REVEGETATION OF MINE TAILINGS THROUGHTHE USE OF BIOSOLID AMENDMENT[1]

I.L. Pepper[2], S.A. Bengson, P.R. Rao, and K.L. Josephson

Abstract. Mine tailings represent the end product of mineral ores that are processed to extract specific metals such as copper. Tailings are in essence crushed rock with 0% organic matter, and can be layered to depths of 30–36m. We evaluated revegetation of mine tailings through the one time application of municipal biosolids. Specifically a 2 hectare copper mine-tailing plot near the Mission Mine in Southern Arizona was designated for this study. Approximately 220 dry tons per hectare of biosolids was added and incorporated in December 1998. The potential for successful revegetation was evaluated by monitoring soil microbial populations, which quickly become established at $\approx 10^7$ heterotrophic bacteria per gram of biosolid amended mine tailings. By September 2001 vegetative cover had increased from zero to 77%. Initially bermudagrass and Russian Thistle were the predominant species involved. More recently Buffalo grass and Lehmans Lovegrass have become more prominent. Monitoring of soil metal concentrations as a function of depth showed that the tailings were the major source of metals, not the biosolids. There was no evidence that metals were leaching under the low rainfall, non-irrigated conditions. Plant tissue metal concentrations showed that phytoremediation could remove metals from the surface depths of tailings. Soil nitrate concentrations varied seasonally and with tailing depth. Nitrogen transformations included ammonification, nitrification and denitrification, which allowed nitrogen to be removed from tailings. Leaching of nitrate appeared to be minimal. Overall biosolid amendment of mine tailings appeared to be a successful technological approach to enhance revegetation of the mine tailings.

Additional Key Words: municipal waste reuse, tailings stabilization

---

[1] Paper was presented at the 2003 National Meeting of the American Society of Mining and Reclamation and The 9th Billings Land Reclamation Symposium, Billings MT, June 3–6, 2003. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] Ian L. Pepper, Professor and Director of the Environmental Research Laboratory at The University of Arizona, Tucson, AZ 85706; S.A. Bengson, Agronomist, ASARCO-Copper Operations, Sahuarita, AZ 85629; P.R. Rao, P.E., Pima County Wastewater Management Department, Tucson, AZ 85701; and K.L. Josephson, Research Specialist Principal, The University of Arizona, Tucson, AZ 85721.

Proceedings America Society of Mining and Reclamation, 2003 pp 961-974
DOI: 10.21000/JASMR03010961

https://doi.org/10.21000/JASMR03010961

Introduction

In the United States, mining is a large industry that provides valuable raw material and creates economic benefit for local communities. However, the potential environmental impact incurred from this industry ranges from unsightly mine tailings to the leaching of toxic elements into nearby waterways and aquifers. In addition, wind blown tailings can result in air pollution. Removal of the original vegetation, soil, and bedrock exposes the valuable copper deposits. In Southwest Arizona, ores containing copper are crushed and processed to remove the copper. Finally, the processed crushed rock is re-deposited on land as a thick slurry. Typically, tailings piles are 30−40 m thick.

The physiochemical characteristics of mine tailings are totally unlike the displaced topsoil that once supported vegetation in any given area. By removing and crushing the ore from the mines and placing it on the surface, minerals may oxidize when exposed to the atmosphere. For example, pyrite (FeS_2) common around coal mines oxidizes to sulfuric acid (H_2SO_4), and iron oxide (($Fe(OH)_3$). Acid mine drainage (H_2SO_4) can then contaminate surface and groundwaters in addition to increasing the solubility of toxic metals. Mining tailings are not the ideal medium on which to grow plants. The crushed rock consists of small fragments with large void spaces in between. There is virtually no organic material present, the cation exchange capacity (CEC) is very low, and there are few macronutrients (N.P.K.) available for the plants. However, the water holding capacity of the material is excellent. Soil biota, in the form of bacteria and fungi, are present in low numbers, and finally, the pH can be low, which increases the likelihood that toxic metals are available to be taken up by the plants. The goals of revegetating mine tailings therefore have to include the application of materials to amend the tailing substrate and provide an adequate environment for plant growth. One potential solution is the use of municipal biosolids.

In 1994, the Arizona Mined Land Reclamation Act was passed that required reclamation of all mining disturbances on private land to a pre-determined post-mining use. In 1996, the Arizona Department of Environmental Quality (ADEQ) adopted new rules allowing for the use of biosolids during reclamation. The Arizona Mining Association (AMA), has estimated that there are 13,355 hectares of active mine sites that can be reclaimed with the use of biosolids. In Southern Arizona, biosolids have been used for almost two decades for land application on agricultural land and the commercial growth of cotton. However, due to large amounts of farmland being sold and retired from agricultural usage, there is currently a shortage of land for the agricultural application of biosolids. Therefore, the concept that is emerging is that of utilizing one waste, namely biosolids, to reclaim another waste material, namely mine tailings. The issue of course, is whether or not this can be done in an environmentally sound manner via a process that is economically viable.

Current Arizona regulations limit the amount of biosolids that can be used to reclaim sites. The lifetime loading rate of biosolid applications to mine tailings is 336 metric tons (dry) per hectare. This amount can be applied as one application. The restrictions are due to concerns over potential nitrogen leaching, as well as additional heavy metal loads from the biosolids, both of which could impact underground aquifers, and therefore human health and welfare. However, field tests have shown that large amounts of biosolids are necessary to effectively reclaim mine tailings. Specifically, at least 250 metric tons (dry) per hectare may be necessary to promote active vegetation of mine tailings in the desert Southwest USA (Bengson, 2000). Thompson and Rogers (1999) conducted greenhouse tests utilizing 67 metric tons per hectare (dry weight basis) of biosolids on three different types of mine tailings ranging from acidic to neutral. The biosolids proved effective in promoting vegetative growth and increasing groundcover. In these studies, there was little evidence of significant leaching of nitrate, nor was there any evidence of heavy metal increases due to biosolid application. Here we describe a case study illustrating the use of biosolids to revegetate and stabilize mine tailings. The overall objective of this study was to evaluate the efficacy of dried biosolids as a mine tailing amendment to enhance site stabilization and revegetation. Specific objectives included.

1. To evaluate the benefits of land application of dried biosolids to mine tailings with respect to revegetation and stabilization.
2. To evaluate the hazards of metals and nitrate associated with the application of dried biosolids to mine tailings. (Note that pathogens were not monitored because of the use of "exceptional quality" biosolids for the project. Exceptional quality biosolids normally contain very low concentrations of pathogens.)

Methods

Experimental Plan

Study Site. A 2 hectare copper mine-tailing plot located near Mission Mine, south of Tucson, Arizona was designated for this study. Biosolids were applied at a rate of approximately 200 metric tons (dry) per hectare across the site in December, 1998 and then seeded with a variety of grass species including: oats, barley, Lehman Lovegrass, buffalo grass, and bermudagrass. Located in the desert Southwest USA, temperatures are routinely high and rainfall infrequent. However, despite this supplemental irrigation was not used in this experiment, since this would be impractical for large-scale revegetation efforts.

Analyses

a. Soil Sample Collection

Soil (biosolid amended mine tailings) cores were taken with a stainless steel auger at 30cm depth increments to a total depth of 150 cm. Samples were sieved and portions immediately used for microbial analyses. The remaining portions of the samples were stored at 4°C prior to other analyses.

b. Heterotrophic Plate Counts

Mine tailings amended with biosolids were diluted and plated on R2A agar plates.

c. Vegetation Transect Analyses

Transects consisted of 33 m lengths taken in random directions throughout the plot. Presence or absence of vegetative cover was evaluated every 30 cm. Five transects were taken during each evaluation.

d. Soil Nitrate Analyses

Tailings were analyzed for NO_3-N concentrations using ion chromatogrphy.

e. Total Organic Carbon (TOC) Analyses

These were conducted using high temperature combustion via a CNS elemental analyzer.

f. Soil Metal Analyses

Tailings were subjected to acid digestion followed by inductively coupled plasma─optical emission spectroscopy (ICP−OES).

Soil Microbial Response to Biosolids. Soil cores to depths of 150 cm were taken prior to biosolid amendment, and at discrete time intervals following biosolid amendment. Pure mine tailings were found to contain virtually no organic matter and very low heterotrophic bacterial populations (approximately 10^3 colony forming units (CFU) per gram of tailings). A large population of heterotrophic bacteria is essential for plant growth and revegetation, and therefore, monitoring soil microbial populations gives an insight into the probability of revegetation prior to plant growth. Biosolids routinely contain very high concentrations of organic matter including the macroelements carbon and nitrogen, which are essential for promoting microbial growth and metabolism. Following biosolid amendment of the mine tailings, heterotrophic bacterial populations increased at the surface to approximately 10^7 CFU per gram (Table 1). Bacteria decreased with increasing depth from the surface, indicating the influence of the biosolid surface amendment on bacterial growth. Table 1 also shows that the microbial populations have at this point been stable for 33 months. Overall, the microbial data show the success of biosolid amendment in changing mine tailings into a true soil-like material capable of supporting significant vegetative growth.

Physical Stabilization. One of the main objectives in stabilizing mine tailings is erosion control. This is generally best accomplished through a revegetation program since the root structures of the plants help to hold soil particles in place. In this experiment, the application of biosolids and the subsequent broadcast of grass seeds were the primary activities to promote site stabilization. Despite the extreme desert conditions, grasses have become established on these tailings. Table 2 shows the results of vegetation transect surveys conducted on this site 14 months, 21 months, and 33 months after initial seeding. The vegetation cover increased from 18% at the 14-month survey to 78.2% after 33 months. At 14 months, the predominant plant species were bermudagrass (*Cynodon dactylon*) and the invasive weed, Russian thistle or tumbleweed (*Salsola tragus*), but by the 33rd month buffalo grass (*Pennisteum ciliare*) and Lehman Lovegrass (*Eragrostis lehmanniana*) had replaced the Russian thistle. Figures 1, 2, and 3 show the progressive increase of vegetation on this site over time. In this case the use of biosolids for enhanced revegetation and stabilization of mine tailings would be considered a success.

Table 1. Plate counts of heterotrophic bacteria at Mission Mine site.

Sample Date	Depth of Sample (cm)				
	0–30	30–60	60–90	90–120	120–150
	---CFU g^{-1}---				
06/26/00	1.01×10^{7}	1.72×10^{6}	3.11×10^{5}	1.54×10^{5}	ND
09/11/00	3.16×10^{6}	4.44×10^{5}	8.12×10^{5}	3.54×10^{4}	ND
01/22/00	2.74×10^{7}	2.05×10^{7}	5.56×10^{5}	2.31×10^{5}	ND
03/26/01	3.76×10^{7}	2.25×10^{6}	1.99×10^{4}	7.83×10^{4}	5.48×10^{4}
06/11/01	7.74×10^{6}	6.86×10^{5}	6.72×10^{4}	1.22×10^{5}	6.36×10^{4}
09/10/01	1.45×10^{6}	5.83×10^{5}	4.10×10^{4}	1.42×10^{5}	1.40×10^{5}
10/29/01	1.30×10^{7}	8.36×10^{5}	2.40×10^{5}	1.41×10^{5}	1.19×10^{5}
01/23/02	1.98×10^{6}	1.67×10^{6}	1.55×10^{6}	8.05×10^{4}	1.22×10^{5}
04/08/02	1.09×10^{7}	1.83×10^{6}	9.06×10^{4}	6.94×10^{4}	8.47×10^{4}

ND = not done

Table 2. Vegetation transects at the Mission Mine site.

	Basal Cover (%)	Crown Cover (%)	Total Cover (%)	Rock (%)	Litter (%)	Bare (%)
	02/23/00 (14 months)					
T–1	15	28	43	3	0	54
T–2	14	16	30	3	8	59
T–3	7	1	8	0	1	91
T–4	1	8	9	2	4	85
T–5	0	0	0	0	5	95
Average	7.4	10.6	18	1.6	3.6	76.8
	09/25/00 (21 months)					
T–1	13	39	52	5	6	37
T–2	11	20	31	6	6	57
T–3	6	45	51	2	1	46
T–4	13	48	61	3	2	34
T–5	1	52	53	0	4	43
Average	8.8	40.8	49.6	3.2	3.8	43.4
	09/24/01 (33 months)					
T–1	4	66	70	2	4	24
T–2	6	62	68	0	6	26
T–3	4	73	77	0	4	19
T–4	0	84	84	0	1	15
T–5	0	92	92	0	0	8
Average	2.8	75.4	78.2	0.4	3	18.4

Figure 1. Mine tailings prior to biosolid amendment**.**

Figure 2. Mine tailings two years after biosolid application**.**

Figure 3. Mine tailings three years after biosolid application.

Evaluation of Potential Hazards—Soil Metal Concentrations. At Site 1, soil nitrate (Table 3) and total organic carbon (TOC) (Table 4) are very high at the surface, but decrease to the levels found in pure mine tailings at lower depths. The fact that nitrate and TOC concentrations generally follow similar patterns is important since it provides substrate and terminal electron acceptor concentrations suitable for denitrification. Data presented in Table 3 show the nitrate concentrations from June 2000 to January 2002. Nitrate concentrations increased during the monsoon rainy season of 2000 most likely due to enhanced ammonification and subsequent nitrification. However, within the soil profile, nitrate concentrations generally decreased with depth. By the winter and spring of 2001, the nitrate concentrations at all soil depths had decreased. There was no evidence of the leaching of nitrate since concentrations at the 90–120 cm depth were always minimal. Therefore, the most likely explanation for decreased nitrates within the soil profile is the process of denitrification. Soil nitrate concentrations became extremely high at both sites in the summer of 2001, again most likely due to nitrogen mineralization and seasonal nitrogen cycling. Specifically during the warmer summer months, rainfall events appear to trigger microbial mineralization of nitrogen as nitrate. Double-digit values of nitrate at the 120–150 cm depth illustrate that there is the potential for some nitrate leaching during some portions of the year.

The application of biosolids to a project site brings some concern about the introduction of heavy metals to the environment. Data from this study show that metal concentrations are fairly consistent with soil depth (Table 5), indicating that the tailings are the major source of metals, not the biosolids. Further evidence of this is shown by the high molybdenum and copper valves typical of mine tailings. At this site, there is little evidence of metals leaching through the soil profile. Additional data was collected on the concentration of molybdenum, copper, and zinc in three plants on the site (i.e., russian thistle, salt cedar, and bermudagrass). Table 6 shows that the uptake of metals by these plants was extremely high. In addition, soil sampled beneath vegetation (Table 5) revealed a decrease in soil metal concentrations.

Table 3. Nitrate concentrations at the Mission Mine site from June 2000 to January 2002.

	Depth of Sample (cm)				
Sample Date	0–30	30–60	60–90	90–120	120–150
	-- mg kg^{-1} --				
06/26/00	645	248	37	3	ND
07/10/00	1518	119	60	4	ND
07/26/00	1032	201	165	70	ND
02/05/01	476	249	333	146	64
03/26/01	192	38	37	13	4
06/11/01	2353	313	143	256	112
07/13/01	2354	594	219	205	51
01/23/02	214	19	236	10	2

ND = Not Done.

Table 4. Total organic carbon (TOC)* at the Mission Mine from February 2001 to January 2002.

Sample Date	Depth of Sample (cm)				
	0–30	30–60	60–90	90–120	120–150
	--- % ---				
02/05/01	1.4	0.2	0.3	0.4	0.3
03/26/01	1.0	0.1	0.2	0.2	0.1
06/11/01	1.6	0.2	0.1	2.0	0.1
07/13/01	1.6	0.4	0.1	0.2	0.2
01/23/02	1.57	0.39	0.11	0.08	0.07

* Mean values

Table 5. Total soil metal concentrations at the Mission Mine site.

Sample Depth (cm)	Total Metals[1] (mg kg^{-1})						
	Mo	Pb	As[2]	Cr	Zn	Cu	Ni
0–30	68.0	23.0	<50	14.0	170	414	8.0
30–60	197	19.0	<50	19.0	111	1480	8.2
60–90	196	27.0	<50	15.0	168	2400	9.0
90–120	180	33.0	<50	15.0	130	1320	8.0
Beneath vegetation 0–30	88.0	19.0	<34	12.0	154	247	<33.0

[1]Data are mean of samples collected on 06/26/00, 07/10/00, 07/26/00, and 06/11/01.

[2]Below detection limit.

Table 6. Total metal concentrations in plant tissue samples at the Mission Mine site.

Plant Type	Total Metal (mg kg^{-1} dry weight basis)		
	Mo	Zn	Cu
Russian Thistle	872	130	35
Salt Cedar	655	94	63
Bermuda Grass	100	116	43

Samples taken 02/02/01.

Conclusion

This study on the application of biosolids to mining tailings at the Mission Mine in Arizona, shows that soil stabilization has been encouraged through revegetation techniques, and that the leaching of nitrate and heavy metals to important water resources has not been observed. This case study gives an indication of the extensive monitoring that is necessary to understand the stabilization process, and the need for long-term monitoring of the process. With careful attention paid to subsurface geologic and hydrologic features at other sites, the application of biosolids can be a feasible revegetation strategy.

Acknowledgment

This work was supported by The University of Arizona, National Science Foundation Water Quality Center.

Literature Cited

Bengson, S.A. 2000. Reclamation of copper tailings in Arizona utilizing biosolids. Mining, Forest and Land Restoration Symposium and Workshop. (Golden, CO, July 17–19 2000).

Thompson, T. L. and M. Rogers. 1999. Reclamation of acidic copper mine tailings using municipal biosolids. Research Report to The Arizona Department of Environmental Quality.