THE EFFECTS OF COMPOST AGE ON THE INITIAL VEGETATIVE COVER ON COARSE TACONITE TAILING ON MINNESOTA'S MESABI IRON RANGE[1]

by

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Abstract. Mineland reclamation rules in Minnesota require that tailing dams be constructed and vegetated to control erosion for dam stability and safety. Coarse taconite tailing used in dam construction tend to resist vegetation stabilization due to several adverse edaphic factors, including: 1) alkaline reaction; 2) lack of organic matter; 3) lack of fine texture; 4) low water-holding capacity; 5) low cation-exchange capacity; 6) lack of plant-available nutrients, particularly nitrogen and phosphorus; 7) a dark color that absorbs and retains heat; and 8) little or no biological activity. These factors make it difficult to establish and maintain a diverse vegetative cover that will meet State standards. The Bureau of Mines implemented a 3x3x3 factorial experiment at United States Steel's Minnesota Ore Operations (Minntac) using 3 compost types (mature composted municipal solid waste - 180-day windrow, intermediate-aged composted municipal solid waste - 90-day windrow, and immature composted municipal solid waste - 45-day windrow), at 3 levels (10, 20, and 40 Mg ha^{-1}), and 3 fertilizer levels (0, 224, and 448 kg ha^{-1} of 18-46-0) in a randomized complete block design. Treatment combinations (27) and controls (3) were assigned to 2.5 by 4 m plots at random. Each treatment and control plot was replicated 3 times. All amendments were incorporated to a depth of 15 cm and plots were hand seeded using smooth brome (Bromus inermis), red fescue (Festuca rubra), perennial ryegrass (Lolium perenne), alfalfa (Medicago sativa), and buckwheat (Fagopyrum esculentum) at 15, 8, 7, 8, and 20 kg ha^{-1}, respectively. The overall cover on the experimental site was 34 % with cover ranging from 0 % to 82 %. First-year results show that the main effects of the rate at which municipal solid-waste composts were applied and the level of fertilization each had a significant effect on cover. The mean total plant density value was 296 stems m^{-2} with a range of 3 to 750 stems m^{-2}. Results indicate that of compost age and the level of fertilization had a significant effect on total plant density.

Additional Key Words: surface stabilization, plant density, municipal solid waste, fertilizer, revegetation.

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Introduction

The disposal of municipal solid-waste (MSW) is an ever-increasing problem. Landfilling and incineration of MSW may be serious sources of air and water pollution. Composting of organic wastes can be an environmentally and economically acceptable means of avoiding disposal, and the use of MSW compost for mineland reclamation is a potential end use for these refuse materials that might otherwise be landfilled.

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Coarse textured taconite tailing is extremely infertile (Dickenson 1972; Blake 1975). Permanent vegetation is inhibited by the tailing's low cation-holding capacity, low nitrogen and phosphorus fertility, low water-holding capacity, and low numbers of microorganisms. Incorporation of garbage compost into sandy soils may improve soil physical and chemical properties (Pritchett and Fisher 1987). By reducing the pore space of coarse materials, the water-holding capacity and cation-exchange capacity are increased (Mays et al 1973), leading to increased vegetation yields. Additionally, the application of organic residues may serve as a source of microorganism inoculum.

Injuries to existing plants or crops have been reported after the application of fresh compost to agricultural land. High C:N ratios immobilize soil nitrogen and can result in nitrogen deficiencies unless corrected by supplemental nitrogen fertilization (Terman et al 1973; Sims 1990). A more stabilized compost product will tend not to immobilize nitrogen when added to soils (Sikora and Sowers 1985). Wong (1985) noted that fresh refuse compost inhibited plant growth and that production increased gradually as the compost matured. Toxic substances evolved from decomposing organic matter may become lethal when unstable organic matter comes in contact with the root system. The phytotoxins in decomposing organic matter represent a transient stage, the duration of which remains undefined (Zucconi et al 1981 a,b).

The purpose of this study was to determine the effect compost maturity and application rate has on initial vegetative cover and density on coarse taconite tailing on the Mesabi Iron Range. Initial results are needed to determine the maturation level of compost required before application to tailing reclamation areas. Results from a concurrent field study examining other organic amendment treatments on coarse taconite tailing are given in an accompanying paper (Norland et al 1991).

Background

The Compost Material. The manufacturing of compost from the organic portion of solid waste is gaining attention as an alternative to landfilling or incineration. Composting offers a volume reduction of up to 4 to 1, with consequent savings in transportation costs and landfill space (Wong 1985). Many potential compost markets exist in Minnesota, including horticulture, agriculture, forestry, and reclamation (University of Minnesota 1987). Although composts are low in plant-available nitrogen, phosphorus, and potassium, the humus content can improve the condition of coarse soil. Jokela (1990) found that garbage composts can increase tree and understory growth without long-term deleterious ecosystem effects. Currently, Minnesota has 3 MSW compost facilities. In the next five years, it is expected that the number will increase 4-fold (Stark, 1990).

The compost used in this study came from RECOMP, Inc., a solid-waste transfer and processing center in St. Cloud, MN. After MSW is delivered to the compost facility, waste unsuitable for composting (such as tires, appliances, and household hazards) are separated and trucked to a secure disposal. Combustible paper products are separated using a trommel screen and are either recycled or trucked to a recovery plant for conversion to fuel for a nearby power plant. The trommel screen also removes recyclable textiles, corrugated boxes, and plastics. Recyclable paper passing through the trommel screen, aluminum, and scrap metal are removed by hand-sorting. The remaining organic MSW, which may include some paper products, is conveyed to the in-vessel composting digester. The waste spends 3 to 4 days in the slowly rotating digesting vessel, where it naturally heats to 55° C. Digester output is screened at 1-1/2 inches, with the oversized fractions discarded (RECOMP, Inc 1990).

Screened output is sent to the curing pad. Compost is placed on the pad in 2- to 3-meter high windrows that are turned mechanically an average of 3 times weekly for a period no less than 3 weeks. Microorganisms digesting the MSW warm it to 55° C. Maintaining thermophilic temperatures in the composting process kills pathogens (Burge et al 1979; McNelly 1989).

After 60 days, the composting process is generally completed. The compost is then run through a 1/2 inch screen to remove any remaining inorganic material. A finished "reclamation grade" compost product has a particulate matter content (obvious pieces of plastics, metals, and glass) of less than 4 % by weight and a moisture content of about 30 % (McNelly 1989).

The use of MSW for plant growth enhancement has some limitations. Municipal solid-waste compost contains residual contaminants such as heavy metals and small fragments of glass and plastic. Toxins in decomposing organic matter can injure plants and limit growth (Zucconi et al 1981a,b). Composts can immobilize soil nitrogen due to their high C:N ratios, resulting in plant nitrogen deficiencies (Terman et al 1973; Sims 1990). Heavy metals in the compost can result in metal accumulation in plant tissue and subsequent transfer to herbivorous animals. Most of the metals, however, are bound in non-bioavailable forms and are relatively unavailable within the environment (Crawford and Johnson 1988). The Minnesota Pollution Control Agency currently regulates base application rates of MSW composts on land, limiting constituents such as nitrogen and heavy metals.

Methods

Site Description

The tailing basin impoundment site is located near Mt. Iron, Minnesota, approximately 325 km north of the Minneapolis - St. Paul area in east central Minnesota. Minntac uses coarse taconite tailing in the construction of dams for their 2,835 hectare tailing basin impoundment. The inner and outer dams (each approximately 46 m wide) are constructed in a series of lifts utilizing trucks to haul the coarse tailing from the crushing and separation plants to the dam construction site. The core of the tailing dam, the area between the inner and outer dams, is filled with fine tailing and is approximately 30 m wide. The total top width of the tailing dam is 122 m.

The normal amount of precipitation for the study area is 688 mm per year, with 66 % (454 mm) occurring as rainfall between May and September. The summer period consists of approximately 109 frost-free days.

Experimental Design

A 3x3x3 unbalanced factorial experiment arranged in a randomized complete block design with 3 replications was initiated in May of 1990. The design included 3 levels of MSW compost and 3 levels of fertilization. Control plots are included in the design. Treatment combinations were assigned to the 2.5 by 4 m test plots at random within each replication.

Three potentially available MSW composts, varying in maturity, were surface applied to experimental plots on the Minnesota Ore Operations site as soil amendments. Each of the MSW composts were supplied by RECOMP, Inc., St. Cloud, Minnesota. The 3 MSW composts used were mature compost (windrowed for 180-days), intermediate aged compost (windrowed for 90-days), and immature compost (windrowed for 45-days). Each of the municipal solid waste composts were applied at rates of 10, 20, and 40 Mg ha^{-1} on a dry weight basis.

Fertilizer applications were based on the rate used for the revegetation of northern Minnesota coarse taconite tailing, typically 448 kg ha^{-1} of diammonium phosphate (18-46-0). The levels of fertilizer used in this experiment were 0 kg ha^{-1}, 224 kg ha^{-1} of 18-46-0 (half the typical rate), and 448 kg ha^{-1} of 18-46-0 (typical rate). The zero application of fertilizer treatment was included to test the effects of each municipal solid waste compost alone.

The control plots consisted of no MSW compost or fertilizer application; no MSW compost, but fertilizer applied at half the rate typically used for coarse taconite tailing revegetation in northern Minnesota; and no organic amendment, but fertilizer applied at the typical rate.

Field Application

All experimental plots were installed during the third week of May, 1990. Following the application of each compost/rate combination, the plot was hand-raked to cover the 10 m^2 area. The appropriate fertilizer treatment was then broadcast onto the plot and all plots, including controls, were rototilled to a depth of 15 cm. Seeding, soil and vegetation sampling, and the analytical procedures followed are discussed in Norland and others (1991).

Results and Discussion

Soil Properties

The chemical properties of the Minntac coarse taconite tailing revealed the potential limitations to plant growth and development to be: (a) a moderately alkaline pH; (b) a lack of organic carbon and organic matter, which limits total nitrogen, plant-available nitrogen, and the cation-exchange capacity of the coarse tailing; (c) low concentrations of extractable phosphorus, calcium, and magnesium; and (d) excessive manganese concentrations, which may be phytotoxic (Table 1). With the exception of manganese, these potential limitations are the same as those at Eveleth Mines (Norland et al 1991). Like Eveleth Mines, soluble salts are not effecting plant growth on the Minntac coarse taconite tailing. The mean value of 2 dS m^{-1} is well below the level at which soluble salts affect plant growth and development. The remaining plant-essential elements and heavy metal concentrations are within ranges typically found in Minnesota soils (Pierce 1980).

The mean pH of the coarse taconite tailing (8.1) falls within the upper range of measured values of mineral soils which make contact with the Mesabi Iron Range (White 1954) and other Minnesota soils (Pluth et al 1970). Nutritionally, the effect of the moderately alkaline pH may be to further decrease the availability of plant-available nitrogen and phosphorus.

Taconite tailing materials generally have a very low, inherent organic carbon and organic matter content (Nater et al 1982; Norland et al 1991). Like Eveleth Mines coarse taconite tailing, Minntac tailing organic carbon content is lower than that of a typical undisturbed soil adjacent to the tailing impoundment (Norland et al 1990). This suggests that little humification has occurred in the coarse taconite tailing. The pre-treatment Minntac coarse taconite tailing samples had a mean of 0.17 % organic carbon, which is lower than the mean value of 1.15 % reported by Nater and others (1982) for northern Minnesota glacial till (overburden) and the 1.93 % reported by Norland and others (1990) for undisturbed soil.

The lack of organic matter severely limits the organic nitrogen content and cation-exchange capacity of the taconite tailing. Like Eveleth Mines, the 3 nitrogen fractions analyzed showed a lack of organic nitrogen and deficiencies in the available forms of nitrogen (Norland et al 1991). In pre-treatment coarse tailing (Table 1), organic nitrogen was 0.01 %, while ammonium- and nitrate-nitrogen were at extremely low levels. The low levels of both organic and available nitrogen indicate that the nitrogen fractions measured are insufficient for plant establishment, and plant growth will be impossible without some form of nitrogen addition.

The mean cation-exchange capacity of the coarse taconite tailing at Minntac (6.9 cmol (+) kg^{-1}) is higher than that at Eveleth Mines (Norland et al 1991), but is still at the lower end of the cation-exchange capacity range found in Minnesota soils (Pluth et al 1970). The cation-exchange capacity of Minntac coarse taconite tailing is, however, typical of northern Minnesota glacial till (Nater et al 1982), of other taconite tailing on the Mesabi Iron Range (Jordan and Dewar 1985; Norland et al 1991), and of northern Minnesota copper-nickel tailing (Borovsky et al 1983). The values at Minntac were expected since the tailing is a silica material with a range in texture from mostly sand to fine gravel.

The mean extractable phosphorus concentration for the pre-treatment taconite tailing was 2 mg kg^{-1}. When compared to Minnesota soils (Pluth et al 1970), this value is extremely low and may be limiting plant

Table 1. Chemical properties of Minntac coarse taconite tailing prior to application of MSW compost treatments.

Property, Unit	Replication I	II	III	Mean
pH	8.1	8.1	8.1	8.1
Conductivity, dS/m	0.2	0.2	0.2	0.2
Total Organic Nitrogen, %	0.01	0.01	0.01	0.01
Nitrate-Nitrogen, mg/kg	0.5	1.6	1.1	1.1
Ammonium-Nitrogen, mg/kg	0.3	1.2	0.5	0.7
Total Organic Carbon, %	0.18	0.18	0.16	0.17
C:N Ratio	18:1	18:1	16:1	17:1
Organic Matter, %	0.31	0.31	0.28	0.30
CEC (cmol/(+) kg)	7.7	5.8	7.2	6.9
Base Saturation, %	91	90	92	91
Extractable (mg/kg)				
Calcium	900	652	848	800
Magnesium	158	136	146	147
Potassium	456	308	449	404
Sodium	5	5	5	5
Phosphorus	2	3	2	2
Sulfate	10	9	12	10
Iron	5,829	4,597	4,897	5,108
Copper	3	2	2	2
Zinc	37	18	5	20
Manganese	1,845	1,664	1,901	1,803
Boron	0.2	0.2	0.2	0.2
Aluminum	84	62	66	71
Cadmium	0.8	0.6	0.6	0.7
Chromium	1.6	1.1	1.3	1.3
Nickel	0.9	0.5	0.6	0.7
Lead	7	5	4	5

growth and development on Minntac coarse taconite tailing. Plant growth and development may also be limited by the low concentrations of calcium (800 mg kg^{-1}) and magnesium (147 mg kg^{-1}). Both essential plant nutrients are below the range found for Minnesota soils (Pierce 1980), but slightly higher than those reported by Norland and others (1991) for Eveleth Mines coarse taconite tailing.

The mean concentration of manganese (1,803 mg kg^{-1}) is at the upper end of the range found in Minnesota soils (Pierce 1980) and above the typical, and apparently safe, soil concentration of manganese is 850 mg kg^{-1} (Bohn et al 1985). Since manganese is required by plants in only small quantities, the manganese concentrations in the Minntac coarse taconite tailing may be at levels that are phytotoxic.

Two months after the application of MSW composts (Table 2), there was some improvement in soil fertility based on the maturity of the compost and rate of application (Table 3), but the initial year results are too variable to identify trends in plant nutrient availability. Increased application rates of 45- and 90-day MSW composts resulted in a decrease in soil pH. The 45- and 90-day composts have a lower inherent pH value than does the 180-day compost. As such, there may still be some acid leachates in the younger composts causing the decrease in soil pH. Both the 90-day, and in particular, the 45-day MSW composts have high concentrations of ammonium ions. The conversion of alkaline ammonium ions to acid nitrates by microbial action may be partially responsible for the decrease in soil pH.

Compost maturity had little effect on total organic carbon, total organic nitrogen, or soil organic matter contents. At the zero application rate, there must have been some hay mulch or other carbon source present in some samples since the organic carbon content in the control (0.97 %) was higher than the organic carbon content when 10, 20, or 40 Mg ha^{-1} of MSW compost, at each maturity tested, was applied.

Total organic nitrogen increased with increasing rates of MSW compost application regardless of maturity (Table 3). The control plots did not have any organic nitrogen, while at the 40 Mg ha^{-1} treatment level total organic

Table 2. Chemical properties of the MSW compost used on Minntac coarse taconite tailing.

Property		Compost Age 45-Day	90-Day	180-Day
pH		6.8	7.0	7.4
Total Organic Nitrogen, %		0.78	0.52	1.14
Nitrate-Nitrogen, mg/kg		1.3	21.4	105.2
Ammonium-Nitrogen, mg/kg		1,218.5	247.5	26.5
Total Organic Carbon, %		17.94	7.24	15.54
C:N Ratio		23:1	14:1	14:1
CEC (cmol/(+) kg)		108.3	57.6	111.6
Base Saturation, %		94	93	93
Elemental Analysis (mg/kg)				
Calcium	(total)	40,806	15,314	26,949
	(extractable)	15,028	7,672	14,818
Magnesium	(total)	1,775	1,565	2,143
	(extractable)	775	497	1,182
Potassium	(total)	2,505	1,722	3,038
	(extractable)	2,203	1,599	2,842
Sodium	(total)	2,736	1,333	1,951
	(extractable)	2,374	1,149	1,853
Phosphorus	(total)	2,112	1,127	2,418
	(extractable)	252	250	320
Sulfur	(total)	5,060	1,870	3,880
	(extractable)	832	992	927
Iron	(total)	3,589	3,043	6,004
	(extractable)	344	253	609
Copper	(total)	160	48	89
	(extractable)	73	29	64
Zinc	(total)	312	183	397
	(extractable)	198	105	244
Manganese	(total)	197	187	253
	(extractable)	57	57	60
Boron	(total)	33	19	34
	(extractable)	NA	NA	NA[1]
Molybdenum	(total)	6	3	4
	(extractable)	NA	NA	NA
Aluminum	(total)	7,678	4,483	7,085
	(extractable)	NA	NA	NA
Cadmium	(total)	2.2	1.1	2.0
	(extractable)	1.1	0.4	0.9
Chromium	(total)	27.2	12.9	24.1
	(extractable)	1.4	1.1	0.2
Nickel	(total)	19	12	24
	(extractable)	6	3	4
Lead	(total)	268	88	226
	(extractable)	108	37	105

[1]Not analyzed.

nitrogen increased to 0.013, 0.011, and 0.009 % in the 45-, 90- and 180-day old composts, respectively. The organic matter content for each of the composts also reflects the presence of straw or some other carbon source in the samples analyzed. The controls had higher organic matter contents than did plots receiving the various aged MSW composts. These results were unexpected since the MSW composts had high organic carbon contents ranging from 7.24 to 17.94 % (Table 1).

Extractable phosphorus was affected by both compost age and rate of application (Table 3). Applications of the 45-day compost did not result in increased tailing phosphorus concentrations, while applications of 90- and 180-day composts did increase tailing phosphorus concentrations to levels typically found in Minnesota soils (Pluth et al 1970). Extractable calcium and magnesium concentrations resulting from MSW compost applications are variable and interpretations of the effects of compost on the concentration of calcium and magnesium cannot be made during the initial growing season. Further monitoring is necessary to determine the chemical responses of the coarse taconite tailing to amendation with various aged MSW composts.

Table 3. Chemical properties of coarse taconite tailing amended with different maturities and rates of MSW composts[1]

	45-day[2]				90-day				180-day			
Property, Unit	0	10	20	40	0	10	20	40	0	10	20	40
pH	8.2	8.2	8.1	8.1	8.3	8.3	8.2	8.0	8.3	8.3	8.3	8.3
EC, dS/m	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.2	0.2
Tot. Org. N, %	0.00	0.003	0.007	0.013	0.00	0.005	0.002	0.011	0.00	0.002	0.004	0.009
NO -N, mg/kg	4.2	3.7	7.0	0.9	4.2	3.9	6.1	9.2	4.2	3.4	5.8	7.2
NH -N, mg/kg	3.0	4.0	1.8	2.8	3.0	3.7	4.3	2.9	3.0	2.0	2.2	2.5
Tot. Org. C, %	0.97	0.78	0.65	0.92	0.97	0.80	0.63	0.97	0.97	0.55	0.77	0.83
C:N Ratio,	NA[3]	260:1	93:1	71:1	NA	160:1	315:1	88:1	NA	275:1	193:1	92:1
Org. Matter, %	1.7	1.3	1.1	1.6	1.7	1.4	1.1	1.7	1.7	0.9	1.3	1.4
Extractable (mg/kg)												
Calcium	441	866	876	670	441	645	493	625	441	688	551	591
Magnesium	82	70	71	76	82	64	76	70	82	72	76	78
Potassium	229	200	196	227	229	202	220	218	229	180	232	248
Sodium	3	9	11	15	3	6	7	15	3	5	9	20
Phosphorus	8	9	13	10	8	9	15	16	8	7	9	17
Sulfate	5	7	10	10	5	7	6	10	5	6	7	14
Iron	6183	4772	4889	5054	6183	5748	5130	5255	6183	5273	5086	5263
Manganese	1830	1467	1487	1443	1830	1901	1504	1514	1830	1540	1587	1455
Copper	2.1	2.2	2.7	3.3	2.1	2.2	2.0	6.6	2.1	2.1	2.4	4.7
Zinc	2.5	4.3	4.4	6.0	2.5	3.0	2.6	7.1	2.5	2.8	3.8	12.2
Boron	0.1	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.3
Aluminum	86	84	86	93	86	92	74	109	86	89	78	109
Cadmium	0.9	0.7	0.8	0.9	0.9	0.9	0.7	0.9	0.9	0.8	0.7	0.8
Chromium	1.9	1.1	1.2	1.2	1.9	1.6	1.2	1.3	1.9	1.5	1.2	1.2
Nickel	1.3	1.0	1.0	1.0	1.3	1.1	0.9	4.2	1.3	3.2	3.1	6.7
Lead	4.4	5.0	5.0	6.1	4.4	4.8	3.7	6.8	4.4	4.3	4.6	9.1

[1]Municpal solid waste compost rates are 0, 10, 20, and 40 Mg ha^{-1}.
[2]Days in compost windrow.
[3]Not applicable.

Each of the MSW composts applied were below the heavy metal limits required for Class I compost by Minnesota law (Table 4). However, the 45- and 90-day MSW composts had plastic, metal, and glass contaminants that were above the 1 % by weight allowed for a Class I compost. Only the 180-day MSW compost would be considered a Class I compost. The concentrations of cadmium, chromium, copper, lead, nickel, and zinc in the upper 15 cm of the amended coarse tailing were at or below the surface concentrations of the same metals in Minnesota soils (Pierce 1980).

Plant Responses

Total plant density (number of stems m^{-2}) and total plant cover (percent) of treated coarse taconite tailing by main effect are shown in Table 4. There were significant differences in total plant density due to the main effects of MSW compost maturity and fertilizer, but not due to the rate of application. There was a significant increase in total plant density when MSW compost windrowed for 180 days was applied. The total plant density of the untreated coarse taconite tailing was 281.4 stems m^{-2}. When 180-day MSW compost was applied, total plant density increased to 335.5 stems m^{-2}. There were no significant differences in total plant density between the control, 45-day, and 90-day MSW composts.

The main effect of amendment rate was not statistically significant. Total plant density of the 10, 20, and 40 Mg ha^{-1} application rates were higher than the control, but not significantly higher. Apparently, the rates of application were not high enough to cause a significant response during the initial growing season. Norland and others (1991) found, during the initial growing season, that only at the 89.6 Mg ha^{-1} application rate was there a significant increase in total plant density over the controls.

Fertilization with diammonium phosphate (18-46-0) had a significant effect on total plant density (Table 5). Both the 224 and 448 kg ha^{-1} fertilizer treatments had significantly higher total plant density values than did the zero application rate, but there was no significant difference in total plant density between the two fertilizer treatments. The highest plant density was attained using 224 kg ha^{-1} of fertilizer. This agrees with what Norland and others (1991) found using the same fertilizer rates on a similar material, but at a different site.

Table 4. Metal limits established by Minnesota PCA for Class I compost.

Metal	Concentration (mg kg^{-1})
Cadmium	10
Chromium	1,000
Copper	500
Lead	500
Mercury	5
Nickel	100
Zinc	1,000

Preliminary results indicate that the use of 180-day MSW compost as an organic amendment will significantly increase plant density on coarse taconite tailing over unamended or coarse tailing amended with younger MSW composts; that application rates of up to 40 Mg ha^{-1} will increase total plant density, but not significantly over that achieved with 10 or 20 Mg ha^{-1}; and that 224 kg ha^{-1} of 18-46-0 fertilizer is necessary to achieve a significant plant density response.

Plant cover exhibited a statistically significant response to the main effects of MSW compost maturity, rate of application, and the rate of fertilizer application (Table 5). There was a significant increase in cover when MSW compost was applied to coarse taconite tailing. Cover increased significantly from 25.7 % in untreated tailing to 35.3, 35.6, and 32.5 % when 45-, 90-, and 180-day MSW composts were applied, respectively. There was no significant difference in cover between the various aged MSW composts. Applications of 90-day MSW compost resulted in the highest cover value during the initial growing season.

Increasing the rate of MSW compost applied significantly increased plant cover (Table 5). Untreated coarse taconite tailing had a cover value of 25.7 %, while application rates of 20 and 40 Mg ha^{-1} produced significantly more cover; 34.6 and 38.5 %, respectively. There was no significant difference in cover between the control and the application rate of 10 Mg ha^{-1}. Apparently the 10 Mg ha^{-1} rate is too low to cause a significant vegetative response in terms of cover.

Although cover increases significantly with increased rates of MSW compost from 0 to 40 Mg ha^{-1}, there are no significant differences in cover between the 10 Mg ha^{-1} rate (30.3 %) and the 20 Mg ha^{-1} rate (34.6 %) and between the 20 Mg ha^{-1} rate and the 40 Mg ha^{-1} rate (38.5 %). This is similar to what Norland and others (1991) found on coarse taconite tailing at another northern Minnesota location. At both experimental sites, however, the greatest plant cover was found on plots with the highest rates of organic residue application.

Increasing the rate of fertilizer application from 0 to 448 kg ha^{-1} significantly increased plant cover. Unfertilized coarse taconite tailing had a cover value of 21.2 %, while applications of 224 and 448 kg ha^{-1} of fertilizer significantly increased cover values to 33.8 and 45.7 %, respectively. The difference in cover between the 224 and 448 kg ha^{-1} fertilizer treatments is significant. This is similar to what Norland and others (1991) found on coarse taconite tailing at another northern Minnesota location. Results obtained during the initial growing season indicate that plant cover of the seeded vegetation can be increased by applying either 90- or 180-day municipal solid waste composts, at a rate of at least 40 Mg ha^{-1}, with 448 kg ha^{-1} of 18-46-0 fertilizer.

Total plant density and cover by MSW compost age and rate of application are shown in Table 6. This table shows that additions of 45-day MSW compost, regardless of rate, decreases total plant density when compared to the control. However, increasing the rate of application of 45-day MSW compost to either 20 or 40 Mg ha^{-1} does significantly increase plant cover over that attained in the control plots.

Increasing the application rate of 90- and 180-day MSW composts from 0 to 40 Mg ha^{-1} significantly increased both plant density and cover. When 10 Mg ha^{-1} of 90-day MSW

Table 5. Main effect plant density (plants m^{-2})[1] and total cover (%) of coarse taconite tailing amended with various maturities of MSW compost during the initial growing season.

Species	Muncipal Solid Waste Compost[2] C	45-day	90-day	180-day	Rate[3] 0	10	20	40	Fertilizer[4] 0	224	448
Grass species	124.1	127.3	154.2	176.2	124.1	141.1	158.0	158.5	105.2	165.8	178.1
alfalfa (_M. sativa_)	118.1	101.7	100.0	112.2	118.1	110.6	102.3	101.0	99.1	114.9	104.0
buckwheat (_F. esculentum_)	38.1	41.6	35.1	46.8	38.1	34.4	43.6	45.6	42.3	43.3	37.0
smallflower buttercup (_R. abortivus_)	0.0	0.2	0.1	0.1	0.0	0.0	0.4	0.1	0.0	0.0	0.4
yellow rocket (_B. vulgaris_)	1.1	0.0	0.0	0.2	1.1	0.0	0.2	0.0	0.0	0.3	0.2
Total Density	281.4a	270.8a	289.4a	335.5b	281.4a	286.1a	304.2a	305.2a	246.2a	324.3b	319.7b
Total Cover	25.7a	35.3b	35.6b	32.5b	25.7a	30.3ab	34.6bc	38.5c	21.2a	33.8b	45.7c

[1]Density values that equal 0.0 contain no plants.
[2]C=Control, 45-day= 45 days in compost windrow, 90-day= 90 days in compost windrow, 180-day= 180 days in compost windrow.
[3]0, 10, 20, and 40 Mg ha^{-1}
[4]0=No Fertilizer, 224=224 kg ha^{-1} of 18-46-0 fertiler, 448=448 kg ha^{-1} of 18-46-0 fertilizer.
Means within the same row and amendment followed by the same letter are not significantly different at the 0.05 level.

compost was applied, there was a nonsignificant decrease in total plant density; however, when the 90-day MSW compost was applied at either 20 or 40 Mg ha^{-1} there was a significant increase in plant density. Plant cover had a significant response when 20 or 40 Mg ha^{-1} of 90-day MSW compost was applied, but the increase when 10 Mg ha^{-1} of 90-day MSW compost was added was insignificant.

Applications of 10, 20, or 40 Mg ha^{-1} of 180-day MSW compost significantly increased plant density over that of unamended coarse taconite tailing, but the density values between the 10, 20, and 40 Mg ha^{-1} rates were not significantly different. Like the 90-day MSW compost, plant cover was significantly increased when either 20 or 40 Mg ha^{-1} of 180-day MSW compost was applied, but there was no significant difference between the 20 and 40 Mg ha^{-1} application rates. There was no significant difference in cover between unamended coarse taconite tailing and the 10 Mg ha^{-1} rate of 180-day MSW compost addition. The greatest plant cover was attained when 90-day MSW compost was applied at 40 Mg ha^{-1} (43.4 %), while the highest density values were attained when 180-day MSW compost was applied at any of the rates tested.

Table 7 lists volunteer species present on the experimental area, but not included within any of the 0.1 m^2 quadrats used for vegetation sampling and analysis. A productive, diverse, self-sustaining plant community may develop following the addition of MSW compost, but the effect of compost age on plant community development has yet to be determined and continued monitoring of the Minntac experimental plot is necessary.

Conclusions

Preliminary results of this long-term study suggest that the application of MSW waste composts windrowed for 90- or 180-days and applied at rates of up to 40 Mg ha^{-1} should not result in any unmanageable agronomic or environmental problems. No changes in coarse taconite tailing chemical properties as a result of MSW compost additions at the rates tested were detected. Continued monitoring will be necessary to determine the effects of MSW composts on tailing chemical and physical characteristics. Initial growing season total plant density and cover results suggest that either 90-day or 180-day MSW composts can be used as organic amendments if they are applied at a rate of 40 Mg ha^{-1} as a minimum and the tailing is fertilized with 448 kg ha^{-1} of 18-46-0 fertilizer.

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Table 6. Plant density (plants m^{-2})[1] and total cover (%) of coarse taconite tailing amended with various maturities of MSW compost during the initial growing season.[2]

Species	45-day[3]				90-day				180-day			
	0	10	20	40	0	10	20	40	0	10	20	40
Grass species	124.1	138.1	118.1	125.6	124.1	122.6	164.4	175.6	124.1	162.6	191.5	174.4
alfalfa (*M. sativa*)	118.1	109.6	100.0	95.6	118.1	93.3	108.9	97.8	118.1	128.9	98.1	109.6
buckwheat (*F. esculentum*)	38.1	29.6	43.3	52.2	38.1	27.0	40.4	37.8	38.1	46.7	47.0	46.7
smallflower buttercup (*R. abortivus*)	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.4	0.0
yellow rocket (*B. vulgaris*)	1.1	0.0	0.0	0.0	1.1	0.0	0.0	0.0	1.1	0.0	0.0	0.0
Total Density	281.4	277.3	262.1	273.4	281.4ab	242.9a	313.7b	311.6b	281.4a	338.2b	337.7b	330.7b
Total Cover	25.7a	30.8ab	37.3b	37.7b	25.7a	29.7ab	33.6b	43.4c	25.7a	30.4ab	32.8b	34.3b

[1]Density values that equal 0.0 contain no plants.
[2]Rates are Mg ha^{-1}.
[3]Days in compost windrow.
Means within the same row and organic amendment followed by the same letter are not significantly different at the 0.05 level.

Table 7. Other species present on the Minntac experimental plots, but not included in the 0.1 m^2 plots.

Species	Life History[1]
Grasses	
yellow foxtail (*Setaria lutescens*)	A
Forbs	
lambsquarters (*Chenopodium album*)	A
prostrate knot weed (*Polygonum aviculare*)	A
mouse-eared chickweed (*Cerastium vulgatum*)	P

[1]A=annual, P=perennial

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