RECLAIMING COARSE TACONITE TAILINGS – ARE ORGANIC AMENDMENTS THE ANSWER?[1]

by

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Abstract In the fall of 1997, five two-ha plots of coarse taconite tailings were revegetated using paper mill residue from two different manufacturers, municipal solid waste compost, municipal class B biosolids, and a mixture of paper residue and biosolids. Although previous test plot and small scale demonstration tests had shown that organic amendments could be used successfully to establish vegetation on coarse tailings, this was the first large scale application. A series of small bins (each about 1 meter by 3 meters) was built to examine the water quality impacts associated with the use of these amendments. After three years, percent cover on all of the amended slopes was at least 50% higher than the cover produced by the standard mineland reclamation practice. Although none of the plots met the strict numeric three-year cover standard of 90%, two plots exceeded 80% and would be judged acceptable reclamation. Despite applying the amendments in the fall after the growing season, there was no substantial impact on the quality of either the surface runoff or the water that infiltrated the tailings. The total volume of surface runoff from all plots was less than 2.2% of the input precipitation. The highest average runoff was from the untreated control plot. Although the initial cost of applying organic amendments to coarse tailings may be more expensive than standard mineland reclamation practices, mining companies typically spend additional money to refertilize and reseed. Despite repeated applications of seed and fertilizer, most areas without organic amendments have not complied with Minnesota's mineland reclamation standards. If the total cost of transporting and applying the amendments is paid by the producer, there is no additional cost to the mining company. As a result, the cost to use organic amendments is the same as standard reclamation. Furthermore, it appears that both paper companies and the wastewater treatment plant can haul and apply their material at the mine for less than it costs to dispose of the material at their current sites.

Keywords: revegetation, mineland reclamation, percent cover, water quality, beneficial reuse.

Introduction

Seventy percent of the United States' iron production comes from Minnesota. Seven operating mines produce 40 million tons of taconite pellets annually by crushing, grinding and magnetically recovering the iron. Since the average grade of the iron ore is about 25% magnetic iron, about three-quarters of the material must be disposed of as waste (tailings). Currently there are about 10,500 ha of land covered with taconite tailing waste. These tailings range in particle size from 3 cm gravel to fine silt and clay. The coarse fraction (medium sand to gravel) is often used to build the dikes for the tailings storage areas. Coarse tailings are low in organic matter, nitrogen, phosphorus, cation-exchange capacity, electrical conductivity, and moisture holding capacity

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(Noyd et al., 1992). The gray/black color of the tailing results in large temperature extremes, especially on slopes that face south or west. The large open expanses typical of these basins create conditions which often result in severe wind erosion.

Minnesota mineland reclamation rules require that all tailings areas be revegetated and achieve a vegetative cover of 90% after three growing seasons, except for slopes that face south or west, where a limit of five growing seasons applies (MN DNR 1980). Standard reclamation practice is to apply 448 kg/ha of diammonium phosphate, 56 kg/ha of a cool season grass mix, and 4.6 mt/ha of hay mulch. Although this approach has been very successful on the medium to fine-grained tailings on the interior of the basins, it has not been effective on the 3000 ha of coarse tailings material. Even after five years, vegetative cover on this material rarely exceeds 60%. In the early 1990's a cooperative research program was begun with the former United States Bureau of Mines and several mining companies, United States Steel (USX) and Eveleth Mining (EVTAC) to examine the use of organic amendments to improve vegetation on coarse tailings areas.

The initial studies were conducted using small plots (2.5m x 4m) that demonstrated the application of organic amendments significantly improved vegetative cover (Eger et al., 1999; McCarthy et al., 1995; Norland et al., 1995, 1993, 1991). Although percent cover generally increased with increasing amounts or organic material, 44.8 mt/ha was selected as a cost effective rate. A small scale demonstration project was conducted on a coarse tailing slope at National Steel Pellet Company. An application of 44.8 mt/ha of municipal solid waste compost produced vegetation which met the three year cover standard (90%) after two growing seasons (Melchert et al., 1994). In 1997, the first full scale application of amendment was made to a 10 ha section of a northeastern facing portion of EVTAC's tailing dam. The objectives of the study were to determine the impact of the organic amendments on the quantity and quality of surface runoff and infiltration, determine vegetative response, and determine the cost of amendment application.

Site Description

EVTAC's processing plant and associated tailings basin are located about 100 km northeast of Duluth (Figure 1). The tailings basin covers about 300 ha and is surrounded by dams made from coarse tailings which are separated during the processing of the ore and truck hauled to the perimeter of the basin. The tailings dams contained three 13 meter high lifts, with a slope of 3:1 and about a 8 meter bench located at the top of each lift. The impact of amendment addition on water quality was studied in a series of 14 small bins located within 1 km of the application on the slope (Figure 1).

Materials

Tailings

The coarse tailings were low in nitrogen, phosphorus, water holding capacity and organic matter (Table 1). The tailings were alkaline, with a pH of 8, and contained about 33% coarse sand, 40% medium sand, 22% fine sand, and 5% silt and clay.

Biosolids

Biosolids are defined as slow-release nitrogen fertilizers produced from treated wastewater. This material was previously called sewage sludge.

Since biosolids contain high concentrations of nitrogen, application rates are generally based on the amount of nitrogen that will be used by the plants during the growing season (agronomic rate). This approach assumes that all the applied nitrogen will be used by the plants so that nitrogen release from the site will be minimized.

Municipal Solid Waste Compost (MSW)

Municipal solid waste compost is composted household garbage. The material used in this study was produced by Microlife USA Inc., which uses a proprietary process that blends animal manure and wood chips with the municipal solid waste. The goal is to produce a more uniform, higher value product.

All MSW compost is regulated by the Minnesota Pollution Control Agency. If the compost contains no biosolids, has been aged for at least 180 days, and contaminant levels are below regulatory limits, the compost is considered a Class 1 material and can be spread without restriction (MPCA, 1998). The primary parameters of concern are heavy metals and PCB's.

Volatile compounds are driven off due to the high heat produced during composting. With the exception of low levels of semi-volatile organic compounds associated with plastics in the compost, most semi-volatile compounds were not detected (Melchert et al., 1994).

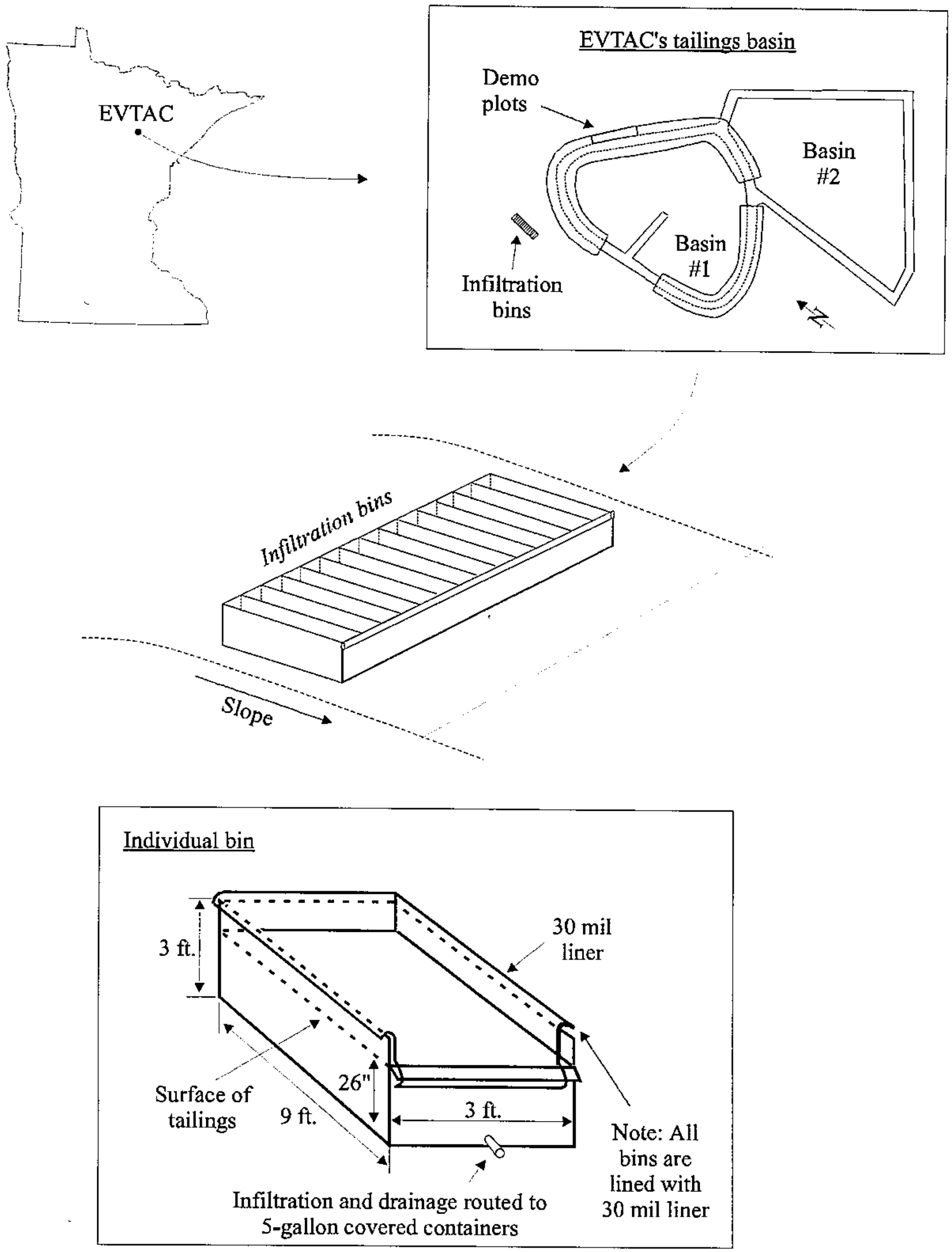


Figure 1. Location of demonstration plots and infiltration bins at EVTAC's tailings basin, and design (schematic) of an individual bin.

Table 1. Organic amendments and tailings chemistry.

Parameters[1]	Tailings	Paper Residue Blandin	Paper Residue Consolidated	Biosolids	MSW	Standards[3]
pH	8.0	7.8	8.1	7.9	7.7	NL
% Organic Matter	0.5	35.9	45.0	15.0	24.8	NL
Nitrate-N	1.0	1.0	3.0	75.5	31.5	NL
% Solids, Total[2]	99.7	36.4	46.8	34.8	61.8	NL
%Solids, Volatile Total[2]	2.66	51.2	50.2	24.1	49.7	NL
Nitrogen, Kjeldahl	16.5	2910	1270	13700	12700	NL
Nitrogen, Ammonia	<0.06	95.9	57.3	239	223	NL
Organic Carbon	10900	257,000	252,400	147,300	172,700	NL
Total Nitrogen	17.5	2911	1273	13776	12732	NL
C:N Ratio	623:1	88:1	198:1	11:1	14:1	NL
Phosphorus						
Bray 1:	30	13	27	85	85	NL
Olsen:	10	14	19	76	76	NL
Potassium	300	20	20	150	720	NL
Arsenic	<11	<2.2	<2.2	<11	<2.2	41
Cadmium	<2.5	<0.50	<0.50	<2.5	12	39
Chromium	<5.0	2.2	3.2	<5.0	28	NL
Copper	<5.0	7.3	15	120	180	1500
Lead	<9.5	<1.9	2.0	11	100	300
Mercury	0.03	<0.02	0.02	0.61	0.50	5
Nickel	<5.0	<1.0	1.1	<5.0	24	420
Selenium	<15	<3.0	<3.0	<15	<3.0	100
Zinc	<16	51	150	140	1200	2800

[1] All values are measured in mg/kg, dry weight basis, except pH, % solids,% organic matter, and the C:N ratio.
[2] This result reported on an as-received basis.
[3] Land application standards: EQ (Exceptional Quality) sludge limits, 40 CFR part 503, EPA 1999, Class 1 compost, MN Rules; Chapter 7035.2836 (MPCA, 1998).
Note: Samples were analyzed by MVTL Laboratories, New Ulm, MN.
NL = no standard listed.

Paper Mill Residue

Paper mill residue is a waste produced from the paper making process and contains primarily wood fiber and clay. It is high in carbon (C), low in nitrogen (N), and is effective at retaining water. In extreme cases, C:N ratios have been as high as 270:1 (Campbell et al., 1995). In a plot study at EVTAC, using paper mill residue containing a de-inking waste, the C:N ratio was 123:1 (McCarthy et al., 1995). Paper residue from two difference processing plants, Blandin Paper, Inc. (Grand Rapids, MN) and Consolidated Paper, Inc. (Duluth, MN) was used in this study.

Methods

Treatments

Seven treatments were applied to the small bins and six treatments were used on the large-scale slope demonstration plots. These were:

- Control (bare tailings without amendment; bins only)
- Standard mineland reclamation (SMR)- bare tailings with 560 kg/ha fertilizer (diammonium phosphate 18-46-0)
- 44.8 mt/ha of Blandin paper mill residue with 996 kg/ha of diammonium phosphate fertilizer
- 44.8 mt/ha Consolidated paper mill residue with 996

kg/ha of diammonium phosphate fertilizer

- 13.2 mt/ha of biosolids (treated organic wastewater material)
- 44.8 mt/ha of municipal solid waste (MSW) compost with 560 kg/ha of diammonium phosphate fertilizer
- 44.8 mt/ha of Blandin paper mill residue and 22 mt/ha of biosolids.

Small Bins

A 20-gauge steel framework of fourteen bins, (each 2.75 m long, 0.9 m wide, and 0.9 m deep), was constructed by EVTAC and placed to create a 3:1 slope. Each bin included a gutter to collect surface runoff (Figure 1).

The bins were lined with an ultraviolet resistant supralloy 30 mil PVC liner. A foundation geotextile was used to protect the liner and a geonet material was placed over the liner to facilitate drainage.

Diammonium phosphate fertilizer (18-46-0), and the amendments were applied manually, and both were incorporated with a garden hoe. The plots were seeded with a standard mineland reclamation seed mix (smooth bromegrass [*Bromus intermis*], red fescue [*Festuca rubra*], perennial rye grass [*Lolium perenne*], timothy [*Phleum pratense*], alfalfa [*Medicago sativa*] birdsfoot trefoi [*Lotus corniculatus*]l, and sweet clover [*Melilotus officinalis*]), mulched with hay by hand, and covered with a plastic landscaping mesh. Treatments were assigned to each bin using a randomized split block design.

Surface runoff and infiltration were collected separately in 180 L plastic containers. Each container held a one liter sample bottle inside a 20 L plastic bucket. Water quality samples were collected primarily during storm events and snow melt. Flow was collected from November 1997 through October 1999.

Demonstration Slope

Six, five hectare plots were established on the northeast side of the tailings basin. Each plot was about 120 meters wide by 170 meters long and contained 3 sloped areas, which were divided by 8 meter wide benches. A three meter divider strip separated each treatment.

All amendments were applied to the slope with a Knight Side Slinger, which was pulled by a tractor up and down the 3:1 slope. After application, the amendments were disced into the coarse tailings using serrated discs. Fertilizer was mixed with the seed and the entire area was hydroseeded. Hay mulch (2.24 mt/ha) was applied with a side shoot tractor and secured by disc anchoring.

Vegetation Sampling

Vegetation density, or percent cover, was used as a means of comparison among the various amendments. In this paper percent cover was the percent of surface area that was covered by live vegetation when viewed directly above the sampling area.

Percent cover was measured in late August by visual plot estimation using a systematic point-quadrant sampling method (Raelson and McKee, 1982). For each bin, the percent cover was visually estimated to the nearest cover class from four 0.5 square meter quadrants. Thirty two quadrats were used for the demonstration plots. The quadrats were systematically placed to avoid edge effects and allow measurement of the entire slope. The percent cover for the plots was determined by averaging all of the cover class measurements.

Results

Amendment Chemistry

All amendments were slightly alkaline, with pH ranging from 7.7-8.1, and contained 15-45% organic matter. The paper mill residues had almost twice as much organic matter as the biosolids and the MSW compost; but had C:N ratios from 88:1 to 198:1. In contrast, the C:N ratio was 11:1 for the biosolids and 14:1 for the municipal solid waste compost (Table 1).

Metals levels in all the amendments were well below all land application regulatory limits. In general, the MSW compost contained the highest level of metals. Metal levels in the tailings were all generally less than detection limits, even for the micronutrients copper and zinc (Table 1).

Flow

Surface Runoff. Surface runoff was minimal from all plots. Total annual yield which was calculated by dividing the volume of runoff by the volume of precipitation that fell on the bin, ranged from 0 to 2.2% (Table 2). Surface runoff was the highest from the control plots.

Infiltration. Although the volume of infiltration water measured from each plot varied within and among treatments, the largest infiltration occurred in the control plots, followed by the plots with standard reclamation (Table 2).

Infiltration can be expressed in terms of water yield, which is defined as the ratio of the amount of outflow to the amount of input:

Table 2. Annual yield, surface runoff and infiltration, 1998-1999.

Treatment	Plot #	Surface Runoff, Yield, %[1]		Infiltration, Yield, %[2]	
		1998	1999	1998	1999[3]
Control	5	0.50	1.80	70	65
	8	0.96	1.97	80	68
SMR	6	0	0.02	68	62
	10	0.01	0.16	77	60
Blandin	1	0.07	0.16	65	48
	11	0	1.03	73	50
Consolidated	2	0.04	0.13	66	44
	12	0.01	1.82	81	45
Biosolids	4	0.03	0.05	65	55
	13	0.01	2.23	69	53
Blandin and Biosolids	3	0.20	0.19	62	34
	9	0.26	0.11	70	46
MSW	7	0.09	0.45	62	46
	14	0.04	0.76	70	51

[1] Surface runoff, yield $= \dfrac{\text{total volume of surface runoff } (m^3/yr)}{\text{total precipitation } (m/yr) \times \text{collecting area of plot} \times 100\% \ (m^2)}$

[2] Infiltration, yield $= \dfrac{\text{total volume of infiltration}}{\text{total precipitation} \times \text{collecting area of plot} \times 100\%}$

[3] 1999 values are estimated, some flow was lost during large rainfall events (Eger et al., 2000).

SMR = Standard Mineland Reclamation

MSW = Compost Municipal Solid Waste

The potential for nutrient runoff should be higher with a fall planting, since there is no vegetative uptake until the following spring; and large flows can be associated with snow melt in this region. However, no major water quality problems were observed in this study. Surface runoff was minimal and the highest concentrations of nitrate were in the range of 3 to 4 mg/L. Total phosphorus concentrations varied but were generally in the range of 0.5 to 1 mg/L (Eger et al., 2000).

Nitrate levels in infiltration samples were also lower than anticipated and were much lower than observed in a previous study where initial concentrations ranged from 20 - 40 mg/L NO_3-N (Melchert et al., 1994). The maximum nitrate concentration measured in this study was 13.3 mg/L for one of the MSW plots. Lysimeters were used to collect samples in the previous study while the EVTAC bins were designed to collect all of the infiltration water and provide a much better measure of the potential water quality impacts than the earlier study.

The concentration of dissolved solids, as measured by specific conductance, decreased over time as soluble constituents present in the amendments were removed. No pattern was observed for any of the trace metals, which tended to remain at low levels over the period of sampling. All of the amendments contained low levels of metals so no significant release was expected.

Vegetation

Although all the amended areas produced more cover than the standard mineland reclamation practice, cover was higher for all treatments in the small bins than

Table 3. Water quality results, infiltration (average concentration per treatment), 1997-1999.

Amendment	Control Plots	MSW Compost	Blandin Paper Mill Residue	Consolidated Paper Mill Residue	Blandin Paper and Biosolids	Biosolids	SMR	Surface Water Standards [1]	Drinking Water Standards [2]
pH	8.45	8.34	8.41	8.37	8.42	8.38	8.39	6.5 to 9.0	6.5 - 8.5 (S)
Specific Conductance (µS/cm)	540	780	610	650	720	620	630		
Nutrients: (mg/L)									
Total Kjeldahl Nitrogen	0.12	1.41	0.72	0.56	0.98	0.58	0.50		
Ammonia-Nitrogen	0.01	0.03	0.02	0.02	0.02	0.01	0.01	0.04 [3]	
Nitrate-Nitrogen	1.3	4.3	2.0	1.5	3.6	3.2	2.9		10
Total Phosphorous	0.02	0.04	0.04	0.03	0.04	0.02	0.03		
Trace Metals: (mg/L)									
Arsenic	0.003	0.006	0.007	0.005	0.005	0.007	0.004	0.053	0.05
Cadmium	<0.001	0.001	0.001	0.001	0.001	0.001	<0.001	0.0015 - 0.0034	0.005
Chromium	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.011 [4]	0.10
Copper	0.001	0.005	0.007	0.008	0.009	0.003	0.003	0.015 - 0.023	1 (S)
Lead	0.001	0.001	0.001	<0.001	0.001	0.002	<0.001	0.008 - 0.019	0.015
Mercury	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.000007	0.002
Nickel	0.001	0.002	0.002	0.002	0.003	0.002	0.002	0.283 - 0.509	0.10
Selenium	0.001	0.001	0.002	0.001	0.002	0.001	0.001	0.005	0.05
Silver	0.001	0.001	0.001	0.001	0.001	0.001	0.001		0.1 (S)
Zinc	0.011	0.012	0.012	0.022	0.013	0.014	0.008	0.191 - 0.343	5 (S)

[1] Surface water quality criteria (chronic standard) for 2B waters (aquatic life and recreation, non-drinking water). Standards for the trace metals are a function of water hardness. A range of 200 mg/L to 400 mg/L was used to compute chronic toxicity values for Cd, Cu, Pb, Ni, and Zn. Metals that do not currently have a standard were left blank. Reference: Minnesota Rules, 1999, Chapter 7050.0222, Waters of the State (http://www.revisor.leg.state.mn.us/arule/7050/0222.htm).

[2] US EPA Office of Ground Water and Drinking Water. Current Drinking Water Standard: National Primary and Secondary (S) Drinking Water Regulations (revised September 11, 1998), http://www.epa.gov/OGWDW/wot/appa.html.

[3] Ammonia standard is for un-ionized ammonia. The fraction of the total ammonia that is un-ionized is a fraction of water temperature and pH and is calculated from the following equations

$$f = \frac{1}{10^{pKa-pH} + 1} \times 100$$

where f = the percent of total ammonia in the un-ionized state and pKa = 0.09 + (2730/T) is the dissociation constant for ammonia f increases as pKa decreases (temperature increases) and pH increases, pKa ranges from 10.09 at 0°C to 9.25 at 25° C, when pH = pKa, f = 0.5. The maximum value of f for all infiltration samples in this study was 33 percent.

[4] The chromium standard was based on Cr^{+6}, standard values for Cr^{+3} ranged from 0.365 to 0.644mg/L (water hardness of 200 to 400 mg/L).

Note: Some anomalous values were not used to calculate the average concentrations (Eger et al., 2000).

$$\text{yield} = \frac{\text{volume of infiltration from plot}}{\text{precipitation x collection area of plot}} \times 100\% \qquad (1)$$

Average annual yield ranged from 40% for the Blandin/biosolids treatment in 1999, to 75% for the control plots in 1998. In 1999, the average yields from the plots with the organic amendments were about 25 to 30% less than the control plots (Table 2).

Water Quality

Surface Runoff. Given the small volume of surface runoff, it was not always possible to conduct a complete analysis of each sample since there was no single date when all plots generated sufficient surface runoff to analyze. There was never enough water collected from the plots with standard mineland reclamation to analyze. None of the values exceeded water quality standards and the maximum nitrate value was 4.5 mg/L (Table 3).

Infiltration. In general, infiltrating water from all the amended plots contained slightly more dissolved solids than the control. Average specific conductance ranged from 540 μS/cm for the control to 780 μS/cm for the MSW bins (Table 3). Specific conductance generally was highest in the initial samples and decreased with time.Average concentration for all trace elements were below drinking water limits, and despite the large amount of nitrogen addition, particularly in the paper mill residue, there was little nitrate release (Table 3). Only three nitrate values exceeded the water quality limit of 10 mg/L (Figure 2).

Vegetation

After three years, all the bins with organic amendments produced more cover than standard mineland reclamation. Average percent live cover exceeded 80% for all amended bins, and met the 90% standard for the municipal solid waste compost, the Blandin paper mill residue and the Blandin residue plus biosolids (Table 4).

Average percent live cover was lower on the demonstration plots than in the bins. None of the treatments produced percent cover in excess of 90%, but all of the amended plots produced more cover than standard mineland reclamation. Average cover values ranged from 34% for the standard mineland reclamation practice to 86% for the municipal solid waste compost (Table 4, Figure 3).

Table 4. Three-year percent cover results, August 2000.

Treatment	Average Live Cover %	
	Bins	Demonstration Plots
Standard Mineland Reclamation	56	34
Paper Mill Residue:		
Blandin	91	57
Consolidated	86	53
Biosolids	82	68
Blandin and Biosolids	92	83
Municipal Solid Waste Compost	90	86
Control	1	NAp

NAP = not applicable

Costs

The cost to reclaim coarse tailings areas at EVTAC ranged from $1235/ha for standard mineland reclamation to $3915/acre for MSW compost (Table 5). The major cost to use the amendments was the cost to transport them to the site. Transportation costs ranged from $3.60/mt for the biosolids (20 km) to $18.20/mt for the MSW compost (180 km).

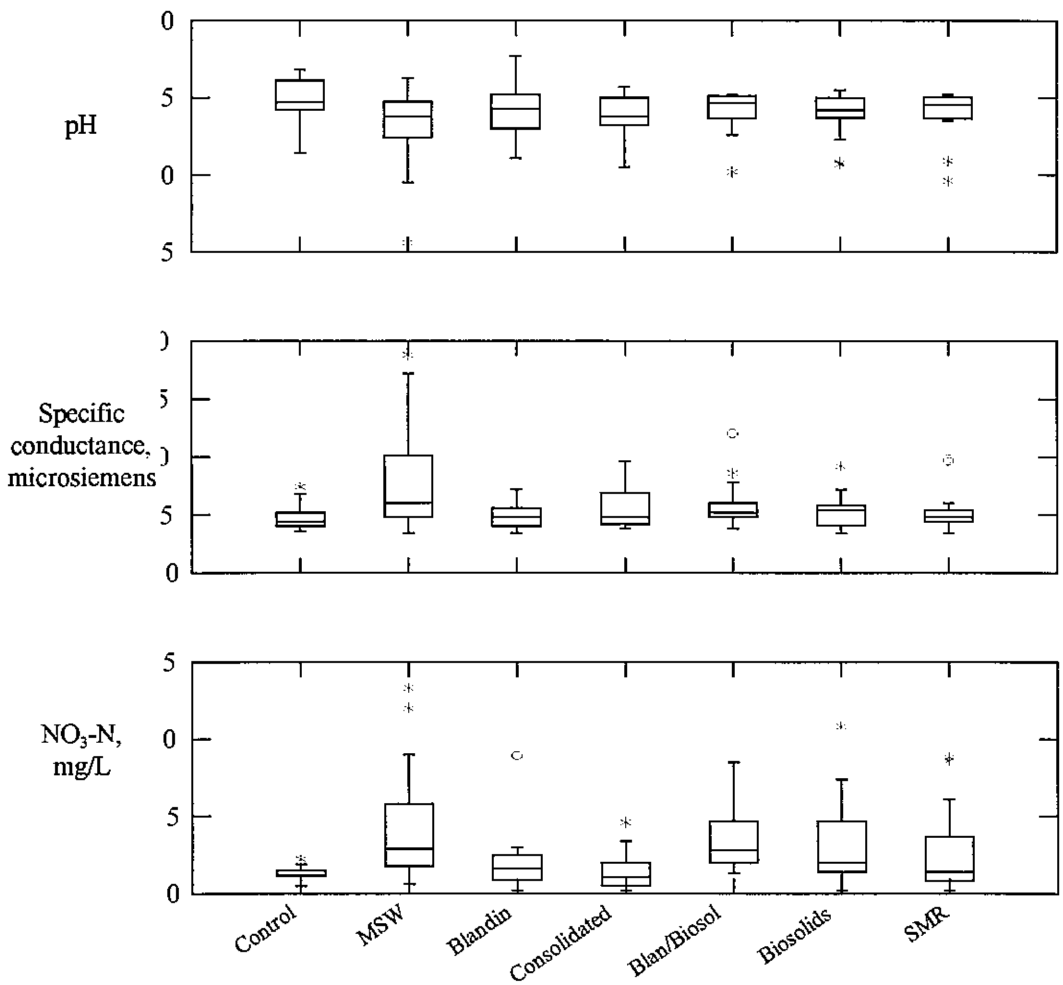
Discussion

Flow

Yields measured in the control plots were comparable to previous data from unvegetated plots, while reduction in yields in the vegetated plots were similar to that observed when stockpiles were covered with soil and vegetated (Eger et al., 1981; Eger et al., 1984). Water is lost through plant evapotranspiration, and water yields from amended plots were about 25 to 30 % less than the unvegetated controls.

Water Quality

The organic amendments were applied to the plots in the fall of 1997. Although this type of application (dormant seeding) has been used for tailings reclamation, a spring planting is more common. Nutrients become depleted as the vegetation grows, and the vegetation reduces the potential for surface flow and erosion.



Note: The lower, middle and upper horizontal lines of the boxes comprise the 25th, 50th and 75th quartiles, respectively. The smaller horizontal lines (at the top and bottom of the two vertical lines) are the maximum and minimum values, except for values that the software (Systat 8.0) calculates to be statistical outliers, which it represents with circles and asterisks.

Figure 2. Box plots of drainage quality data (average per treatment) from the EVTAC infiltration bins, 1997 to 1999. (Circles and asterisks are statistical outliers.)

on the large demonstration slope. On the small bins, all the applications were done by hand, so there was a much more uniform application of amendment, seed, fertilizer and mulch. In addition, the mulch was held in place with a plastic landscape mesh, so most of it was retained on the plot. The results from the demonstration plots are more typical of the percent cover that could be expected from a large scale application.

After three years municipal solid waste compost produced the highest percent cover (Figure 3). MSW compost has consistently produced successful vegetation in all previous field trials (Eger et al., 1999). Although the percent cover did not quite meet the numeric standard of 90%, the vegetation would be considered acceptable (S. Dewar, personal communication). Percent cover for the standard mineland reclamation practice was 34%, slightly lower than the normally observed range for this approach of 40 to 60%. The lower cover could be the result of unusually dry weather during the first growing season. Rainfall in July and August of 1998 was only 47% of normal.

For the amended plots, percent cover was the lowest on the paper mill residues. Despite the addition of extra nitrogen fertilizer, the C:N ratios were still too high. The C:N ratios for amendments should not exceed 30:1, and it is desirable to have the ratio below 20:1. If the ratio exceeds 30:1, nitrogen from the soil is used to assist in the breakdown of the amendment and is not available for plant growth. If the ratio falls between 20:1 to 30:1 there is sufficient nitrogen to breakdown the material, but little of the nitrogen in the amendment is released to the vegetation (Donahue et al., 1977) The C:N ratio was less than 30:1 for the biosolids and the MSW compost, but despite the addition of extra nitrogen, the C:N ratio for both the Blandin and Consolidated residue exceeded the maximum value. The C:N ratio for the Blandin material was 37:1, and 48:1 for the Consolidated residue.

Each producer determined the application rate for their material. The amount of additional nitrogen that was added to assist in the breakdown of the paper mill residue was based on previous test work and not on a specific target C:N ratio (McCarthy et al., 1995).

When biosolids were added to the paper mill residue to supply the additional nitrogen, percent cover improved markedly, exceeding that of the individual applications of paper mill residue or the biosolids. The C:N ratio was still greater than 30:1, but the addition of extra organic matter improved the vegetative growth.

In the future, it may be possible to improve vegetative success with paper mill residue by changing the application method. Additional inorganic fertilizer could be added to improve the C:N ratio or the residue could be added to the slope the year before the area is planted. The residue would begin to break down and by the second year, the nitrogen demand would have decreased and some of the nutrients within the residue would be more available to the newly planted vegetation.

Costs

The additional cost of using organic amendments compared to standard reclamation ranged from \$215/ha for biosolids to \$2680/ha for municipal solid waste compost. Paper mill residue increased the cost by about \$1725/ha. In previous studies with MSW compost, there was no cost for the material (Melchert, et. al., 1994). If the purchase price of the compost is subtracted, the additional cost relative to standard reclamation is \$1875/ha, comparable to the cost to use the paper mill residue (Table 5).

Although the use of organic amendments may appear to increase costs, the standard mineland reclamation practice has not produced sufficient vegetative cover to meet Minnesota regulatory standards. As a result, mining companies have spent additional money either to refertilize or sometimes to replant entire areas. If the entire area is replanted, reclamation costs double from \$1235/ha to \$2470/ha, and while percent cover improves, it still does not meet the 90% cover standard.

Based on estimates of disposal costs, it appears that Blandin, Consolidated and the Virginia Waste Water Treatment Plant can apply their material at EVTAC for less than their current disposal cost (Table 6). As a result, there would be no additional cost to the mining company, and the mining company could save about \$124/ha if it could replace the inorganic fertilizer with biosolids (Table 5). The use of these amendments would not only provide a beneficial reuse, but also save the generators money and allow mining companies to meet reclamation standards without increasing their cost.

Conclusions

By the end of the third growing season, percent cover on all of the amended plots was greater than the percent cover on the standard mineland reclamation plot. Although none of the plots met the three-year cover standard, two plots did exceeded 80% cover (MSW compost and Blandin paper mill residue with biosolids) and would be considered acceptable reclamation under Minnesota DNR rules.

No serious water quality problems were observed.

Table 5. Cost summary, EVTAC demonstration plots, 1997

Treatment	Amendment Costs ($/wet mt)				Amendment per hectare		Costs $/hectare			
	Material	Transportation	Application[1] (Spreading & incorporation)	Total	wet mt	dry mt	Amendment[2]	Fertilizer	Application, Seed & Mulch	Total
Standard Mineland Reclamation	0	0	0	0	0	0	0	125	1110	1235[3]
Blandin	0	8.80	4.40	13.20	123.2	44.8	1630	220	1110	2960
Consolidated	0	11.10	5.50	16.60	96.3	44.8	1595	220	1110	2960
Biosolids	0	3.60	5.25	8.85	38.1	13.2	335	0	1110	1445
Blandin & Biosolids	0	8.80 3.60	4.40 5.25	13.20 8.85	123.2 63.7	44.8 22	2190	0	1110	3300
MSW Compost	10	18.15	7.70	25.85	72.6	44.8	2680	125	1110	3915

[1]Application included spreading the material on the slope with a Knight side slinger and incorporating the material with a disc.
[2]Amendment cost was calculated by multiplying the cost per wet metric ton by the total number of wet metric tons applied (Eger et al., 2000)
[3]Average cost for standard reclamation (S. Dewar, personal communication). The cost of fertilizer was factored out by assuming a cost of fertilizer of $220/metric ton.

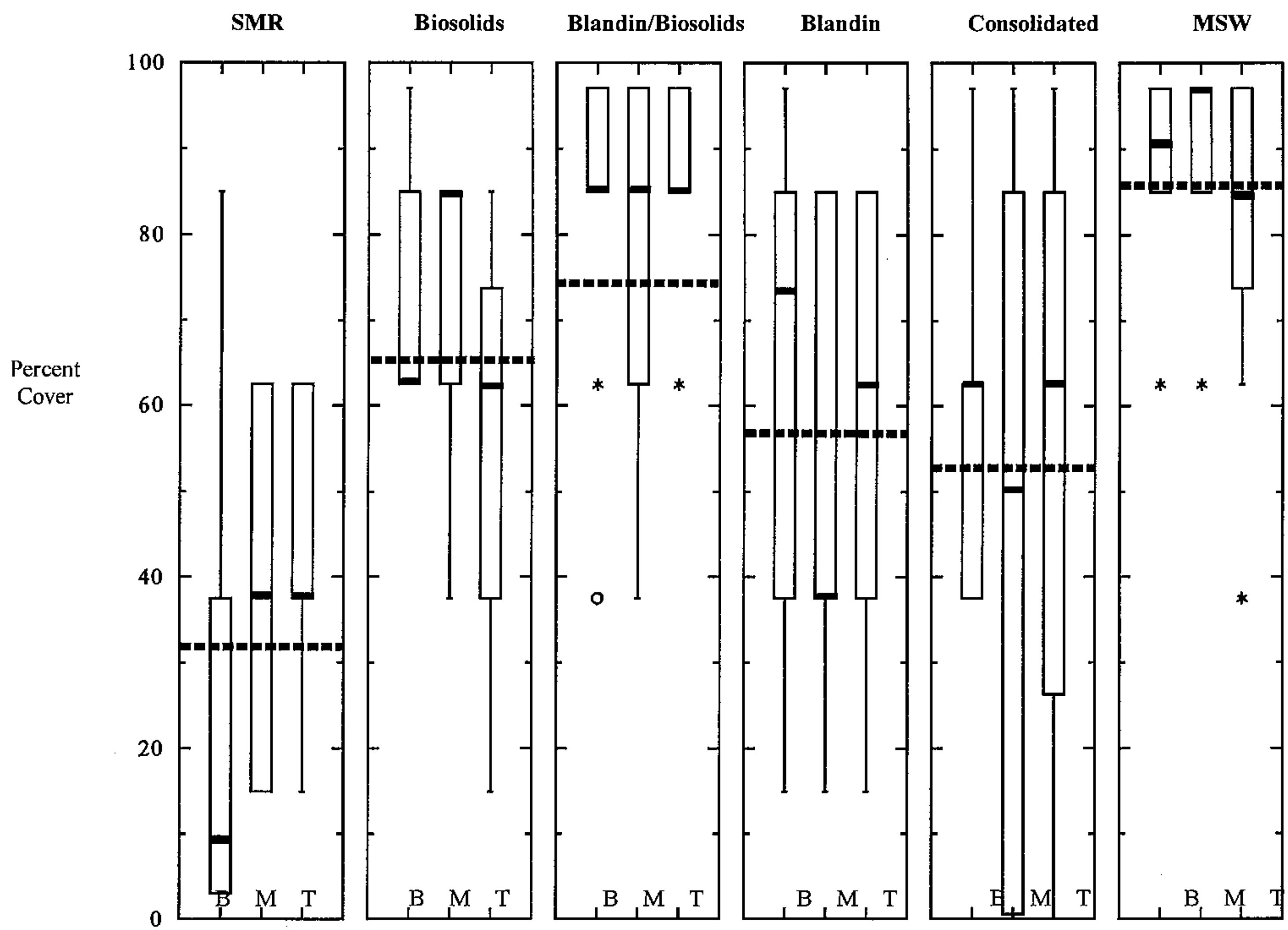


Figure 3. Box plots of three year percent live cover on the bottom (B), middle (M) and top (T) lifts of the six EVTAC demonstration plots. The dashed horizontal lines represent the mean value of all data from the three lifts, and the dark horizontal lines shown for each box are the median of each lift's data. Circles and asterisks indicate statistical outliers. SMR=standard mineland reclamation, MSW=municipal solid waste compost.

Table 6. Cost comparison; disposal vs. reclamation.

Producer	Cost to Haul and Apply Material at EVTAC ($/wet mt)	Standard Disposal Cost* ($/wet mt)	Savings if applied at EVTAC	
			$/wet ton	%
Blandin	$13.20	17.60-19.80	4.40-6.60	25-33
Consolidated	$16.60	$22.00	5.40	25
Virginia WWTP	$8.80	19.90	1.10	11

*Disposal costs are estimates and may vary over time.

Specific conductance, total Kjeldahl nitrogen and nitrate nitrogen were slightly higher in the amended plots than in the control. With the exception of three nitrate values, concentrations in infiltrating water were all below primary drinking water standards.

Using organic amendments cost from $250 to $2700/ha more than a single application of inorganic fertilizer, seed and mulch (standard mineland reclamation practice). The cost difference decreases if the area must be replanted, and it is less expensive to apply biosolids than to refertilize and replant.

Except for the MSW compost, the cost to apply material at EVTAC has been estimated to be less than the cost of current disposal practices. If the producer of the organic amendment pays for the transportation and application of the material, mining companies may be able to use these amendments to meet reclamation standards without any additional cost.

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