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Low levels organic amendments improve fertility and plant cover on non-acid generating gold mine tailings

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ABSTRACT

We tested the use of low quantities of organic amendments (5.3 t ha^{-1} papermill sludge and 5.6 t ha^{-1} woodchips) and fertilizer in enhancing the cover and survival of vegetation on mine tailings. Plots were subdivided and seeded with a mix of grasses and/or alfalfa and planted with native *Picea mariana*. The papermill sludge amendment and grass seeding resulted in the highest plant cover and survival of plant *P.* seedlings. This amendment and the subsequent plant establishment lead to improvements in substrate aggregation and organic content. Other amendment treatments never exceeded 50% cover, and did not improve substrate physical characteristics. The initial pulse of chemical nutrients provided by amendments was relatively short-lived, with all amendment treatments returning to their background levels within one to two growing seasons. This study suggests that certain abandoned tailings dumps can be revegetated with minimal input.

1. Introduction

Among the most harmful and long lasting environmental liabilities of many mine operations is the generation of huge quantities of milled and processed waste rock (i.e., tailings) that are dumped on large areas of land (Ripley et al., 1996). Given remote nature of many of Canada's boreal mining operations, as well as the loose environmental regulations governing the industry during much of the country's mining history, this region is littered with thousands of abandoned mine sites, some of which contain tailings ponds (Hogan and Tremblay, 2008). During active mining, tailings impoundments tend to remain under ponded water (Blowes et al., 2003). Depending on the climate and the position of the water table, once abandoned, the tailings surface will dry (Barbour, 1994). This leaves them susceptible to erosion. It is estimated that 63,000 tons of particulate emissions are generated per year from mine tailings dumps in Canada (MSSC, 1991). The drying of tailings ponds can also increase their oxidation. When sulfides are present in the tailings both abiotic and biotic reactions can result in the generation of large quantities of acids (Tordoff et al., 2000). Mine tailings ponds also remove land from important ecological functions such as carbon sequestration, nutrient cycling, habitat, water regulation and filtration (Ripley et al., 1996; Anielski and Wilson, 2002). Colonization of tailings by surrounding native vegetation may take centuries due to the tailings toxic and infertile nature (Mendez and Mainer, 2008). Therefore, site remediation is required to re-establish a functioning ecosystem.

In situations where erosive transport of the tailings is a significant concern, one of the most popular and practical techniques is to encourage a vegetative cover capable of binding the substrate. This approach, termed phytostablilization, takes advantage of the physiology and growth morphology of cover vegetation to mechanically bind particles, and in some cases adsorb and sequester substances present within the tailings environment (Beesley et al., 2014; Mendez and Maier, 2008). This may also provide protection from acidification and metal contamination to groundwater (Tordoff et al., 2000).

Tailings have low fertility for plant growth. They have a uniform particle size distribution (lacking clay size particles), and low organic matter content, resulting in a lack of nutrients, low poor soil structure and poor water and nutrient holding capacity (Johnson et al., 1994; Ripley et al., 1996; Lottermosser, 2007). Given the infertility and toxicity of mine tailing, phytostabilization generally requires some form of amendments for successful plant growth and development. Often this involves the addition of organic material and inorganic fertilizer. The addition of organic matter provides nutrients and a source of soil biota including bacteria, fungi as well as invertebrates capable of mineralizing the organic matter into plant available nutrients (Kohler et al., 2014). The need of additional inorganic fertilizer will depend on the C:N ratio of the organic material (Vagstad et al., 2001). Materials with a

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carbon to nitrogen ratio greater than ~25:1 will likely immobilize available nitrogen into microbial biomass, while materials with a lower ratio will lead to net mineralization of nitrogen (Brady and Weil, 2008). As a result, materials with low C: N ratios (e.g., animal manures, composted materials, as well as some municipal and industrial sludge) can improve nutrient availability on the short term while materials with high C:N ratios (e.g., straw, peat, wood chips and bark) require the addition of inorganic fertilizer. Organic amendments can also greatly improve aeration, water infiltration and retention, as well as seedbed characteristics (Johnson et al., 1994; Burger et al., 2009). Organic materials can bind and retain heavy metals, thereby reducing their availability for plant uptake (Calace et al., 2011). While this absorption alleviates some phytotoxicity on the short term, during decomposition these metals may be released back into the soil, leading to regression in plant performance over time (Bradshaw et al., 1978).

Agronomic plant (grasses and forbs) are commonly used in land reclamation. They have well established fertility requirements and rapidly establish a ground cover (Lea, 1982). This helps to stabilize the tailings and helps to build up organic matter (Ripley et al., 1996). Ideally, this pioneering vegetation allows native vegetation to invade the site by increasing soil fertility and capturing seed (Osman and Barakbah, 2011). However, established swards of agronomic plants may also hinder the establishment of native plant species through competitive exclusion (Burger et al., 2010).

The purpose of this study was to determine if low quantities of readily available organic amendments would be useful in establishing a plant cover on an abandoned mine tailings site. Organic amendments to soil are often applied at rates of around 150 t ha^{-1} (reviewed in Tandy et al., 2008). The transport and application of this amount of material to abandoned mines, that have limited access and infrastructure, may be prohibitively expensive. We also wanted to determine if the amendments, combined with the plant cover would aid in the growth and survival of native tree species. The site we worked on is an abandoned gold mine in southeastern Manitoba. This a non acid generating site where heavy metal available is likely not an issue for plant growth (Young 2013). In the seventy-plus years since it was created approximately 60% of the tailings pond has naturally succeeded to a black spruce-larch (*Picea mariana-Larix laricina*) dominated forest on the lower elevations of the tailings pond, with vegetation invading the site from the edge at about 1.5 m per year (Young et al., 2013). Our earlier work showed that the establishment of plants on the unvegetated section site is limited by a lack of plant available nutrients and organic matter, as well as compaction and issues relating to water availability (Renault, 2006).

2. Materials and methods

2.1. Site description

The mine tailings left by Gunnar gold mine are situated near the west shore of Beresford Lake within Nopiming Provincial Park, in southeastern Manitoba, Canada (50°51.37′, 95°29.60′). This region receives an approximate 557 mm of precipitation annually and average monthly temperatures range between −25.1 and 24.9 °C (Environment Canada, 2012). The mine was active from 1936–1942, during which time 260,000 tons of mineral ore was processed. The tailings are composed largely of quartz, calcite, plagioclase, pyrite, Fe-oxides, galena, sphalerite, as well as micas and clays (Lambert, 2001). The mine mill pumped tailings to a lowland depression that covers an area of 11 hectares. About half of the area is below water, and covered by a wetland. The non-vegetated tailings occupy an area of approximately 360 by 120 m and show a range of elevation varying by around 1.8 m.

Table 1
Fertility characteristics of the Gunnar Gold mine tailing deposit, June 2009 (mean ± SE; $n = 20$).

pH	8.1 ± 0.04
Conductivity ($dS\,m^{-1}$)	2.6 ± 0.3
Texture	
Sand (%)	82.6
Silt (%)	12.9
Clay (%)	4.5
Bulk density (g cm^3)	1.40 ± 0.03
Inorganic nitrogen ($\mu g\,g^{-1}$)	3.40 ± 0.70
Available phosphorous ($\mu g\,g^{-1}$)	0.28 ± 0.03
Available potassium ($\mu g\,g^{-1}$)	424 ± 16
Organic carbon (%)	0.28 ± 0.01

2.2. Experimental design and treatments

The experiment was set up in a completely randomized design with four amendment treatments applied to experimental plots that were subdivided into four equal sized subplots, each receiving a different seeding treatment. Twenty 15 m by 15 m plots were established in early June 2009, covering much of the unvegetated mine tailings. This number of plots maximized the area being actively revegetated, and allowed each amendment strategy to be replicated five times. In order to minimize the variation between plots, any areas that had pre-existing vegetation or organic matter build-up, as well as areas with highly varying topography and regions disturbed by ephemeral surface streams were avoided. The plots were amended with either a: (1) low fertilizer rate and no organic amended, (2) high fertilizer rate and no organic amendment, (3) low fertilizer rate and papermill sludge or (4) low fertilizer rate and wood chips. Preliminary studies on this site showed that without a fertilizer application, no seeded plants would survive (Renault et al., 2006). We therefore chose not to have control plots without fertilizer. The fertilizer was a 13-week slow-release, granular product with a NPK mix of 25-5-10 (Brett Young Seeds, Winnipeg, Manitoba). The low and high fertilization rates were equivalent to 100 kg N ha^{-1} and 250 kg N ha^{-1}, respectively. The papermill sludge was obtained from the Tembec papermill in Pine Falls, MB. This facility combines three separate waste streams to produce their final sludge: primary sludge (settled out from primary clarification), secondary sludge (largely dead bacteria and protozoa from conventional aerobic activated processes), and pulped newspaper and magazines. The sludge was dewatered with the use of a gravity table, belt-press, and screw-press yielding a product with the following nutrient contents:

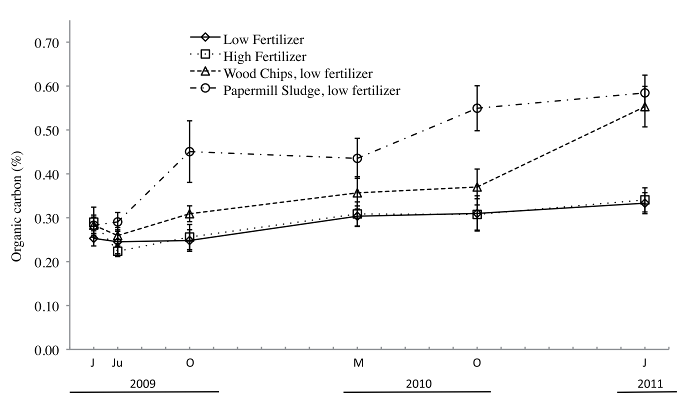

Fig. 1. Organic carbon (%) in amended Gunnar mine tailings throughout 2009–2011 field seasons J: June, Ju: July, O: October, M: May (mean ± SE; $n = 5$). The June 2009 measurements were made prior to the application of treatments. A repeated measures ANOVA showed a significant ($P < 0.0001$) amendment and sample date interaction.