Thomas H. DeLuca
Elisa L. Lynch

Assessment of Amendments in the Reclamation of an Abandoned Mine in Montana

Abstract

There are numerous no-responsible-party abandoned mine sites on public lands in western Montana that have been inactive for more than 70 years, yet remain bare of vegetation and drain acidic water to mountain streams. Montana lacks widespread availability of organic materials commonly used in mine reclamation and there is limited information available regarding the efficacy of alternative organic mine reclamation amendments. Replicated field and laboratory studies were undertaken to assess how various surface treatments influence metal mobility and restoration of tailing piles along a second order tributary to the Blackfoot River. Laboratory incubations were carried out by treating tailings with nothing (control), aged log-yard waste, or composted sewage sludge (Eko Kompost, Missoula, MT) with or without lime. After four weeks, tailings were analyzed for pH and exchangeable Pb, Cu, and Fe. Field plots (2 m x 4 m) were treated as above, seeded with native wheatgrass species, and analyzed for pH, exchangeable Pb, Cu, and Fe, microbial biomass, and vegetative cover after eight weeks and 12 months. All liming treatments significantly increased pH and reduced levels of exchangeable metals. Aged log-yard waste alone had little or no effect on pH or levels of exchangeable metals and actually increased levels of exchangeable Pb. Compost applications had only a slight effect on pH, but significantly reduced levels of exchangeable metals and increased levels of microbial biomass. Compost plus lime resulted in the lowest levels of exchangeable metals and greatest vegetative cover. The ability of compost to reduce metal mobility and increase microbial and vegetative activity without a significant change in pH indicate that nutrient availability and reduced metal bioavailability play an important role in site restoration.

Key Words: Log yard waste, composted sewage sludge, metal complexation, restoration.

Introduction

There are currently over eight thousand no-responsible-party abandoned mine sites in western Montana about 30 percent of which reside on federal lands (Montana Bureau of Mines and Geology Abandoned Mine Lands Database, Butte, MT). Many of these sites are abandoned gold, lead (Pb) and copper (Cu) mines that involved the mining and processing of sulfide minerals. The formation of fine textured mine tailings in the processing of the ores creates a high surface area that enhances the oxidation of sulfide minerals to sulfate creating an infertile, highly acidic substrate in which little or no vegetation is established and subsurface drainage and overland flow contribute metal laden acidic drainage to neighboring riparian areas. Most of these mine sites have remained bare of vegetation 70 to 100 years after being abandoned, thus creating a semi-permanent scar on the

Thomas H. DeLuca, Assistant Professor of Forest Soils, School of Forestry, University of Montana, Missoula, MT 59812 (Corresponding Author).
Elisa L. Lynch, Graduate Research Assistant, Environmental Studies, University of Montana, Missoula, MT 59812.

landscape. The lack of a responsible party or federal funds to reclaim these sites requires that an inexpensive and efficient means of site restoration be identified to allow establishment of native vegetation and, thus, reduce metal contamination of surface and ground water and to improve forest aesthetics.

Reclamation of most acid mine sites in Montana is limited to lime applications, to neutralize the acidity of surface soils, and seeding with native grass species (Neuman *et al.* 1993). However, vegetation establishment on limed tailings is greatly limited by poor physical conditions, lack of plant nutrients, and reduced microbial activity, resulting in a gross infertility not readily overcome by the application of synthetic fertilizers (Sopper 1992). For example, revegetation of a heap leach gold mine in Montana was found to be more successful in plots treated with composted sewage sludge or composted yard waste than those plots treated with synthetic N fertilizer (Vodehnal 1993).

The use of composted sewage sludge in the reclamation of abandoned hard rock mine sites has been studied extensively in the Eastern U.S. (Sopper 1992). Sewage sludge provides a source of organic matter, nutrients, and water holding capacity not otherwise available on these abandoned mine sites (Sopper 1992, Rodgers and Anderson 1995). Metal mobility in sewage sludge or composted sewage sludge amended soils or mine tailings may be reduced by surface sorption of metals to the applied organics or by the formation of insoluble organo-metal complexes (Simeoni *et al.* 1984, Pritchel *et al.* 1989, Leita and De Nobili 1991, Cavallaro *et al.* 1993). Metals that are complexed by humic acids (>10,000 dalton polyphenolic compounds) tend to be insoluble, whereas metals complexed by fulvic acids (several hundred dalton polyphenolic compounds) normally remain soluble (Stevenson, 1994). The humic acid content of sewage sludge is increased during the composting process thereby improving the physical and biochemical properties of sludge as soil amendment and increasing the concentration of metal complexation sites within the amendment (Simeoni *et al.* 1984, Leita and De Nobili 1991).

The population density of the eastern United States results in the production of large quantities of sewage sludge; however, the industrial density of these same regions results in sewage sludge that has high concentrations of heavy metals. The metal concentrations found in eastern sewage sludge often precludes its application to cropland, but is, instead, used in mine reclamation (Sopper 1992). The low population density in Montana greatly reduces the widespread availability of organic materials commonly used in mine reclamation. Aged log-yard waste (LYW) is available across western Montana and has been identified as a possible amendment for abandoned mine restoration (Campbell and Tripepi 1992).

It is not clear how LYW might influence metal mobility compared with lime or compost. The humification process of composting sewage sludge with wood waste should result in a higher ratio of humic acid to fulvic acid than aged LYW (Leita and De Nobili 1991). Complexation of metals by humic acids greatly reduces metal solubility compared to fulvic acids (Sposito *et al.* 1982, Stevenson 1994).

The purpose of the work reported was to assess the effect of surface applied composted sewage sludge or aged LYW with and without lime application on: (1) concentrations of exchangeable metals in acid mine tailings; (2) levels of microbial biomass and revegetation success; and (3) restoration of a small no-responsible-party abandoned mine site in western Montana.

Table 1. *Physical and chemical characteristics of mine tailings (Sandbar Creek) and organic amendments.*

		Characteristics				Total Digestible		
Material	pH[1]	Sand	Silt	Clay	Organic C[2]	Fe[3]	Cu[3]	Pb[3]
		g/kg				mg/kg		
Sandbar Creek	2.7	480	200	320	44	4,580	540	240
Eko Kompost	6.3	—	—	—	3,400	345	257	9
LYW	7.5	—	—	—	3,500	95	14	1

[1] pH determined in a 2:1 solution (0.01 M $CaCl_2$)

[2] Total organic C determined by Walkley Black method (Nelson and Sommers, 1982).

[3] Total digestible (aqua regia digest) Fe, Cu, and Pb, analysis on inductive coupled plasma spectrophotometer.

Study Area

Laboratory and field experiments were carried out on mine tailings from a small abandoned mine along Sandbar Creek in the Helena National Forest near Lincoln, Montana. The chemical and physical characteristics associated with the mine tailings and organic materials are given in Table 1. Analysis of total digestible metals (aqua-regia digest and analyses on ICP) led us to focus our experiments on levels of exchangeable Pb, Fe, and Cu.

Materials And Methods

Laboratory studies were conducted on dried and sieved (2 mm) mine tailings collected from Sandbar Creek. Tailing samples of 100 g were amended with either nothing, 10 g or 20 g of composted sewage sludge (Eko Kompost, Missoula, MT), or 10 g of aged LYW (Lincoln Pole Yard, Lincoln, MT), with or without the addition of lime as 1.5 g of $CaCO_3$ and 1 g CaO to bring the tailings pH to 6.5 (Adams and Evans 1962). The treated tailings were brought to 60 percent water holding capacity, mixed thoroughly, and placed in 250 ml French square bottles and allowed to incubate in a constant temperature chamber for 4 weeks. Water content was measured and adjusted on a weekly basis. Exchangeable metals were extracted by adding 100 ml of 2 M KCl to each bottle. The suspensions were shaken for 60 minutes, filtered through Whatman #2 filter papers, and then analyzed for Pb, Fe, and Cu by atomic adsorption spectrophotometer (AAS) (Baker and Amacher 1982, Burau 1982, Olson and Roscoe 1982).

Field plots were established by preparing 20-2 m by 4 m plots in a randomized complete block design on two sets of tailings piles at Sandbar Creek. Plots were amended with either nothing (control), 30 Mg lime as CaO/ha (to bring tailings pH to 6.5, (Adams and Evans 1962), 24.4 Mg LYW/ha, 24.4 Mg composted sewage sludge/ha with and without lime. Lime was incorporated to a depth of 15 cm and compost and LYW were incorporated to a depth of 7.5 cm. Plots were seeded with 20 kg/ha of slender wheatgrass and thick spike wheatgrass, raked in to a depth of 3 cm, and watered weekly for 3 weeks. Field plots were sampled to a depth of 7.5 cm 8 weeks and 12 months after treatment and analyzed for microbial biomass (DeLuca and Keeney 1993), pH, and exchangeable metals (Pb, Cu, and Fe) as described above. Plots were observed for percent grass surface cover 12 weeks and 12 months after treatment. Numbers of seed heads per plot and numbers of native pine seedlings per plot were counted 12 months following treatment. Data were analyzed by analysis of variance using PC-SAS (SAS Institute). Mean separations were determined by lsd ($P < 0.05$).

Results And Discussion

Concentrations of exchangeable metals in mine tailings from Sandbar Creek were significantly reduced by both compost and lime treatments (Table 2). Copper, Fe, and Pb were the only metals present in significant quantities in the Sandbar Creek mine tailings, based on an aqua-regia digest and analyses on ICP. Lime applications increased tailings pH to 7.0 and reduced exchangeable Pb, Fe, and Cu by 84 - 100 percent. This decrease in exchangeable metals with an increase in pH primarily reflects the precipitation of Pb, Cu, and Fe into insoluble oxide forms (Lindsay 1979). The 10 percent compost application rate resulted in a significant decrease in exchangeable metals, but no change in pH. The 20 percent compost application rate increased pH to 3.4, reduced the exchangeable metals concentrations by 60 to 95 percent, and resulted in exchangeable Cu and Fe concentrations that were not significantly different from lime amendments.

Log yard waste resulted in only a slight decline in exchangeable Cu and Fe and actually increased levels of exchangeable Pb compared to the control (Table 2). DeLuca and Lynch (1996) reported that levels of water soluble Fe were increased by LYW applications and that water soluble Cu levels were detectable only in the control and in LYW treated tailings from Sandbar Creek. The increase in exchangeable Pb and water soluble Fe may have been a result of the greater concentration of low molecular weight of organic complexes associated with the non-humified LYW (DeLuca and Lynch 1996) resulting in colloid assisted mobility (Stevenson 1994). There was no antagonistic effect of compost or log yard waste on lime amendments. These results underscore the ability of compost to complex metals and reduce their bioavailability in acidic mine tailings with or without lime additions (Sopper, 1992), but bring into question the utility of LYW as a reclamation amendment.

Results obtained in field studies were similar to those found in the laboratory (Table 3, 4). Lime treatments

Table 2. *Tailings pH and concentration of exchangeable Pb, Fe, and Cu in Sandbar Creek mine tailings treated with compost or log-yard waste (LYW) with or without lime, lime alone or no treatment and incubated in the laboratory at 25°C for 4 weeks.*

Treatment	Exchangeable[1]			
	Pb	Fe	Cu	pH
	mg/kg			
Control	14.6	256	14.4	2.9
Lime	4.6	12	0.0	7.1
LYW	18.2	186	10.0	3.0
10% Compost	10.4	42	3.2	3.0
20% Compost	8.4	12	0.4	3.4
LYW + Lime	3.8	12	0.0	6.9
10% Comp. + Lime	4.2	12	0.0	7.0
20% Comp. + Lime	2.4	10	0.0	6.9
lsd ($P < 0.05$)	1.4	28	0.5	0.2

[1] Exchangeable metals measured by extraction of tailings with 2 M KCl and analysis on atomic absorption spectrophotometer

greatly reduced the levels of exchangeable metals in the surface 7.5 cm of mine tailings. Compost applications alone significantly increased tailings pH and reduced levels of exchangeable Pb and Fe over the control during the first growing season and 12 months after treatment. Unlike lime amendments, compost applications reduce levels of exchangeable metals primarily by surface sorption and by the formation of organo-metal complexes (Stevenson 1994). Although these organic complexes may degrade over time, we observed no significant change in levels of extractable metals on compost treated plots one year following treatment. Log-yard waste had no significant effect on tailings pH nor on levels of exchangeable Pb, Fe, or Cu (Table 3, 4). The high level of exchangeable Fe found in the control

Table 3. *Tailings pH and concentration of exchangeable Pb, Fe, and Cu in Sandbar Creek mine tailings 8 weeks following treatment of tailings with compost, log-yard waste (LYW), compost plus lime, lime alone, or no treatment.*

Treatment	Exchangeable[1] Pb	Fe	Cu	pH
	-----------	mg/kg	-----------	
Control	294	585	10.7	2.6
Lime	4	8	0.7	9.2
LYW	234	416	8.9	2.8
Compost	55	31	2.8	3.5
Compost + Lime	3	10	0.4	8.6
lsd ($P < 0.05$)	221	428	10.8	0.9

[1] Exchangeable metals measured by extraction of tailings with 2 M KCl and analysis on atomic absorption spectrophotometer.

Table 4. *Tailings pH and concentration of exchangeable Pb, Fe, and Cu in Sandbar Creek mine tailings 12 months following treatment of tailings with compost, log-yard waste (LYW), compost plus lime, lime alone, or no treatment.*

Treatment	Exchangeable[1] Pb	Fe	Cu	pH
	-----------	mg/kg	-----------	
Control	328	291	10.3	2.6
Lime	4	17	0.6	8.3
LYW	298	247	9.4	2.7
Compost	80	47	0.6	3.1
Compost + Lime	5	17	0.6	7.8
lsd ($P < 0.05$)	107	216	10.8	1.0

[1] Exchangeable metals measured by extraction of tailings with 2 M KCl and analysis on atomic absorption spectrophotometer.

and LYW plots eight weeks following treatment was a likely result of the high variability associated with the placement of plots on two separate tailings piles or, perhaps, a function of the oxidation of Fe exposed to air over an eight week period following the mixing of tailings to a 15 cm depth without application of treatments that reduce metal mobility.

Microbial biomass C as estimated by fumigation-extraction is a good index of the active fraction of C in soils (Tate 1995). Microbial biomass was greatest in compost treated plots and was higher in compost alone plots than in compost plus lime plots (Fig. 1). The initial levels of microbial biomass in the surface 7.5 cm of compost treated mine tailings were similar to that found in the surface 7.5 cm of native riparian soil (579 mg biomass C/kg soil) at Sandbar Creek. However, levels of microbial biomass declined from over 600 mg/kg eight weeks following treatment to about 350 mg/kg 12 months following treatment. Microbial biomass was found to be significantly greater than the control only in compost treated plots 12 months following treatment. Microbial biomass in tailings treated with lime was significantly greater than the control 8 weeks following treatment, but this difference was not observed 10 months later. Tailings treated with LYW showed no significant change in microbial biomass.

Grass was unable to germinate or grow on the control or LYW treated plots (Fig. 2), which was likely a result of a lack of available nutrients. The application of LYW as an organic amendment to tailings piles did not positively influence vegetation establishment or microbial biomass because of the high C:N ratio (560:1) and high metal bioavailability on these plots. Grass establishment was observed on lime and compost treatments and was greatest on compost plus lime plots. It should be noted however, that the grass establishment numbers are based on percent ground cover and not on biomass production. The grass growing on the lime alone plots was highly chlorotic and had burned tips, whereas the grass on the compost treated plots was green, thick, and healthy. Compost treatments supply N and P that were likely limited on the lime treated plots. Grass on compost plus lime treated plots had an average of nine seed heads/plot compared to less than one per plot for all other treatment. The

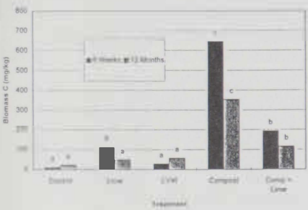

Figure 1. *Microbial biomass in surface 7.5 cm of tailings 8 weeks and 12 months after treatment with lime, log-yard-waste (LYW), compost, or compost plus lime. For a given date, bars with the same letter are not significantly different ($P \geq 0.05$).*

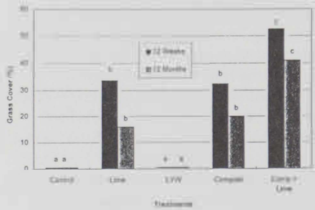

Figure 2. *Percent vegetative cover on plots 12 weeks and 12 months after treatment with lime, log-yard-waste (LYW), compost, or compost plus lime (for a given date, bars with the same letter are not significantly different ($P \geq 0.05$).*

compost plus lime plots were found to have eight native pine seedlings/plot one year after treatment compared to three for lime treated plots and two/plot on compost alone and control plots.

The observed decline in levels of microbial biomass in compost treated tailings was likely a result of the decomposition of metabolic organic matter associated with the compost. This suggests that annual applications of composted sewage sludge might have to be made for long term effective reclamation of acidic mine tailings. Alternatively, the annual degradation of plant shoot and root biomass on compost treated plots may ultimately offset the loss of metabolic organic matter from the compost, allowing the system to eventually reach steady state.

Plots receiving compost alone maintained the highest levels of microbial biomass and allowed for grass establishment with only a slight increase in tailings pH through the first year following treatment. This indicates that nutrient availability and reduced metal bioavailability, afforded by compost applications, may play a more important role in site restoration than correction of tailings pH.

Conclusions

Both lime and compost applications alone or in combination were effective at reducing levels of exchangeable metal concentrations in mine tailings 1, 2, and 12 months following treatment. Compost alone had no significant effect on pH, but greatly reduced levels of exchangeable metals as a result of metal sorption and complexation. Log-yard-waste applications had little or no effect on levels of exchangeable metals and actually increased Fe solubility in laboratory studies. Amendment of tailings with compost increased microbial biomass and allowed for the initiation of vegetative growth on the tailings piles at Sandbar Creek for the first time since their deposition. Lime applications initially increased microbial biomass, but these levels were not different from the control 12 months following treatment.

The establishment of grass should reduce overland flow and decrease leaching with increased evapotranspiration associated with plant growth. Increased plant growth on these plots will begin to increase levels of soil organic matter resulting in continued microbial activity. The aged LYW used in this study does not appear to be an effective medium for mine reclamation without the addition of a N source. The C:N ratio of the LYW is about 560:1 resulting in rapid immobilization of available N and limited microbial activity. The material also has little effect on metal mobility, and may actually increase metal solubility in some cases. It is recommended that this material only be used in the presence of an added N source or following composting to reduce the C:N ratio and increase the humic acid content thereby increasing its utility in the reclamation of acid mine tailings. The effect of compost applications on reducing levels of exchangeable metals, establishment of vegetation, and enhancement of microbial biomass with little or no effect on tailings pH indicates that nutrient availability and reduced metal bioavailability may play a more important role in site restoration than correction of tailings pH via liming. However, the combination of lime and composted sewage sludge clearly provided the most effective reclamation amendment in our studies.

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