REVEGETATION OF MINING WASTE USING ORGANIC AMENDMENTS AND EVALUATING THE POTENTIAL FOR CREATING ATTRACTIVE NUISANCE FOR WILDLIFE[1]

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Abstract: The project was performed under the Mine Waste Technology Program, which is funded by the U.S. Environmental Protection Agency (EPA) and jointly administered by EPA and the U.S. Department of Energy (DOE) through an Interagency Agreement. (IAG No. DW89938513-01-0 and DOE Contract No. DE-AC22-96EW 96405)

The objectives of this project are to demonstrate that use of organic amendments enhances the establishment and growth of grass on lead mill tailings and evaluates the affect 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 floatation tailings at the Big River Mine Tailings site (BRMTS) and coarse-textured gravity separation tailings at the Leadwood Chat Tailings site (LCTS)) contain elevated concentrations of Pb, Zn, and Cd. This project was evaluated for three growing seasons (2000, 2001, and 2002).

At the end of each growing season, vegetative cover and biomass production were quantified, and tailings and vegetation samples were obtained and analyzed. In addition, at the end of the third growing season, core samples were collected in designated plots to evaluate compost incorporation and root penetration and to perform microbiological characterization, which will be presented in a future report. Also, precipitation data was compiled for each growing season.

Vegetation evaluations and analyses of plant tissues and tailings materials indicate differences among amendment types and application rates are environmentally significant. In general, compost has been very effective in establishing and maintaining adequate vegetation cover and biomass production under reduced precipitation conditions. This is due to in part to improved soil structure, water holding capacity, and soil nutrient content. Compost also reduced plant uptake of metals two to three fold compared to those observed in the controls.

Key words: vegetation, organic amendments, tailings, and compost, and bioavailability

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Introduction

This Summary Report has been prepared specifically for the Mine Waste Technology Program (MWTP), Activity III, Project 23- *Revegetation of Mining Waste Using Organic Amendments and Evaluating the Potential for Creating Attractive Nuisance for Wildlife Project,* which addresses the U.S. Environmental Protection Agency (EPA) technical issues of *Mobile Toxic Constituents in Water.*

Project 23 is a three-year project (2000, 2001, and 2002) to evaluate the feasibility of using organic amendments to enhance the establishment and maintenance of vegetative cover on mine tailings, stabilize toxic metals, and reduce the plant uptake of metals. This summary report presents second growing season results and compares these results with those of the first growing season (MSE July 2001).

Project Objectives

The following three quantitative objectives have been developed for the project:

- Achieve long-term vegetative cover of ≥50%;
- Reduce the plant availability of metals (Cd, Pb, and Zn) in treated tailings as compared to the control (untreated tailings); and
- Evaluate the herbivore toxicity of the plant materials established on the various treatment plots, according to the following acceptance criteria: (National Academy of Science 1980):

  Cd ≤ 2.0 mg/kg

  Pb ≤ 40 mg/kg

  Zn ≤ 300 mg/kg

These criteria were based on professional judgment, since no universally accepted standards exist for these elements; specific site conditions were considered when establishing these standards for success. The criteria stated in the Quality Assurance Project Plan (QAPP) (MSE June 2000) were based upon a review of then available literature. A subsequent 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 initially in the QAPP (MSE October 2001). Therefore, the QAPP herbivore toxicity acceptance criteria have been modified as follows:

Cd $\leq$ 5.0 mg/kg

Pb $\leq$ 40 mg/kg

Zn $\leq$ 500 mg/kg

Description of Test Sites

The selected sites for this project are the Big River Mine Tailings Site (BRMTS) near Desloge, Missouri and the Leadwood Chat Tailings Site (LCTS) near Leadwood, 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 two sites. 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 (Figure 1).

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 Response, 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 Lead, Cadmium, and Zinc; 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 is 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 7 years of age have blood-lead concentrations exceeding the health-based standard of 10 micrograms per deciliter (MSE, October 2001).

Plot Design

MSE Technology Applications, Inc., (MSE) established field plots at the two sites described above. Three organic amendments were selected and applied at three different rates (low, medium, and high). The three organic amendments were:

- Milorganite - a commercially available organic fertilizer composed of heat-dried activated biosolids in a fine granular form;
- Ormiorganics - a commercially available compost with a mixed residential yard waste feedstock, and;
- St. Peter's Compost - a non-commercial compost composed of 40% biosolids and 60% mixed residential yard waste feedstock.

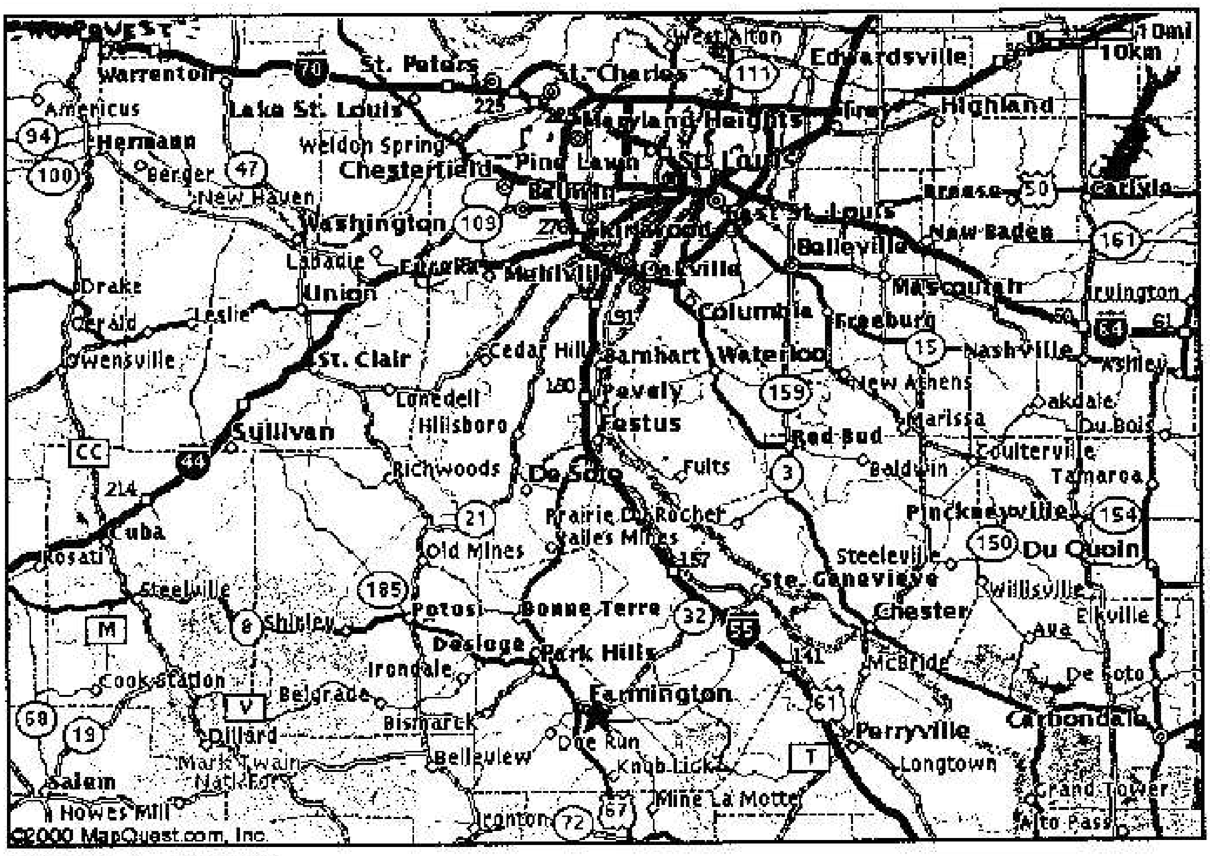

Figure 1-1. Site map.

Each site consisted of 40 plots (4 rows with 10 plots in each row). Each row contained plots of 3 organic amendments at each of 3-application rates plus 1 control plot that received only inorganic fertilizer. The various treatments were arranged using a randomized block design. Each organic amendment/application rate combination was replicated four times at each site. The respective site plot locations are shown in Figure 1. Table 1 defines the treatments for the plots. Figure 2 shows the layout of the plot design with the field codes. The plant species selected for the demonstration was tall fescue (*Festuca aerundinacea* Schreb., cv. Kentucky 31). Tall fescue is a cool-season, perennial grass adapted to the area's climate.

Table 1. Treatment 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 cu.yd./acre) 1.5 inches (200 cu.yd./acre) 2 inches (266 cu.yd./acre)	D E F
St Peter's Compost	1 inch (133 cu.yd./acre) 1.5 inches (200 cu.yd./acre) 2 inches (266 cu.yd./acre)	G H I
Control	No organic amendments, fertilizer only	K

Technical details pertaining to the baseline characterization, establishment, and maintenance of the 2 test sites (BRMTS and LCTS) are provided in the first interim report (MSE July 2001).

Overview of Methods

This section provides a brief summary of field and laboratory methods utilized in this study. Technical details are provided in the first interim report (MSE July 2001) and initial QAPP (MSE June 2000).

Field Methods

Vegetation Analysis. Quantitative estimation of plot-specific vegetative cover plus harvesting of leaf and stalk biomass (LSB) was performed by Bauer Technical Services, Inc. A 1-by 3 meter (m) grid divided into three 1m-squares was placed at the approximate center of each plot. Aerial groundcover observations were made for each square. Biomass data were obtained by harvesting the vegetation from within each square. LSB production was determined by Key Agricultural Services, Inc., via drying the clipped biomass in a forced air oven at 60°C for 72 hours and then weighing the material.

Figure 2. Plot Layout *Figure 1-1. Plot Layo*

Plant Sampling for Laboratory Analysis. 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 the samples were washed and prepared for analysis.

Sampling of Tailings. After LSB clipping was completed, MSE collected a composite sample (comprised of 5 sub samples) of the upper 15 cm of tailings within each plot. These samples were placed in labeled bags and then sent to the HKM Laboratory for preparation and analysis.

Soil Moisture Analysis. MSE performed soil moisture analysis in the field from the treatments that met the criteria for the first and second growing seasons (2-inch application of St. Peters compost) the third growing season (2002).

Core Sampling Analysis. MSE collected core samples from the treatments that met the criteria for the first and second growing season (2-inch applications St. Peter's Compost) for 2002, to observe and photograph the tailings profile and evaluate compost corporation and root penetration.

Laboratory Methods

Plant Tissues. The potential for surface contamination of the LSB samples (by mill tailings) was mitigated by washing the tissues in dilute soap solution (0.1% by volume), followed by rinsing with deionized water. Plot-specific aliquots of dried LSB were dissolved in a nitric-perchloric acid mixture, following EPA's Method SW-846 3050B. The digestates were analyzed for the target elements via ICP-OES, in accordance with SW-846 Method 6010B.

Tailings. A number of physicochemical parameters were evaluated for each of the plot-specific mill tailings samples. Such parameters included those relevant to soil/plant growing conditions (e.g., percent sand, silt, clay; NPK levels) or to assessing soil treatment effectiveness (e.g., plant available metals levels). Parameter-specific analytical methods are presented in Section 5.0 of the initial QAPP (MSE June 2000). It should be noted that acid extractable metals analyses used the same procedures as utilized for plant tissues. Plant available metals used the Diethylenetriamene pentacetic acid-Ammonium Bicarbonate (DTPA-AB) extraction procedure, followed by ICP-OES analyses of the filtrates.

Results and Discussion

Summaries of the critical data collected during each growing season (for the 2000 and 2001, 2002 data is currently being analyzed) are presented in the following sections. The summary tables consist of averages of the four replicated plots for each treatment at each site. The raw data for vegetation and tailings analyses are available. Descriptions of the sampling procedures, frequencies, and sampling locations can be found in the QAPP (MSE June 2000). All sampling and fieldwork was performed according to procedures outlined in the project specific QAPP or according to existing Standard Operating Procedures (SOPs).

Precipitation Results

The Doe Run Company operated a meteorological station located approximately 1¼ miles from the BRMTS and 3½ miles from the LCTS, through August 2001. That station was relocated to a new site during September, so was not collecting data during that month. A National Weather Service station is located at the Farmington, Missouri airport approximately 9½ miles from the Doe Run station. Together, these stations generated precipitation information that is generally representative of the two plot sites.

Precipitation during the 2001 growing season was quite variable, as evidenced by the monthly precipitation data presented in Table 2, Part B. Early spring (March and April) rainfall was well below normal, as was for the month of September. Rainfall during July and August was above normal. Although the total growing season precipitation was approximately four inches less than average, the timing of that precipitation was much more significant. Tall fescue, which is growing on the plots, is classified as a "cool season" grass. Most of the annual growth of cool season grasses takes place during the spring and fall. Therefore, adequate soil moisture during those seasons is of much greater importance, with regards to plot vegetative production, than is moisture received during mid-summer.

Overall, the vegetation data show the effect of continued below-normal precipitation combined with the absence of supplemental irrigation during the second growing season. As noted in Table 2, Part A, the plots were irrigated after planting and during periods of low precipitation in 2000 to ensure successful establishment. With less rain and no supplementary irrigation in 2001, results indicate significantly less vegetation than year 1 for all treatments.

BRMTS

Vegetation Cover and Production. The BRMTS cover and production data from year 2001 are compared to those for year 2000 in Table 3.

Table 2. Precipitation Summaries for the 2000 and 2001 Growing Seasons (inches).

Part A. Growing Season 2000[a]				
Month	Doe Run Stn.	Farmington Airport	Farmington Airport (1961-1990)	Deviation from Long Term
March	1.7	2.6	4.2	-1.6
April	2.9	N/A	3.9	—
May	2.6	2.8	4.0	-1.3
June	3.8	5.9	3.4	+2.5
July	4.0	3.3	3.7	-0.4
August	3.5	3.2	4.0	-0.8
September	0.7	2.1	3.5	-1.5
Total	23.0	20.0	27.0	-3.1

Part B. Growing Season 2001[b]				
Month	Doe Run Stn.	Farmington Airport	Farmington Airport (1961-1990)	Deviation from Long Term
March	1.6	1.0	4.2	-3.2
April	2.4	2.6	3.9	-1.2
May	3.3	3.6	4.0	-0.5
June	4.2	3.5	3.4	+0.1
July	8.2	5.0	3.7	+1.3
August	3.6	5.8	4.0	+1.8
September	N/A	1.1	3.5	-2.4
Total	23.0	23.0	27.0	-4.1
Notes:	[a] Doe Run data taken from Ref. 1 plus personal communication with Mr. Jim Chance (for March datum), while annual and long-term average data for Farmington airport were obtained from the National Climatic Center. [b] Doe Run and Farmington Airport data were obtained from company sources and NCC, as above; N/A= not available (i.e., missing data).			

All treatments met the ≥50% cover criteria including the control for 2000. However, for 2001, only the Ormiorganics and St. Peter's Compost treatments met the cover criteria. Although Milorganite appears to improve production and cover compared to the control, it is less effective than the two compost treatments.

Table 3. Big River Mine Tailings Vegetation Comparison for 2000 & 2001.

	Average Coverage (%)			Average Production (gm/m^2)		
Treatment (Rate)	2000	2001	% Diff.	2000	2001	% Diff.
Milorganite						
1,450 lb/acre (A)	97	27	-72	300	24	-92
2,200 lb/acre (B)	89	30	-66	320	33	-90
2,900 lb/acre (C)	69	32	-53	280	56	-80
Overall Average	**85**	**30**	**-64**	**300**	**38**	**-87**
Ormiorganics						
1 inch (D)	100	61	-39	610	110	-81
1.5 inch (E)	100	69	-31	610	140	-78
2 inch (F)	100	80	-20	590	230	-60
Overall Average	**100**	**70**	**-30**	**600**	**160**	**-73**
St. Peter's Compost						
1 inch (G)	100	67	-32	480	190	-61
1.5 inch (H)	99	83	-17	480	300	-36
2 inch (I)	97	87	-10	480	390	-19
Overall Average	**99**	**79**	**-20**	**480**	**290**	**-39**
Control						
No organics applied (K)	81	13	-77	200	3	-98

Note: [a] Percent change=(2001-2000/2000) (100).

Decreases in both plant cover and production were greatest with the control plots. The next greatest decreases occurred on the Milorganite plots, followed by the Ormiorganics plots. The smallest decreases were observed on the St. Peter's compost plots. Based on this data, the most successful treatment for the 2001 growing season was St. Peter's compost at the highest application rate; average cover for that treatment decreased 10% from that measured in 2000, and average production decreased 19%.

In 2001, increased application rates correlated with the increased cover and production results for all compost treatments. This is in contrast with data from 2000, which did not show application rates to be well correlated with either cover or production for any of the treatments. It may be concluded that higher application rates of organic amendments may be more beneficial during periods of moisture stress (i.e., low soil moisture) than when moisture is adequate.

Figures 2, 3, 4, and 5 show the BRMTS plot site right after planting and at the end of each growing season.

Figure 2. BRMTS in April 2000, after planting.

Figure 3. BRMTS in September 2000, after first growing season.

Figure 4. BRMTS in September 2001 after second growing season.

Figure 5. BRMTS in September 2002 after third growing season.

Plant Tissue Analysis. Plant tissue analytical data are used to evaluate the uptake of the target metals into LSB, and to compare the results with the objectives for potential herbivore toxicity for Cd, Pb, and Zn. Table 4 shows the data for year 1 (2000) compared to year 2 (2001).

Table 4. Big River Tailings Plant Tissue Metal Analysis Comparison for 2000 & 2001.

	Cd (mg/Kg)			**Pb (mg/Kg)**			**Zn (mg/Kg)**		
Treatment	**2000**	**2001**	**% Diff.**	**2000**	**2001**	**% Diff.**	**2000**	**2001**	**% Diff.**
Milorganite									
1,450 lb/acre (A)	1.5	8.4	460	42	110	160	220	210	-4.5
2,200 lb/acre (B)	1.7	8.9	420	40	100	150	210	180	-14
2,900 lb/acre (C)	1.5	7.3	3390	39	76	95	210	160	-24
Overall Average	**1.6**	**8.2**	**420**	**40**	**97**	**140**	**220**	**190**	**-14**
Ormiorganics									
1 inch (D)	1.0	4.1	310	28	43	54	120	100	-17
1.5 inch (E)	1.0	3.5	250	23	27	17	120	77	-36
2 inch (F)	1.0	2.2	120	24	23	-4.2	170	75	-56
Overall Average	**1.0**	**3.3**	**230**	**25**	**31**	**24**	**140**	**85**	**-39**
St. Peter's Compost									
1 inch (G)	0.80	3.3	310	23	21	-8.7	150	150	0.0
1.5 inch (H)	1.4	1.8	29	30	13	-57	150	150	0.0
2 inch (I)	0.70	2.3	230	25	20	-20	180	120	-33
Overall Average	**1.0**	**2.5**	**150**	**26**	**18**	**-31**	**160**	**140**	**-13**
Control									
No application (K)	1.4	7.7	450	42	120	186	230	220	-4.3

The established herbivore toxicity criteria for the metals of concern were Cd ≤ 5.0 mg/kg, Pb ≤ 40 mg/kg and Zn ≤ 500 mg/kg. All treatments were below the herbivore toxicity criteria for Cd except the Milorganite in 2001. Most of the Milorganite treatments for 2000 and all the Milorganite treatments for 2001 exceeded the Pb criteria. The Ormiorganic low application rate treatment also exceeded the Pb criteria in 2001. All treatments were below the criteria for Zn.

There was a significant increase in Cd levels from 2000 to 2001 for all treatments except for the St. Peter's compost medium application rate. Overall, the control and Milorganite treatments appear to inadequately control Cd and Pb uptake. Subsequent use of such LSB as a sole food source may pose a hazard to wildlife and/or livestock species if grown without soil amendment. Although the Ormiorganics high application rate treatments results are generally satisfactory, the best overall control of target metals uptake is by St. Peter's compost high application rate, it actually showed a net decrease in Pb concentration.

Tailings Analysis

Acid Extractable Metals. Composite samples of tailings from each plot were collected at the end of the 2000 and 2001 growing seasons, and analyzed for acid extractable metals levels; Table 6 shows the laboratory results for these 2 sampling events.

Table 6. Big River Tailings Metal Analysis (Acid Extractable) Comparison for 2000 & 2001.

	Cd (mg/Kg)				**Pb (mg/Kg)**				**Zn (mg/Kg)**		
Treatment/Rate	**2000**	**2001**	**% Diff.**		**2000**	**2001**	**% Diff.**		**2000**	**2001**	**% Diff.**
Milorganite											
1,450 lb/acre (A)	11	15	36		1200	1200	0.0		600	620.	3.3
2,200 lb/acre (B)	11	13	18		920	910	-1.1		540	510	-5.6
2,900 lb/acre (C)	11	13	18		830	870	4.8		540	540	0.0
Overall Average	**11**	**13**	**18**		**970**	**1000**	**3.1**		**560**	**560**	**0.0**
Ormiorganics											
1 inch (D)	11	12	9.1		1000	1000	-0.0		530	510	-3.8
1.5 inch (E)	12	12	0.0		950	1100	16		580	550	-5.2
2 inch (F)	10	11	10		780	760	-2.6		490	440	-10
Overall Average	**11**	**12**	**9.1**		**920**	**950**	**3.3**		**530**	**500**	**-6.0**
St. Peter's Compost											
1 inch (G)	11	13	22		820	860	4.9		530	510	-3.8
1.5 inch (H)	10	11	10		800	750	-6.3		530	480	-9.4
2 inch (I)	10	10	0.0		980	1000	2.0		520	470	-9.6
Overall Average	**10**	**11**	**12**		**870**	**870**	**0.0**		**530**	**490**	**-7.5**
Control											
No application (K)	11	12	9.1		930	920	-1.1		560	540	-3.6

Based on the acid extractable data, there appears to be no significant decrease in total metal levels in the soil due to any of the treatments.

Plant Available Metals. A summary of the analytical results for DTPA-AB extractable metals levels in tailings for the 2000 and 2001 growing seasons is presented in Table 8.

This analytical data is used to evaluate the plant availability of metals (Cd, Pb, and Zn) in the treated tailings as compared to the untreated (control).

Table 8. Big River Tailings Metal Analysis (Plant Available) Comparison for 2000 & 2001.

	Cd (mg/Kg)			**Pb (mg/Kg)**			**Zn (mg/Kg)**		
Treatment/Rate	**2000**	**2001**	**% Diff.**	**2000**	**2001**	**% Diff.**	**2000**	**2001**	**% Diff.**
Milorganite									
1,450 lb/acre (A)	1.8	2.7	50	530	430	-19	170	170	0.0
2,200 lb/acre (B)	2.9	3.2	10	320	300	-6.3	170	160	-5.9
2,900 lb/acre (C)	3.3	3.3	0.0	290	310	6.9	180	180	5.9
Overall Average	**2.7**	**3.1**	**15**	**380**	**350**	**-7.9**	**170**	**170**	**0.0**
Ormiorganics									
1 inch (D)	2.1	2.0	-4.8	300	310	3.3	140	140	0.0
1.5 inch (E)	2.0	2.0	0.0	260	310	19.	140	130	-7.1
2 inch (F)	1.9	2.3	21	200	230	15	120	130	-8.3
Overall Average	**2.0**	**2.1**	**5.0**	**250**	**290**	**16**	**130**	**130**	**-0.0**
St. Peter's Compost									
1 inch (G)	2.2	2.4	9.1	220	220	0.0	130	130	0.0
1.5 inch (H)	2.4	2.7	13	210	200	-4.7	140	130	-7.1
2 inch (I)	1.8	2.0	11	250	310	24	120	120	0.0
Overall Average	**2.2**	**2.4**	**9.1**	**230**	**240**	**4.3**	**130**	**130**	**0.0**
Control									
No application (K)	2.8	2.4	-14	290	330	14	170	160	-5.9

The overall average plant available Cd concentration for the treated plots were similar to the untreated control plots for both 2000 and 2001. The plant available Pb concentration for the Milorganite plots were greater than that of the control plots. The low Milorganite applications rate plots resulted in elevated Pb concentration, whereas, the high Milorganite applications rate was similar to the control. Since Milorganite does not contain high levels of Pb and the volume of Milorganite applied was low, it is probably that the elevated concentration of Pb is an anomaly due to the chemical variability of the tailings themselves. It is thus concluded that Milorganite did not change the plant availability of Pb.

The concentrations of plant available Zn in samples of compost plot materials were approximately three-quarters those of the controls, indicating that both composts are capable of reducing the plant availability of Zn metals. The compost treatments also reduced the plant availability of Cd and Pb in most instances. For 2000, the average plant available Pb for the plots receiving the low applications of Ormiorganics compost was slightly higher than for the control plots.

LCTS

Plant Cover and Production. The LCTS cover and production data from year 2001 are compared to year 2000 in Table 9. The validity and usefulness of second growing season data were compromised by vandalism at the site that destroyed some of the individual plots and damaged others. As a result, the data summarized below are derived from fewer replications than for year 2000.

The only treatments that met the ≥50% criteria were St. Peter's Compost high application rate for both 2000 and 2001. Of the organic treatment plots, decreases in both cover and production were greatest with the Milorganite plots, followed by the Ormiorganics plots. The smallest decrease in cover was observed on the St. Peter's compost plots, and the average production for all three application rates of St. Peter's compost was nearly identical to that for the first growing season. However, that overall average was the result of increased production for the St. Peter's compost medium application rate. As with the BRMTS site based on this data, the most successful treatment for the 2001 growing season was St. Peter's compost at the highest application rate; average cover for that treatment decreased only 5.4% from that measured in 2000, and average production decreased 13%.

Table 9. Leadwood Mine Tailing Vegetation Comparison for 2000 & 2001.

	Average cover (%)				Average Production (gm/m^2)		
Treatment/Rate	**2000**	**2001**	**% Diff.**		**2000**	**2001**	**% Diff.**
Milorganite							
1,450 lb/acre (A)	1.9	0.3	-84.2		3.0	1.0	-67
2,200 lb/acre (B)	4.8	2.2	-54.2		6.0	2.7	-55
2,900 lb/acre (C)	5.8	2.2	-62.1		9.1	3.6	-60
Overall Average	**4.2**	**1.6**	**-62**		**6.0**	**2.4**	**-60**
Ormiorganics							
1 inch (D)	31	14	-55		61.	34	-44
1.5 inch (E)	31	25	-19		90	72	-20
2 inch (F)	32	17	-47		93	50	-46
Overall Average	**34**	**18**	**-47**		**81**	**52**	**-36**
St. Peter's Compost							
1 inch (G)	32	20	-38		83	63	-24
1.5 inch (H)	39	32	-18		85	110	29
2 inch (I)	56	53	-5.4		150	130	-13
Overall Average	**42**	**35**	**-17**		**100**	**100**	**-0.0**
Control							
No application (K)	0.4	0.2	-50		.1	.1	0.0

As with the BRMTS, the vegetation data show the effects of successive dry years. The LCTS plots were not irrigated immediately following planting in 2000, but were irrigated beginning in early summer of that year during periods of low precipitation (MSE July 2001). Year 2 results show considerably less vegetation than year 1 for all but the St. Peter's compost high application rate treatment. Given the percent of cover and production data for the control plots, there is insufficient information to assess any annual vegetative trends for this treatment.

The decreases in percent cover at the LCTS plots were similar to those at BRMTS (Table 9), but decreases in production at LCTS were substantially less. Both cover and production for the LCTS' St. Peter's compost plots increased with increasing application rates, but that association was less evident for the other treatments.

Figures 6, 7, 8, and 9 show the BRMTS plot site right after planting and at the end of each growing seasons.

Figure 6. LCTS in April 2000, after planting.

Figure 7. LCTS in September 2000, after first growing season.

Figure 8. 2001 LCTS in September 2001 after second growing season.

Figure 9. LCTS in September 2001, after the third growing season.

Plant Tissue Analysis. The plant tissue analytical data are used to evaluate the uptake of the target metals into LSB, and to compare the results with the objectives for potential herbivore toxicity for Cd, Pb, and Zn. Table 10 shows the data for year 1 (2000) compared to year 2 (2001). The evaluation criteria used were the same as those for the BRMTS.

Table 10. Leadwood Tailings Plant Tissue Metal Analysis Comparison for 2000 & 2001.

	Cd (mg/Kg)			**Pb (mg/Kg)**			**Zn (mg/Kg)**		
Treatment (Rate)	**2000**	**2001**	**% Diff.**	**2000**	**2001**	**% Diff.**	**2000**	**2001**	**% Diff.**
Milorganite									
1,450 lb/acre (A)	8.6	6.9	-20	100	77	-23	340	250	-26
2,20 lb/acre (B)	8.8	8.6	-2.3	110	120	9.1	370	240	-35
2,900 lb/acre (C)	9.3	9.1	-2.2	100	150	50	390	310	-21
Overall Average	**8.9**	**8.2**	**-7.9**	**110**	**110**	**0.0**	**370**	**270**	**-27**
Ormiorganics									
1 inch (D)	4.2	7.1	69	46	74	61	240	310	29
1.5 inch (E)	3.3	5.2	58	38	59	55.0	230	230	-0.0
2 inch (F)	3.9	3.7	-5.1	40	61	53	320	260	-19
Overall Average	**3.8**	**5.3**	**40**	**41**	**65**	**59**	**260**	**260**	**0.0**
St. Peter's Compost									
1 inch (G)	5.3	6.4	21	49	76	55	220	220	0.0
1.5 inch (H)	3.3	4.3	30	43	48	12	200	170	-15
2 inch (I)	3.4	5.0	47	37	47	27	170	160	-5.9
Overall Average	**4.0**	**5.2**	**30**	**43**	**57**	**33**	**200**	**190**	**-5.0**
Control									
No application (K)	no harv.	no harv.	Undefined	No harv.	no harv.	Undefined	no harv.	No harv.	Undefined

The established herbivore toxicity criteria for the metals of concern were Cd ≤ 5.0 mg/kg, Pb ≤ 40 mg/kg and Zn ≤ 500 mg/kg. In 2000, all treatments were below the herbivore toxicity criteria for Cd except the Milorganite treatments. In 2001, only the Ormiorganics medium and high application rate and St. Peter's Compost medium applications rates were below the Cd criteria. In 2000, only the Ormiorganics medium and high application rate and St. Peter's Compost high application rate treatments were below the Pb criteria. In 2001, all treatments exceeded the Pb criteria. All treatments for both 2000 and 2001 were below the criteria for Zn. Subsequent use of such LSB as a sole food source may pose a hazard to wildlife and/or livestock species if grown without soil amendment.

Comparing the data from 2000 to 2001, show some differences. Milorganite treatments exceeded the established criteria but had minimal change for (d and Pb) levels and a minimal decrease for Zn levels from 2000 to 2001. Both compost treatments resulted in increase in Cd and Pb levels in 2001. The Ormiorganics had no change in Zn levels. The St. Peter's Compost had a minimal decrease in Zn levels.

The LCTS control plots did not produce enough LSB to sample and analyze in either growing season (Table 10), so no comparisons with the other treatments can be made.

For Milorganite and Ormiorganic treatments, metals concentrations in plant tissues did not appear to be strongly correlated to amendment application rates. However, St. Peter's compost treatments showed some correlation; with increasing metals concentrations in plant tissues with increasing amendment application rates for Cd. Pb, and Zn.

Tailings Analysis

Acid Extractable Metals. Composite samples of tailings from each plot were collected at the end of the 2000 and 2001 growing seasons, and then analyzed for acid extractable metals levels; Table 11 presents the laboratory results for these 2 seasons.

Based on the acid extractable data, there appears to be no significant increase Cd, Pb or Zn concentration due to any of the treatments.

Plant Available Metals

A summary of the analytical results for DTPA-AB extractable metals levels for the growing seasons 2000 and 2001 is presented in Table 12. This analytical data is used to evaluate the plant availability of metals (Cd, Pb, and Zn) in the treated tailings as compared to the untreated (control).

Table 11. Leadwood Mine Tailings Metal Analysis (Acid Extractable) Comparison for 2000 & 2001.

	Cd (mg/Kg)			**Pb (mg/Kg)**			**Zn (mg/Kg)**		
Treatment/Rate	**2000**	**2001**	**% Diff.**	**2000**	**2001**	**% Diff.**	**2000**	**2001**	**% Diff.**
Milorganite									
1,450 lb/acre (A)	55	67	22	3110	4400	42	2600	3500	35
2,200 lb/acre (B)	62	59	-4.8	4700	4900	4.3	3000	3000	0.0
2,900 lb/acre (C)	445	47	6.8	4200	4800	14.	2100	2500	19
Overall Average	**54**	**57**	**5.6**	**4000**	**4700**	**18**	**2600**	**3000**	**15**
Ormiorganics									
1 inch (D)	44	76	73	4400	3400	-23	2100	3700	76
1.5 inch (E)	58	58	0.0	3100	2800	-9.7	2800	3000	7.1
2 inch (F)	52	67	29	3300	2600	-21	2500	3500	40
Overall Average	**51**	**67**	**31**	**3600**	**2900**	**-19**	**2500**	**3400**	**36**
St. Peter's Compost									
1 inch (G)	57	56	-1.7	6600	3800	-42	2800	2900	3.6
1.5 inch (H)	53	64	21	2900	3400	17	2600	3400	31
2 inch (I)	54	66	22	2000	3000	50	2600	3400	31
Overall Average	**55**	**62**	**13**	**3800**	**3400**	**-11**	**2700**	**3300**	**22**
Control									
No application (K)	50	56	12	4110	2700	-34	2400	2900	21

The overall average plant available Cd concentration for the treated plots was similar to the untreated (control) plots for both 2000 and 2001. For 2000, the average Pb concentration for Milorganite was greater than the control plots, but less than the control plots in 2001. Both compost treatments Pb concentrations were less than the control plots, which indicate that both composts are capable of reducing this plant availability of Pb. For the average Zn concentrations, all three treatments were less than the untreated (control) plots.

Table 12. Leadwood Tailings Metal Analysis (Plant Available) Comparison for 2000 & 2001.

	Cd (mg/Kg)				Pb (mg/Kg)				Zn (mg/Kg)		
Treatment/Rate	**2000**	**2001**	**% Diff.**		**2000**	**2001**	**% Diff.**		**2000**	**2001**	**% Diff.**
Milorganite											
1,450 lb/acre (A)	3.3	3.5	6.1		230	230	0.0		280	360	29
2,200 lb/acre (B)	3.2	3.5	9.4		240	210	-13		290	300	3.4
2,900 lb/acre (C)	3.0	3.4	13		220	210	-4.5		250	310	24
Overall Average	**3.2**	**3.5**	**9.4**		**230**	**220**	**-4.3**		**270**	**320**	**19**
Ormiorganics											
1 inch (D)	2.9	3.0	3.4		200	200	0.0		260	250	-3.8
1.5 inch (E)	3.0	3.7	23		190	220	16		250	240	-4.0
2 inch (F)	3.5	3.6	2.8		220	220	0.0		230	240	4.3
Overall Average	**3.2**	**3.4**	**6.3**		**200**	**200**	**0.0**		**240**	**240**	**0.0**
St. Peter's Compost											
1 inch (G)	3.4	2.9	-15		180	200	11		220	250	14
1.5 inch (H)	3.6	3.2	-11		180	190	5.6		220	230	4.5
2 inch (I)	3.8	3.5	-7.9		170	190	12		230	220	-4.3
Overall Average	**3.6**	**3.2**	**-11**		**180**	**190**	**5.6**		**220**	**230**	**4.5**
Control											
No application (K)	3.1	4.1	32		210	230	9.5		300	370	23

Summary and Conclusions

BRMTS

Vegetation Cover and Production. Table 3 indicates that control and Milorganite treatments failed to meet the $\geq 50\%$ vegetative cover technology acceptance criterion in 2001, after two back-to-back dry years; both Ormiorganics and St. Peter's compost treatments satisfy this criterion. Furthermore, increased application rates of compost are associated with increased percent plant cover measurements. Compost probably increases the moisture retention capability of these soils, and subsequently mitigates the adverse effects of low precipitation during and after the growing season.

Annual decreases in production were >85% for both control and Milorganite treatments and are judged to be environmentally significant. The overall 73% decrease in biomass production for the Ormiorganic treatments is probably significant; while the overall 39% decline associated with St. Peter's compost treatments may be of some concern regarding long-term technological viability. However, it is important to note that the St. Peter's compost high application rate had the lowest reductions of cover (10%) and production (19%) for all of the treatments evaluated.

Plant tissue Analysis.

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

Tailings Analysis (Plant Available)

The Ormiorganics and St. Peter's Compost appear to reduce the concentrations of plant available metals compared to the control, indicting that the compost amendments did tie up some of the metals. Concentrations of plant available metals in Milorganite treatment plots were either greater than or close to the control plots, indicating that Milorganite did not change the availability of these metals.

LCTS

The Ormiorganics and St. Peter's Compost appear to reduce the concentrations of plant available metals for Pb and Zn compared to the control, which indicates that the compost amendments did tie up some of the metals. Milorganite treatments did not significantly change the plant availability of Cd, Pb or Zn, and the two compost treatments did not significantly change the plant availability of Cd.

Vegetation Cover and Production. Table 9 indicates that only the St. Peter's compost treatment continued to meet the $\geq 50\%$ vegetative cover technology acceptance criterion, after two back-to-back dry years. In addition, this treatment continued to rank highest in LSB production in 2001; the decline from the 2000 peak value was only about 13%.

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. However, the results do indicate that compost reduces the uptake of metals when compared to the Milorganite treatments.

Tailings Analysis

The Ormiorganics and St. Peter's Compost appear to reduce the concentrations of plant available metals for Pb and Zn compared to the control, which indicates that the compost amendments did tie up some of the metals. Milorganite treatments did not significantly change the plant availability of Cd, Pb or Zn, and the two compost treatments did not significantly change the plant availability of Cd.

CONCLUSIONS

BRMTS.

Based on the first growing season results, the Ormiorganics compost treatment had performed the best at the BRMTS. However, the collective results for 2000 and 2001 indicate that St. Peter's compost high application rate treatment (i.e., 2 inches application of St. Peter's compost) is now the best performer at this site. Observations supporting this conclusion are as follows:

- St. Peter's compost high application rate considerably exceeds the $\geq 50\%$ vegetative criterion, exhibited greatest biomass production (kg dry LSB/m^2) in both years, and exhibited the lowest annual decreases in both cover (-10%) and production (-19%) of all 10 treatments evaluated; while
- acid extractable metals levels in LSB are amongst the lowest for all 10 treatments, and are less than the metals-specific wildlife herbivore toxicity criteria.

LCTS.

Based on the first growing season results, St Peter's compost treatment had performed the best at the LCTS. This observation is reinforced by the results for the 2001 growing season. The collective observations supporting this conclusion are as follows:

- St. Peter's compost high application rate is the only treatment (of 10 total) that met the vegetative cover criterion in both growing seasons, that exhibited the highest production in both years, as well as exhibiting lowest annual decreases in both cover (-5%) and production (-11%).

However, none of the 10 treatments complied with the wildlife Pb toxicity criterion. In addition, acid extractable and plant available metals levels at LCTS were generally higher than those measured at BRMTS. MSE suggests that compost application rates used at the LCTS were not great enough to adequately treat the levels of soluble target metals present in these "soils." Thus, higher St. Peter's compost (or other organic treatment) application rates will probably be needed to comply with the Cd and Pb plant and herbivore toxicity criteria.

MSE monitored these research plots (at both sites) and collect tailings and plant tissue samples for the last growing season 2002. The data is being analyzed and evaluated and a final report will be completed by April 2003 that summarizes all project results, and will include a technology application cost analysis.

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