REVEGETATION OF MINING WASTE USING ORGANIC SOIL AMENDMENTS AND EVALUATION OF THE POTENTIAL FOR CREATING ATTRACTIVE NUISANCES FOR WILDLIFE

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ABSTRACT

The objectives of this project are to demonstrate the use of organic amendments to enhance the establishment and growth of grass on lead mine tailings and evaluate the effect of those amendments on plant uptake of metals. Two sources of compost and an organic fertilizer derived from municipal sewage treatment plant sludge were incorporated into two types of tailings near Desloge, Missouri, and the replicated plots were planted with grass. Both types of tailings (fine-textured flotation tailings and course-textured gravity separation tailings) contain elevated concentrations of lead (Pb), zinc (Zn), and cadmium (Cd). This project will be evaluated for three growing seasons.

At the end of the first growing season, vegetative cover and biomass production were quantified, and tailings and vegetation samples were obtained and analyzed. Preliminary results indicate the amendments improved both establishment and growth; differences among amendment types and application rates were significant; and plant uptake of metals was not great enough to impact area wildlife. Additional results of the first growing season will be discussed.

Key words: *vegetation, organic amendments, tailings, compost*

1. INTRODUCTION

This interim report has been prepared specifically for the Mine Waste Technology Program (MWTP), Activity III, Project 23, *The Revegetation of Mining Waste Using Organic Amendments and Evaluating the Potential for Creating Attractive Nuisance for Wildlife Project.*

This demonstration project involves developing information on establishing vegetation to stabilize mine waste and mill tailings surfaces by applying organic amendments. The overall project is intended to illustrate the feasibility of using organic amendments to improve growth media conditions, reduce wind and water erosion, enhance plant establishment, stabilize toxic metals, and reduce the plant uptake of metals that could present a food chain risk for foraging wildlife.

1.2 Scope of the problem

Thousands of abandoned mine and mineral processing sites throughout the United States pose significant environmental hazards in addition to being unattractive. The federal government and responsible parties need to develop cost-effective remedial approaches to effectively manage these large areas. Natural revegetation is often prevented in these areas because of low pH, phytotoxic concentrations of metals, poor physical structure for plant growth, nutrient deficiencies, and slopes that are too steep for plant establishment.

Mine waste reclamation research frequently includes the addition of organic amendments since mine waste materials are typically subsurface in origin and have minimal organic matter content. Biosolids, compost, livestock manure, green manure, crop residues, wood wastes, and other organic materials have been demonstrated to improve vegetation establishment and growth in a variety of settings (Ref. 1). However, the diversity of organic materials used and the lack of uniformity within each category of material make comparisons among sites and studies difficult. In addition, while it is generally agreed that organic amendments are capable of stabilizing metals in mine waste, the potential for postreclamation impacts on wildlife due to plant uptake of those metals requires further research.

1.3 Project description

Organic amendments have the ability to stabilize heavy metals present in mineral waste material. Also, the amendments increase plant nutrient levels and water-holding capacity, which enhance the ability of the waste materials to support vegetative cover. The purpose of this project is to develop technical information regarding the use of organic amendments to improve tailings conditions, reduce erosion, enhance plant establishment, and stabilize metals. In addition, the ability of the selected organic amendments to reduce uptake of metals from mine wastes into vegetation will be evaluated.

The primary objectives of this project are to demonstrate the use of organic amendments to enhance the establishment and growth of grass on lead (Pb) mine waste and mill tailings and evaluate the effect of those amendments on plant uptake of metals into aboveground biomass.

More specifically, the following three quantitative objectives have been developed for the project.

- Achieve long-term vegetative cover of $\geq$50% in treated plot areas.
- Reduce plant availability of metals [Cd, Pb, and Zn] in treated tailings as compared to the control (untreated tailings).
- Evaluate the herbivore toxicity of plant material resulting from the various treatment plots, according to the following criteria[1] (Ref. 2):

  -Cd $\leq$ 0.5 milligram per kilogram (mg/kg)
  -Pb $\leq$ 30 mg/kg
  -Zn $\leq$ 300 mg/kg

These criteria were based on professional judgement since no universally accepted standards exist for these parameters, and specific site conditions should be considered when establishing standards for success. The criteria stated in the quality assurance project plan (QAPP) were based on a review of then-available literature. A continuing literature search indicates the herbivore toxicity criteria could be improved via substitution of data for wildlife species (e.g., deer) for the domestic sheep-related toxicity criteria used in the QAPP (Ref. 3). Therefore, the QAPP herbivore toxicity criteria have been modified as follows:

- -Cd ≤ 2.0 mg/kg
- -Pb ≤ 40 mg/kg
- -Zn ≤ 300 mg/kg

1.4 Description of test sites

Selected sites for this project were the Big River mine tailings site (BRMTS) and the Leadwood chat tailings site (LCTS) near Desloge, Missouri. The objective was to select two sites with dissimilar tailings types for comparison. The Doe Run Company and EPA Region 7 assisted in locating these choices. Both sites are located within a mining region known as the "old lead belt," which encompasses approximately 110 square miles and is 70 miles south of St. Louis, Missouri (Ref. 4).

The BRMTS site is composed of fine-grained tailings that resulted from a froth/chemical flotation process for concentrating metals in milled ore. The LCTS is composed of coarse tailings that resulted from coarse milling and gravity separation of metals from ore. The BRMTS is a National Priorities List (NPL) site under the Comprehensive Environmental Reponse, Compensation, and Liability Act of 1980. The site includes approximately 600 acres of mine tailings that were deposited between 1929 and 1958. The tailings have elevated levels of Pb, Cd, and Zn; the surface water and fish in the nearby Big River contain elevated concentrations of Pb. The LCTS is somewhat smaller and is not currently an NPL site. Tailings there also contain elevated levels of Pb, Cd, and Zn. This site includes both mill and chat tailings. The chat tailings area where the plots were established includes approximately 20 acres. Wind erosion and airborne dust have transported contaminants to surrounding areas and are a potential hazard to on-site workers and nearby residents, especially children. A 1997 human health exposure study by the Missouri Department of Health shows that 17% of area children under seven years of age have blood-lead concentrations exceeding the health-based standard of 10 micrograms per deciliter (Ref. 4).

1.5 Selected organic amendments

The organic amendments selected for evaluation in this project are two sources of mature organic compost and a product derived from municipal wastewater treatment plant biosolids. Criteria for selecting the specific organic amendments included the following:

- – a major supplier capable of delivering the required amount of organic amendment to the site,
- – a cure time of at least eight weeks at 120 °F to 140 °F to destroy weed seed and pathogens, and
- – a compost screened to meet Grade A standards.

The three selected organic amendments for the demonstration were as follows:

- Milorganite is an organic, heat-dried activated biosolid produced in a fine granular form. Heat-treated for sterilization, it is inoffensive and easy to handle.

Note: These criteria are taken from the maximum tolerable level of dietary minerals for domestic sheep. The Pb and Cd numbers are based on human food residue considerations. Source: *The Mineral Tolerance of Domestic Animals,* National Academy of Sciences, Washington, D.C., 1980.

- Ormiorganics is a commercially available compost produced from mixed residential yard waste materials. This compost is produced by Organic Resource Management, Inc. (ORMI) of St. Louis, Missouri.

- St. Peters Compost is an organic amendment containing 40% biosolids and 60% mixed residential yard waste materials. This compost is produced by the community of St. Peters, Missouri. It is not currently marketed but is used by St. Peters for public works projects.

2.0 EXPERIMENTAL DESIGN

MSE established field plots at the BRMTS and the LCTS to evaluate three organic amendments that were applied at three different rates (low, medium, high). Application rates of 1 inch [133 cubic yards per acre (yd^3/acre)], 1.5 inches (200 yd^3/acre), and 2 inches (266 yd^3/acre) of compost were used during this project. The Milorganite was also applied at three rates: 1,450 pounds/acre, 2,200 pounds/acre, and 2,900 pounds/acre. Weight-per-acre calculations were not meaningful for the compost materials because moisture contents of the composts were variable. Granular inorganic fertilizer was also applied to the plots to a depth of approximately six inches prior to applying the organic amendments. The nitrogen-phosphorus-potassium (NPK) rate provided by the inorganic fertilizer was held constant for all plots, including the control plots.

Each site consisted of 40 plots (4 rows with 10 plots in each row). Each row contained a plot with each of the three organic amendments at each of the three application rates, plus one control plot that only received the inorganic fertilizer. The control plots did not receive organic amendments. The only variables during this study were the types and application rates of organic amendments. Each organic amendment/application rate combination was replicated four times at both sites. The various treatments were arranged using a randomized block design. Table 1 defines the treatment/application rate used in the plots. Figure 1 shows the layout of the plot design with the field codes.

The plant species selected for the demonstration was tall fescue (Kentucky 31 variety). Tall fescue is a long-lived perennial grass that is compatible with the area climate and is currently growing on tailings with similar chemical characteristics.

2.1 Field monitoring

Once the plots were planted, MSE field engineers monitored them monthly from May through September 2000. Monitoring tasks consisted primarily of making general observations, photographing each plot at each site, and removing weeds. Minor repairs to the erosion control blankets at the LCTS were performed in May because the erosion control blankets had been torn and rolled up in several spots due to high winds. No additional repairs were required during the remainder of the growing season.

2.2 Precipitation and plot irrigation

Plot irrigation was not part of the initial design for this project. However, the Desloge, Missouri, area experienced below-normal

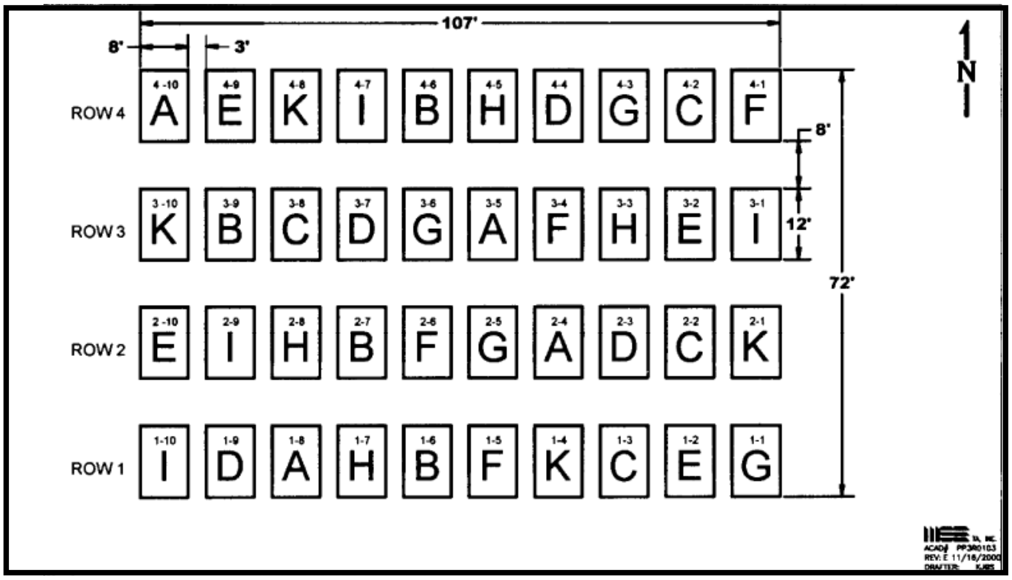

Figure 1. Layout of the plot design with field codes.

precipitation before and during the 2000 growing season. Consequently, plot irrigation became necessary to reduce concerns that dry conditions would impact the research results and possibly require replanting. Precipitation was monitored daily, and criteria were established for plot irrigation. The criteria were based on a 30-year monthly average of 1 inch per week. Accordingly, irrigation was applied if less than 0.50 inch of rainfall was recorded during a given week and applied the equivalent of 1 inch of rainfall (total of 6,000 gallons of water per site) during each irrigation event. A total of 4 inches was applied to both sites.

3.0 RESULTS AND DISCUSSION

The vegetation at BRMTS and LCTS was harvested, and tailings samples were collected and analyzed at the end of the first growing season in September 2000. A summary of the

Table 1. Treatment of plot definitions.

Organic Amendment	Application Rate (low, medium, high)	Field Code
Milorganite	1,450 lb/acre 2,200 lb/acre 2,900 lb/acre	A B C
Ormiorganics	1 inch (133 yd^3/acre) 1.5 inches (200 yd^3/acre) 2 inches (266 yd^3/acre)	D E F
St. Peters Compost	1 inch (133 yd^3/acre) 1.5 inches (200 yd^3/acre) 2 inches (266 yd^3/acre)	G H I
Control	Fertilizer only	K

critical data collected is presented in the following sections. The sampling procedures, frequencies, and sampling locations can be found in the project-specific QAPP (Ref. 5).

All field activities were conducted by MSE, with assistance from a subcontracted vegetation survey consultant, Bauer Technical Services, Inc. All sampling and field work was performed according to procedures outlined in the project- specific QAPP or according to existing standard operating procedures.

3.1 Vegetation analysis overview

Bauer Technical Services, Inc. was contracted by MSE to perform a quantitative vegetation survey to evaluate plant growth and production on the vegetation research plots. A 1- by 3-meter (m) grid, divided into three 1-m squares, was placed at the approximate center of each plot as shown in Figure 2. Aerial groundcover observations were made for each square. Production data were obtained by harvesting the vegetation from within each square. The aerial groundcover and vegetation harvesting was done September 21 through September 25, 2000. All aerial observations were done by John Bauer with MSE oversight.

3.1.1. Aerial groundcover (vegetative cover)

The percent cover on each 8- by 12-foot plot was determined as given below.

- A 1- by 3-m grid, divided into three 1-m squares, was placed at the approximate center of each plot.
- A second 1-m square grid, divided into 25 squares, was placed over each of the meter squares; each 20-centimeter (cm) square thus represented 4% of the meter square.

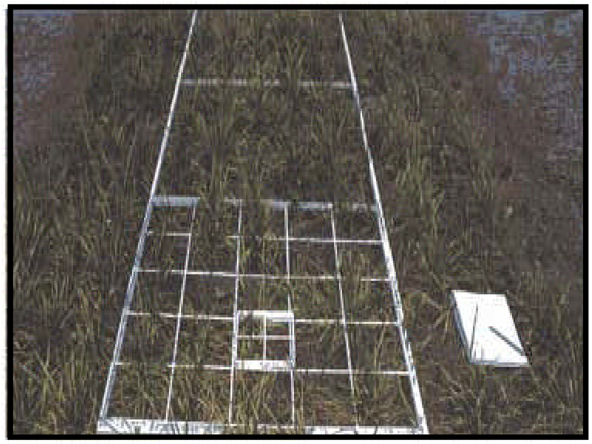

Figure 2. Grid system used for vegetation analysis.

- If needed (due to sparse vegetative cover), a third grid consisting of four 10-cm squares, each representing 1% of the meter square, was placed over each 20-cm square.
- Also, if needed, each 10-cm square(above) was visually divided into halves representing 50% cover. If each 10-cm square had only a trace amount of cover, a "T" for trace was marked in the field notes. Trace amounts of cover were not included in the cumulative percent cover.

The percent cover for each grid square above was defined as aerial groundcover observations. The data for each grid square used were recorded in the field logbook. In the office, accumulated grid percentages were summed, and a total percent cover for each meter square was recorded. If the cumulative percent cover was less than 3, it was recorded as such.

3.1.2. Production data

After aerial observations were completed, the grid squares were removed, leaving the 1- by 3-m grid in place. Production data were obtained by individually harvesting all the vegetation from each of the meter squares. The production from each meter square of the grid was boxed or bagged and labeled as A, B, and C, respectively. The harvesting was conducted using a hedge trimmer and hand grass clippers. The harvesting height was approximately 1 inch above ground surface. A total of 80 vegetation plots were observed, and 77 were harvested. No harvestable vegetation was present in three of the four Leadwood control (K) plots.

The harvested material was shipped to Key Agricultural Services, Inc. (KEY-AG) for dry weight determination. At KEY-AG, the vegetation samples were dried at 140°F (60 °C) in a forced-air oven for 72 hours and then weighed. Either a representative subsample or the entire sample was ground in a stainless-steel Macro Wiley Mill fitted with a 2-millimeter screen, and then bagged for shipment to the HKM Laboratory in Butte, Montana, for chemical analysis.

3.1.3. Plant tissue metals

MSE also collected samples of vegetation after Bauer Technical Services, Inc. harvested the vegetation from each plot. These samples were hand-clipped along the east edge of each harvested area. The vegetation samples were bagged and sent to the HKM Laboratory where they were washed and prepared for analysis.

Detailed laboratory protocols were developed and followed to remove surface contamination from the plant tissue samples prior to proceeding with sample digestion and analysis. Such contamination resulted from field conditions that allowed tailings dust from the areas surrounding the plots to be deposited on the grass leaves and stems; dust was observed on the plant materials at the time of harvesting. It should be noted, however, that complete removal of such contaminants may not be possible, and the resulting data should be considered with that in mind. Because aluminum (Al) levels found in plant tissue samples were very low compared with Al levels in the tailings, it may be concluded that surface contamination did not contribute significantly to the metals' levels reported for plant tissue samples. It is well known that plants do not take up significant amounts of Al; therefore, this analysis can be made.

3.1.4. Tailings analysis

After the vegetation was harvested, MSE collected a composite sample of surface material from each plot at each site. The sample depth was 0 to 6 inches. These composite samples were comprised of five subsamples obtained from the four corners and center of the plots. The samples were placed in labeled sample bags and sent to the HKM Laboratory for analysis. Descriptions of the sampling procedures, frequencies, and sampling locations can be found in the project-specific QAPP (Ref. 5).

A summary of the tailings data collected from the BRMTS and the LCTS is presented in the following sections. The overall average of the four replicated plots for each treatment/ application rate is also presented in the following summary tables to compare between treatments.

3.2 Big River mine tailings site results

Summaries of BRMTS vegetation cover and production, plant tissue analysis, and tailings analysis data are presented in Table 2. The following conclusions are based on these data and observations made during on-site plot establishment and monitoring activities.

Vegetation analysis

Vegetation was successfully established on all BRMTS plots, including the controls. The vegetative cover objective of ≥50% was far exceeded on all plots. The control plots averaged approximately 80% cover; the Milorganite plots averaged approximately 85% cover; and the Ormiorganics and St. Peters compost plots averaged 100% and more than 98% cover, respectively. Also, there was no apparent difference in biomass production data between organic amendments application rates.

Figure 3 shows the BRMTS plots after incorporating the amendments, and Figure IV shows the plots after seven months of growth. These photos indicate successful vegetation of all the BRMTS plots.

Plant tissue analysis

The plant tissue analysis data indicated plant uptake of metals did occur. Metal concentrations for the Milorganite plots were similar to those for the control plots. The two compost treatments significantly reduced plant tissue metal concentrations compared to the control and analysis of Milorganite plots.

Plant-available tailings analysis

The Ormiorganics and St. Peters compost appeared to reduce the concentrations of plant-available metals compared to the control, indicating that compost amendments did tie up

Table 2. BRMTS summary data.

	Vegetation Analysis		Plant Tissue Analysis (Acid Extractable)			Tailing Analysis (Plant Available)		
Treatment/Rate	Average % Cover	Average Production (g/m^2)	Cd (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Cd (mg/L)	Pb (mg/L)	Zn (mg/L)
Milorganite								
1,450 lb/acre (A)	96.8	297.2	1.5	42.4	221.2	0.91	265.4	84.5
2,200 lb/acre (B)	88.5	319.3	1.7	39.6	212.5	1.45	157.8	83.1
2,900 lb/acre (C)	68.8	283.9	1.5	38.7	211.0	1.64	147.0	89.5
Overall Average	**84.7**	**300.1**	**1.6**	**40.4**	**215.0**	**1.30**	**195.9**	**85.6**
Ormiorganics								
1 inch (D)	100	606.1	1.01	27.7	119.8	1.05	150.5	67.9
1.5 inches (E)	100	614.5	1.00	23.0	119.9	1.00	129.0	68.2
2 inches (F)	100	588.3	1.00	23.5	169.6	0.97	100.0	62.0
Overall Average	**100**	**602.9**	**1.00**	**24.6**	**135.0**	**1.00**	**126.7**	**66.2**
St. Peters Compost								
1 inch (G)	99.6	477.0	0.88	23.2	154.0	1.12	108.5	64.6
1.5 inches (H)	99.1	476.9	1.40	30.1	151.7	1.20	104.4	68.9
2 inches (I)	96.7	481.5	0.72	24.9	175.0	0.92	124.2	57.4
Overall Average	**98.4**	**478.5**	**1.00**	**26.0**	**139.0**	**1.07**	**113.3**	**63.2**
Control								
(K)	80.5	202.1	1.48	41.9	233.2	1.40	144.4	84.8

Figure 3. BRMTS in April 2000.

Figure 4. BRMTS in September 2000.

some of the metals. Concentrations of plant-available Cd and Zn in samples of Milorganite treatment plots were similar to those in samples of the control plots, indicating that Milorganite did not change the availability of these metals.

3.3 Leadwood chat tailings site results

Summaries of LCTS vegetation cover and production, plant tissue analysis, and tailings analysis data are presented in Table 3. The following conclusions are based on those data and observations made during on-site plot establishment and monitoring activities.

Vegetation analysis

All treatments, including the control, were

Table 3. LCTS summary data.

	Vegetation Analysis		Plant Tissue Analysis (Acid Extractable)			Tailing Analysis (Plant Available)		
Treatment/Rate	**Average % Cover**	**Average Production (g/m²)**	**Cd (mg/kg)**	**Pb (mg/kg)**	**Zn (mg/kg)**	**Cd (mg/L)**	**Pb (mg/L)**	**Zn (mg/L)**
Milorganite								
1,450 lb/acre (A)	1.90	2.98	8.55	102.15	343.00	1.64	117.4	140.6
2,200 lb/acre (B)	4.80	5.95	8.80	113.75	371.25	1.60	118.2	144.5
2,900 lb/acre (C)	5.80	9.12	9.27	104.37	392.00	1.51	109.6	125.0
Overall Average	**4.43**	**6.05**	**8.80**	**107.00**	**367.00**	**1.59**	**115.3**	**137.0**
Ormiorganics								
1 inch (D)	30.9	61.42	4.18	45.78	240.25	1.46	99.7	128.5
1.5 inches (E)	39.0	89.59	3.28	38.36	227.80	1.52	93.2	122.8
2 inches (F)	32.3	93.26	3.93	39.8	315.75	1.76	110.0	113.8
Overall Average	**34.1**	**81.42**	**3.80**	**41.10**	**259.00**	**1.58**	**100.4**	**121.8**
St. Peters Compost								
1 inch (G)	32.3	82.65	5.3	48.68	218.25	1.68	91.3	109.5
1.5 inches (H)	38.9	85.00	3.33	42.55	202.25	1.80	87.3	112.2
2 inches (I)	55.8	146.02	3.42	36.58	170.16	1.91	85.4	113.0
Overall Average	**42.3**	**104.56**	**4.00**	**42.10**	**195.00**	**1.81**	**87.8**	**111.7**
Control								
(K)	0.4	0.09	-*	-*	-*	1.53	108.0	147.4
NOTE: *Insufficient vegetation to perform analysis.								

Figure 5. LCTS in April 2000.

Figure 6. LCTS in September 2000.

below the ≥50% cover criteria established in the QAPP, except for the St. Peters compost high application rate. Milorganite was less effective than the two compost treatments. Ormiorganics compost resulted in somewhat lower production than the St. Peters compost. In general, both cover and production were correlated with increasing application rates for all treatments. Production increased with increasing organic amendment application rates for the Milorganite and both compost treatments; however, that correlation was not as linear as for St. Peters compost.

Figure 5 shows the plots after incorporation of the amendments, and Figure 6 shows the plots after seven months of growth. These photos indicate that the LCTS plots sustained growth following the addition of organic amendments.

Although the grass established on the Ormiorganics and St. Peters compost plots appeared to be healthy and generally provided good, uniform coverage, the average percent cover exceeded the criteria of 50% only for the high application rate of St. Peters compost. Overall averages for all three application rates of Ormiorganics and St. Peters composts were approximately 34 to 42%, respectively. The Milorganite treatments produced very little cover, although significantly more than the control treatment. The control plots had only a few scattered plants.

Plant tissue analysis

The plant tissue analysis data indicate plant uptake of metals did occur. Since there was insufficient vegetation to perform plant tissue analysis for the control plots, a comparison between the treated plots and the control plots could not be performed. These results indicate that compost reduces the uptake of metals when compared with the Milorganite treatments. At the BRMTS, the plant tissue metals for the Milorganite treatments approximated those of the control treatment. If it can be assumed that a similar relationship exists for the LCTS, it may be inferred that compost reduces the uptake of metals when compared to the control treatment.

Concentrations of Cd and Pb exceeded the herbivore toxicity criteria for all treatments.

Concentrations of Zn exceeded the criteria for all of the Milorganite treatments and for the high application rate of Ormiorganics. Based on the established criteria, if vegetation growing on the LCTS plots was a herbivore's sole source of forage, it would be considered potentially toxic.

Plant-available tailings analysis

Results of the analysis of amended tailings materials indicate the Milorganite treatments did not significantly change the plant availability of Cd, Pb, or Zn. The Ormiorganics treatments had no effect on plant-available Cd and little affect on Pb, but appeared to reduce the availability of Zn somewhat, especially at the highest application rate. Plant-available Cd increased for the St. Peters compost treatment samples; however, plant-available Pb and Zn decreased.

4. CONCLUSIONS

This project was performed to investigate the use of organic amendments in establishing vegetation on Pb tailings and to evaluate the effect of those amendments on the uptake of metals present in the tailings into aboveground plant tissues.

Based on the first growing season results, the Ormiorganics compost treatment performed the best at the BRMTS, and the St. Peters compost treatment performed the best at the LCTS. The Milorganite treatments did not perform as well at either site.

MSE will monitor these research plots during May through September for the next two growing seasons. Monitoring will consist primarily of making general observations, photographing each plot and each site, and removing weeds. It is not anticipated that replanting will be necessary; sufficient vegetative cover has been established at both sites to evaluate the effects of the various treatments. At the end of each year in September, the vegetation at BRMTS and the LCTS will be harvested, and tailings samples will be collected and analyzed. A final report will be prepared at the end of the third growing season (2002) that will summarize all project results and will include a cost analysis.

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