STANDING CROP BIOMASS AND COVER ON AMENDED COARSE TACONITE IRON ORE TAILING[1]

by

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Abstract. The purpose for reclaiming mineral related mining waste sites is to stabilize them to prevent wastes from being moved by wind and water. Principal methods used to stabilize mining waste are physical, chemical, and vegetative. The ecological approach used to research stabilization of northern Minnesota coarse taconite tailing is a combination of physical and vegetative stabilization techniques. The Bureau of Mines has implemented a series of unbalanced factorial experiments on two sites based on amendments used, rate of application, and level of fertilization. At both Minntac and Eveleth Mines, total cover has exhibited progressive increases through three growing seasons. Total cover at Minntac has increased from none to 34% the first growing season, 41% the second growing season, and 56% the third growing season. There are four treatment combinations that are within 12 percentage points of State reclamation requirements. At Eveleth Mines, total cover has increased from none to 49% the first growing season, 55% the second growing season, and 67% the third growing season. There is one treatment combination that exceeds and eight treatment combinations that are within 10 percentage points of State requirements of 90% cover after three growing seasons.

Additional Key Words: mine waste stabilization, municipal solid waste compost, yard waste compost, peat, fertilization

Introduction

Recent shifts in national issues to greater concern for regulations and the environment has caused more emphasis to be placed on research to help solve the environmental problems associated with coal and non-coal

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mining-related activities and waste production. A major concern is the stabilization of solid wastes produced by the mineral industry, as these wastes account for 80% of the nation's non-agricultural, land-disposed solid wastes (Veith and Kaas, 1988). Johnson and Paone (1982) estimated that between 1930 and 1980 more than 2.03 million hectares of land in the United States were affected by the mining and mineral processing industries; with surface mining affecting 85% of this total, 10% from processing plants, and 5% affected by underground mining. Soni and Vasistha (1986) estimated that in 1986, 360,000 hectares of land was disturbed by mining and this was projected to increase to 924,000 hectares per year in the year 2000.

Materials discarded include overburden and waste rock from the mining and benefication of low-grade copper, lead, zinc, phosphate rock, mica, talc, iron ore; and from the chemical treatment of copper, uranium, gold, and other ores. Stabilization of these wastes through soil development and plant community development are necessary if permanent stands are to be established on these wastes for acceptable mine closure.

Stabilization or reclamation of ineral waste varies according to the specific waste type. In general, hard rock mine tailing and waste rock are nutrient poor (deficient in plant nutrients), contain excessive salts and heavy metals that are toxic to plants, lack organic matter, lack normal microbial populations, are low in plant available water, are subject to erosion resulting in air and water quality problems, and lack other physical properties (such as structure) required for sustaining a vegetative community.

The primary purpose to reclaim mineral-related mining waste sites is to stabilize them to prevent the waste from being moved by wind and water. The principal methods used to stabilize mining wastes are physical, chemical, and vegetative (Donovan et al., 1976; Hunt, 1983; Dean et al., 1986). Physical stabilization protects or isolates the waste materials from the environment by covering them with a physical barrier. Chemical stabilization involves incorporation of chemical compounds into mining-related waste to form a wind or water resistant crust that will effectively stop wind or water erosion. Vegetative stabilization is a preferred reclamation method for both active and abandoned mineral-related wastes sites; it is more permanent, has better esthetics, and allows for a wider range of end uses at closure (Dean et al., 1986).

Stabilization of mine waste through vegetation establishment should accomplish one or more of the following goals: (1) fugitive dust control, (2) erosion control to prevent dam wall rupture, (3) erosion control to prevent runoff of surface particles and subsequent sediment disposition in water courses, (4) a reduction in water percolating through mine wastes, particularly acidic wastes and wastes which release heavy metals, (5) esthetic improvement of the waste areas, and (6) acceleration of natural succession on waste areas (Watkin and Watkin, 1982).

Above- and below-ground plant organs provide effective protection from the physical effects of wind and water erosion. Vegetation grown on mineral wastes can reduce wind velocity, capture fugitive dust particles, reduce raindrop impact by intercepting the kinetic energy of rainfall, reduce water runoff by improving infiltration, reduce soil dispersal and movement through aggregation, and reduce or impede overland flow of water and sediment. As a result, a stable mineral waste may increase the amount of water available for plant growth and development.

Vegetative stabilization also improves the chemical and biological characteristics of the mine waste by increasing the organic matter content, nutrient supplying power, cation-exchange capacity, and biological activity of the waste material. These improvements can accelerate the development of a viable nutrient cycle and self-sustaining vegetative cover.

Two approaches have been used to stabilize/reclaim mine wastes and other chemically degraded soils: (1) engineering approaches and (2) ecological approaches (Logan, 1992). Engineering approaches rely on external measures for soil restoration, while ecological approaches attempt to stimulate inherent soil processes to restore the soil to some acceptable steady-state condition.

Engineering approaches to reclamation are used in cases of extreme soil degradation, where other approaches are unfeasible, unacceptably slow, or where resources for reclamation are great (for example, U.S. EPA Superfund Sites) (Logan, 1992). Removal, immobilization, or chemical transformation of chemical contaminants are examples of engineering approaches.

Ecological approaches to stabilization involve the manipulation of inherent soil processes to improve chemical, physical, and biological properties of mine wastes or immobilize, mobilize, transform, and degrade contaminants associated with mine wastes. Ecological approaches utilize one or more of the following: (1) landscape stabilization, (2) liming strongly acid soils, (3) acid neutralization of alkaline soils, (4) organic matter addition, (5) fertilization, and (6) vegetation establishment.

Historically, the approach used to stabilize mineral wastes, particularly tailing materials, has been to use inorganic fertilizers to establish vegetative cover. The ecological approach used in this research on the stabilization of northern Minnesota coarse taconite iron ore tailing is the development of a combination of physical and vegetative stabilization techniques, specifically, additions of organic residues to enhance vegetative establishment.

The purpose of this paper is to report on standing crop biomass of vegetation two years after establishment and cover three years after establishment. Biomass and cover variables were measured on coarse taconite iron ore tailing field plots treated with seven different organic residues in combination with fertilizer at two experimental sites on the Mesabi Iron Range.

Methods

Site Description

Studies were conducted at two active tailing basins in northern Minnesota; USX Corporation's, USS Steel Division, Minnesota Ore Operations (Minntac) taconite mine near Mt. Iron, Minnesota (325 km north of the Minneapolis-St. Paul metropolitan area) and Eveleth Mines Fairlane Plant 16 km south of Eveleth, Minnesota (300 km north of the Minneapolis-St. Paul metropolitan area).

Minntac uses coarse taconite tailing in the construction of dams for their 3,000 hectare tailing basin impoundment. The inner and outer dams, each about 46 m wide at the top, are constructed in a series of lifts using trucks to haul the coarse tailing from the crushing and separation plants to the dam construction site. The slope of the dam is no steeper than angle of repose. The core of the tailing dam, the area between the inner and outer dams, is filled with fine tailing and is about 30 m wide. The total top width of the tailing dam is 122 m with an average height of about 10 m. The Minntac tailing basin impoundment is bordered by upland sites consisting of quaking aspen (Populus tremuloides Michx.), bigtooth aspen (Populus grandidentata Michx.), paper birch (Betula papyrifera Marsh.), balsam fir (Abies balsamea (L.) Mill.), white spruce (Picea glauca (Moench) Voss), and mixed conifers (Pinus spp.) and low wetland areas dominated by willow (Salix spp.), speckled alder (Alnus rugosa (Du Roi) Spreng.), cattail (Typha spp.), and rattlesnake grass (Glyceria canadensis (Michx.) Trin.).

Eveleth Mines used coarse taconite tailing in the construction of a dam for their 300 hectare tailing basin impoundment. The dam was constructed in a series of lifts using trucks to haul coarse tailing from the crushing and separation plants to the construction site. The height of the Eveleth Mines tailing dam is about 36 m with a width of about 20 m at the top sloped at the angle of repose. The Eveleth Mines tailing basin impoundment is bordered by upland sites consisting of quaking aspen (Populus tremuloides Michx.), bigtooth aspen (Populus grandidentata Michx.), paper birch (Betula papyrifera Marsh.), balsam fir (Abies balsamea (L.) Mill.), white spruce (Picea glauca (Moench) Voss), and mixed conifers (Pinus spp.) and low wetland areas dominated by willow (Salix spp.), speckled alder (Alnus rugosa (Du Roi) Spreng.), black spruce (Picea mariana (Mill.) BSP), tamarack (Larix laricina (Du Roi) K. Koch.), and cattail (Typha spp.).

Mean annual precipitation for both study sites is 688 mm per year, with 66% or 454 mm occurring as rainfall between May and September. The summer period consists of about 109 frost-free days. The seasonal air temperature varies from -38 °C (-36 °F) in the winter to 33 °C (91 °F) in the summer.

Experimental Design

Unbalanced factorial experiments arranged in randomized complete block designs with three replications were initiated in May 1990 at each tailing basin site (Figures 1 and 2). Each experiment included three levels of organic residue and three levels of fertilization. Control plots are included in each experiment. Treatment combinations were assigned to 2.5 by 4 m test plots at random within each replication.

At Minntac, three potentially available municipal solid waste (MSW) composts, varying in maturity, were surface-applied to the experimental plots as soil amendments. Compost maturity is defined as the degree of compost stability in physical, chemical, and biological properties (He et al., 1992). Each of the MSW composts were supplied by RECOMP, Inc., St. Cloud, Minnesota. The three 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 MSW composts were applied at rates of 10, 20, and 40 Mg ha^{-1} on a dry weight basis.

At Eveleth Mines, four potentially available organic residues were surface applied to experimental plots as soil amendments. The organic residues used and their origin were composted yard waste (RECOMP, Inc., St. Cloud, Minnesota), two mature MSW composts that had been windrowed for 180 days (RECOMP, Inc., St. Cloud, Minnesota), and reed/sedge peat (University of Minnesota-Duluth, Natural Resources Research Institutes's Fens Research Facility located near Zim, Minnesota). The difference between the two MSW composts is that one 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 used at Eveleth Mines were applied at rates of 22.4, 44.8, and 89.6 Mg ha^{-1} on a dry weight basis.

Fertilizer applications at both experimental sites were based on the rates used for revegetation of northern Minnesota coarse taconite tailing; typically, 448 kg ha^{-1} of granular diammonium phosphate (DAP) with a grade of 18-46-0. The levels of fertilizer used in these experiments were 0, 224 (half the typical rate), and 448 kg ha^{-1} (typical rate of DAP). Zero application of fertilizer was included to test the effects of each organic amendment alone on vegetative response.

Control plots consisted of no organic amendment or fertilizer application; no organic amendment, but 224 kg ha^{-1} DAP; and no organic amendment, but 448 kg ha^{-1} DAP.

Field Application

All experimental plots were installed May 1990. Following the application of each organic amendment/rate combination, plots were hand-raked to cover the 10 m^2 area. The appropriate fertilizer treatment was then broadcast onto the plots and all plots, including the controls, were roto-tilled to a depth of 15 cm. All seeding, tailing, and analytical procedures followed in the filed experiments are discussed in Norland and others (1991a). Chemical properties of the unamended Minntac and Eveleth Mines coarse taconite iron

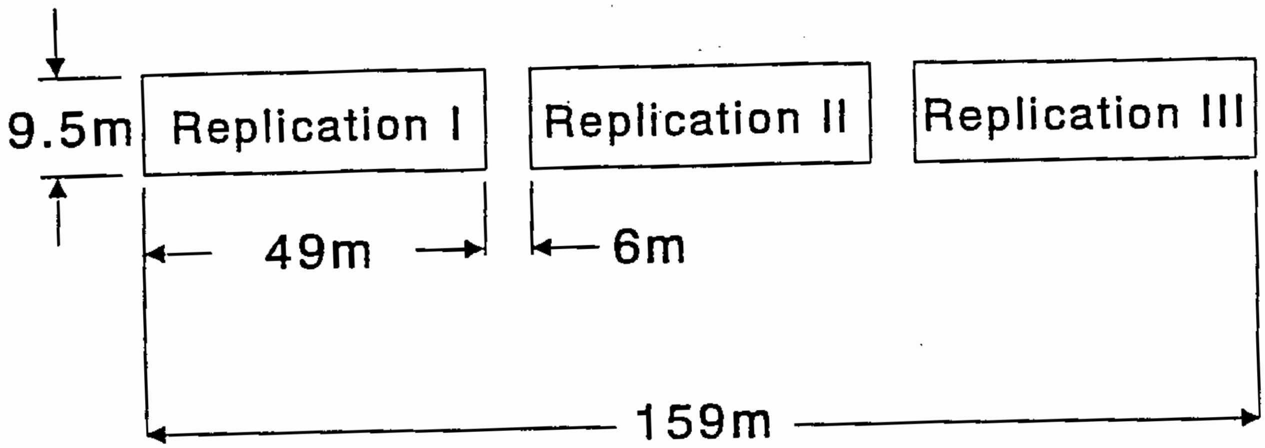

Figure 1. Minntac MSW compost experimental area.

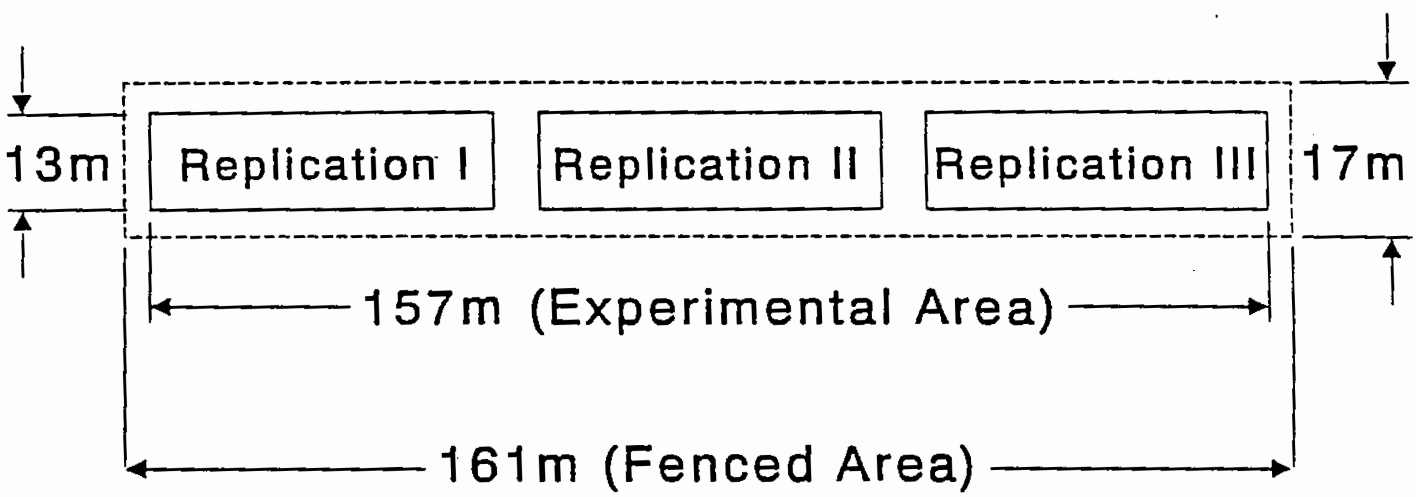

Figure 2. - Eveleth Mines organic residue experimental area.

ore tailing and of the organic amendments used have been reported by Norland and others (1991a,b).

Vegetation Sampling and Analysis

Measurements of vegetation foliar cover, litter, and bare tailing were made using a cover-point optical point projection device (Norland et al., 1992). Cover measurements were taken in June and August 1992.

In July 1991 vegetation at both Minntac and Eveleth Mines was clipped to determine standing crop biomass. Within each replicated treatment plot, three samples were taken by placing a 0.1 m^2 circular quadrat onto the tailing surface and clipping all live vegetation at the tailing surface. Plant litter, excluding decomposing hay mulch, within the quadrat was collected at the same time. All living plant material and its litter from each quadrat was placed into labeled paper bags and placed in an iced cooler for transport back to the laboratory for analyses.

After clipping, the plants were sorted to species, weighed, dried to a constant mass at 65°C in a forced air drier, and then reweighed. Standing crop biomass for Minntac and Eveleth Mines replicated treatment plots are reported as g m^{-2}.

Variations in vegetative foliar cover, litter, bare tailing, and standing crop biomass among the unamended and amended treatments were analyzed using a 3-way analysis of variance at the 5% probability level. The general linear models (GLM) 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. Contrast statements were used to determine where mean differences occurred.

Results and Discussion

Vegetative cover, litter and total cover were used to evaluate seeding success, vegetation establishment, and species composition on coarse taconite iron ore tailing after three growing seasons. Vegetative cover and litter were chosen as the variables to measure plant response to treatment since coarse taconite tailing reclamation success is determined by vegetative cover and its litter (Minnesota Department of Natural Resources, 1980).

Vegetation, Litter, and Bare Tailing

Minntac. During the third growing season (1992) there was a change in the cover variable response (total, plant, litter, and bare tailing) to the main effect treatments compared to years one and two (Norland et al., 1991b,1992). Only the rate of MSW compost application and rate of fertilizer application resulted in statistically significant responses (Table 1), compost maturity had no statistically significant effect on the cover variables. The cover variables were, however, affected by whether or not compost was applied. There were increases in cover variables when MSW composts, regardless of age, were applied to coarse taconite iron ore tailing. Foliar cover in unamended plots decreased from 23.1% during the second growing season (1991) to 21.4% during the third growing season (1992), but showed an increase when MSW compost was applied. Foliar cover increased from 21.4% in unamended tailing to 42.6% when 45-day, 41.4% when 90-day, and 45.5% when 180-day MSW composts were applied; litter cover increased from 9.0% in unamended tailing to 16.5% when 45 day, 16.1% when 90 day, and 13.8% when 180 day MSW compost were applied; while total cover significantly increased from 30.4% in unamended tailing to 59.1% when 45 day, 57.5% when 90 day, and 59.2% when 180 day MSW compost were applied. There is no significant difference in cover values between the various aged MSW composts. During the third growing season length or time of windrowing has no effect on cover, apparently the composts have stabilized or matured in the tailing to give comparable results regardless of beginning age.

Increasing the rate of MSW compost increased foliar and total cover (Table 1). Unamended coarse taconite tailing had a foliar cover value of 21.4%, while applications of MSW compost increased foliar cover to 37.6% at 10 Mg ha^{-1}, 42.8% at 20 Mg ha^{-1}, and 50.0% at 40 Mg ha^{-1} and total cover to 52.6% at 10 Mg ha^{-1}, 58.4% at 20 Mg ha^{-1}, and 65.8% at 40 Mg ha^{-1}. As the application rate of MSW compost is increased from 0 to 40 Mg ha^{-1}, there are increases in foliar and total cover. The increase in total cover is linear. The difference in foliar cover between the 10 and 20 Mg ha^{-1} application rates is not significant.

Increasing the rate of application of 18-46-0 (DAP) fertilizer from 0 to 448 kg ha^{-1} increased foliar and total cover. Unfertilized coarse taconite tailing had a foliar cover value of 27.4%, while applications of 224 kg ha^{-1} of DAP increased foliar cover to 43.3% and applications of 448 kg ha^{-1} DAP increased foliar cover to 52.2%. This fertilizer treatment effect was similar to the first and second growing season cover response. Total cover showed an increase from 37.5% in unfertilized plots to 60.2% in plots fertilized with 224 kg ha^{-1} DAP and 69.6% in plots fertilized with 448 kg ha^{-1}. Apparently, some initial fertilization at the time of compost application will be necessary for optimal plant cover development.

Mean percent litter continued to be statistically higher in plots amended with MSW compost and fertilizer than in unamended plots (Table 1). Although litter was higher in amended plots, there was no significant difference in litter between the types of MSW compost used, the rates at which MSW compost was applied, or the rate at which DAP fertilizer was applied.

Mean bare tailing continued to exhibit a significant decline during the third growing season when amendments were applied (Table 1). Bare tailing was estimated because a decrease in the amount of bare ground reflects an improvement in soil stability. Hofmann and others (1983) found that soil protection against runoff and erosion was best estimated by percentage of bare ground on reclaimed mined land. The decrease in bare tailing with the application of amendments suggests that MSW compost and fertilizer applications are not only providing the nutrients for plant establishment and

Table 1. Main effect cover (%) response on Minntac coarse taconite iron ore tailing during the third growing season.

Dependent Variable	Municipal Solid Waste Compost[1] Control	45 day	90 day	180 day
Foliar Cover	21.4a	42.6b	41.4b	45.4b
Litter	9.0a	16.5b	16.1b	13.8b
Total Cover	30.4a	59.1b	57.5b	59.2b
Bare Tailing	69.6a	40.9b	42.5b	40.8b

Table 1. (continued).

Dependent Variable	Rate[2] 0	10	20	40
Foliar Cover	21.4a	37.6b	42.8b	50.0c
Litter	9.0a	15.0b	15.6b	15.8b
Total Cover	30.4a	52.6b	58.4c	65.8d
Bare Tailing	69.6a	47.4b	41.6c	34.2c

Table 1. (continued).

Dependent Variable	Fertilizer[3] 0	224	448
Foliar Cover	27.4a	43.3b	52.2c
Litter	10.1a	16.9b	17.4b
Total Cover	37.5a	60.2b	69.6c
Bare Tailing	62.5a	39.8b	30.4c

[1]Control=no compost added, 45-day=45days in compost windrow, 90-day=90 days in compost windrow, 180-day=180 days in compost windrow.
[2]Amendment rates=0, 10, 20, and 40 Mg ha^{-1}.
[3]Fertilizer rates=0, 224, and 448 kg ha^{-1} of 18-46-0 fertilizer.
Means within the same row followed by the same letter are not significantly different at the 0.05 level.

growth, but are contributing to improved tailing stability. The results suggest that foliar, litter, and total cover increase and bare tailing decreases with the application of MSW compost. This trend has taken place over three growing seasons with continued improvement in tailing stability through vegetation establishment expected. Best results were generally achieved with higher rates of both mature MSW compost and DAP fertilizer. Mean total cover at the Minntac site across all treatments and treatment combinations was 56%, this is an overall increase of 22 percentage points from the initial growing season.

There is a significant interaction between MSW compost age and rate of fertilization (Table 2). Increasing the rate of fertilization from 0 to 448 kg ha^{-1} within each amendment type (none, 45, 90 day, and 180 day MSW compost) resulted in increased foliar and total cover; however, there are no differences in foliar and total cover between 224 and 448 kg^{-1} fertilizer treatments within the none (control), 45 day MSW compost, foliar cover within the 90 day MSW compost, and total cover within the 180 day MSW compost. There are significant differences in litter and total cover within the 90 day MSW compost treatment between the 224 and 448 kg^{-1} treatments and foliar cover within the 180 day MSW compost treatment between the 224 and 448 kg ha^{-1} treatment. In all cases, the application of MSW compost without fertilizer gave comparable results to 448 kg ha^{-1} DAP fertilizer without compost.

Increasing the application rate of fertilizer within the control, 45, 90, and 180 day MSW compost from 0 to 448 kg ha^{-1} increased foliar cover. When no fertilizer was applied the percent foliar cover was 4.0% in the control, 24.4% in the 45 day MSW compost, 29.8% in the 90 day MSW compost, and 35.9% in the 180 day MSW compost. The addition of 224 or 448 kg ha^{-1} of DAP fertilizer resulted in increases in foliar cover in each MSW compost used; however, increases in foliar cover between fertilizer rates in the control, 45 day, or 90 day MSW composts treatments were not significant. Cover was the same in each control or compost type used whether 224 or 448 kg ha^{-1} DAP was used. Only in the mature 180 day MSW compost did foliar cover increase with the application of 448 kg ha^{-1} of DAP fertilizer. In fact, there was no significant difference in foliar cover between the zero and 224 kg ha^{-1} DAP fertilizer treatment when 180 day MSW compost was used.

Litter cover values were not significantly affected by the interaction between control, 45, and 180 day MSW compost treatments and rate of fertilization (Table 2). Only the interaction between the 90 day MSW compost treatment and rate of fertilization was significant. As the rate of fertilizer application increased from 0 to 224 or from 224 to 448 kg ha^{-1}, the interaction was not significant. However, the increase from 0 to 448 kg ha^{-1} resulted in an increase in litter on plots treated with 90 day MSW compost.

Total cover reflected the foliar cover and litter responses to the interaction between MSW compost age and rate of

Table 2. Interaction effect of age of MSW compost and fertilizer rate on cover (%) response on Minntac coarse taconite iron tailing during the third growing season.[1,2]

Dependent Variable	Control 0	Control 224	Control 448	45 day 0	45 day 224	45 day 448
Foliar Cover	4.0a	33.2b	27.0b	24.4a	47.4b	55.9b
Litter	3.0	11.0	13.0	12.7	19.3	17.4
Total Cover	7.0a	44.2b	40.0b	37.1a	66.7b	73.3b
Bare Tailing	93.0a	55.8b	60.0b	62.9a	33.3b	26.7b

Table 2. (continued).

Dependent Variable	90 day 0	90 day 224	90 day 448	180 day 0	180 day 224	180 day 448
Foliar Cover	29.8a	42.6b	51.9b	35.9a	43.1b	57.1c
Litter	9.0a	16.0ab	23.4b	11.0	17.3	13.0
Total Cover	38.8a	58.6b	75.3c	46.9a	60.4b	70.1c
Bare Tailing	61.2a	41.4b	24.7c	53.1a	39.5b	29.9b

[1]Control=no compost added, 45 day=45 days in compost windrow, 90 day=90 days in compost windrow, 180 day=180 days in compost windrow.
[2]Fertilizer rates=0, 224, and 448 kg ha^{-1} of 18-46-0 fertilizer.
Means within the same row and age of MSW compost followed by the same letter are not significantly different at the 0.05 level.

fertilization (Table 2). In general, the application of fertilizer, regardless of rate, increased total cover within the control and MSW compost treatment plots. However, when the rate of fertilizer application was increased from 0 to 224 kg ha^{-1} and from 224 to 448 kg ha^{-1} within the control, 45, and 180 day MSW compost the only significant difference was due to fertilizer application. There were no differences in total cover within these treatments when either 224 or 448 kg ha^{-1} DAP fertilizer was used; however, with the exception of the control, the highest total cover was attained in compost treated plots treated with 448 kg ha^{-1} of DAP. In the 90 day MSW compost treatment, however, there is a significant increase in total cover as the rate of fertilizer application is increased from 0 to 224 to 448 kg ha^{-1}. When these composted materials are used it appears that at least 224 kg ha^{-1} of DAP fertilizer will be necessary to achieve maximum total cover during the third growing season.

As the rate of fertilizer increased from 0 to 448 kg ha^{-1} within each compost type, there were decreases in the percentage of bare tailing. There were no differences in percent bare tailing between the 224 and 448 kg ha^{-1} fertilizer application rate within the control, 45, and 180 day MSW compost; however, the percentage of bare tailing between the 224 and 448 kg ha^{-1} fertilizer treatments within the 90 day MSW compost treatment showed a significant decrease. The decrease in percentage of bare tailing in all MSW compost and fertilizer treatment combinations indicates the need of at least 224 kg ha^{-1} of DAP fertilizer in combination with any of the various aged MSW composts for tailing stabilization to occur.

There is a significant interaction between the rate at which MSW compost was applied and rate of fertilizer application (Table 3). Increasing the rate of fertilization from 0 to 448 kg ha^{-1} within the 0, 10, 20, and 40 Mg ha^{-1} application rates, resulted in increases in foliar, litter, and total cover and decreases in the percentage of bare tailing depending on the rate of fertilization used. There were increases in foliar cover when the rate of fertilization was increased from 0 to 224 kg ha^{-1} DAP in the 0, 10, and 20 Mg ha^{-1} rate; however, within each of these application rates there was no difference in foliar cover when the rate of fertilization was increased from 224 to 448 kg ha^{-1} DAP. Within the 40 Mg ha^{-1} organic amendment application rate, 448 kg ha^{-1} of DAP was necessary to cause an increase in foliar cover. There was no difference in foliar cover between the 0 and 224 kg ha^{-1} DAP fertilizer rates when 40 Mg ha^{-1} of MSW compost was applied.

Except for the 10 Mg ha^{-1} MSW compost application rate, litter cover values were not significantly affected by the interaction between rates of organic amendment and fertilizer application (Table 3). Only when 448 kg ha^{-1} of DAP was applied within the 10 Mg ha^{-1} compost application rate did litter increase when compared to the 0 and 224 kg ha^{-1} fertilizer application rates.

The 0 and 40 Mg ha^{-1} MSW compost application rates responded similarly to fertilizer treatments. In both cases, there was an increase in total cover as the rate of fertilization increased from 0 to 448 kg ha^{-1}; however, there was no difference in total cover within in compost rate between the 224 and 448 kg ha^{-1} fertilization rates. The 10 and 20 Mg ha^{-1} compost treatments responded in similar fashion to fertilization with DAP. In both cases there were significant increases in total cover as the amount of fertilizer applied increased from 0 to 224 kg ha^{-1} and from 224 to 448 kg ha^{-1}. Apparently, the lower compost application rates have a higher fertilizer requirement for the same type of plant response that could be expected with higher application rates of compost and lower rates of fertilizer. For example, the total cover of the 40 Mg ha^{-1} compost application treatment with 0 kg ha^{-1} DAP has a mean cover of 53%. This value is higher than that achieved with either 224 or 448 kg ha^{-1} DAP without compost. It appears that the best

Table 3. Interaction effect of rate of MSW compost application and fertilizer rate on cover (%) response on Minntac coarse taconite tailing during the third growing season.[1,2]

Dependent Variable	0	0 224	448	0	10 224	448
Foliar Cover	4.0a	33.2b	27.0b	22.4a	41.0b	49.4b
Litter	3.0	11.0	13.0	9.7a	15.0ab	20.4b
Total Cover	7.0a	44.2b	40.0b	32.1a	56.0b	69.8c
Bare Tailing	93.0a	55.8b	60.0b	67.9a	44.0b	30.2c

Table 3. (continued).

Dependent Variable	0	20 224	448	0	40 224	448
Foliar Cover	27.4a	45.0b	56.0b	40.3a	47.1a	59.4b
Litter	10.3	17.7	18.7	12.7	20.0	14.7
Total Cover	37.7a	62.7b	74.7c	53.0a	67.1b	74.1b
Bare Tailing	62.3a	37.3b	25.3c	47.0a	32.9b	25.9c

[1]Amendment rates=0, 10, 20, and 40 Mg ha^{-1}.
[2]Fertilizer rates=0, 224, and 448 kg ha^{-1} of 18-46-0 fertilizer.
Means within the same row and age of MSW compost followed by the same letter are not significantly different at the 0.05 level.

combination of amendments for cover at the Minntac site for coarse taconite iron ore tailing stabilization would be, any of the various aged MSW composts applied at 40 Mg ha^{-1}, with at least 224 kg ha^{-1} of DAP.

The percentage of bare tailings supports this premise, as the rate of fertilizer application was increased from 0 to 224 or 448 kg ha^{-1} within each compost application rate, there were decreases in the percentage of bare tailing. As stated earlier, this provides an indication of stabilization on mined lands.

Those treatment combinations giving the highest total cover values are: 180 day MSW compost, 20 Mg ha^{-1}, 448 kg ha^{-1} DAP (69.9%); 180 day MSW compost, 40 Mg ha^{-1}, 224 kg ha^{-1} DAP (70.0%); 180 day MSW compost, 10 Mg ha^{-1}, 448 kg ha^{-1} DAP (73.0%); 90 day MSW compost, 10 Mg ha^{-1}, 448 kg ha^{-1} DAP (73.0%); 45 day MSW compost, 40 Mg ha^{-1}, 224 kg ha^{-1} DAP (73.0%); 90 day MSW compost, 40 Mg ha^{-1}, 448 kg ha^{-1} DAP (77.0%); 90 day MSW compost, 20 Mg ha^{-1}, 448 kg ha^{-1} DAP (77.0%); 45 day MSW compost, 20 Mg ha^{-1}, 448 kg ha^{-1} DAP (77.9%); and 45 day MSW compost, 40 Mg ha^{-1}, 448 kg ha^{-1} DAP (79.0%). With the best combination(s) of organic and inorganic amendments, coverage requirements are 11 percentage points less than required by Minnesota law after three years; however, the values using compost as a soil amendment and soil conditioner are closer to the requirements established by the State of Minnesota than are values obtained using inorganic fertilizer alone.

Eveleth Mines. Cover variables were significantly affected by the type of organic amendment used, rate of application, and fertilizer rate at the Eveleth Mines experimental site. This in contrast to what Borovsky and others (1983) found for northern Minnesota copper-nickel tailing; in their study, the incorporation of peat or topsoil had no effect on plant cover.

Cover variables responded to the type of organic residue, rate of application and rate of fertilizer application (Table 4). There were significant increases in litter and total cover variables when organic residues were applied to coarse taconite tailing; however, foliar cover was slightly lower during the third growing season, June data, than the second. There was a period in late through the middle of June where rainfall or water was limiting; however, later in the growing season rainfall returned to normal, even excessive, and preliminary data (not analyzed) suggest that foliar cover does in fact increase. Even though lower than the second growing season, foliar cover increased from 17.0% in untreated tailing to 42.8% when MSW compost without added diaper residue was applied, 43.6% when MSW compost with added diaper residue was applied, 47.1% when reed/sedge peat was applied, and 50.4% when composted yard waste compost was applied.

Total cover, however, increased from 31.7% in unamended tailing to 67.1% when MSW compost with added diaper residue was applied, 67.5% when MSW compost without added diaper residue was applied, 71.4% when reed/sedge peat was added, and 72.7% when composted yard waste was added. In all cases, third year total cover values are higher than those achieved during the first and second growing seasons. All of the organic residue types used had significantly higher foliar and total cover values than did the control. There were also differences between the organic residue types used with composted yard waste having significantly higher total and foliar cover percentage than did MSW composts with and without added diaper residue. There were no differences in foliar and total cover percentages between the MSW composts with and without added diaper residues and the reed/sedge peat. Additionally, there were no differences in foliar and total cover percentages between composted yard waste and reed/sedge peat applications.

During the third growing season there was a difference in mean percent litter between the control plots and plots amendment with organic residues (Table 4). In all cases, plots amended with organic residues had significantly higher mean litter cover values than did the control plots; however there was no difference in percent litter between the organically amended plots.

Table 4. Main effect cover (%) response on Eveleth Mines coarse taconite iron ore tailing during the third growing season.

Dependent Variable	Control	Organic Amendment[1] YW	MSW-W	MSW-O	Peat
Foliar Cover	17.0a	50.4b	43.6c	42.8c	47.1bc
Litter	14.7a	22.3b	23.5b	24.7b	24.3b
Total Cover	31.7a	72.7b	67.1c	67.5c	71.4bc
Bare Tailing	68.3a	27.3b	32.9c	32.5c	29.6bc

Table 4. (continued).

Dependent Variable	0	Rate of Application[2] 22.4	44.8	89.6
Foliar Cover	17.0a	39.4b	47.4c	51.0c
Litter	14.7a	20.8b	21.4	28.8
Total Cover	31.7a	60.2b	68.8c	79.8d
Bare Tailing	68.3a	39.8b	31.2c	20.2d

Table 4. (continued).

Dependent Variable	0	Rate of Fertilization[3] 224	448
Foliar Cover	36.9a	45.6b	48.8b
Litter	18.6a	24.9b	25.4b
Total Cover	55.5a	70.5b	74.2b
Bare Tailing	44.4a	29.5b	25.8b

[1]Control=no compost added, YW=composted yard waste, MSW-W=municipal solid waste compost with diaper residue added to 8 %, MSW-O=municipal solid waste compost with diaper residue added to 2 %, P=reed/sedge peat.
[2]Rate of Application= 0, 22.4, 44.8, and 89.6 Mg ha^{-1}.
[3]Rate of fertilization= 0, 224, and 448 kg ha^{-1} of 18-46-0 fertilizer.
Means within the same row and main effect followed by the same letter are not significantly different at the 0.05 level.

Each organic residue type showed an increase in percent total cover from the first to second to third growing season, while the control decreased from the first to second growing season, but increased again in the third. Total cover in control plots decreased from 36.4% in the first growing season to 24.8% in the second, but increased to 31.7% during the third growing season. Municipal solid waste compost with added diaper residue had nonsignificant increases in total cover from 52.9 to 54.7% from the first to second growing season, but showed a significant increase to 67.1% during the third growing season. Municipal solid waste compost without added diaper residue, reed/sedge peat, and compost yard waste continue to exhibit significant increases in total cover from 67.5%, 71.4%, and 72.7%, respectively.

Increasing the rate of organic residue significantly increased foliar and total cover (Table 4). Unamended coarse taconite tailing had a foliar cover value of 17.0%, while applications of organic residues compost significantly increased foliar cover to 39.4% at 22.4 Mg ha^{-1}, 47.4% at 44.8 Mg ha^{-1}, and 51.0% at 89.6 Mg ha^{-1}. There were no differences in foliar cover between the 44.8 Mg ha^{-1} and 89.6 Mg ha^{-1} application rates. Total cover increased from 31.7% in unamended tailing to 60.2% at 22.4 Mg ha^{-1}, 68.8% at 44.8 Mg ha^{-1}, and 79.8% at 89.6 Mg ha^{-1}. As the rate of application was increased from 0 to 89.6 Mg ha^{-1}, both foliar and total increased.

At each rate of application, percent total cover increased from the first to second growing season, while the control had a decrease from the first to second growing season, but increased again during the third growing season. Total cover in control plots decreased from 36.4% in the first growing season to 24.8% in the second and increased again to 31.7% during the third growing season. At 22.4 Mg ha^{-1} there was no effect on total cover from 45.5 to 49.4% between the first and second growing seasons; however at 22.4 Mg ha^{-1} there was an increase in total cover to 60.2 percent during the third growing season. At application rates of 44.8 and 89.6 Mg ha^{-1} there were significant increases in total cover from 49.1 to 56.2% at 44.8 Mg ha^{-1} and from 55.5 to 65.9% at 89.6 Mg ha^{-1} from the first to second growing season. This increase continued into the third growing season with 68.8% at 44.8 Mg ha^{-1} and 79.8% at 89.6 Mg ha^{-1}.

Increasing the rate of application of 18-46-0 (DAP) fertilizer from 0 to 448 kg ha^{-1} affected foliar and total cover three years after application. Unfertilized coarse taconite tailing had a foliar cover value of 36.9%, while applications of 224 kg ha^{-1} DAP significantly increased foliar cover to 45.6% and applications 448 kg ha^{-1} DAP increased foliar cover to 48.8%. There was no difference in cover between the 224 and 448 kg ha^{-1} fertilizer treatments. This fertilizer effect is different than the first year fertilizer, where increasing DAP applications from 224 kg ha^{-1} to 448 kg ha^{-1} increased cover, but not the second year. Total cover increased from 55.5% in unfertilized plots to 70.5% in plots fertilized with 224 kg ha^{-1} DAP and 74.2% in plots fertilized with

448 kg ha^{-1} DAP. Total cover between 224 and 448 kg ha^{-1} fertilizer treatments was not different.

Mean percent litter was statistically higher in plots amended with organic residues and fertilizer than in unamended plots (Table 4). Additionally, percent litter cover increased as the rate of organic residue application increased. Although litter was significantly higher in amended plots when compared to the controls, there were no differences in litter between the types of organic residues used or rates of DAP fertilizer used. There were, however, significant differences in percent litter as the rate of organic residue application increased. Mean percent litter exhibited a significant increase from 14.7% at 0 Mg ha^{-1} to 20.8% at 22.4 Mg ha^{-1}, 21.4% at 44.8 Mg ha^{-1}, and 28.8% at 89.6 Mg ha^{-1}. The difference in litter cover between the 22.4 and 44.8 Mg ha^{-1} rates were not significant, but they are significantly different from the percent litter cover at 89.6 Mg ha^{-1}.

Mean bare tailing decreased when amendments were used (Table 4). The decrease in bare tailing with the application of amendments continues to suggest that organic residues and fertilizer applications are needed to provide nutrients and retain moisture for plant establishment and growth. The results suggest that foliar, litter, and total cover can be increased and bare tailing decreased with the applications of mature MSW compost, reed/sedge peat, or composted yard waste, at a rate of 89.6 Mg ha^{-1}, with 224 kg ha^{-1} of DAP fertilizer. Mean total cover at the Eveleth Mines site across all treatments was 67% during the third growing season, this is an overall increase of 18 percentage points from the initial growing season and 12 percentage points from the second growing season.

There was no interaction between the type of organic residue used and the rate of application during the third growing season. There was, however, a significant interaction between organic residue type and rate of fertilizer application during the third growing season (Table 5). Increasing the rate of fertilization from 0 to 448 kg ha^{-1} within the plots without organic residue, MSW compost with and without added diaper residue, and reed/sedge peat treatments all resulted in a significant increase in total cover; however, there were no significant differences in foliar cover between the 224 and 448 kg ha^{-1} fertilizer treatments within each amendment type. There was no difference in foliar cover when 224 kg ha^{-1} of DAP fertilizer was added to MSW compost with and without added diaper residue when compared to MSW applications with 0 kg ha^{-1} DAP fertilizer. Additionally, there were no differences in foliar and total cover when fertilizer was added to composted yard waste treatments. It appears that 224 kg ha^{-1} of DAP fertilizer with the addition of MSW composts and reed/sedge peat was enough to increase total cover significantly over the other treatments except when MSW composts are applied. When this is done it appears to be necessary to add 448 kg ha^{-1} of DAP fertilizer. Foliar and total cover was not affected by the addition of fertilizer when composted yard waste was used as the organic amendment. Litter cover values were not affected by the interaction between

Table 5. Interaction effect of the type of organic amendment and fertilizer rate on cover (%) response on Eveleth Mines coarse taconite iron ore tailing during the third growing season.[1,2]

Dependent Variable	Control		
	0	224	448
Foliar Cover	1.0a	29.0b	21.0b
Litter	6.0	17.0	21.1
Total Cover	7.0a	46.0b	44.1b
Bare Tailing	93.0a	54.0b	55.9b

Table 5. (continued).

Dependent Variable	Composted Yard Waste		
	0	224	448
Foliar Cover	51.0	49.3	50.9
Litter	21.0	21.7	24.1
Total Cover	72.0	71.0	75.0
Bare Tailing	28.0	29.0	25.0

Table 5. (continued).

Dependent Variable	MSW-W		
	0	224	448
Foliar Cover	36.2a	44.4ab	50.3b
Litter	17.3	28.8	24.4
Total Cover	53.5a	73.2b	74.7b
Bare Tailing	46.5a	26.8b	25.3b

Table 5. (continued).

Dependent Variable	MSW-O 0	224	448
Foliar Cover	35.9a	45.3ab	47.2b
Litter	20.3	24.7	29.0
Total Cover	56.2a	70.0b	76.2b
Bare Tailing	43.8a	30.0b	23.8b

Table 5. (continued).

Dependent Variable	Reed/Sedge Peat 0	224	448
Foliar Cover	35.8a	49.1b	56.3b
Litter	20.1	27.0	25.7
Total Cover	55.9a	76.1b	82.0b
Bare Tailing	44.1a	23.9b	18.0b

[1]Control = no organic amendment applied, MSW-W=municipal solid waste compost with diaper residue added to 8%, MSW-O = municipal solid waste compost with diaper residue added to 2%.
[2]Rate of fertilization= 0, 224, and 448 kg ha^{-1} of 18-46-0 fertilizer.
Means within the same row and main effect followed by the same letter are not significantly different at the 0.05 level.

organic residue type and rate of fertilizer application (Table 5).

As the rate of fertilizer application increased from 0 to 224 or 448 kg ha^{-1}, there were decreases in the percentage of bare tailing. There were no differences in percent bare tailing between the rates of fertilizer application within each type of organic residue.

There is a significant interaction between the rate of organic residue application and rate of fertilizer application (Table 6). Increasing the rate of fertilization from 0 to 448 kg ha^{-1} within the 0, 22.4, 44.8, and 89.6 Mg ha^{-1} application rates resulted in an increase in foliar and total cover; however, there were no differences in foliar or total cover between the 224 and 448 kg ha^{-1} fertilizer treatments within each rate of organic residue application. It appears that 224 kg ha^{-1} of DAP fertilizer within each rate of organic residue application was enough to increase foliar and total cover over cover with no fertilizer addition. Litter cover values were not significantly affected by the interaction between the rate of organic residue applications and rate of fertilization application (Table 6).

As the rate of fertilizer application increased from 0 to 224 or 448 kg ha^{-1}, there were decreases in the percentage of bare tailing. There were no significant differences in percent bare tailing between the rates of fertilizer application within each rate of organic residue application.

At Eveleth Mines, total cover across all treatments and treatment combinations has increased from none to 49% the first growing season, to 55% the second growing season, and 67% the third growing season. There was one treatment combination of organic residue, rate, and fertilizer at Eveleth Mines that exceeds and eight treatment combinations that were within 10 percentage points of State requirements the third growing season.

The treatment combination that exceeds State requirements of 90% cover of vegetation and its litter after three growing seasons was reed/sedge peat applied at 89 Mg ha^{-1} with 448 kg ha^{-1} of DAP fertilizer. This treatment combination has a mean total cover value of 91%. The other treatment combinations that are within 10 percentage points of State requirements include: (1) reed/sedge peat applied at 44.8 Mg ha^{-1} with 224 kg ha^{-1} DAP (87%); (2) MSW compost with added diaper residue at 89.6 Mg ha^{-1} with 448 kg ha^{-1} DAP (84%); (3) MSW compost without added diaper residue at 89.6 Mg ha^{-1} with 224 kg ha^{-1} DAP (83%); (4) reed/sedge peat at 89.6 Mg ha^{-1} with 224 kg ha^{-1} DAP (82%); (5) composted yard waste at 89.6 Mg ha^{-1} with no fertilizer and 448 kg ha^{-1} DAP (both with 82% total cover); (6) MSW compost with added diaper residue at 89.6 Mg ha^{-1} with 224 kg ha^{-1} DAP (81%); and (7) composted yard waste at 89.6 Mg ha^{-1} 224 kg ha^{-1} DAP (80%).

Standing Crop Biomass

Minntac. The results of the factorial analyses of variance for assessing the effect of compost age, rate of compost application, and rate of fertilizer application on live aboveground biomass, litter, and total biomass (live aboveground biomass + litter) are listed in Table 7. The main effects of rate of compost application and rate of fertilizer application were significant for all characteristics.

Aboveground live biomass increased when MSW compost was applied, but there were no differences between the various aged composts (Table 8). Aboveground live biomass increased significantly as the rate of MSW compost, regardless of type, and DAP fertilization increased (Table 8). Unamended coarse taconite iron ore tailing had an average aboveground biomass value of 44.33 g m^{-2}, aboveground live biomass increased to 81.97 g m^{-2} at 10 Mg ha^{-1}, 87.62 g m^{-2} at 20 Mg ha^{-1}, and 103 g m^{-2} at 40 Mg ha^{-1}. Although there is a progressive increase in aboveground biomass from 0 to 40 Mg ha^{-1}, there was no difference in aboveground biomass between the 10 and 20 Mg ha^{-1} application rates.

Table 6. Interaction effect of rate of organic amendment application and fertilizer rate on cover (%) response on Eveleth Mines coarse taconite iron ore tailing during the third growing season.[1,2]

Dependent Variable	0	0 224	448
Foliar Cover	1.0a	29.0b	21.0b
Litter	6.0	17.0	21.1
Total Cover	7.0a	46.0b	42.1b
Bare Tailing	93.0a	54.0b	57.9b

Table 6. (continued).

Dependent Variable	0	22.4 224	448
Foliar Cover	29.8	42.1	46.4
Litter	17.3	23.0	22.0
Total Cover	47.1a	65.1b	68.4b
Bare Tailing	63.9a	44.5b	43.3b

Table 6. (continued).

Dependent Variable	0	44.8 224	448
Foliar Cover	41.0	47.7	53.6
Litter	15.3	24.0	25.0
Total Cover	56.3a	71.7b	78.6b
Bare Tailing	43.7a	28.3b	21.4b

Table 6. (continued).

Dependent Variable	0	89.6 224	448
Foliar Cover	48.4	51.4	53.3
Litter	26.6	29.6	30.3
Total Cover	75.0a	81.0ab	83.6b
Bare Tailing	25.0a	19.0ab	16.4b

[1]Amendment rate=0, 22.4, 44.8, and 89.6 Mg ha^{-1}.
[2]Rate of fertilization= 0, 224, and 448 kg ha^{-1} of 18-46-0 fertilizer.
Means within the same row and main effect followed by the same letter are not significantly different at the 0.05 level.

Table 7. Factorial analysis of variance (F value) of the effect of compost age, rate of compost application, and rate of fertilizer application on various biomass parameters of species sampled on amended Minntac coarse taconite iron ore tailing.

Dependent Variable	Effect[1] A	R	F	A*R	A*F	R*F	A*R*F
Live aboveground biomass	1.49	7.41***	105.36***	1.97	0.79	1.21	1.13
Litter	1.44	3.69	50.78***	2.07	1.15	1.76	1.52
Total biomass	1.68	8.12***	127.66***	0.55	1.37	1.01	1.75

[1]A=age of compost (df=2), R=rate of compost application (df=3), F=rate of fertilizer application (df=2), A*R=age of compost-rate of compost application interaction (df=6), A*F=age of compost-rate of fertilizer application interaction (df=4), R*F= rate of compost application-rate of fertilizer application interaction (df=6), A*R*F= age of compost-rate of compost application-rate of fertilizer application interaction (df=12).
*P<0.05, **P<0.01, ***p<0.001.

Table 8. Main effect biomass (g m^{-2}) response on Minntac coarse taconite iron ore tailing during the second growing season.

Dependent Variable	Municipal Solid Waste Compost[1] Control	45 day	90 day	180 day
Live Aboveground Biomass	44.33a	96.57b	90.10b	86.61b
Litter	34.20	34.85	37.32	31.32
Total Biomass	78.53a	131.42b	127.42b	117.93b

Table 8. (continued).

Dependent Variable	Rate[2] 0	10	20	40
Live Aboveground Biomass	44.33a	81.97b	87.62b	103.69c
Litter	34.20	28.96	36.64	37.89
Total Biomass	78.53a	110.93b	124.26bc	141.58c

Table 8. (continued).

Dependent Variable	Fertilizer[3] 0	224	448
Live Aboveground Biomass	39.88a	91.94b	127.43c
Litter	16.91a	35.61b	50.88c
Total Biomass	56.79a	127.55b	178.31c

[1]Control=no compost added, 45-day=45days in compost windrow, 90-day=90 days in compost windrow, 180-day=180 days in compost windrow.
[2]Amendment rates=0, 10, 20, and 40 Mg ha^{-1}.
[3]Fertilizer rates=0, 224, and 448 kg ha^{-1} of 18-46-0 fertilizer.
Means within the same row followed by the same letter are not significantly different at the 0.05 level.

Increasing the rate of application of DAP fertilizer from 0 to 448 kg ha^{-1} increased live aboveground biomass. Aboveground biomass of unfertilized coarse taconite iron ore tailing was 39.88 g m^{-2}, while applications of 224 kg ha^{-1} DAP increased aboveground biomass to 91.94 kg ha^{-1} and applications of 448 kg ha^{-1} DAP increased aboveground biomass to 127.43 kg ha^{-1}.

Litter mass was not affected by either the addition of MSW compost or the rates at which they were applied (Table 8). There are no differences between the various aged MSW compost (including the control) or the rates (including the control) and the amount of litter mass. However, fertilization with DAP did have a highly significant effect on litter mass. Unfertilized plots had a litter mass of 16.91 g m^{-2}, while applications of 224 kg ha^{-1} DAP increased litter mass to 35.61 g m^{-2} and applications of 448 kg ha^{-1} DAP increased litter mass to 50.88 g m^{-1}. This is similar to what Wilson and Tilman (1991) found for an old-field plant community.

The total amount of biomass (live aboveground biomass + litter) increased when MSW compost was applied, but there were no differences between the various aged composts (Table 8). Total biomass increased significantly as the rate of MSW compost, regardless of type, and DAP fertilization increased (Table 8). Unamended coarse taconite iron ore tailing had an mean total biomass value of 78.53 g m^{-2}, biomass significantly increased to 110.93 g m^{-2} at 10 Mg ha^{-1}, 124.26 g m^{-2} at 20 Mg ha^{-1}, and 141.58 g m^{-2} at 40 Mg ha^{-1}. Although there is a progressive increase in total biomass from 0 to 40 Mg ha^{-1}, the difference in total biomass between the 10 and 20 Mg ha^{-1} and 20 and 40 Mg ha^{-1} application rates is not significant. However, the difference in total biomass between the 10 and 40 Mg ha^{-1} application rates is significant.

Increasing the rate of application of DAP fertilizer from 0 to 448 kg ha^{-1} increased total biomass. The total biomass of unfertilized coarse taconite iron ore tailing was 56.79 g m^{-2}, while applications of 224 kg ha^{-1} DAP increased total biomass to 127.55 kg ha^{-1} and applications of 448 kg ha^{-1} DAP increased total biomass to 178.31 kg ha^{-1}. The difference in total biomass between the 224 and 448 kg ha^{-1} fertilizer treatments is significant.

Eveleth Mines. Results of the factorial analyses of variance for assessing the effect of organic residue type, rate of application, and rate of fertilizer application on live above-ground biomass, litter, and total biomass (live aboveground biomass + litter) are listed in Table 9. The main effects of organic residue type, rate of application, and rate of fertilizer application were significant for all characteristics.

Aboveground live biomass varied with the type of organic residue used, and increased as rate of organic residue application increased and rate of DAP fertilization increased (Table 10). Unamended coarse taconite iron ore tailing at Eveleth Mines had an average aboveground live biomass value of 40.62 g m^{-2} which is similar to unamended coarse tailing aboveground live biomass value at Minntac of 44.33 g m^{-2}. Aboveground live biomass significantly increased with the application of organic residues and as the type of organic residue applied changed. The application of MSW compost with and without added diaper residues increased aboveground live biomass to 119.07 and 109.81 g m^{-2}, respectively. There was no difference in biomass between the MSW compost

Table 9. Factorial analysis of variance (F value) of the effect of organic residue type, rate of application, and rate of fertilizer application on various biomass parameters of species sampled on amended Eveleth Mines coarse taconite iron ore tailing.

Dependent Variable	Effect[1] T	R	F	T*R	T*F	R*F	T*R*F
Live aboveground biomass	49.44*	186.68*	59.61*	2.77	1.34	1.61	1.54
Litter	28.09*	12.44*	127.87*	1.92	1.25	1.49	1.71
Total biomass	54.85*	125.39*	107.38*	0.97	1.48	1.27	1.66

[1]T=type of organic residue (df=3), R=rate of compost application (df=3), F=rate of fertilizer application (df=2), T*R=type of organic residue-rate of compost application interaction (df=9), T*F=type of organic residue-rate of fertilizer application interaction (df=6), R*F= rate of compost application-rate of fertilizer application interaction (df=6), T*R*F=type of organic residue-rate of compost application-rate of fertilizer application interaction (df=18).*P<0.05.

types used. The application of reed/sedge peat and composted yard waste resulted in an increase in aboveground live biomass to 145.43 and 153.30 g m^{-2}, respectively. There was no difference in biomass between applications of reed/sedge peat and composted yard waste, but applications of both resulted in higher aboveground live biomass than applications of MSW compost.

Aboveground live biomass significantly increased from 40.62 g m^{-2} in unamended plots as the rate of organic residue application increased. Aboveground live biomass increased to 108.17 g m^{-2} at 22.4 Mg ha^{-1}, 115.50 g m^{-2} at 44.8 Mg ha^{-1}, and 172.04 g m^{-2} at 89.6 Mg ha^{-1}. Although there is a progressive increase in aboveground biomass from 0 to 89.6 Mg ha^{-1}, there is no difference in aboveground biomass between the 22.4 and 44.8 Mg ha^{-1} application rates. The difference in aboveground live biomass between the 22.4 and 44.8 Mg ha^{-1} rates of application and the 89.6 Mg ha^{-1} rate of organic residue application is significant.

Increasing the rate of application of DAP fertilizer from 0 to 448 kg ha^{-1} significantly increased live aboveground biomass. The aboveground biomass of unfertilized coarse taconite iron ore tailing was 101.59 g m^{-2}, while applications of 224 kg ha^{-1} DAP increased aboveground biomass to 135.59 g m^{-2} and applications of 448 kg ha^{-1} DAP significantly increased aboveground biomass to 137.47 g m^{-2}. The difference in biomass between 0 and the 224 and 448 kg ha^{-1} fertilizer treatments is significant.

Litter mass was affected by the addition of organic residues and the rates at which they were applied (Table 10). This was in contrast to Minntac

Table 10. Main effect biomass (g m^{-2}) response on Eveleth Mines coarse taconite iron ore tailing during the second growing season.

Dependent Variable	Control	Organic Residue Type[1] YW	MSW-W	MSW-O	R/S Peat
Live Aboveground Biomass	40.62a	153.30b	119.07c	109.81c	145.43b
Litter	41.97a	48.50b	45.18ab	33.42c	46.66b
Total Biomass	82.59a	201.80b	164.25c	143.23d	192.09b

Table 10. (continued).

Dependent Variable	Rate[2] 0	22.4	44.8	89.6
Live Aboveground Biomass	40.62a	108.17b	115.50b	172.04c
Litter	41.97a	39.92a	47.68b	42.72a
Total Biomass	82.59a	148.09b	163.18c	214.76d

Table 10. (continued).

Dependent Variable	Fertilizer[3] 0	224	448
Live Aboveground Biomass	101.59a	135.59b	137.47b
Litter	29.98a	47.70b	52.38c
Total Biomass	131.57a	183.29b	189.25b

[1]Control=no compost added, YW=composted yard waste, MSW-W=municipal solid waste with added diaper residue, MSW-O=municipal solid waste without added diaper residue, R/S Peat=reed/sedge peat.
[2]Amendment rates=0, 22.4, 44.8, and 89.6 Mg ha^{-1}.
[3]Fertilizer rates=0, 224, and 448 kg ha^{-1} of 18-46-0 fertilizer.
Means within the same row followed by the same letter are not significantly different at the 0.05 level.

where there were no differences in litter mass due to either MSW compost age or rate of application. Litter mass was highest in plots amended with composted yard waste, reed/sedge peat, and MSW compost with added diaper residue. There were no differences in litter mass between these amended plots. Litter mass was lowest in plots treated with MSW compost without added diaper residue. The litter mass of control plots, 41.97 g m^{-2}, was higher than plots treated with MSW compost without added diaper residue, but this value is lower than litter mass found in plots treated with composted yard waste or reed/sedge peat. There was no difference in litter mass between the control plots and plots treated with MSW compost with added diaper residue.

There were also significant differences in litter mass between the various rates of organic residue application. The highest litter mass, 47.68 g m^{-2}, was found in plots amended at a rate of 44.8 Mg ha^{-1}. There were no significant differences in litter mass between the 0, 22.4, and 89.6 Mg ha^{-1} application rates; however, each had lower litter masses than did the 44.8 Mg ha^{-1} application rate.

Fertilization with DAP also had a highly significant effect on litter mass. As the amount of fertilizer applied is increased from 0 to 448 kg ha^{-1} there is an increase in litter mass. Unfertilized plots had a litter mass of 29.98 g m^{-2}, while applications of 224 kg ha^{-1} DAP significantly increase litter mass to 47.70 g m^{-2} and applications of 448 kg ha^{-1} DAP significantly increased litter mass to 52.30 g m^{-1}. The difference in litter mass between the 224 and 448 kg ha^{-1} fertilizer treatments is significant. This similar to what Wilson and Tilman (1991) found for an old-field plant community, litter mass was greater in fertilized than unfertilized plots and to what was found at Minntac.

The total amount of biomass (live aboveground biomass + litter) increased when organic residues were applied and varied when different organic residues were used (Table 10). Total biomass increased from 82.59 g m^{-2} in unamended plots to 143.23 g m^{-2} in plots amended with MSW compost without added diaper residue, 164. 25 g m^{-2} in plots amended with MSW compost with added diaper residue, 192.09 g m^{-2} in plots amended with reed/sedge peat, and 201.80 g m^{-2} in plots amended with composted yard waste. There were differences in total biomass between each organic amendment type except between composted yard waste and reed/sedge peat where there is no difference in total biomass. Total biomass increased as the rate of organic residue, regardless of type, and DAP fertilization increased (Table 10). Unamended coarse taconite iron ore tailing had an mean total biomass value of 82.59 g m^{-2} which is similar to Minntac), biomass significantly increased to 148.09 g m^{-2} at 22.4 Mg ha^{-1}, 163.18 g m^{-2} at 44.8 Mg ha^{-1}, and 214.76 g m^{-2} at 89.6 Mg ha^{-1}. There was a progressive increase in total biomass from 0 to 89.6 Mg ha^{-1}, with each rate being significantly different from the other. The increase in total plant biomass is due to increased tailing fertility, particularly nitrogen and phosphorus.

This agrees with what Tilman and Wedin (1991) found along an experimental nitrogen gradient using infertile glacial outwash sands in east central Minnesota, total biomass was increasingly greater on more nitrogen rich soil mixtures. However, unlike Tilman and Wedins's experiment (1991) plant traits, total plant biomass, and soil nutrient levels have not stabilized after the third year of growth. Each rate of organic residue application used at Eveleth, except the 0 Mg ha^{-1} rate, was significantly higher in total biomass than the rates used at Minntac. The highest total biomass at Minntac was 141.58 g m^{-2} at 40 Mg ha^{-1}.

It is apparent that in these infertile habitats, the amount and availability of tailing resources were limiting plant biomass. This agrees with Tilman's (1987,1988) theory that plant mainly compete for soil resources in unproductive habitats since little or no plant growth occurred when organic residues or fertilizer were not applied.

Increasing the rate of application of DAP fertilizer from 0 to 448 kg ha^{-1} increased total biomass. The total biomass of unfertilized coarse taconite iron ore tailing was 131.57 g m^{-2}, while applications of 224 kg ha^{-1} DAP increased total biomass to 183.29 kg ha^{-1} and applications of 448 kg ha^{-1} DAP increased total biomass to 189.85 kg ha^{-1}. The difference in total biomass between 0 and the 224 and 448 kg ha^{-1} fertilizer treatments is significant. The effect of fertilization on total biomass was not as great at Eveleth Mines as it was at Minntac or as great as the type of organic residue used or rate of application. Typically, stabilization of tailing through vegetation establishment using fertilizers requires intensive management and annual fertilizer additions for several years. In general, vegetation stabilization efforts are usually minimal, with fertilization alone and after initial vegetation establishment, poor physical and biological conditions, not having been addressed, prevent the development of stable carbon and nitrogen cycles (Sopper, 1992).

Conclusions

Results obtained after three growing seasons suggest that foliar, litter, and total plant cover increase and bare tailing decrease and that live above-ground, litter, and total biomass will increase when composted yard waste, reed/sedge peat, and composts are used as organic amendments. Best results were obtained when these amendments were applied at a rate of 89.6 Mg ha^{-1}, with at least 224 kg ha^{-1} of diammonium phosphate fertilizer.

Vegetative cover is required by the Minnesota Department of Natural Resources' Rules Relating to Mineland Reclamation (6 MCAR 1.0401-10406) on all tailing basins, dikes, and dams and it must meet the following standards: "After 3 growing seasons following the point when according to the permit to mine, a surface, structure, facility, or element no longer scheduled to be disturbed or used in a manner that would interfere with establishment and maintenance of vegetation, a 90% ground cover, consisting of living vegetation and its litter, shall exist on all areas, except slopes which face south and west. Such sloped areas shall attain the 90% ground cover requirement within 5 growing season following the point when initiation of vegetation is required. Where this standard is not met, or where unvegetated rills or gullies more than 9 inches deep form and erosion is occurring, the surface shall be repaired and replanted during the next normal planting period."

To date, no mining company on Minnesota's Mesabi Iron Range which uses coarse taconite iron ore tailing materials in the construction of dikes and dams has successfully met this regulation. Additionally, "Within 10 growing seasons after the point when according to the permit to mine, a surface, structure, facility, or element is no longer scheduled to be disturbed or used in a manner that would interfere with the establishment and maintenance of vegetation, an area shall have a vegetative community with characteristics similar to those in an approved reference area. The vegetation on a reference area may be either planted or naturally occurring. For the purpose of controlling erosion, it shall be self-sustaining, regenerating, or a stage in a recognized vegetation succession which provides wildlife habitat or other uses such as pasture or timber land. Reference areas must be representative of the site conditions and possible uses which might exist on mining landforms. "In the present studies, total cover across all treatment combinations at Minntac and Eveleth Mines has exhibited linear increases through three growing seasons. At Minntac, total cover has increased from none (prior to experimental manipulation) to 34 % the first growing season, 41% the second growing season, and 56% the third growing season. There are four treatment combinations of MSW compost age, rate of application, and fertilization rate at Minntac that are within 12 percentage points of State of Minnesota requirements. At Eveleth Mines, total cover has increased from none (prior to experimental manipulation) to 49% the first growing season, 55% the second growing season, to 67% the third growing season. There was one treatment combination of organic residue type, rate of application, and fertilization rate at Eveleth Mines that exceeds and eight treatment combinations that are within 10 percentage points of State of Minnesota requirements. These data suggest that acceptable vegetative cover can be achieved if organic amendments are available near the reclamation site.

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