	963

Table 6. LS means for final (Oct 1999) percent plant cover estimates affected by P treatment and biosolids application. (N=192, SE=7.54, p<.001).

P Treatment		LSMEAN
Nonbiosolids	Control	NS
	1	35.83bc*
	2	31.46c
	3	37.08bc
Biosolids	Control	55.75ab
	1	46.25bc
	2	63.25a
	3	53.33ab

NS, nonsignificant at the .05 probability level.

*Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 7. LS means for final (Oct 1999) biomass weights affected by P treatment and biosolids application. (N=64, SE=12.57, p<.001).

	P Treatment	LSMEAN
Nonbiosolids	Control	NS
	1	NS
	2	NS
	3	31.42*cd$^{\oplus}$
Biosolids	Control	77.08$^{\#}$bc
	1	44.38$^{\#}$ab
	2	69.92$^{\#}$ab
	3	79.85$^{\#}$a

NS, nonsignificant at the .05 probability level.

*,$^{\#}$ significant at the .05, .001 levels, respectively.

$^{\oplus}$Within columns, means followed by the same letter are not significantly different according to LSD (0.05).

Table 8. Mean N concentrations of test plots.

Plot	Preamend* Sep 98	2nd Sampling Nov 98	3rd Sampling Mar 99	4th Sampling Jun 99	5th Sampling Oct 99
			mg kg^{-1}		
Nonbiosolids	445	1485	1790	1473	1780
Biosolids	445	1399	652	2392	1009

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