# Waste for Wastelands
## Reclaiming Taconite Tailings Basins with Organic Amendments

**Paul Eger, Glenn Melchert, Steve Dewar**

Taconite tailings basins cover 10,500 hectares in northern Minnesota. Since these tailings are primarily quartz and iron oxides, water quality has not been an issue, but establishing vegetation on the coarse fraction of the tailings has been a major problem. Reclamation rules require that (1) percent cover must equal 90% after three to five years (depending on slope and aspect), and (2) vegetation must be self-sustaining after ten years. Typical cover on coarse tailings, even after five years, has ranged from 40 to 60%. Despite repeated application of seed and fertilizer, less than 10% of the coarse tailings areas meet standards. Application of 10 to 90 mt/ha of various organic amendments, including: peat; yard waste compost; municipal solid waste compost; and paper processing waste; have been shown to dramatically affect vegetative success. Although plots that received 90 mt/ha of peat were the most successful in meeting the three-year standard, some of the plots with as little as 10 mt/ha of amendment produced 90% cover after five years. Application of 22.4 to 89.6 mt/ha of waste from paper manufacturing was also effective in meeting long-term reclamation standards. Data from these studies suggest that the application of 22.4 to 44.8 mt/ha of organic amendment will meet reclamation standards within five years, and will be no more costly than the industry's current unsuccessful practices, if the source of the amendment is within 100 km of the mining area. In the fall of 1997, the first full scale application of organic amendments was made.

**Additional Key Words:** biosolids, compost, paper processing, percent cover, biomass, revegetation, tailings, taconite, iron mining, Minnesota.

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## Introduction

Minnesota produces about 70% of the United States' iron ore. Seven operating mines produce 40 million tons of taconite pellets annually by crushing, grinding and magnetically separating the ore from the host rock. Since the average grade of the iron ore is about 25% magnetic iron, about three-quarters of the material must be disposed of as tailings. Currently there are about 10,500 ha of land covered with taconite tailing waste. These tailings range in particle size from coarse gravel to fine silt and clay. The coarse fraction 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 (Noyd et al. 1992), and slopes can exhibit extensive gullying. The gray/black color of the tailing results in large temperature extremes, especially on slopes that face south or west, and the large open expanses typical of these basins subject these areas to considerable wind erosion.

State mineland reclamation rules require that all tailings areas be vegetated 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 hectares (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), Eveleth Mining (EVTAC), and National Steel Pellet Company (National), to examine the use of organic amendments to improve vegetation on coarse tailings areas. The amendments have included peat, yard waste compost, municipal solid waste compost, and material from the paper manufacturing industry. This paper summarizes the findings of these early studies and discusses the first large-scale application of various organic amendments to a 12 ha section of a coarse tailings dam.

## Site Description

Studies were conducted at three mines in northern Minnesota (Figure 1). The initial studies at USX and EVTAC were small scale (2.5 m x 4 m) plot studies, begun in 1990. The EVTAC study examined the use of peat, yard waste compost, and municipal solid waste compost, while the USX study used only municipal solid waste compost (Norland and Veith, 1995) Plots using paper processing material were begun in 1992 at EVTAC (McCarthy et al., 1994) and a small (0.1 ha) demonstration plot using MSW compost was established at National Steel Pellet Company in 1993 (Melchert et al. 1994). In 1997, 2.0 hectare areas of a coarse tailings dam at EVTAC were treated with municipal solid waste compost, municipal biosolids, paper processing material from two different manufacturers and a combination of municipal biosolids and paper processing material.

Northern Minnesota experiences short, mild summers and long, cold winters, with monthly averages ranging from -12.3°C in January to 18.1°C in July and a mean annual temperature of 4°C. Mean annual precipitation is 688 mm, of which about 510 mm is lost through evapotranspiration (Myette, 1991).

## Materials

### Tailings

Tailings at all three locations are low in nitrogen and phosphorus, water holding capacity and organic matter. The tailings at USX and EVTAC have a larger percentage of coarse sand and gravel sized material since at these facilities the coarse fraction of the tailings are physically separated during the processing phase. The coarse tailings are hauled by truck to the tailings area and used to construct the dams. At National, all the tailings are pumped to the tailings basin and all the fractions settle by gravity. As a result the National tailings have a higher percentage of silt and clay sized particles (Table 1).

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Figure 1. Site map. Organic amendment sources.

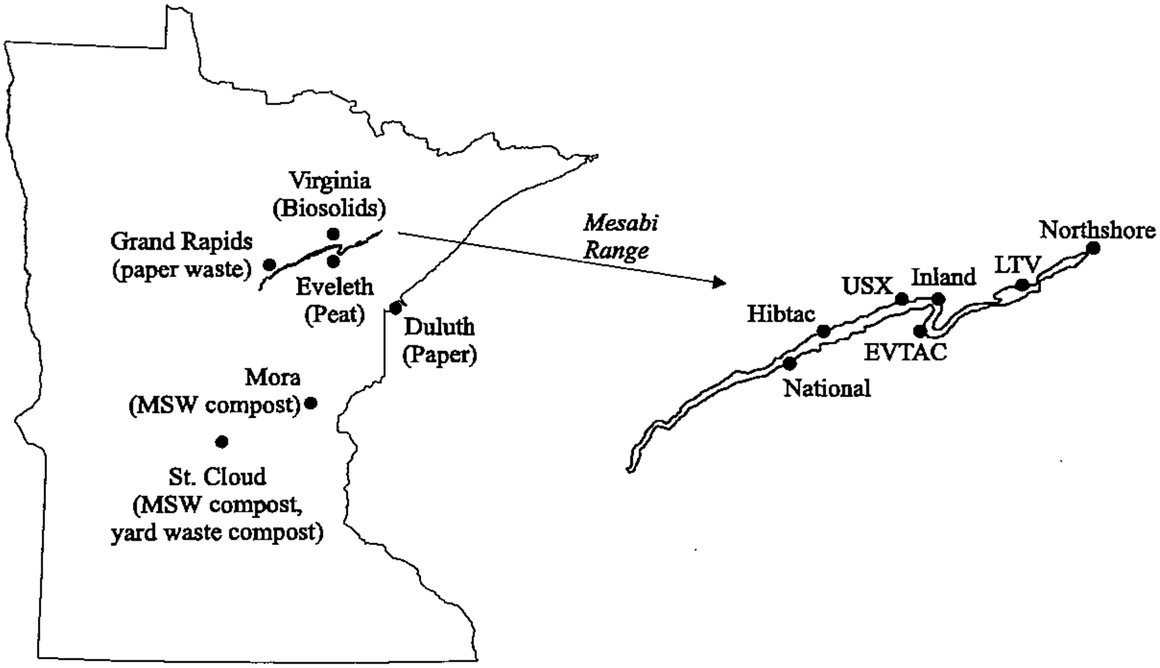


Table 1. Size distribution of Tailings.

| Particle size mm | Mesh* | Soil Class | % Retained | | |
|---|---|---|---|---|---|
| | | | EVTAC | USX | National |
| >4.76 | 4 | gravel | - | - | 2.3 |
| 2 | 10 | coarse sand | 33 | 39 | - |
| 1.7 | 12 | medium sand | - | - | 26 |
| .85 | 20 | medium sand | - | - | 24.0 |
| .5 | 35 | medium sand | 40 | 45 | - |
| .42 | 40 | medium sand | - | - | - |
| .25 | 60 | fine sand | - | - | 27.1 |
| .18 | 80 | fine sand | 15 | 10 | - |
| .15 | 100 | fine sand | - | - | 5.2 |
| .106 | 140 | fine sand | 7 | 3.5 | - |
| .075 | 200 | fine sand | - | - | 5.8 |
| .053 | 270 | silt | 2.5 | 1 | 1.9 |
| .053 | -270 | silt/clay | 2.5 | 1.5 | 8.1 |

* Different screen sizes were used in the different studies.
- no data.

## Organic Amendments

The organic amendments were obtained from a variety of sources (Figure 1). The chemical characteristics of each amendment are summarized in Table 2.

Peat. Minnesota has the largest area (about 2.7 million ha) of peatlands in the lower 48 states. In 1998, peat was mined for horticultural use at seven sites, and about 45,000 mt was produced (25,000 mt sphagnum, 20,000 mt reed-sedge). Peat generally is acidic and has high moisture retention properties. The peat used in the EVTAC study was a reed sedge product obtained from the University of Minnesota's Natural Resources Research Institute Fens Research facility located near Zim, MN.

Yard Waste Compost. In Minnesota, yard waste (leaves, grass clippings) must be separated from household waste. This material is composted by municipalities throughout the state. The material used in the EVTAC study was a screened compost obtained from Recomp in St. Cloud, MN.

Municipal Solid Waste Compost (MSW). In the early 1990's Minnesota was a leader in the development of municipal solid waste compost facilities. Currently there are five plants still producing compost, and one site is currently being reconditioned and hopes to reopen within the next year (Wirth, 1998). At these sites, household waste is sorted to remove hazardous and recyclable materials, and the rest is composted. Material in these studies has come from several different sources. The material used at USX and EVTAC came from a facility in St. Cloud, MN, while the material for the National and large-scale EVTAC project were produced at Mora, MN. All the composts meet the Minnesota Pollution Control Agency standards for Class 1 material (material that meets these standards can be spread without restriction).

Paper Processing Waste. Forestry is an important industry in northern Minnesota, and a substantial percentage of the harvest is used to produce paper. In the paper making process, the bark is removed from the trees and the wood fiber is pulverized and mixed with water and clay and then filtered to produce paper. Some of the wood fibers are too small to be used as paper and need to be disposed. This material is settled in large thickeners and filtered to produce a material that is about 40% solids with about 40% organic matter. Carbon:Nitrogen (C:N) ratios are very high, often exceeding 100:1.

The original small plots at EVTAC used a material from a plant in Illinois, while material from both Blandin Paper in Grand Rapids, MN and from Consolidated Paper in Duluth, MN were used in the full scale application. Daily production ranges from about 60 mt/day for Blandin to 200 mt/day for Consolidated.

Municipal Biosolids. The biosolids for the large-scale application at EVTAC were obtained from a nearby treatment plant which serves four small towns in northern Minnesota. The plant provides standard secondary treatment using anaerobic digestion and produces a Class B product.

## Methods

### Small Plots (USX, EVTAC)

The original studies were conducted with small plots, 2.5 x 4 m, on level surface. In general, amendments were weighed and applied manually and then tilled into the tailings with a rear tine rototiller. Variables included the rate of amendment addition (10 to 89.6 mt/ha) and the amount of fertilizer addition (0 to 448 kg/ha of diammonum phosphate, 18-46-0).

Fertilizer was generally applied with the amendment and incorporated with a tiller to a depth of approximately 15 cm. Seed (the equivalent of 57 kg/ha) was applied by hand and the plot was lightly raked to cover the seeds, and the equivalent of 4.5 mt/ha of hay mulch was hand spread over the plots. Each plot was then covered with a piece of erosion netting and staked. The seed mixes varied slightly between studies but generally contained cool season species such as brome, alfalfa, sweet clover, and timothy.

Percent cover was measured in each plot with a cover point projection sampler and biomass was measured in two to three 0.1 $m^2$ sub plots. (Additional detail on plot construction and methods can be found in Norland et al., 1991, 1992, 1993, 1995, and McCarthy et al., 1995).

### Demonstration (National Steel Pellet Company)

The 0.1 ha plots were constructed with standard farm and reclamation equipment. Based on the preliminary results from the small plot studies, an application rate of 44.8 mt/ha was selected. The MSW compost was applied with a manure spreader. The fertilizer (224 kg/ha of 18-46-0) was applied with a broadcast spreader and incorporated into the tailing to a depth of approximately 15 cm with a disc. The plot was seeded at a rate of 56 kg/ha (50 lb/acre) with a grasslegume cool-season mix with a broadcast spreader. After seeding, the plot was immediately mulched with hay at the rate of 4.5 mt/ha (2 tons/acre). The mulch was then crimped to a depth of about 7.5 cm.

Percent cover was measured using a systematic point-quadrat sampling method (Raelson and McKee, 1982) to estimate cover within a 95% statistical confidence. Biomass was estimated by clipping all aboveground plant material from six randomly selected 0.1-$m^2$ quadrats.

Full Scale Application (EVTAC)

The area used for this study was a north facing slope of the tailings basin dam. The dam is about 50 meters tall and was constructed in three lifts of 16 meters each. Each lift has a slope of 3:1 and is separated by a 5 meter bench. The organic amendments were trucked to the site and loaded with a front end loader into a Knight Side Slinger, which applied the material to the slope. All amendments, with the exception of the municipal biosolids, were applied at a rate of 44.8 mt/ha. The biosolids were applied at a rate of 2.6 mt/ha to provide a nitrogen application equivalent to standard mineland reclamation. Fertilizer was applied (560 kg/ha of 18-46-0) with a broadcast spreader and the slope was tilled with an off-set disc. Additional fertilizer was applied to the paper waste to provide additional nitrogen to assist in the breakdown of the material. A cool season grass mixture was applied to all plots at a rate of 56 kg/ha, and the area mulched with 4.5 mt/ha and crimped with a disc.

## Results

Amendment Chemistry

With the exception of peat, all the amendments were slightly alkaline, with pH ranging from 7.3 to 8.1, and contained 9-36% organic carbon (Table 2). Peat had a pH of 5.3 and contained the highest percentage of organic matter. The paper mill wastes had almost twice as much organic carbon as the municipal biosolids and the MSW compost. The C:N ratios were also very high in the paper mill solids (69:1 for Blandin and 196:1 for Consolidated).

Metals levels in all the amendments were well below the Class 1 compost, the EQ sludge limits, and MN PCA criteria for land application of industrial by-products (MN PCA, 1998; Table 3). In general, the MSW compost contained the highest level of metals (Table 2). Total metal levels in the tailings were all generally less than detection limit, even for the micronutrients copper and zinc.

Concentrations of a large suite of organic compounds were measured in the MSW compost; most compounds were not detected (Melchert et al., 1994. No pesticides or PCBs were detected in the MSW compost used in the demonstration project at National, and the only semivolatile compounds detected were butylbenzylphthalate and bis (2-ethylhexyl) phthalate. The concentrations of these compounds were 5.1 and 451 mg/kg, respectively. Phalates are commonly found in plastics, so these elements were most likely released from the small plastic particles present in the compost when the sample was heated during the extraction.

Amendment Application

Standard farm equipment was adequate for the application and incorporation of the MSW compost at the demonstration project at National. The manure spreader distributed the compost rather evenly over the small sloping plot. A simple pass with a standard disc did not evenly incorporate the compost in the tailing. Most of the compost remained on or near the surface with only a small amount mixed to 15 cm. The disc, either while incorporating the compost or during crimping of the mulch, tended to concentrate the compost in narrow bands rather than uniformly distributing the material across the plot.

Farm equipment was too small and unstable to be used for the full scale application. The Knight Side Slinger successfully applied all the amendments to the large 3:1 slope. Application was quite uniform over the entire plot area and no operational problems were encountered.

Vegetation

Small Plots. Detailed results for the first years of the small plot studies have been reported in various papers (Norland et al., 1991, 1992, 1993; McCarthy et al., 1995). The objective of this paper is to summarize these results and determine optimum addition rates for reclaiming coarse tailings areas.

Municipal Solid Waste Compost, Yard Waste Compost, Peat. In general vegetation increased with fertilizer rate and the rate of organic amendment. At the same application rate, the difference between organic amendments was generally small. On average, the peat plots at EVTAC were the most successful in producing 90% cover after three years. Plots with 44.8 mt/ha and 448 kg/ha fertilizer and those with 89.6 mt/ha of peat and

Table 2. Page 1 of 2. Chemical properties of taconite tailings and organic amendments used at EVTAC and USX.

| Property | EVTAC Small Plots | | | | USX Small Plots | | EVTAC Full-Scale Application | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tailings | Yard Waste | MSW | Hemic Peat | Tailings | MSW | Tailings | Blandin Paper Waste | Consol. Paper Waste | Municipal Biosolids | MSW |
| pH | 8.2 | 7.3 | 7.3 | 5.3 | 8.1 | 7.4 | 8.0 | 7.8 | 8.1 | 7.9 | 7.7 |
| Total Organic Nitrogen % | 0.00 | 1.18 | 1.18 | 2.51 | 0.01 | 1.14 | .0017 | 0.3 | .13 | 1.4 | 1.3 |
| Nitrate-Nitrogen, mg/kg | 0.5 | 136.2 | 81.6 | 140.9 | 1.1 | 105.2 | 1.0 | 1.0 | 3.0 | 75.5 | 31.5 |
| Ammonium-Nitrogen, mg/kg | 0.2 | 10.4 | 20.1 | 29.1 | 0.7 | 26.5 | <0.06 | 95.9 | 57.3 | 239 | 223 |
| Total Organic Carbon, % | 0.08 | 10.35 | 16.25 | 35.82 | 0.17 | 15.54 | .29 | 20.8 | 26.1 | 8.7 | 14.4 |
| C:N Ratio | - | 9:1 | 14:1 | 14:1 | 17:1 | 14:1 | 176:1 | 69:1 | 196:1 | 6:1 | 11:1 |
| **Elemental Analysis (mg/kg):** | | | | | | | | | | | |
| Phosphorous: Total | - | 1,928 | 2,223 | 1,532 | - | 2,418 | - | - | - | - | - |
| Phosphorous: Extractable | 3 | 555 | 343 | 75 | 2 | 320 | 10 | - | - | - | - |
| Calcium: Total | - | 15,489 | 27,111 | 17,439 | - | 26,949 | - | - | - | - | - |
| Calcium: Extractable | 481 | 10,390 | 14,418 | 3,228 | 800 | 14,818 | 600.0 | 2400 | 4200 | 3700 | 5600 |
| Magnesium: Total | - | 2,504 | 2,425 | 2,148 | - | 2,143 | - | - | - | - | - |
| Magnesium: Extractable | 146 | 1,355 | 1,170 | 445 | 147 | 1,182 | 190 | 120 | 250 | 3600 | 1200 |
| Potassium: Total | - | 4,131 | 2,960 | 383 | - | 3,038 | - | - | - | - | - |
| Potassium: Extractable | 493 | 3,967 | 2,769 | 109 | 404 | 2,842 | 300 | 20 | 20 | 150 | 720 |
| Sodium: Total | - | 191 | 1,867 | 41 | - | 1,951 | - | - | - | - | - |
| Sodium: Extractable | 11 | 177 | 1,564 | 9 | 5 | 1,853 | 40 | 70 | 110 | 120 | 200 |
| Iron: Total | - | 3,254 | 5,897 | 9,173 | - | 6,004 | - | - | - | - | - |
| Iron: Extractable | 4,203 | 246 | 577 | 1,772 | 5,108 | 609 | 29.2 | 7.5 | 12.4 | 64.1 | 47.5 |

- indicates no data reported
EVTAC and USX data from Norland (1991)

Table 2. Page 2 of 2. Chemical properties of taconite tailings and organic amendments used at EVTAC and USX.

| Property | | EVTAC Small Plots | | | | USX Small Plots | | EVTAC Full-Scale Application | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Tailings | Yard Waste | MSW | Hemic Peat | Tailings | MSW | Tailings | Blandin Paper Waste | Consol. Paper Waste | Municipal Biosolids | MSW |
| Copper: | Total | - | 11 | 84 | 9 | - | 89 | <5.0 | 7.3 | 15 | 120 | 180 |
| | Extractable | 2 | 4 | 58 | 5 | 2 | 64 | 1 | 0.6 | 0.9 | 3.5 | 3.4 |
| Zinc: | Total | - | 87 | 392 | 32 | - | 397 | <16 | 51 | 150 | 140 | 1200 |
| | Extractable | 4 | 43 | 243 | 18 | 20 | 244 | 5.2 | 5.5 | 8.2 | 11.4 | 11.9 |
| Manganese: | Total | - | 349 | 244 | 301 | - | 253 | - | - | - | - | - |
| | Extractable | 811 | 138 | 61 | 181 | 1,803 | 60 | 7 | 1.1 | 1.1 | 14.6 | 8.5 |
| Boron: | Total | - | 15 | 34 | 10 | - | 34 | - | - | - | - | - |
| | Extractable | 0.1 | - | - | - | 0.2 | - | 0.7 | 1 | 0.7 | 1 | 2.8 |
| Molybdenum: | Total | - | 2 | 4 | 3 | - | 4 | - | - | - | - | - |
| | Extractable | - | - | - | - | - | - | - | - | - | - | - |
| Aluminum: | Total | - | 2,644 | 6,856 | 3,219 | - | 7,085 | - | - | - | - | - |
| | Extractable | 77 | - | - | - | 71 | - | - | - | - | - | - |
| Cadmium: | Total | - | 0.5 | 2.0 | 0.5 | - | 2.0 | <2.5 | <0.50 | <0.50 | <2.5 | 12 |
| | Extractable | 0.5 | 0.2 | 0.9 | 0.2 | 0.7 | 0.9 | - | - | - | - | - |
| Chromium: | Total | - | 7.1 | 24.3 | 5.9 | - | 24.1 | <5.0 | 2.2 | 3.2 | <5.0 | 28 |
| | Extractable | 0.9 | 1.3 | 1.0 | 1.1 | 1.3 | 0.2 | - | - | - | - | - |
| Nickel: | Total | - | 7.1 | 20.3 | 7.7 | - | 24 | <5.0 | <1.0 | 1.1 | <5.0 | 24 |
| | Extractable | 0.6 | 1.9 | 4.6 | 2.3 | 0.7 | 4 | - | - | - | - | - |
| Lead: | Total | - | 33 | 218 | 15 | - | 226 | <9.5 | <1.9 | 2.0 | 11 | 100 |
| | Extractable | 3 | 16 | 103 | 5 | 5 | 105 | - | - | - | - | - |

- indicates no data reported

EVTAC and USX data from Norland (1991)

Table 3. Comparison of tailings and organic amendments with land application standards.

| | Concentrations in mg/kg | | |
|---|---|---|---|
| | Tailings[1] | Organic Amendments[2] | Standards[3] |
| Arsenic | <11 | <2.2 - <11 | 41 |
| Cadmium | <2.5 | <0.5 - 12 | 39 |
| Copper | <5.0 | 9 - 180 | 1500 |
| Lead | <9.5 | <1.9 - 226 | 300 |
| Mercury | 0.03 | <0.02 - 0.61 | 5-17 |
| Nickel | <5.0 | <1.0 - 24 | 420 |
| Selenium | <15 | <3 - <15 | 100 |
| Zinc | <16 | 32 - 1200 | 2800 |

[1]EVTAC Tailings
[2]Range from all studies for all amendments; most comprehensive data available from EVTAC full-scale study.
[3]Standards are from Class 1 Compost, Exceptional Quality Sludge, and Land Application of Industrial Byproducts, MNPCA, 1998.

224 and 448 kg/ha of fertilizer exceeded 90% cover. Plots with 89.6 mt/ha of yard waste and 448 kg/ha fertilizer also met the 90% cover standard (Figures 2, 3). All the EVTAC plots with 44.8 mt/ha (except the MSW compost and peat that received no fertilizer) had at least 75% cover after three years. With 448 kg/ha of fertilizer, plots with 10, 20, and 22.4 mt/ha of MSW produced 75-80% cover (Figures 2, 3). Increasing the amount of fertilizer improved 3-year cover results, particularly at the lower rate of organic addition (Figure 3).

After five years, almost all of the organic amended plots were at or near the 90% cover standard with the exception of the lowest addition rates and no fertilizer (Figure 1). Percent cover on plots that received the standard reclamation procedure (448 kg/ha inorganic fertilizer and no organic amendments), ranged from 40-43% after three years to 55-70% after year five.

Cover was substantially lower on MSW plots that received no additional fertilizer, but the difference in percent cover observed between the plots which had received a full and ½ rate of fertilizer disappeared at the 5-year measurement.

Paper Processing Waste. Data from these plots is limited to 1, 2, and 7-year results. After two years, all the plots with additional fertilizer had higher percent cover, and for those plots with 22.4-44.8 mt/ha, cover was between 85-90% (Figure 4). Cover decreased with increasing amounts of paper waste and the percent cover at the highest addition rate (179 mt/ha) was less than the unamended plots. After seven years, the percent cover for the standard reclamation plots was 50%, while for all plots with 22.4 and 44.8 mt/ha of paper waste exceeded 90%. Increasing the amount of inorganic fertilizer improved the percent cover in the unamended plots to 80%, and substantially improved vegetation in the 89.6 mt/ha ton acre plot but did not appear to affect the results for the 22.4 to 44.8 mt/ha plots. Percent cover decreased for plots with 179 mt/ha of paper waste, particularly when no additional fertilizer was added. Percent cover dropped to as low as 47% for plots with 179 mt/ha paper waste and no additional fertilizer.

Demonstration Area. Percent cover on the MSW plot has met and maintained the 90% cover standard since year two. Cover on the plot with no amendment reached a maximum of 50% in year two (Figure 5).

Full Scale Application. Rainfall in July and August of 1998 was only 47% of normal and, as a result, the first year results may not be representative. Percent cover ranged from 25% for the Consolidated Paper addition to 65% for the Blandin Paper application.

## Discussion

Percent cover is defined as the amount of the surface that when viewed from above is covered by

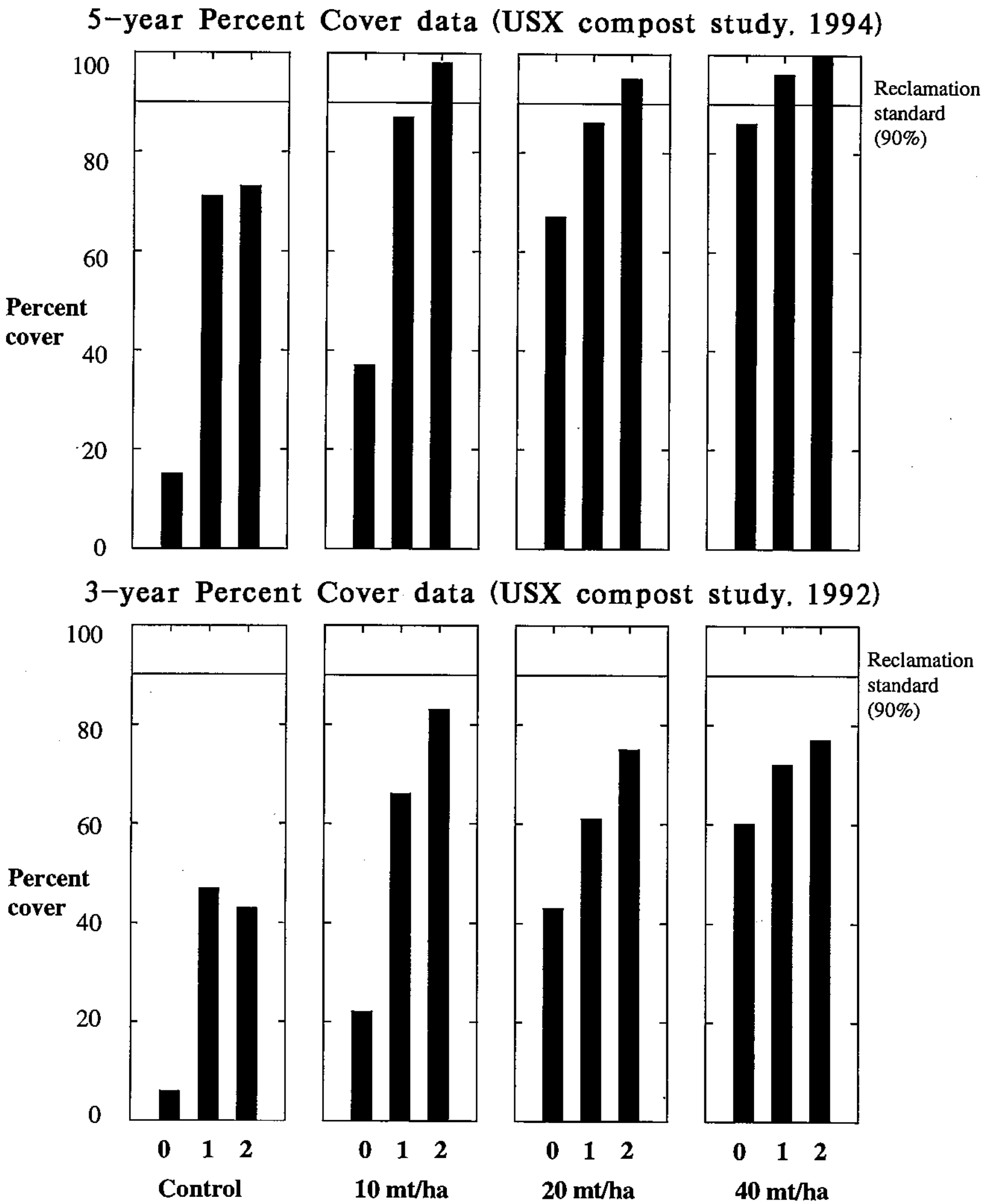


Figure 2. Percent cover data (1992 and 1994) from the USX compost study. Key: 0 = no fertilizer, 1 = 224 kg/ha of 18-46-0 fertilizer, 2 = 448 kg/ha of 18-46-0 fertilizer.

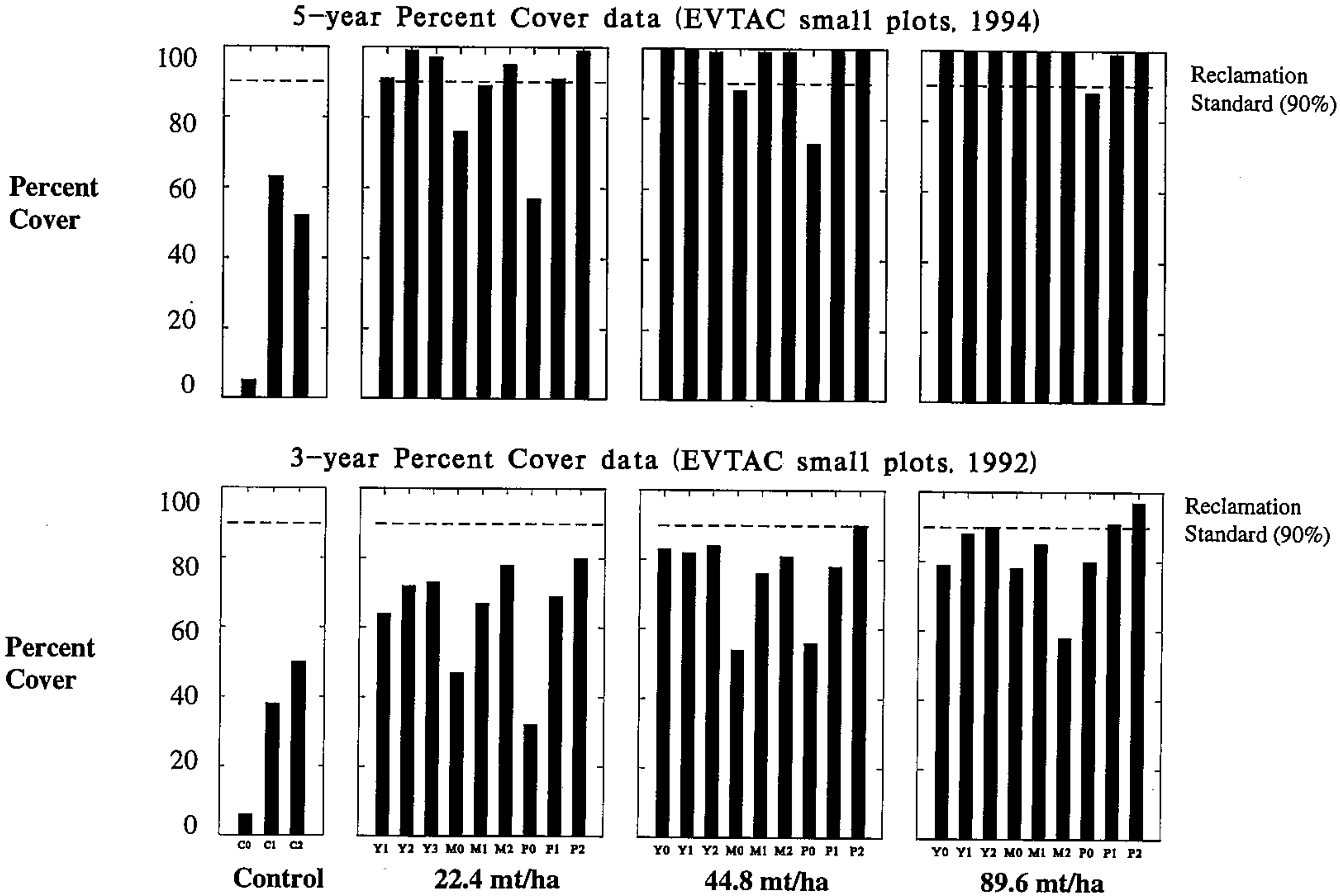


Figure 3. Vegetation results from the EVTAC compost study. Key: C = control, Y = yard waste compost, M = municipal solid waste compost, P = humic peat, 0 = no fertilizer added, 1 = 224 kg/ha 18-46-0 NPK fertilizer added, 2 = 448 kg/ha fertilizer added. Control plots received no organic amendments.

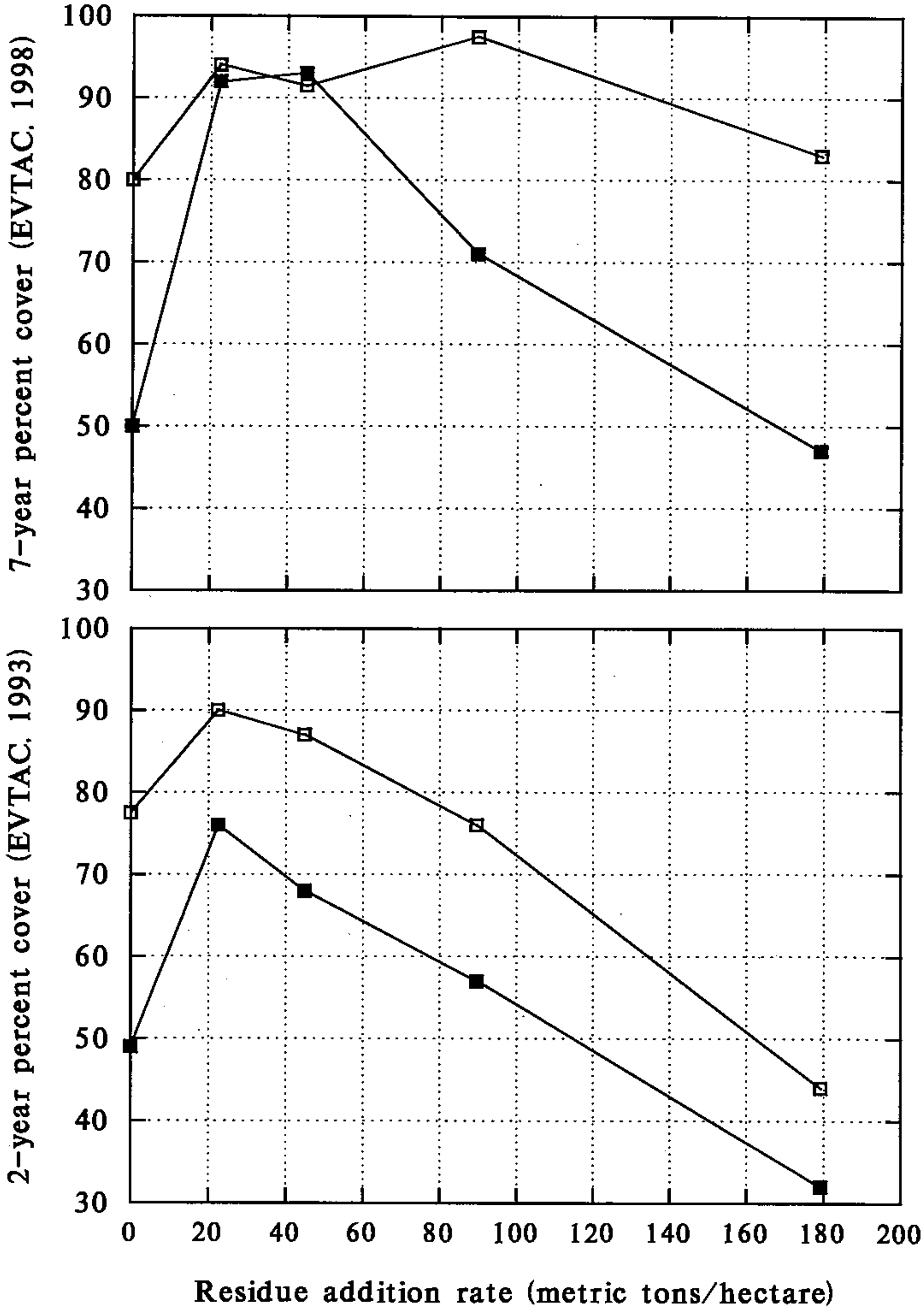


Figure 4. Vegetation results from NRRI's study of the addition of paper mill de-inking residue to tailings basin plots. (The dark squares represent results from the plots that received 448 kg/ha diammonium phosphate; the open squares represent results from plots that received 996 kg/ha.)

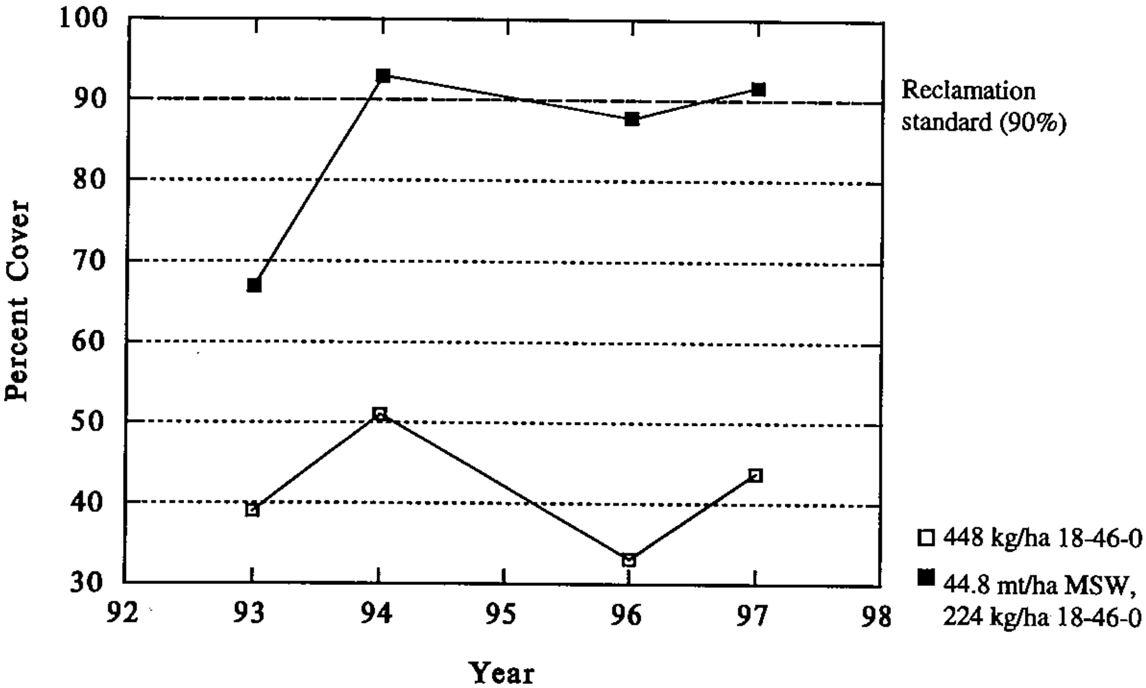


Figure 5. Percent cover at National Steel Company's demonstration site.

surface that when viewed from above is covered by vegetation, either living or dead, including litter. The Minnesota Rules do not include any requirement on species composition or total biomass, but do require that after ten years vegetation on an area be self-sustaining, regenerating and at a recognized stage of ecological succession.

Based on the results from the small plots, applications of as little as 10 to 22.4 mt/ha of organic amendments were successful in establishing vegetation on coarse taconite tailings and meeting reclamation standards after five years. Higher rates of organic addition were needed to meet standards within three years. The demonstration project confirmed that a 44.8 mt/ha application of MSW compost would meet reclamation standards within three years on a larger sloped area, while the full-scale application demonstrated that a variety of amendments could be successfully applied to coarse tailings slopes.

The main role of most of the organic amendments used in this study is to provide water holding capacity to the coarse tailings. Moisture holding capacity in unamended coarse tailings is about 4.5%, less than 20% of the value for fine tailings.

It is this difference in available water that contributes to the large difference in vegetative success between the fine and coarse tailings, since chemically the fractions are very similar. Standard mineland reclamation practices almost always produce vegetation that meet the 90% percent cover requirement after three years on fine tailings, but produces only about 50% cover on coarse tailings in the same time period.

The organic amendments contain relatively little nutrient value and, as a result, vegetation improves when inorganic fertilizer is applied with these amendments. In general, only the yard waste plots produced vegetation that met standards without inorganic fertilizer at all application rates. Vegetation in both the MSW compost and peat plots benefitted measurably from the addition of inorganic fertilizer. Only at the highest organic addition rate (89.6 mt/ha) did percent cover meet the 90% standard without inorganic fertilizer.

Paper waste is not composted and, as a result, the carbon to nitrogen ratio is much higher than the other amendments. In order for soil bacteria to efficiently breakdown organic material the carbon to nitrogen ratio needs to be less than 30:1. If nitrogen levels are too low, the bacteria will use the nitrogen in the soil. This reduces the amount of nitrogen available to vegetation and growth is restricted. Application of supplemental fertilizer improved short-term vegetation for all rates of paper waste addition and was necessary for paper waste application rates greater than 44.8 mt/ha. At 89.6 mt/ha only the plot with supplemental fertilizer met long-term reclamation standards. One of the reasons the plots with high levels of paper waste had lower percent cover was the lack of available nitrogen. It was also difficult to effectively mix the large volume of paper waste on the small plots.

## Costs

The cost for standard reclamation of tailings is around $1240 ha for flat areas, and slightly higher for tailings dam slopes. Full-scale application of the organic amendment at EVTAC was $6/mt or $270/ha. Transportation costs for 18 mt truck loads were about $2 to $3/km. At an application rate of 44.8 mt/ha with an amendment less than 50% moisture and located within 100 km, the transport cost was under $1000/ha. In the past, companies have had to refertilize or replant entire coarse tailing areas at a cost of $500 to $1240/ha and still have not been able to meet reclamation standards. Reclamation costs can be lowered by reducing the amount of organic amendment applied. In small plots, long-term reclamation standards were met with additional rates as low as 10 to 22.4 mt/ha. Adding organic material would increase overall reclamation costs, but if the amendment is within 100 km, the increased cost to apply 44.8 mt/ha would be no more than typically spent by a mining company to re-treat a coarse tailings area.

## Conclusion

While as little as 10 mt/ha of organic amendment was successful in producing 90% cover after five years on small plots, higher rates of addition improved cover after three years. The three year standard was met on the demonstration slope with a 44.8 mt/ha application. Although reclamation costs increase with increasing application rates, the 44.8 mt/ha is a cost effective rate, meeting the reclamation standard within three to five years and increasing reclamation costs by less than $1240/ha for locally available amendments.

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