# GS-24 Phytoremediation and revegetation of mine tailings and bio-ore production: progress report on plant growth in amended tailings and metal accumulation in seedlings planted at Central Manitoba (Au) minesite (NTS 52L13)

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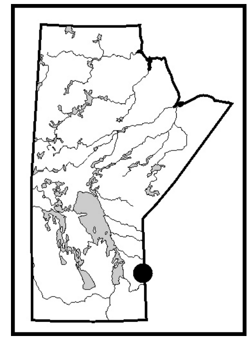

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## Summary

This report summarizes the results of the 2004 field season for a study initiated in 2000 to determine the potential for revegetation, phytoremediation and phytomining of gold mine tailings at Central Manitoba (Au) minesite in southeastern Manitoba. Metal accumulation was recorded in plant tissues of woody seedlings harvested after three growing seasons. None of the studied plant species accumulated enough metals to be suitable for phytomining and phytoremediation; however, significant accumulations of Cu were recorded in tamarack, dogwood, Jack pine and white spruce growing on site 1. Vegetation naturally growing close to site 1 accumulated very low levels of Cu suggesting that the seeds of the adapted existing vegetation would be the best candidates for revegetation purposes. A new field experiment was designed in 2003 to test the benefits of amendments (humic material, peat and fertilizer) on survival and growth of alfalfa, slender wheatgrass and meadow fescue. The results of the 2004 experiment showed that the selected species responded differently to the addition of humic material to the tailings. While alfalfa showed an increase in growth with the highest concentration of humic amendment, slender wheatgrass and meadow fescue showed decreased growth and survival rates with increased application rates.

## Introduction

It has been estimated that 6000 active, abandoned or orphaned minesites are present in Canada (Standing Committee on Natural Resources, 1997). The tailings cover large areas of the Canadian Shield, have no vegetative cover and are a source of dust and heavy metal contamination. The Central Manitoba gold mine tailings deposit, situated 170 km northeast of Winnipeg, is one such site that has undergone sufficient oxidation of these sulphide minerals to release acid and mobile metals into the environment. Reclamation of this site with the establishment of self-sustaining vegetative cover would stabilize the tailings and reduce oxidation and heavy metal release. A study was initiated in 2000 (Renault et al., 2000) to determine plant species suitable for the revegetation, phytoremediation (a technology that uses plants to remove soil contaminants [Salt et al., 1995]) and phytomining (a technology that involves the use of plants to concentrate metals, followed by harvesting and metal extraction [Anderson et al., 1999]) of tailings. It has been shown that the establishment of vegetative cover is limited by the chemical and physical properties of the tailings, such as poor moisture availability, low pH, toxic metal concentrations, poor soil/root aeration in low moist areas, low nutrient levels and potentially ionic stress from high solute concentrations (Renault et al., 2001, 2002, 2003). Treating the tailings may overcome some of these limitations allowing for increased plant growth and establishment by increasing the soil organic carbon, promoting soil structural development, increasing the acid buffering capacity of the tailings, as well as increasing the nutrient holding ability.

## Objectives

The long-term goal of this study is to define limiting factors for phytoremediation and revegetation of mine tailings and other sites contaminated with heavy metals. This study will establish the scientific basis for remediation of mine tailings and extraction of heavy metals by phytomining techniques. Practical experience will be gained in the routine remediation of mine tailings and possibly in the extraction of heavy metals. The suitability of selected species for phytomining of base metals and gold will be tested in terms of the quality and costs of bio-ore production and economic effectiveness.

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## Geological setting and description of experimental sites

Tailings associated with the Central Manitoba (Au) deposit were selected for this study. A description of the geological setting of this deposit is detailed in Renault et al. (2000, 2001). Three experimental sites were chosen in 2000 based on the proximity to the tailings edge and vegetation cover, exposure to sun and wind, and drainage conditions (Renault et al., 2000, 2002). In 2003, a fourth site was selected in the middle of the tailings on the east side of the minesite.

## Results

### *Elemental analysis of plant tissues*

Tamarack (*Larix laricina*), jack pine (*Pinus banksiana*), yellow willow (*Salix lutea*), white spruce (*Picea glauca*) and red-osier dogwood (*Cornus stolonifera*) seedlings planted on sites 1 and 3 were harvested after three growing seasons, washed carefully and freeze-dried prior to elemental analysis. On site 2, none of the seedlings planted survived, most likely due to the high level of oxidation of the tailings (low pH of 3.5 to 4). Most of the seedlings planted on site 3 survived for at least three growing seasons, but they showed only minimal growth. On site 1, only a few seedlings survived in the non-oxidized areas (pH of 6.5 to 7) and they had very limited growth. In addition, mosses were growing on site 3, suggesting a higher amount of organic matter in this site compared to site 1. This could have improved the plant growth on site 3. These observations suggest that an amendment, such as organic matter, is required to improve plant growth on tailings as it would modify the pH of the tailings. Leaf tissues from mature willow, white spruce and tamarack naturally growing on the tailings (close to site 1) were also submitted for elemental analysis. A summary of the elemental analysis is presented in Table GS-24-1.

**Table GS-24-1: Elemental analysis of shoot tissues harvested from the field (sites 1 and 3 and close to site 1).**

| Samples | Cu (ppm) | Au (ppb) | Fe | B | Al | Sr | Mn | Mg | K |
|---|---|---|---|---|---|---|---|---|---|
| Tamarack | | | | | | | | | |
| site 1* | 25 (R) | 3 (R) | R | ++ | R | + | + | - | - |
| site 1** | 332 (+++) | 73 (+++) | ++ | + | + | R | R | - | - |
| Willow | | | | | | | | | |
| site 1* | 53 (+) | 11 (+) | + | +++ | R | R | R | - | - |
| site 1** | 175 (++) | 14 (+) | + | ++ | R | R | R | - | - |
| site 3** | 96 (+) | 15 (+) | +++ | + | R | R | R | - | - |
| White spruce | | | | | | | | | |
| site 1* | 14 (R) | 4 (R) | R | + | R | R | + | - | - |
| site 1** | 274 (+++) | 70 (+++) | ++ | + | + | R | R | - | - |
| site 3** | 161 (++) | 18 (+) | ++ | + | + | R | R | - | - |
| Dogwood | | | | | | | | | |
| site 1** | 306 (+++) | 9 (R) | + | + | R | R | R | - | - |
| site 3** | 69 (+) | 0 | + | + | R | R | R | - | - |
| Jack pine | | | | | | | | | |
| site 1** | 276 (+++) | 39 (++) | ++ | + | + | R | R | - | - |
| site 3** | 121 (++) | 35 (++) | ++ | R | + | R | R | - | - |

Symbols: *, naturally growing close to the site; **, seedlings planted on site and harvested after three growing seasons; R, within the normal range for plant tissues; +, two to three times higher than the normal range for plant tissues; ++, four to five times higher than the normal range for plant tissues; +++, more than five times higher than the normal range for plant tissues; -, less than the normal range for plant tissues

The level of Cu, an element in high concentration in the tailings, normally ranges from 6 to 40 ppm in plants. In the shoot tissues of all the seedlings planted on site 1, the Cu levels were significantly higher than normal and the tissues from site 3 also showed higher levels but to a lesser extent (Table GS-24-1). This difference could be attributed to the difference in pH between the two sites. The wider range of pHs (4 to 5 in oxidized zones and 6.5 to 7 in non-oxidized zones) at site 1 compared to site 3 (pH 5 to 7) could in part explain the difference in Cu uptake observed in the studied plants. Copper is more available to plants at a low pH than at a higher pH. The higher amount of Cu in the plants of site 1 could have also contributed to their low survival rate. Although, the accumulation of Cu was for most species more than five times higher than the average range, the level of Cu in tissues was still too low to be able to use the plants for phytoremediation and phytomining purposes. A maximum accumulation of 0.0332% of the plant dry weight was measured in the studied plants while plants used for phytoremediation accumulate at least 0.1% of their dry biomass. Trees naturally growing close to site 1 had lower levels of Cu than the analyzed seedlings (Table GS-24-1), similar to levels found in trees growing in non-contaminated areas. This result suggests that the plants that have been able to grow from seeds to maturity on the minesite have developed metal stress avoidance mechanisms to limit the uptake of Cu and thus limit its toxic effects. Although this type of mechanism is not suitable for phytoremediation, it would be very beneficial for the revegetation of tailings. Further work will focus on collecting seeds of plants naturally growing close to the site and growing them on tailings in controlled conditions.

Elemental analysis also showed that the conifers accumulated the highest levels of Au (Table GS-24-1). Tamarack and white spruce planted on site 1 accumulated approximately 20 times more Au than the trees naturally growing close to the site. Jack pine was able to accumulate eight times more Au than the normal range for plants. However, the values did not exceed 73 ppb (µg/kg dry weight), representing only 0.0000073% of the plant dry weight, which is too low a level to be able to use the plants for phytomining purposes.

It is likely that the growth of the seedlings in the tailings has been affected by the uptake of elements, such as B and Al, that can cause toxicity (Table GS-24-1). The levels of B and Al in the samples from sites 1 and 3 were higher than the normal range for plants. In addition, high levels of Fe and, to a lesser extent, Sr and Mn were recorded in some species further interfering with plant metabolism. Nutrient deficiency (low Mg and K) was also recorded in all seedlings.

The results suggest that the tree seedlings tested in this experiment experienced high levels of stress and, in addition, did not accumulate enough Cu or Au to be usable for phytoremediation and phytomining. Methods to improve the growth rates of the tree seedlings and enhance metal accumulation should be investigated. Future work will also focus on non-woody species.

### *Tailings amended with modified humic substances*

The addition of humic substances to soil has been shown to stimulate root growth and increase fresh weight in some plants (O'Donnell, 1972; Piccolo et al., 1992). Modified humic substances (mainly composed of humic, fulvic acids, potassium and phosphate) from coal mining have been found to possess chemical properties similar to those of humified organic matter (Ozdoba et al., 2001). These modified humic substances were added to the tailings at site 4 in 2004. Four different rates of application were used, 0, 2, 3 and 4 grams of carbon per kilogram dry weight of tailings (g/kg C). The top 10 to 15 cm of the tailings was mixed using a rotor tiller. Seeds of alfalfa (*Medicago sativa*), meadow fescue (*Festuca pratensis*) and slender wheatgrass (*Agropyron trachycaulum*) were placed on the treated tailings surface in June, the seeds were then covered with a layer of peat (2.0 ± 0.5 cm). The seedlings were fertilized (with a 20:20:20/N:P:K fertilizer) twice and watered four times over a three-month period (June–September).

Three months after seeding, plant survival and dry plant biomass were determined (Figures GS-24-1, -2). For the four application rates, alfalfa exhibited no significant differences in survival while slender wheatgrass and meadow fescue showed a decrease in survival with increasing treatment rate (Figures GS-24-1, -3). The addition of the modified humic material to the tailings increased the conductivity (over 2, 3 and 4 times the control values for 2, 3 and 4 g/kg C, respectively), mainly due to addition of $K^+$ and $PO_4^{3-}$. These ions could have created osmotic stress, which reduced the amount of water in the soil that was available to the plant. This osmotic stress may have led to the decrease in survival and growth in the meadow fescue and slender wheatgrass. Alfalfa showed a significant increasing trend in dry shoot biomass with increasing amendment rate (Figure GS-24-2). Slender wheatgrass and meadow fescue did not show any improvement in the 2 g/kg C treatment and even showed a reduction in biomass in the two highest rates of amendment. These results suggest that selecting the appropriate species and treatment rate is required when applying modified humic substances to mine tailings.

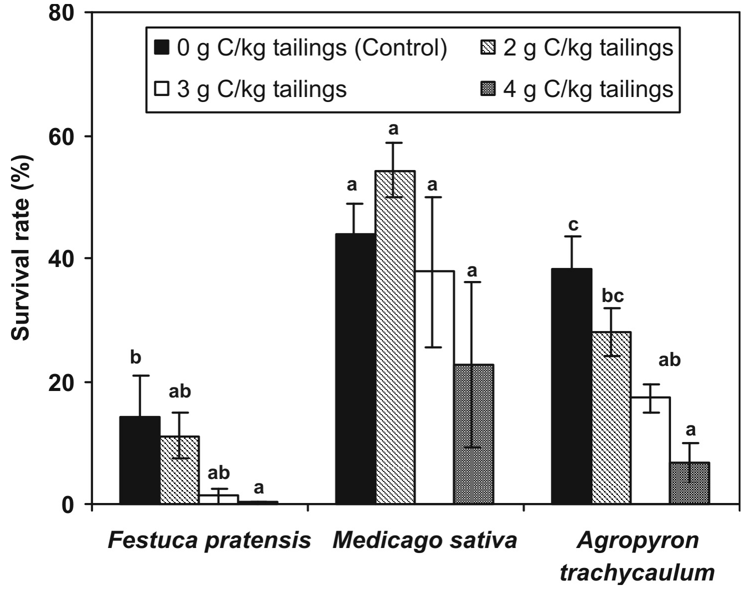


*Figure GS-24-1: Survival rate of selected species at harvest. Each bar represents the mean value with the standard error. (*, significant difference from control).*

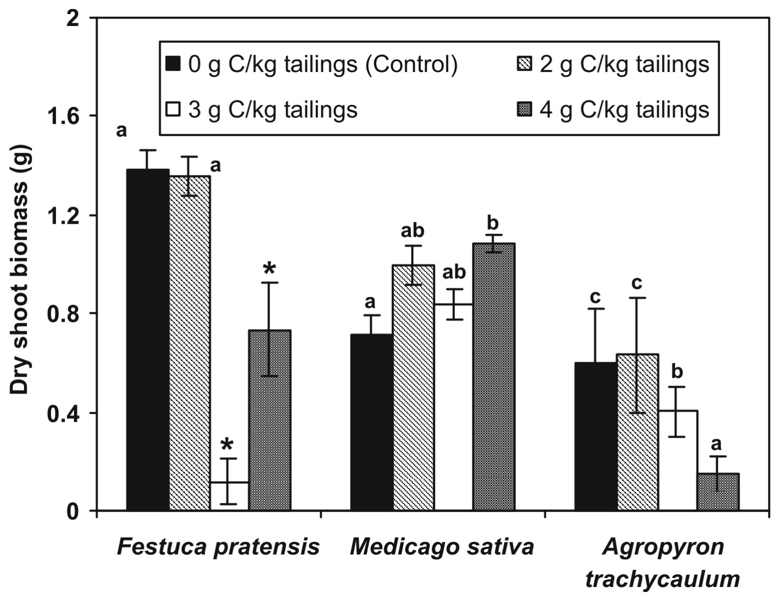


*Figure GS-24-2: Dry shoot biomass of selected species at harvest. Each bar represents the mean value with the standard error. (*, significant difference from control; **, insufficient data to conduct statistical analysis).*

## Economic considerations

The re-establishment of self-sustainable forest systems in mine tailings areas is a major environmental issue. The development of methods that can limit the impact of industry on the environment will provide long-term benefits to Canada and people living near the mines.

## Acknowledgments

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***Figure GS-24-3****: Site 4, three months after seeding. (area 1 is the control area (0 g/kg C); area 2 had 2 g/kg C applied; area 3 had 3 g/kg C applied; area 4 had 4 g/kg C applied; a is alfalfa; b is slender wheatgrass; c is meadow fescue).*

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