GS-15 Revegetation of tailings at the Gunnar minesite, Manitoba (NTS 52L14): plant growth in tailings amended with paper-mill sludge

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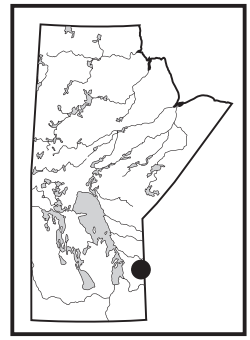

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Summary

A small-scale field experiment was designed in 2007 to test the effects of rototilling, fertilizing, microbial inoculation and amending Gunnar tailings with paper-mill sludge on plant establishment and growth. Microbial inoculation of some plants, such as pine, seems to have improved their survival rates in the absence of paper-mill sludge. Although the amendment of tailings with paper-mill sludge and fertilizer improved the growth of willow and tamarack, there was no significant effect of paper-mill sludge on plant survival and grass cover. The results suggest that the wet conditions in the spring of 2007 partly diminished the beneficial effect of paper-mill sludge and fertilizer on plant growth demonstrating that the drainage of tailings should be taken into account during revegetation of mine tailings.

Introduction

The tailings from the Gunnar gold mine in Nopiming Provincial Park (lat. 50°51.37′, long. 95°15.31′) are located in a depression south of the mine and cover approximately 11 ha (Slivitzky, 1996). Half of the tailings have been revegetated by natural succession, whereas the rest of the tailings are only sparsely vegetated in cracks and on accumulated organic debris. The tailings are relatively neutral with the pH ranging from 6.4 to 8.1 (Slivitzky, 1996; Londry and Sherriff, 2005). The surface water of the tailings was not found to contain significant amounts of metals or cyanides (Slivitzky, 1996), although the concentrations of copper, arsenic and cyanide in the tailings have been found to exceed the Canadian Interim Remediation Criteria for Soil (CIRCS) agricultural and/or residential/parkland guidelines in some areas of the tailings (Slivitzky, 1996).

In previous studies with Central Manitoba (Au) mine tailings, it has been shown that the addition of amendments (fertilizer and paper-mill sludge) improve the growth of plants by increasing the aeration and organic matter content, and improving the water and oxygen availability (Renault et al., 2004; Renault and Green, 2005; Green and Renault, in press). A preliminary field experiment conducted in 2006 at the Gunnar minesite has shown that the addition of paper-mill sludge to tailings can improve plant growth and reduce the effects of environmental stress (Renault et al., 2006). A greenhouse experiment also showed that inoculating alders (*Alnus sp*.) with nitrogen-fixing bacteria initially increased plant mortality but then increased subsequent plant growth (Markham, 2005). In the same experiment, inoculating alders with ectomycorhizal fungi (*Paxillus involutus*) also increased plant growth but to a lesser extent. A field planting of alders confirmed that pre-inoculation with nitrogen-fixing bacteria is essential for increased performance.

Objectives

The objective of the study is to conduct a small-scale experiment to determine the effects of paper-mill sludge and fertilizer on the establishment and growth of grasses, plants, shrubs and trees species in Gunnar tailings. We also found that black spruce (*Picea mariana*) growing on the site had an endophytic bacterium in their roots. We therefore wanted to determine if this bacterium would increase the performance of conifers planted on the tailings. The long-term goal is to provide recommendations for the revegetation of mine tailings in Manitoba.

Materials and methods

In May 2007, four experimental plots (2.5 x 10 m) were randomly selected on an unvegetated section of the Gunnar mine tailings. Each experimental plot was divided into three (0.5 x 10 m) subplots (control, fertilizer and paper-mill sludge with fertilizer treatment) and rototilled to a depth of 15 cm. No amendment was applied to the control subplot. The fertilizer subplot from each replicate received a treatment of 1400 kg/ha of fertilizer (10-3-6, N-P-K), and the last subplot was amended with both fertilizer and paper-mill sludge at a rate of 1400 kg/ha and 5.6 kg/m^2, respectively. Following application of the amendments, the subplots were rototilled again. Tailings samples were taken from between the subplots in May for analysis (conductivity, pH, phosphorus, nitrogen and organic matter). A portion of each of the 12 subplots was sown in June, one week after preparing the treatments, with a seed mixture of 20 kg/ha tall wheatgrass (*Agropyron elongatum*), 20 kg/ha alfalfa (*Medicago sativa*) and 20 kg/ha red fescue (*Festuca rubra*). Each subplot was also vegetated with inoculated and non-inoculated Jack pine (*Pinus banksiana*), black spruce (*Picea mariana)* and green alder (*Alnus viridis* ssp. *crispa*). The pine and spruce were inoculated with a culture of the

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rhizobacteria, isolated from *P. mariana* roots (8 x 10^6 cells), that was injected from cell suspension into the rooting zone or with a culture of *Paxillus involutus* that was previously shown to increase plant growth on the Central Manitoba mine tailings (Markham, 2005). This inoculation was carried out by placing agar blocks of the culture next to fine roots. The alders were inoculated with a crushed nodule suspension of green alder nodules collected from the region. Red osier dogwood (*Cornus sericea*), willow (*Salix*), tamarack (*Larix laricina*), fir (*Abies*) and coneflower (*Echinacea purpurea*) seedlings were also planted (Figure GS-15-1). Mine tailings samples were taken from each of the subplots in July for analysis.

The exchangeable phosphorus of the samples was measured using the Olsen's extraction method (Kalra and Maynard, 1991). The conductivity of the tailings was measured using the 1:1 (v/v) water slurry method (Schofield and Taylor, 1955) and recorded with a Traceable™ Portable Conductivity Meter and Accumet pH meter (Fisher Scientific). The organic matter was measured with the loss-on-ignition (Kalra and Maynard, 1991). In September 2007, plant establishment, growth and injury/stress were assessed. Tailings samples were collected in each plot for determination of bulk density and element content (analysis will be done in the autumn of 2007).

Results and discussion

In May 2007, we made observations of the 2006 experimental plots. Some plants, including alfalfa, red fescue, slender wheatgrass (*Agropyron trachycaulum)* as well as red osier dogwood, were growing in the 2006 plots amended with paper-mill sludge while very little growth occurred in the control plots (Figure GS-15-2; see Renault et al., 2006, for experimental design). However, by the end of the season some of the plants were suffering from stress, mainly the red osier dogwood, suggesting that the amount of fertilizer used in 2006 may not have

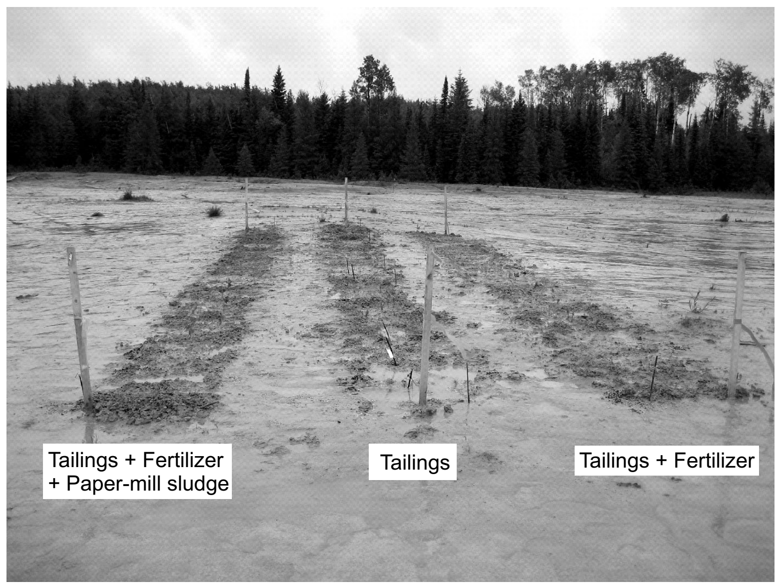

Figure GS-15-1: *Experimental plot (control, fertilizer and paper-mill sludge with fertilizer) at Gunnar minesite, Manitoba, in June 2007.*

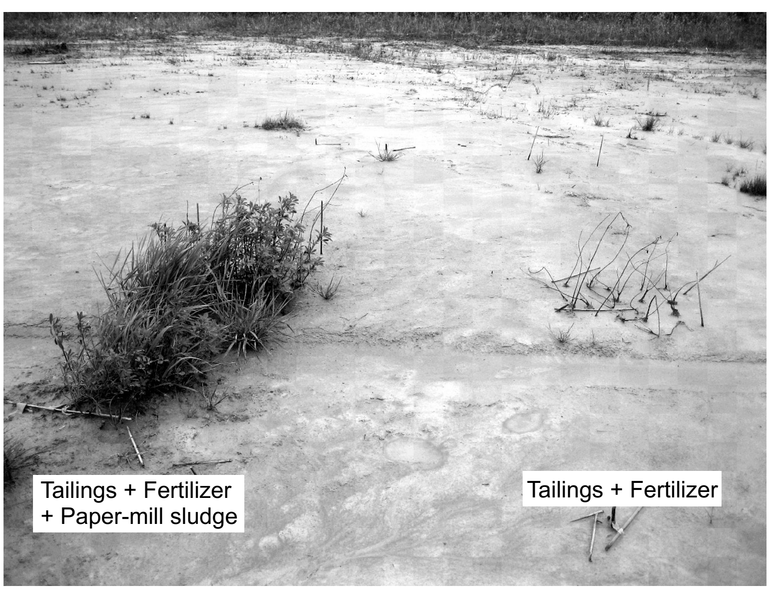

Figure GS-15-2*: Experimental plot 2006: plants growing in tailings with fertilizer and in tailings amended with paper-mill sludge and fertilizer, at Gunnar minesite, Manitoba, in May 2007.*

been sufficient.

Survival rates of the grasses and seedlings in the 2007 plots are summarized in Table GS-15-1. Unlike in 2006, the results of the 2007 experiment showed no significant difference in grass cover and seedlings (tamarack, willow, red osier dogwood and coneflower) survival between the treatments. This was mainly due to the high variability in the results between the four replicates. Replicate 1 had no grass growing in any of the treatments while replicate 2 had results similar to the 2006 season (Figure GS-15-3). Although, overall the survival results did not show a beneficial effect of the amendments, tamarack and willow seedlings (Figure GS-15-4) growing in tailings amended with paper-mill sludge and fertilizer were larger than the plants growing in the unamended tailings suggesting that the addition of paper-mill sludge and fertilizer can improve plant growth. Overall survival of the inoculated plants was poor. None of the alders survived and only two of the rhizobacteria-inoculated spruce (on the paper-mill sludge amended plots) survived. However, survival of the rhizobacteria-inoculated pine was significantly increased in the control and fertilizer plots compared to non-inoculated plants. On the paper-mill sludge amended plots there was no effect of inoculation on plant survival.

Analysis of the tailings samples collected in May and July revealed that the addition of fertilizer and paper-mill sludge did not significantly increase the organic matter, nitrogen or phosphorus content of the tailings (Table GS-15-2). This result is likely due to the wet conditions in the tailings during site preparation and planting, as well as the heterogeneity of the tailings. A larger scale experiment is required to increase the sample size. It was observed that the beneficial effect of rototilling (Szczerski, 2007) and paper-mill sludge addition (Green and Renault, 2007) to limit compaction was partly diminished by the high amount of precipitation in May and June, 2007. The addition of amendments was not sufficient enough to prevent the oxygen deficiency that limited plant survival and growth. Furthermore, leaching of nutrients could have occurred in the wet tailings and limited plant growth.

These results suggest that to revegetate mine tailings sites proper drainage of the tailings should be considered. Furthermore, to determine the suitability of paper-mill sludge as an amendment, a larger scale field study should be undertaken at the Gunnar minesite.

Economic considerations

Reclamation of land impacted by the extraction of natural resources is a current challenge for the government and industry. Fundamental revegetation techniques such as seedbed preparation, fertilization and seeding

Table GS-15-1: Survival of seedlings and grasses growing in amended tailings for three months, Gunnar minesite, Manitoba, summer 2007. The values represent the means of four replicates plus or minus the standard error.

Plant/shrub/tree	Control plot (tailings)	Fertilizer-amended plot	Sludge- + fertilizer-amended plot
		Cover (%)	
Grasses	3.8 ± 1.4	7.5 ± 3.1	10.9 ± 6.9
Alfalfa	0	0	0
		Survival (%)	
Red osier dogwood	50 ± 24	37.5 ± 25	62.5 ± 19
Willow sp	44 ± 18	50 ± 24	87 ± 14 (larger plants)
Tamarack	76 ± 17	32 ± 21	54 ± 12 (slightly larger plants)
Fir	0	0	0
Coneflower	12 ± 10	38 ± 28 (less chlorosis)	38 ± 28
Control alder	0	0	0
Inoculated alder	0	0	0
Control pine	12.5 ± 7.9	8.5 ± 4.9	25 ± 16
Paxillus involutus-inoculated pine	12.5 ± 7.9	37.8 ± 17.0	20.8 ± 7.9
Rhizobacteria-inoculated pine	45.8 ± 18.5	25.0 ± 16.0	12.5 ± 7.2
Control spruce	0	0	0
Paxillus involutus-inoculated spruce	0	0	0
Rhizobacteria-inoculated spruce	0	0	8.3

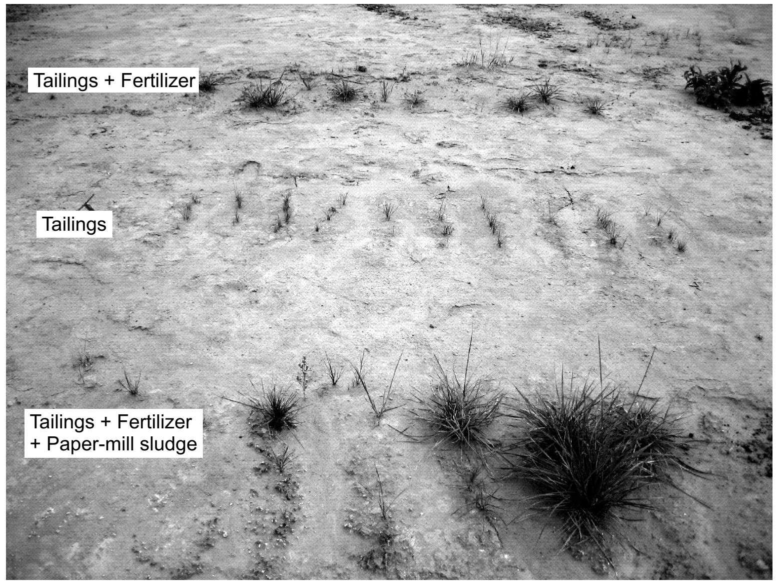

Figure GS-15-3: *Grasses growing in unamended tailings, tailings amended with fertilizer and tailings amended with paper-mill sludge and fertilizer at Gunnar minesite, Manitoba, in September 2007.*

are often times inadequate for successful revegetation of mine tailings (Munshower, 1994). Research oriented toward using readily available amendments, such as paper-mill sludge, to increase revegetation success on such sites would benefit the paper-mill industry, mining industry as well as the government and future land users.

Acknowledgments

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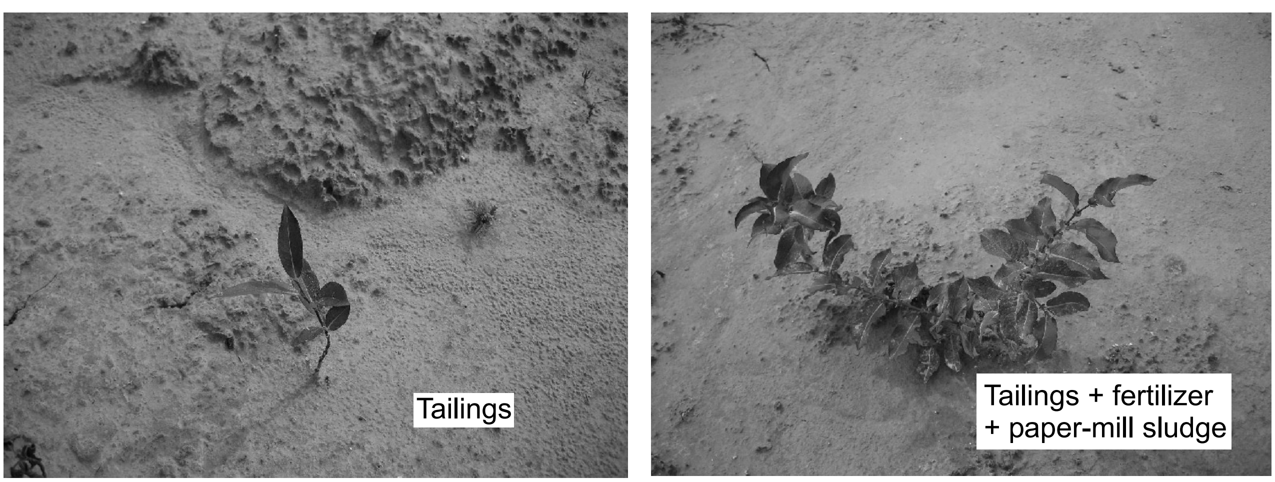

Figure GS-15-4: *Willow growing in unamended tailings and in tailings amended with paper-mill sludge and fertilizer at Gunnar minesite, Manitoba, in September 2007.*

Table GS-15-2: Tailings analysis prior to treatments and post treatments. The values represent the means plus or minus the standard error of four replicates. Note, there is no significant difference between untreated and treated tailings.

	Control plot (tailings)	Fertilizer-amended plot	Sludge- + fertilizer-amended plot
May 2007 (prior to treatment)			
Conductivity (mS/m)	287 ± 38		
pH	8.15 ± 0.07		
Phosphorus (ppm)	0.65 ± 0.31		
Nitrogen (ppm)	9.91 ± 2.67		
Organic matter (%)	1.92 ± 0.24		
July 2007 (post treatment)			
Conductivity (mS/m)	360 ± 68	430 ± 57	346 ± 75
pH	8.33 ± 0.11	8.46 ± 0.07	8.32 ± 0.13
Phosphorus (ppm)	1.26 ± 0.64	2.94 ± 1.94	1.50 ± 0.81
Nitrogen (ppm)	8.2 ± 4.0	4.9 ± 1.7	6.5 ± 1.7
Organic matter (%)	2.54 ± 0.24	2.55 ± 0.16	3.01 ± 0.20

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