INITIAL VEGETATIVE COVER ON COARSE TACONITE TAILING USING ORGANIC AMENDMENTS 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 wind and water erosion for dam stability, safety, and dust control. 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 productive vegetative cover that will meet State standards. The Bureau of Mines implemented a 4x3x3 factorial experiment at Eveleth Mines using four organic amendments (2 municipal solid- waste composts - both windrowed 180-days, composted yard waste, and hemic peat), at 3 levels (22.4, 44.8, and 89.6 Mg ha^{-1}), and 3 fertilizer levels (0, 224, and 448 kg ha^{-1} of 18-46-0) arranged in a randomized complete block design. Treatment combinations (36) 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 the 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 49 % with cover ranging from zero to 91 %. First-year results show that the main effects of type of organic amendment used, the rate at which the organic residues were applied, and the level of fertilization each had a significant effect on cover. The mean total plant density value on the experimental site was 384 stems m^{-2} and ranged from zero to 790 stems m^{-2}.

Additional Key Words: surface stabilization, plant density, compost, peat, fertilizer, revegetation.

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Introduction

Recent shifts in national issues to greater concern for regulations and the environment has caused the U.S. Bureau of Mines to focus more of its research activities in the area of mining-related environmental research. A major concern of this increased activity is the stabilization of solid wastes produced by the minerals industry, as these wastes account for 80 % of the nation's nonagricultural, land-disposed solid wastes (Veith and Kaas 1988).

The taconite industry in northern

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Minnesota is located along the Mesabi Iron Range. Minnesota is a major domestic iron ore producer, and, therefore, a major producer of mining wastes. The 7 active operations are capable of producing 60 million tons of taconite pellets per year (MRRC 1989). Pellet production requires taconite ore to be crushed, concentrated, and processed. This results in 2 tons of tailing for every ton of pellets. Tailings are impounded within dikes, most of which are constructed from coarse textured tailing. Tailing basins can cover many square kilometers. Today there are approximately 10,125 hectares of active tailing basins in northeastern Minnesota. This basin area will be doubled when mining is completed by the year 2030 (Dewar and Berglund 1983).

Minnesota's mineland reclamation rules require mining operators to establish a permanent vegetative cover when areas are completed. Without the stabilizing effect of vegetation, coarse tailing dams are prone to erosion. The dam structures must be stabilized with a self-sustaining vegetative cover within 3 years after final disturbance, and this vegetation must provide 90 % cover of the ground. Eroded, unstable dams can threaten life and property downstream. This becomes particularly important after mine closure, when mine operators are not there to maintain tailing dam structures.

In an effort to meet vegetation requirements on coarse tailing, mine operators presently utilize high rates of fertilizer, seed, and mulch. After a first year of good growth, vegetation production and cover usually declines (Jordan and Dewar 1985). Earlier studies have shown that coarse tailing is not toxic to vegetation, but is extremely infertile (Dickenson 1972; Blake 1975). Permanent vegetation is inhibited by the tailing's low ability to adsorb and hold cations, inability to provide nitrogen and phosphorus, low water-holding capacity, and lack of microorganisms.

Disposal of municipal solid-waste (MSW) is an ever increasing problem. There is widespread agreement that municipal wastes should be recycled and reused. Composting MSW and adding it to soil for improved vegetative growth is a feasible alternative to land disposal. With the increased costs of landfills, the number of composting facilities has increased rapidly in recent years (Goldstein 1988). Opportunities now exist for solid-waste compost use in mine land reclamation (Hart 1968; Stark 1987; University of Minnesota 1987; Jokela et al 1990).

Successful establishment of vegetation may be accomplished with additions of organic matter. Hemic peat incorporated into coarse taconite tailing increases ground cover and biomass response (Norland et al 1990). Results from field experiments have shown increased crop yields from applications of solid waste composts (Mays et al 1973). Hemic peat, MSW, or yard waste composts incorporated with coarse taconite tailing will add organic matter and may favorably alter the physical and chemical characteristics of the tailing, thus enhancing plant growth.

In 1989, the Bureau, in cooperation with the Minnesota Department of Natural Resources - Division of Minerals, began a study to develop coarse tailing revegetation technology for the taconite industry of northern Minnesota, with possible future application to similar problems throughout the country. Since little natural soil material is available on the site for amending the coarse tailing dams, and the cost of such an effort would be prohibitive even if material was available, our research led us to utilize local or readily available organic residues as soil amendments to provide desirable soil qualities for the coarse tailing waste material. This research was expanded in 1990 to include coarse tailing test sites at 2 mining operations, one experimenting with several types of organic residues, and the other looking at the age of composted MSW as a factor in vegetative response.

The purpose of this paper is to assess initial vegetative cover and density on a series of coarse tailing field plots treated with 4 organic amendments (2 MSW composts, composted yard waste, and hemic peat) in combination with fertilizer. Initial results indicate the short-term effects of composts and peat applied to coarse tailing on vegetation establishment. Results from a concurrent field experiment examining compost maturity and its effect on vegetation establishment will be given in a companion paper (Norland et al 1991).

Background Information

Mesabi Iron Range. The Mesabi Iron Range of northern Minnesota is part of the Lake Superior Iron Ore District. This district includes all the major iron ore ranges in the upper Midwest: the Marquette and Menominee in Michigan; the Gogebic, in both Michigan and Wisconsin; and the Vermillion, Cuyuna, and Mesabi Iron Ranges in Minnesota. Geologically, northern Minnesota's severely glaciated surface and its position on the Precambrian bedrock complex of the Laurentian Shield distinguish it from other major iron ore ranges in the upper Midwest.

The Mesabi Iron Range is part of The Biwabik Iron Formation that extends across the northern part of the state from Grand Rapids on the west to Ely on the east. It is about 160 km long, outcrops in a 5-km wide band, and averages 180 meters in thickness. As the largest of the three iron ore ranges in Minnesota, and the only one currently producing iron ore, the Mesabi Iron Range has been supplying iron ore since 1892 (Norland et al 1990). To date, over 3.6 billion metric tons of iron ore concentrates have been shipped from the Mesabi, with about 50 billion metric tons of crude ore remaining in reserve (West 1990).

Almost all Minnesota iron ore production today is produced on the eastern half of the Range where volcanic intrusions baked the sedimentary ores and converted the iron-bearing rock into taconite. Taconite is a hard, siliceous rock, containing up to 35 % recoverable iron as magnetite.

The Mesabi Iron Range is unique among the various iron ranges, with its century-old landscape of large, open-pit mines and mountains of mining residues in a climate of short, warm summers and comparatively severe, snowy winters. All of this in a setting of lake-studded glacial landforms and dense forests of conifers and northern hardwoods. The climate and related environmental conditions set the Mesabi Iron Range apart from other regions with similar bedrock geology and large open-pit mines.

Organic Residues. Composts are organic residues that have been mixed, piled, moistened, and allowed to undergo thermophilic decomposition until the original organic materials have been substantially decomposed. The final products can be easily worked into the soil and have properties that may promote soil aggregation. It can also enhance soil fertility by increasing the cation-exchange capacity of the soil and the slow release of plant-essential nutrient elements, and introduce soil microorganisms essential for the establishment of nutrient cycling processes and symbiotic relationships between microbes and plants.

Hemic peat is in an intermediate stage of decomposition and has chemical, physical, and biological properties similar to composted materials. Additionally, the peat may contain a seed bank of desirable native species that may be adapted to the environmental conditions of coarse taconite tailing.

Methods

Site Description

The tailing basin site is located 16 km south of Eveleth, Minnesota, which is approximately 300 km north of the Twin Cities of Minneapolis and St. Paul, in east central Minnesota. Eveleth Mines uses coarse taconite tailing in the construction of dikes for their 285 hectare tailing basin impoundment.

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

Four potentially available organic wastes or residues were surface applied to experimental plots on the Eveleth Mines site as soil amendments. The organic wastes used, their origin, and availability were composted yard waste (RECOMP, Inc., St. Cloud, MN - potentially available), 2 mature MSW composts that had been windrowed for 180-days (RECOMP, Inc., St. Cloud, MN - potentially available), and hemic peat (University of Minnesota - Duluth, Natural Resources Research Institute's Fens Research Facility located near Zim, MN - potentially available). The difference between the 2 MSW composts is that 1 contained soiled, disposable diaper residues in the amount typically found in MSW (2 % by weight), while the second MSW compost contained soiled, disposable diaper residues at an 8 % by weight level. Each of the organic amendments were applied at rates of 22.4, 44.8, and 89.6 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 was included to test the effects of each organic amendment alone on plant growth and development.

The control plots consisted of no organic amendment or fertilizer application; no organic amendment, but fertilizer applied at one-half the typical rate; and no organic amendment, but fertilizer applied at the typical rate.

Species Used

Table 1 contains a complete list of the grass and forb species selected for study and the amounts of each within the mix. The species selected for the mix and their rates of application were based on species that are typically used while attempting to establish a permanent vegetative cover on coarse taconite tailing in northern Minnesota. Each of these species is available from local seed dealers and will grow under the harsh climatic variables of northern Minnesota.

Field Application

All experimental plots were completed during the fourth week of May 1990. The rates of application for each of the organic amendments, on a dry weight basis, were determined and appropriate amounts of each were weighed on-site. Following application, each amendment was hand-raked to cover the 10 m^2 plot area and the appropriate fertilizer treatment was then broadcast onto the plot. All plots, including the controls, were then rototilled to a depth of 15 cm.

Following rototilling, each plot was hand-raked to prepare the amended tailing surface for seeding. All seeding was accomplished by hand using the same species mixture. Following seeding, each plot was again lightly raked to incorporate the seeds into the tailing and mulched with hay at a rate of 4.48 Mg ha^{-1}. The mulch was held in place by netting stapled into the coarse taconite tailing.

Soil Sampling and Analysis

Coarse tailing samples were taken in each of the 117 plots in May 1990 prior to treatment, and again from non-rhizosphere locations in July 1990. Three randomly located sub-samples in each plot were taken to a depth of 15 cm with a soil recovery probe. Sub-samples were composited, based on treatment combination, into 39 samples. All samples were submitted to the Department of Soil Science Research Analytical Laboratory, University of Minnesota, for chemical analysis, shown in Table 2. The chemical properties of the organic amendments used are shown in Table 3.

Vegetation Sampling and Analysis

Measurements of cover and plant density were taken monthly, from June 1990 through August 1990. The August data are reported as they are representative of the growing season. Cover determinations were made using a cover-point optical point projection device. This prototype instrument was designed for use in point-intercept cover

Table 1. Species selected for use in the seed mix and the application rate of each species based on pure live seed (PLS).

Species	Amount of Seed (lb PLS acre^{-1})	Amount of Seed (kg PLS ha^{-1})
Grasses		
smooth brome (*Bromus inermis*)	13	14.6
red fescue (*Festuca rubra*)	7	7.8
intermediate wheatgrass (*Agropyron intermedium*)	6	6.7
perennial ryegrass (*Lolium perenne*)	6	6.7
Leguminous Forbs		
alfalfa (*Medicago sativa*)	7	7.8
Non-Leguminous Forbs		
buckwheat (*Fagopyrum esculentum*)	18	20.2

Table 2. Chemical properties of Eveleth Mines coarse taconite tailing prior to organic residue treatments.

Property, Unit	Replication I	II	III	Mean
pH	8.2	8.1	8.2	8.2
Conductivity, dS/m	0.1	0.4	0.2	0.2
Total Organic Nitrogen, %	0.00	0.00	0.00	0.00
Nitrate-Nitrogen, mg/kg	0.5	0.6	0.5	0.5
Ammonium-Nitrogen, mg/kg	0.1	0.5	0.1	0.2
Total Organic Carbon, %	0.05	0.11	0.08	0.08
Organic Matter, %	0.09	0.19	0.14	0.14
CEC (cmol (+)/kg)	5.3	4.9	5.2	5.1
Base Saturation, %	97	96	93	95
Extractable (mg/kg)				
Calcium	502	470	470	481
Magnesium	155	143	139	146
Potassium	499	468	511	493
Sodium	12	12	9	11
Phosphorus	2	3	3	3
Sulfate	3	1	5	3
Iron	4,175	4,535	3,898	4,203
Copper	1	2	2	2
Zinc	3	4	4	4
Manganese	860	893	681	811
Boron	0.2	0.1	0.1	0.1
Aluminum	79	86	65	77
Cadmium	0.5	0.6	0.5	0.5
Chromium	0.9	1.0	0.7	0.9
Nickel	0.4	0.7	0.7	0.6
Lead	3	3	3	3

sampling. The projection is made with large diameter objective and microscope optics magnified 5X. A microscope reticle is incorporated to provide a set of extremely fine cross hairs for projection of a point as dimensionless as possible. The Cover-point optical point projector was mounted on a standard photographic tripod head. A moveable mirror was mounted on a 1 meter bar that had 10 stops spaced every 10 cm to be used as measuring points. The bar was attached to the tripod and had a separate leg for stability. Cover was determined by looking through an eyepiece and recording hits or misses (as determined by the cross hairs) along the 10 sample points on the bar. Three multiple point samples were taken within each treatment plot.

Plant density measurements were taken in 3 randomly selected 0.1 m^2 sample points (quadrats) within each of the treatment plots. Values of plant density (the number of individual organisms of a species within each

Table 3. Chemical properties of the organic amendments used on Eveleth Mines coarse taconite tailing.

Property		Yard Waste[1]	MSWW[2]	MSWO[3]	Hemic Peat
pH		7.3	7.1	7.3	5.3
Total Organic Nitrogen, %		1.18	1.38	1.18	2.51
Nitrate-Nitrogen, mg/kg		136.2	162.3	81.6	140.9
Ammonium-Nitrogen, mg/kg		10.4	201.6	20.1	29.1
Total Organic Carbon, %		10.35	19.00	16.25	35.82
C:N Ratio		9:1	14:1	14:1	14:1
CEC (cmol (+)/kg)		86.2	144.4	108.3	58.0
Base Saturation, %		92	93	95	35
Elemental Analysis (mg/kg)					
Calcium	(total)	15,489	38,630	27,111	17,439
	(extractable)	10,390	17,380	14,418	3,228
Magnesium	(total)	2,504	2,292	2,425	2,148
	(extractable)	1,355	1,225	1,170	445
Potassium	(total)	4,131	4,383	2,960	383
	(extractable)	3,967	4,222	2,769	109
Sodium	(total)	191	4,924	1,867	41
	(extractable)	177	4,374	1,564	9
Phosphorus	(total)	1,928	2,975	2,223	1,532
	(extractable)	555	201	343	75
Sulfur	(total)	1,640	6,700	3,990	2,615
	(extractable)	130	2,455	992	188
Iron	(total)	3,254	5,890	5,897	9,173
	(extractable)	246	619	577	1,772
Copper	(total)	11	166	84	9
	(extractable)	4	101	58	5
Zinc	(total)	87	399	392	32
	(extractable)	43	352	243	18
Manganese	(total)	349	257	244	301
	(extractable)	138	92	61	181
Boron	(total)	15	45	34	10
	(extractable)[4]	-	-	-	-
Molybdenum	(total)	2	6	4	3
	(extractable)[4]	-	-	-	-
Aluminum	(total)	2,644	12,879	6,856	3,219
	(extractable)[4]	-	-	-	-
Cadmium	(total)	0.5	2.6	2.0	0.5
	(extractable)	0.2	1.7	0.9	0.2
Chromium	(total)	7.1	35.1	24.3	5.9
	(extractable)	1.3	1.9	1.0	1.1
Nickel	(total)	7.1	22.5	20.3	7.7
	(extractable)	1.9	6.1	4.6	2.3
Lead	(total)	33	252	218	15
	(extractable)	16	141	103	5

[1]Composted yard waste.
[2]Municipal solid waste compost with added disposable diaper residue.
[3]Municipal solid waste compost without added disposable daiper residue.
[4]Not run.

sampling area) were calculated on a per square meter area basis. Total plant density (number of stems within each sampling area) were also calculated. Because of identification difficulties with immature grasses, the density values for the seeded grasses (smooth brome, red fescue, intermediate wheatgrass, and perennial ryegrass) are grouped together under the heading of grass.

Variations in plant cover and density among the unamended and amended treatments were analyzed using a 3-way analysis of variance at the 5 % probability level. The general linear models procedure (SAS Institute, Inc. 1988) was used to perform all analysis of variance tests. Multiple comparisons were made of the means using Tukey's studentized range test on all main effect means. Orthogonal contrasts were also used to determine where mean differences occurred.

Results and Discussion

Soil Properties

The chemical properties of the Eveleth Mines coarse taconite tailing revealed potential limitations to plant growth and development to be: (a) a moderately alkaline pH; (b) a lack of organic carbon and organic matter limiting the total nitrogen content, the plant-available nitrogen, and the cation-exchange capacity of the tailing; and (c) low concentrations of extractable phosphorus, calcium, and magnesium (Table 2). Soluble salts, as indexed by conductivity, are not affecting plant growth on Eveleth Mines coarse taconite tailing. The mean value of 0.2 dS m^{-1} is below the level at which soluble salts affect plant growth and development. The remaining plant-essential elements and heavy metal concentrations are within their respective ranges for Minnesota soils (Pierce 1980).

The mean pH value of the taconite tailing (8.2) falls within the upper range of measured pH values of mineral soils that make contact with the Mesabi Iron Range, 4.5 to 8.4 (White 1954). Nutritionally, the effect of the moderately alkaline pH may be to further decrease the availability of a limited amount of plant-available nitrogen and phosphorus.

Taconite tailing generally has a very low inherent organic carbon and organic matter content unless soil horizons or other sources of organic matter are incorporated (Nater et al 1982). The organic carbon content of the tailing is lower than that found in soils typical of northern Minnesota, suggesting that little humification has taken place. (Norland et al 1990). Since carbon is assumed to be 60 to 70 % of the total mass of organic matter, the lack of organic carbon also suggests a low organic matter content. The pre-treatment Eveleth Mines coarse tailing has a mean organic matter content of 0.14 %, which is lower than the mean value of 1.15 % for northern Minnesota glacial till (overburden) reported by Nater and others (1982).

The lack of organic matter severely limits the organic nitrogen content and cation-exchange capacity of the taconite tailing. The 3 nitrogen fractions measured (total organic (Kjeldahl) nitrogen, ammonium-nitrogen, and nitrate-nitrogen) showed the lack of organic nitrogen and deficiencies in the available forms of nitrogen. In pre-treatment coarse taconite tailing, organic nitrogen was not detectable, while ammonium-nitrogen and nitrate-nitrogen were at extremely low levels. The low levels of plant-available nitrogen and the lack of organic nitrogen indicated that the nitrogen content of the coarse tailing is insufficient and plant establishment and growth will be nearly impossible.

The cation-exchange capacity of coarse taconite tailing samples ranged from 4.9 to 5.3 cmol (+) kg^{-1} (Table 2). These values are generally lower than those found in Minnesota soils (Pluth et al 1970), but typical of northern Minnesota overburden waste (Nater et al 1982), taconite tailing (Jordan and Dewar 1985), and Minnesota copper-nickel tailing (Borovsky et al 1983). The values obtained at Eveleth Mines are expected, since the tailing is a silica material with a texture range of mostly sand and fine gravel with little, if any, clay or organic matter content.

The mean Bray 1 extractable phosphorus concentration for the pre-treatment coarse tailing was 3 mg kg^{-1}, which is very low and may be limiting plant growth and development. The mean concentration of both calcium (481 mg kg^{-1}) and magnesium (112 mg kg^{-1}) of pre-treatment coarse taconite tailing are significantly lower than the calcium and magnesium concentration range in Minnesota soils (Pierce 1980). These low concentrations may be contributing to the limited plant growth and development on coarse taconite tailing.

In the first year following the application of the various organic amendments, soil fertility generally improved with increased rates of organic residue application. Soil pH decreased, while nitrate-nitrogen, phosphorus, calcium, and magnesium concentrations increased; as did the total organic carbon, total organic nitrogen, and organic matter contents. In general, with the exception of soil pH, conductivity, ammonium-nitrogen, and the C:N ratio, all soil elemental concentrations were higher in the high-rate amendment treatments

Table 4. Chemical properties of organically amended and unamended coarse taconite tailing[1]

	MSW-W[2]				MSW-O[3]				Composted Yard Waste				Hemic Peat			
Property, Unit	0	22.4	44.8	89.6	0	22.4	44.8	89.6	0	22.4	44.8	89.6	0	22.4	44.8	89.6
pH	8.0	8.0	7.9	7.8	8.0	7.9	7.9	8.1	8.0	8.0	8.1	8.3	8.0	7.9	7.7	7.5
EC, dS/m	0.1	0.2	0.2	0.3	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
Tot. Org. N, %	0.0	0.007	0.016	0.03	0.00	0.013	0.013	0.23	0.00	0.003	0.014	0.024	.0	0.013	0.036	0.045
NO -N, mg/kg	4.1	3.5	6.6	8.3	4.1	3.2	16.2	6.6	4.1	2.8	2.9	2.2	4.1	2.7	1.9	3.0
NH -N, mg/kg	2.3	0.6	0.5	0.7	2.3	0.9	1.6	0.3	2.3	2.6	0.8	0.2	2.3	2.5	3.8	1.9
Tot. Org. C, %	0.73	1.17	0.77	1.00	0.73	0.47	1.07	0.87	0.73	0.73	0.97	1.03	0.73	1.07	1.33	1.15
C:N Ratio,	NA[4]	167:1	48:1	33:1	NA	36:1	82:1	38:1	NA	243:1	69:1	43:1	NA	82:1	37:1	26:1
Org. Matter, %	1.3	2.0	1.3	1.7	1.3	0.8	1.8	1.5	1.3	1.3	1.7	1.8	1.3	1.8	2.3	2.0
Extractable (mg/kg)																
Calcium	137	233	251	315	137	188	293	448	137	159	225	314	137	212	317	456
Magnesium	53	52	53	52	53	49	56	65	53	48	54	64	53	65	70	91
Potassium	227	249	268	281	227	258	262	286	227	246	280	326	227	243	217	216
Sodium	13	24	28	37	13	20	32	42	13	14	15	12	13	14	15	18
Phosphorus	14	21	19	22	14	13	24	22	14	13	20	29	14	10	19	18
Sulfate	7	9	9	13	7	8	11	13	7	7	7	7	7	6	5	6
Iron	4108	4351	4575	4997	4108	5066	4244	4726	4108	5210	4459	4441	4108	4591	5147	4853
Manganese	802	887	967	1078	802	928	761	771	802	1094	887	886	802	781	1085	1012
Copper	1.6	3.1	4.1	4.5	1.6	2.1	4.1	6.2	1.6	3.2	2.2	2.1	1.6	2.3	2.9	2.3
Zinc	1.1	3.4	4.1	4.5	1.1	3.4	7.8	16.2	1.1	1.8	2.2	3.0	1.1	1.5	1.6	2.1
Boron	0.1	0.2	0.3	0.4	0.1	0.1	0.4	0.4	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.2
Aluminum	76	73	87	108	76	100	105	143	76	75	80	75	76	108	103	119
Cadmium	0.6	0.6	0.7	0.7	0.6	0.7	0.6	0.7	0.6	0.8	0.6	0.7	0.6	0.6	0.7	0.7
Chromium	0.9	1.1	0.9	1.2	0.9	1.0	1.5	1.1	0.9	1.1	1.2	1.0	0.9	1.3	1.1	1.1
Nickel	0.5	0.6	1.0	1.0	0.5	0.5	0.8	1.0	0.5	0.8	1.3	0.7	0.5	0.8	1.0	0.5
Lead	2.7	4.0	5.9	7.7	2.7	4.4	6.5	10.4	2.7	3.6	3.2	3.9	2.7	3.1	3.6	3.3

[1]Organic amendment rates are 0, 22.4, 44.8, and 89.6 Mg/ha.
[2]Municipal solid waste compost with diaper residue added to 8 percent.
[3]Municipal solid waste compost with diaper residue at 2 percent.
[4]Not applicable.

than in the untreated taconite tailing or the lower organic amendment treatments. Differences in chemical properties that exist between organic residue treatments and rates of application, except for those identified, are beyond the scope of this paper and will be discussed in future publications.

Hemic peat was the only organic residue that caused a linear decrease in soil pH (Table 4). As the rate of application was increased from 0 to 89.6 Mg ha^{-1}, there was a corresponding decrease in pH from 8.0 to 7.5, that was apparently due to leachates from this moderately acidic organic residue or the organic acids produced from the decomposition of hemic peat.

The application of composted yard waste at either 44.8 or 89.6 Mg ha^{-1} resulted in an increase in soil pH. An increase in pH of 0.3 units occurred between the 0 and 89.6 Mg ha^{-1} treatment levels, probably due to the exchangeable bases present or the alkaline nature of the compost itself (pH 7.3). Norland and Veith (1991) found that similar additions of composted yard waste to slightly acidic lead-zinc chat tailing increased soil pH from 6.8 to 7.0. Little or no change is soil pH occurred when MSW composts were applied, indicating the inability of 180-day MSW compost to affect the soil pH.

Total organic carbon, total organic nitrogen, and soil organic matter contents increased with increasing rates of organic residue applications (Table 4). Total organic carbon increased from 0.73 % in untreated chat to 1.00, 0.87, 1.03, and 1.15 % in the 89.6 Mg ha^{-1} MSW compost with added diaper residues, MSW compost without added diaper residues, composted yard waste, and hemic peat treatments, respectively. At the lower application rates, there were variable results; indicating that the site was still in the process of stabilizing chemically.

The total organic nitrogen content of amended coarse taconite tailing ranged from 0.013 to 0.045 % compared to 0.00 % for unamended taconite tailing. In each organic residue treatment, there is an increase in total nitrogen as the rate of application increases (Table 4). The organic nitrogen levels were highest in the 89.6 Mg ha^{-1} organic residue treatment levels.

In general, organic matter content increased with increasing rates of application of each organic residue. However, there appears to be localized heavier deposits of organic residues within each of the treatment plots as a result of initial, uneven spreading of the organic residue on the plot followed by the rototilling of the organic residue. Nater and others (1982) reported that the incorporation of peat, topsoil, or other organic materials into the overburden during stripping or deposition can produce localized deposits of high organic matter concentrations. Localized deposits of organic matter may have occurred in the MSW compost with added diaper residues (22.4 Mg ha^{-1} treatment), MSW compost without added diaper residues (44.8 Mg ha^{-1} treatment), and hemic peat (44.8 Mg ha^{-1} treatment). The significance of organic matter is that it supplies nearly all the nitrogen, 50 to 60 % of the phosphate, as much as 80 % of the sulfur, and a large part of the boron and molybdenum absorbed by plants from unfertilized soils (Bohn et al 1985).

Extractable phosphorus concentrations increased with increasing organic residue application rates (Table 4). The highest concentrations of phosphorus were at the 44.8 and 89.6 Mg ha^{-1} treatment levels. Epstein and others (1976) found that compost applied at 40 t ha^{-1} resulted in increased soil phosphorus levels. Amended coarse taconite tailing sample means at the 44.8 and 89.6 Mg ha^{-1} treatment levels are above the maximum phosphorus levels that Pluth and others (1970) found in the A horizon of 16 soil series in Minnesota. The initial low levels of phosphorus in the pre-treatment coarse taconite tailing are related to the low levels of phosphorus in the ore (Table 2.).

Extractable potassium (with the exception of hemic peat), calcium, and magnesium (with the exception of MSW waste compost with added diaper residues) all exhibited increased concentrations with increasing rates of organic residue application (Table 4). The organic amendment used should provide sufficient amounts of calcium, magnesium, and potassium necessary for plant growth in the coarse tailing.

Further soil and monitoring will be necessary to quantify the effects of the organic amendments on tailing pH levels, organic matter content, organic nitrogen and carbon content, available nitrogen forms, and soil phosphorus concentrations.

All of the composts used were within the heavy metal limits required for Class I compost by Minnesota law (Table 5). Uncontaminated Class I composts are available for unrestricted resale and use for residential, municipal, agricultural, and commercial used. Class I composts derived from municipal solid wastes, free of sludge or regulated industrial wastes, contain less than 1 % contaminants (plastics, metals, and glass) by weight and meet metal concentration restrictions. Maximum metal concentrations in the Class I composts are 1,000 mg kg^{-1} each of chromium and zinc, 500 mg kg^{-1} each of copper and lead, 100 mg kg^{-1} of nickel, 10 mg kg^{-1} of cadmium, 5 mg kg^{-1} of mercury, and 1 mg kg^{-1} PCB. Each of the organic residues used in this study are well below these levels (Table 3). Concentrations of cadmium, chromium, copper, lead, nickel, and zinc in the upper 15 cm of coarse tailing are below the surface concentrations of the same metals in Minnesota soils (Pierce 1980). Additionally, the concentrations of iron and manganese in the Eveleth Mines coarse taconite tailing are within the range found in undisturbed Minnesota soils (Pierce 1980).

Plant Response

Total plant density (number of stems m^{-2}) and total plant cover (percent) on treated coarse taconite tailing by main effect are shown in Table 6. There were significant differences in total plant density due to the main effects of organic amendment type and their rate of application, but not due to inorganic fertilizer. In another study utilizing the same rates of fertilization, Norland and others (1990) found that the main effect of fertilization did not have a significant effect on plant density. Except for yard waste and MSW compost with added diaper residues, there was a significant increase in total plant density when organic residues were applied. The total plant density of untreated coarse

Table 5. Metal limits established by Minnesota PCA for Class I composts.

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

taconite tailing was 305.2 stems m^{-2}. When MSW compost without added diaper residues or hemic peat were used as organic soil amendments, total plant density increased to 398.4 and 453.4 stems m^{-2}, respectively. Hemic peat had the highest total density of any of the organic residues used. Norland and others (1990) found that the total plant density of a cover crop seeded on coarse taconite tailing was highest (197 stems m^{-2}) when hemic peat was applied at a rate of 22.4 Mg ha^{-1}.

The seeded grass species were dominant on the coarse taconite tailing (Table 6). The density of the grass species present on the untreated taconite tailing was 195.9 stems m^{-2}, which was 64 % of the total plant density on untreated taconite tailing. Seeded alfalfa (Medicago sativa) had a density of 77.4 stems m^{-2} on untreated coarse taconite tailing, which was 25 % of the total plant density on the untreated tailing. Norland and Veith (1991), in a study on the stabilization of lead-zinc chat tailing, found that seeded leguminous forbs, including alfalfa, did not emerge on the untreated chat. Buckwheat (Fagopyrum esculentum) had a density of 31.9 stems m^{-2} which was 10 % of the total density on untreated taconite tailing. There were no volunteer forbs on the untreated coarse taconite tailing.

The addition of organic residues resulted in increased plant density, but not always significant increases. Additions of both composted yard waste and MSW compost with added diaper residues did result in increased total plant density, but these increases were not significantly different from the untreated coarse taconite tailing. The seeded species accounted for 99 % of the total plant density for both composted yard waste and MSW compost with added diaper residues. Grasses accounted for 59 and 61 %, alfalfa 30 and 29 %, and buckwheat 10 and 9 % of the total plant density for composted yard waste and MSW compost with added diaper residues, respectively. Volunteer species made up a small, insignificant portion of the total plant density for both organic residue types.

Additions of MSW compost without added diaper residues and hemic peat resulted in significant increases in total plant density, from 305.2 stems m^{-2} in untreated coarse taconite tailing to 398.4 and 453.3 stems m^{-2} with MSW compost without added diaper residues and hemic peat, respectively. The difference in total plant density between composted yard waste and MSW composts with and without added diaper residues is not significant; and the difference between MSW composts with and without diaper residues and hemic peat are not significant (Table 6). For MSW without added diaper residues, the seeded species accounted for 99 % of the total plant density with similar grass (60 %), alfalfa (30 %), and buckwheat (9.5 %) contributions to the total plant density with very little volunteer vegetation.

Additions of hemic peat to coarse taconite tailing resulted in the highest total plant density, 453.3 stems m^{-2}, when compared to untreated or other organically amended plots (Table 6). The seeded vegetation, however, accounted for only 89 % of the total plant density, significantly lower than the other organic amendments. When hemic peat was applied, seeded grass species and buckwheat contributed similar percentages of 57 and 9 %, respectively, to the total plant density; while alfalfa contributed 23 %, which is lower when

Table 6. Main effect plant density (plants m^{-2})[1] and total cover (%) of organically amended and unamended coarse taconite tailing during the initial growing season.

Species	Organic Amendment[2] C	YW	MSW-W	MSW-O	P	Rate[3] 0	22.4	44.8	89.6	Fertilizer[4] 0	224	448
Grass species	195.9	204.6	227.8	239.3	256.3	195.9	225.5	220.5	250.0	215.3	243.6	228.7
alfalfa (*M. sativa*)	77.4	103.3	106.5	120.7	106.0	77.4	109.2	106.7	111.7	107.9	107.3	105.0
buckwheat (*F. esculentum*)	31.9	35.6	33.8	37.9	39.8	31.9	39.0	33.7	37.6	37.0	36.8	35.3
common skullcap (*S. galericulata*)	0.0	0.0	0.0	0.0	11.6	0.0	0.6	2.0	6.1	3.3	1.9	2.8
common smartweed (*P. pensylvanicum*)	0.0	0.0	0.2	0.1	8.8	0.0	1.1	1.9	3.9	2.4	2.3	1.6
Indian mustard (*B. juncea*)	0.0	0.0	0.0	0.0	12.5	0.0	0.8	2.3	6.2	3.1	2.8	2.7
kochia (*K. scoparia*)	0.0	0.0	0.0	0.0	0.4	0.0	0.1	0.0	0.2	0.1	0.0	0.2
lambsquarters (*C. album*)	0.0	1.1	0.2	0.4	18.0	0.0	2.5	3.9	8.4	4.5	4.4	4.7
velvetleaf (*A. theophrasti*)	0.0	0.9	0.0	0.0	0.0	0.0	0.2	0.3	0.2	0.5	0.0	0.1
Total Density	305.2a	345.5ab	368.5abc	398.4bc	453.4c	305.2a	379.0ab	371.3ab	424.3b	374.1	399.1	381.1
Total Cover	36.4a	46.5b	52.9b	49.8	50.7b	36.4a	45.4b	49.1bc	55.5c	38.6a	49.7b	58.4c

[1]Density values that equal 0.0 contain no plants.
[2]C=Control, YW=Yard Waste, MSW-W=Municpal Solid-Waste Compost with diaper residue added to 8 %, MSW-O Municipal Solid-Waste Compost with diaper residue at 2 %, P=Hemic Peat.
[3]0, 22.4, 44.8, and 89.6 Mg ha^{-1}
[4]0=No Fertilizer, 224=224 kg ha^{-1} of 18-46-0 fertilizer, 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.

compared to the other organic residues. Volunteer species contributed 11 % of the total plant density when hemic peat was applied. Hemic peat apparently has a seed bank of species which will germinate and survive on coarse taconite tailing.

The main effect of amendment rate was statistically significant, indicating that as the rate of application increased, so too did total plant density. Total plant density of the 22.4, 44.8, and 89.6 Mg ha^{-1} application rates were higher than the control; however, only at the 89.6 Mg ha^{-1} application rate was plant density (424.3 stems m^{-2}) significantly higher than the control. There were no significant differences in total plant density between the control (305.2 stems m^{-2}), 22.4 Mg ha^{-1} (379.0 stems m^{-2}), and 44.8 Mg ha^{-1} (371.3 stems m^{-2}) application rates; and between the 22.4, 44.8, and 89.6 Mg ha^{-1} application rates.

Fertilization with inorganic nutrients had no significant effect on plant density (Table 6). The highest plant density (399.1 stems m-^{2}) was attained using the 224 kg ha^{-1} of 18-46-0 fertilizer. At an application rate of 448 kg ha^{-1} of 18-46-0 fertilizer, plant density was similar to the control. The lack of response to fertilization with 18-46-0, in terms of total plant density, is similar to that found by Norland and others (1990) in a study on the response of a cover crop to applied organic and inorganic soil amendments on similar coarse taconite tailing.

Preliminary results indicate that MSW waste composts windrowed for 180-days and hemic peat, each applied at a rate of 89.6 Mg ha^{-1}, and without fertilization, will result in high plant density values for seeded vegetation on northern Minnesota coarse taconite tailing.

Plant cover exhibited a statistically significant response to the main effects of organic residue type, rate of application, and fertilizer application (Table 6). There is a significant increase in cover when organic residues are applied to coarse taconite tailing. Cover increased from 36.4 % in untreated tailing to 46.5, 49.8, 50.7, and 52.9 % in the composted yard waste, MSW without added diaper residues, hemic peat, and MSW with added diaper residues, respectively. There is no significant difference in cover between the organic residues used. The highest cover was obtained when MSW compost with added diaper residues was applied.

Table 7. Plant density (plants m^{-2})[1] and total cover (%) of organically amended coarse taconite tailing during the initial growing season.[2]

Species	Composted Yard Waste 0	22.4	44.8	89.6	MSW-W[3] 0	22.4	44.8	89.6	MSW-O[4] 0	22.4	44.8	89.6	Hemic Peat 0	22.4	44.8	89.6
Grass species	195.9	200.4	210.4	203.0	195.9	206.3	212.2	264.8	195.9	244.4	231.9	241.5	195.9	250.7	227.4	290.7
alfalfa (_M. sativa_)	77.4	102.2	107.4	100.4	77.4	97.8	101.5	120.4	77.4	126.3	117.0	118.9	77.4	110.4	100.7	107.0
buckwheat (_F. esculentum_)	31.9	35.2	33.7	37.8	31.9	39.3	25.2	37.0	31.9	38.9	38.1	36.7	31.9	42.6	31.9	38.9
common skullcap (_S. galericulata_)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	8.1	24.4
common smartweed (_P. pensylvanicum_)	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.0	0.0	0.0	0.4	0.0	4.4	7.0	14.8
Indian mustard (_B. juncea_)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	9.3	24.8
kochia (_K. scoparia_)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.7
lambsquarters (_C. album_)	0.0	0.4	0.7	2.2	0.0	0.0	0.4	0.4	0.0	0.4	0.0	0.7	0.0	9.3	14.4	30.4
velvetleaf (_A. theophrasti_)	0.0	0.7	1.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Density	305.2	338.9	353.3	344.1	305.2a	343.4ab	339.7ab	423.0b	305.2a	409.6b	387.0b	398.2b	305.2a	423.3b	404.7b	531.7c
Total Cover	36.4a	43.7ab	47.1b	44.8b	36.4a	48.1b	49.1b	61.4c	36.4a	46.7b	49.8b	53.0b	36.4a	43.0ab	50.2b	58.7c

[1]Density values that equal 0.0 contain no plants.
[2]Rates are Mg/ha.
[3]Municipal solid-waste compost with diaper residue added to 8 %.
[4]Municipal solid-waste compost with diaper residue at 2 %.
Means within the same row and organic amendment followed by the same letter are not significantly different at the 0.05 level.

Increasing the rate of organic residue application had a significant effect on plant cover. As the application rate increased from zero to 89.6 Mg ha^{-1}, there was an increase in plant cover. Untreated coarse taconite tailing had a cover value of 36.4 %, while application rates of 22.4, 44.8, and 89.6 Mg ha^{-1} significantly increased cover values to 45.4, 49.1 and 55.5 %, respectively. There is no significant difference in plant cover between the 22.4 and 44.8 Mg ha^{-1} application rates and between the 44.8 and 89.6 Mg ha^{-1} application rates. In contrast, Norland and others (1990) found no significant difference in ground cover when hemic peat was applied at rates of 4.48 and 22.4 Mg ha^{-1}.

Increasing the rate of fertilizer application also significantly increased plant cover. Unfertilized coarse taconite tailing had a cover value of 38.6 %, while applications of 224 and 448 kg ha^{-1} of 18-46-0 increased cover values to 49.7 and 58.4 %, respectively. The difference in cover between the 224 and 448 kg ha^{-1} fertilizer treatments is significant.

This is in contrast to what Norland and others (1990) found, that there was no significant difference in an initial cover crop when either 224 or 448 kg ha^{-1} of 18-46-0 were applied.

Initial results indicate that plant cover can be increased on coarse taconite tailing by applying composted yard waste, MSW composts with or without added diaper residues, or hemic peat at a rate of 89.6 Mg ha^{-1} with at least 224 kg ha^{-1} of 18-46-0 fertilizer.

Total plant density and cover by organic residue treatment and rate of application are shown in Table 7. This table shows that although increased rates of composted yard waste does increase plant density, this increase is not significantly different from untreated coarse taconite tailing. Increasing the rate of application of composted yard waste does, however, significantly increase plant cover. Municipal solid waste composts with and without added diaper residues show significant increases in total plant density and cover with increasing rates of application. Municipal solid

Table 8. Other species present on the Eveleth Mines experimental plots, but not included in the 0.1 m^2 plots.

Species	Life History[1]
Grasses	
crabgrass (Digitaria sanguinalis)	A
green foxtail (Setaria viridis)	A
yellow foxtail (Setaria lutescens)	A
quackgrass (Agropyron repens)	P
Forbs	
prostrate pigweed (Amaranthus blitoides)	A
redroot pigweed (Amaranthus retroflexus)	A
wild buckwheat (Polygonum convolvulus)	A
white campion (Lychnis alba)	B
field mint (Mentha arvensis)	P

[1]A=annual, B=biennial, P=perennial

waste compost with added diaper residues and hemic peat had the highest cover and plant density values of any of the organic amendments used. After the initial growing season, if the goal is high plant density providing a high cover value, MSW composts windrowed for 180-days or hemic peat applied at a rate of 89.6 Mg ha^{-1} with at least 224 kg ha^{-1} of 18-46-0 should be considered as soil amendments.

Table 8 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 organic residues, but this has yet to be determined and continued monitoring during the coming years will be necessary.

Conclusion

Preliminary results of this long-term study suggest that the applications of composted yard waste, MSW composts windrowed for 180-days, and hemic peat at rates up to 89.6 Mg ha^{-1} should not result in any unmanageable agronomic or environmental problems. The organic amendments used appear to be acting as a source of organic matter and slow-release source of macro- and micronutrients for plant nutrition and microbial growth (particularly as a source of nitrogen and phosphorus). Immobilization of nitrogen may be a problem at the lower application rates, but with the addition of inorganic nitrogen this does not appear to be a serious problem. Results obtained during the initial growing season indicate that plant density and cover will increase when composted yard waste, MSW composts windrowed for 180-days, and hemic peat are used as organic amendments, when these amendments are applied at a rate of 89.6 Mg ha^{-1}, and at least 224 kg ha^{-1} of 18-46-0 fertilizer is used. The use of MSW composts and hemic peat resulted in similar vegetative responses during the initial growing season.

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