Soil amendments to increase vegetative growth on developing Technosols

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Abstract:

Building on previous studies of Technosols manufactured from crushed waste rock and board mill residuals (20:80) for use in mine reclamation, this study investigates the additions of selected soil amendments to improve fertility and soil moisture retention capacity to enhance seedling and transplant survival. This biochamber growth study set for predicted 2030 post-mine closure spring climatic conditions for the Boreal Shield Region north of Lake Superior investigated the suitability of elemental Sulphur (S0), wood boiler ash, N-Rich®, surface humus forms from stockpiled Gleysolic and Podzolic soils as amendments to promote growth of Annual Ryegrass (Lolium multiflorum). Applications of 10% (v/v) Humic Gleysol Humus Form material and wood ash at 80 t ha^{-1} promoted maximum root development. Addition of S^0 Prills (1.5% w/w) produced the greatest increase in both above and below ground biomass. The blending of N-Rich® at 34 t ha^{-1} induced a measured in-situ soil electrical conductivity of 14 $\mu S\ cm^{-1}$ after simulated storm rainfall events (1 cm rainfall hr^{-1}), with bulk through-flow containing high concentrations of dissolved Ca, Mg, K, and low Na. Soil sample analyses illustrated that N-Rich® applications provided the highest enrichment of available soil nutrients to support the growth of ryegrass, with chemical analyses highlighting the overall need for amendment application to the manufactured growth media to support healthy vegetative growth.

Introduction

Site reclamation, a key component in mine closure plans, requires research into cost-effective reclamation methods beneficial to both the mining industry and the post-mining environment. Soil materials which are commonly added to sites as part of reclamation efforts include stockpiled soils removed during mine construction (Gaster, Karst, & Landhäusser, 2015;

Sorenson, Quideau, MacKenzie, Landhäusser, & Oh, 2011), as well as soils constructed from a combination of stockpiled overburden materials and organic materials such as peat (MacKenzie & Quideau, 2010). These soils, often with unusual physical and chemical properties as a result of their diverse origins, follow different development trajectories from those of natural soils (Leguédois et al., 2016). These soils are classified as Technosols by the World Reference Base for Soil Resources due to the strong influence human activities have had on their formation (IUSS Working Group WRB, 2014).

Figure 1. Barrick-Hemlo Operations.

Figure 1. Large mine rock pile produced from open pit mining activities.

Manufacturing a soil for mine reclamation from local industrial waste materials such as mine overburden or lumber mill residuals could have considerable environmental and economic benefits such as the decrease in costs for the transport of large volumes of soil material from diverse locations, leading to a reduction in greenhouse gas emissions. Technosol manufacturing could use waste products which are otherwise valueless. However, long-term studies of Technosol development to determine their utility as a reclamation material, are necessary to provide an understanding of how material maturation may affect plant survival and growth. Ongoing research using a Technosol to revegetate a non-acid generating rock pile from a gold mine in the Boreal Shield has demonstrated that crushed mine rock blended with woody lumber mill residuals are able to support indigenous vegetation such as green alder (*Alnus viridis*), even at early stages in soil development (Vanderhorst *et al*., 2016; Watkinson, 2014). Further study into the improvement of soil properties to enhance their ability to support larger and more diverse communities of native Boreal vegetation with Technosol maturation will provide insight into the use of Technosols created for mine reclamation. One method to promote improvement of soil properties may be through the addition of different amendments. For the current study the amendments added to the Technosol are: N-Rich®, a lime stabilized sewage sludge, as a source of available NPK and trace nutrients; Sulphur prills as a source of sulphur; local forest humus form (LFH horizons) as a source of local propagules, plant nutrients released by decomposition, and also as a pH buffer to local soil conditions; wood ash from the boiler system at the White River mill as a major nutrient source (N, P, K, S, Ca, Mg and trace elements); and stored Orthic Humic Gleysolic soil material as an organic matter, nutrient and local microbial and fungal propagule source. The 80% Organic Matter (OM) Technosol is currently set up in a field experiment on the mine site for four years to mature, while ongoing growth chamber experiments investigate the utility of amendment addition to promote vegetative growth. This current study investigates the addition of the various soil amendments and application rates to Technosols manufactured from 80% OM and 20% finely crushed mine rock to improve fertility and soil moisture retention capacity to enhance grass seedling development.

Materials and Methods

Soil Material and Amendments

The manufactured soil used in this growth chamber study was composed of 80% woody organic material and 20% finely crushed mine rock from the Barrick Williams open-pit mine in Hemlo, ON (Watkinson *et al.*, 2014). The woody residuals, obtained from the (former) Domtar White River Sawmill, contained sawdust, bark, and off-cuttings derived primarily from boreal coniferous trees (Watkinson *et al.*, 2014). A total of ten soil amendments were applied and compared to the productivity of the Technosol (Treatment 1) (Table 1). The resulting eleven treatments consist of: 80% OM and 20% crushed mine rock Technosol, wood Ash obtained from White River, Ontario mixed at rates 40 t ha^{-1} and 80 t ha^{-1}; five cm of a Humus Form (LFH horizons) collected near White River, ON, both being incorporated into the Technosol material to simulate scarification effects and applied at 5 cm surface application layer; Sulphur Prills (S°) broadcasted at 40 kg ha^{-1}, 70 kg ha^{-1} and 100 kg ha^{-1}; N-Rich® applied and blended at 17 t ha^{-1} and 34 t ha^{-1}; stockpiled Humic Gleysol obtained from the mine site area was also blended at

10% soil v/v throughout the soil profile materials. Each treatment was replicated 7 times and the amended soils were randomly distributed over four Styrofoam blocks each containing 24 separate growth wells. The Growth Chamber conditions were set for predicted 2030 post-mine closure spring climatic conditions. The species used for the study was Annual Ryegrass and 32 mL of deionized water was applied twice per week to each soil to moisten evenly throughout the replicates. Soil Monitoring Probes (EC sensors and EM50 loggers from DecagonTM Devices) were installed in one replicate of each treatment for the last four weeks of plant to record soil temperature (C), volumetric water content (m^3/m^3), and the in situ electrical conductivity (mS cm^{-1}) of the soil solution phase. Leachate sampling tubes were attached to each sample's drain hole to collect the bulk throughflow following three simulated rainfall events over a three-day period nearing the end of the experiment immediate prior to harvest at eight weeks of growth. Electrical Conductivity of these solutions was assessed using an Oakton CON Meter with EC probe; the pH of soil leachates was measured with a Fisher Accument AB15 pH meter equipped with an Accumet Combination pH electrode and the concentration of dissolved elements in these solutions was determined by ICP-MS in the ELRFS ISO 17025 accredited laboratory.

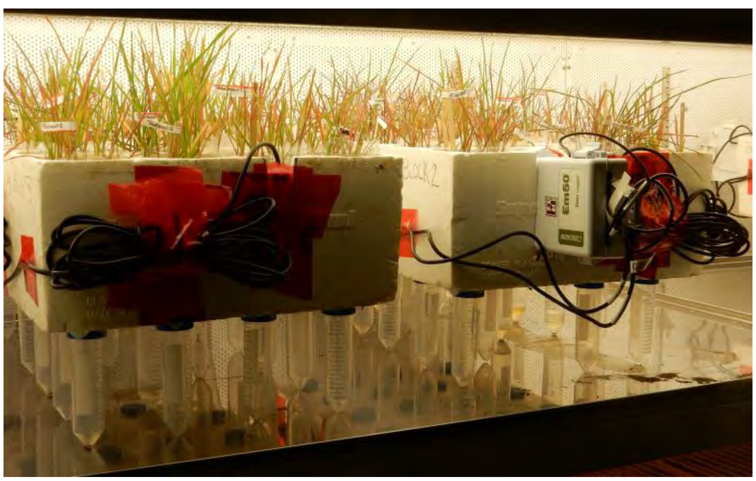

Figure 3. Soil Moisture Monitoring Probes and leachate sampling tubes connected to Styrofoam blocks.

Table 1: Treatments, application rates and method of application to the 80% woody residuals and 20% crushed mine rock Technosol for the 8 week growth study of ryegrass.

Treatment Number	**Amendment**	**Application Rate**	**Method of Application**
Treatment 1:	80% OM Technosol		
Treatment 2	Wood Ash	40 t ha^{-1}	Incorporated
Treatment 3	Wood Ash	80 t ha^{-1}	Incorporated
Treatment 4	LFH	5cm	Incorporated
Treatment 5	LFH	5cm	Surface
Treatment 6	Sulphur Prills (S^o)	40 kg ha^{-1}	Incorporated
Treatment 7	Sulphur Prills (S^o)	70 kg ha^{-1}	Incorporated
Treatment 8	Sulphur Prills (S^o)	100 kg ha^{-1}	Incorporated
Treatment 9	N-Rich®	17 t ha^{-1}	Incorporated
Treatment 10	N-Rich®	34 t ha^{-1}	Incorporated
Treatment 11	Stockpiled Humic Gleysol	10%	Incorporated

Results and Discussion

Ryegrass Biomass

Significant differences were found for shoot dry mass ($P<0.001$). The highest shoot dry mass mean was observed in Treatment 8, Sulphur Prills at 100 kg ha^{-1} (3.20g) and the lowest biomass was obtained by Treatment 3, wood Ash 80 t ha^{-1} (2.61 g). Significant differences were also found in shoot length biomass ($P<0.001$), with Sulphur Prills 100 kg ha^{-1} yielding the highest length mean (12.93 cm). The N-Rich® at 17 t ha^{-1} obtained the lowest shoot length (cm) observed throughout the treatments.

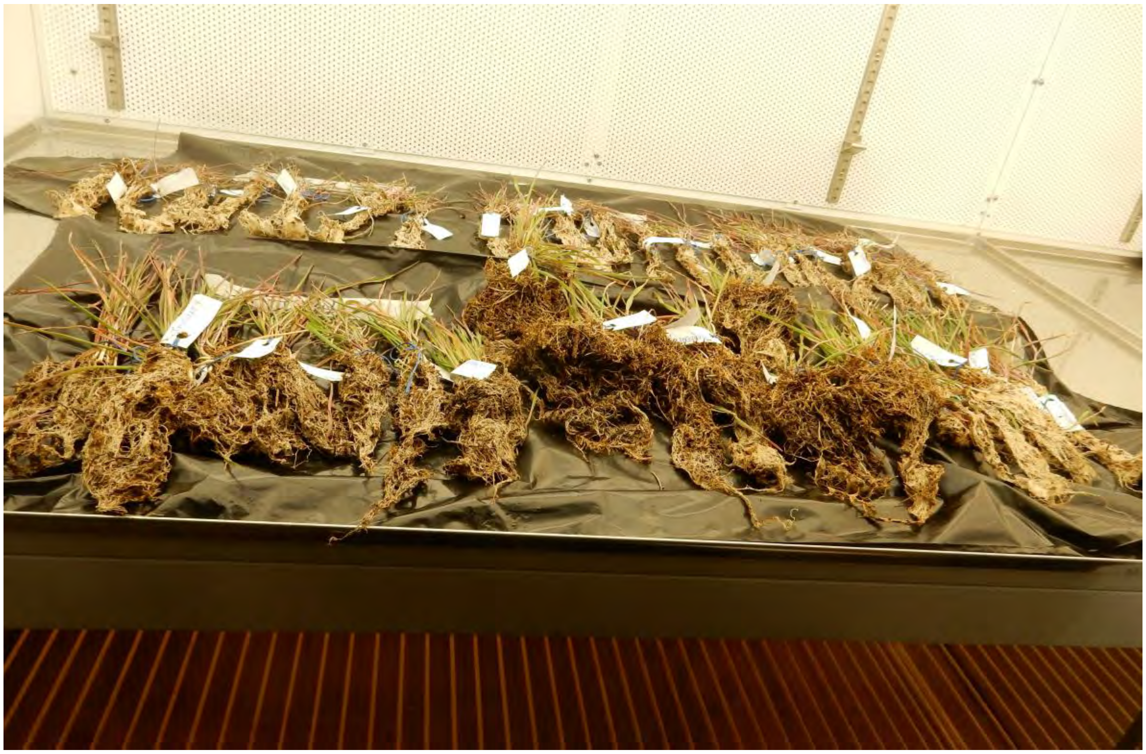

Figure 4. The harvest of Annual Ryegrass at 8 weeks of growth.

Although there was no significant difference (P=0.198) found in root weight (g) when comparing the different treatments, there was an observable difference in the root architecture between the treatments. The root development with the application of Wood Ash 40 t ha^{-1}, Sulphur Prills 100 kg ha^{-1} and stockpiled Humic Gleysol (10 % v/v) have a larger volume root ball, with the roots being thicker and more developed when compared to the rest of the treatments. The LFH treatments were removed from root weight analysis due to contamination of the roots by humus layer. There was no significant difference found in root length (P=0.054) and root:shoot ratio (P=0.606) in this study.

Figure 5. Annual Ryegrass biomass after 8 weeks of growth.

Soil Monitoring Probes

The application of a surface LFH (5 cm thick) induced the highest average Volumetric Water Content (VMC) at 0.164 m^3/m^3, with the application of Sulphur Prills at 40 kg ha^{-1} having lowest VMC at 0.024 m^3/m^3 (Table 4). The soil solution EC (mS/cm) for N-Rich® treatments was the highest of all experimental treatments, with N-Rich® 34 t ha^{-1} application rate being 0.393 mS/cm, and the Sulphur Prills (40 t ha^{-1}) and the 80% OM Technosol control being the lowest in the study at 0.010 mS/cm. Higher electrical conductivity is indicative of higher dissolved nutrient ion content in the soil solution. The maximum temperature throughout the treated Technosols were obtained by the 80% OM Technosol without any vegetation at 27.1^{o}C being ^{o}C 9.5^{o}C higher than the growth chamber set point. The treated soil with vegetation to attain the highest increase in temperature was the Sulphur Prills 100 kg ha-1 application at 25.6^{o}C, which is 7.5^{o}C higher than the parent material.

Water Samples

The leachates from the N-Rich® treatments had the highest electrical conductivity, with the lower rate of N-Rich® at 17 t ha^{-1} attaining an extremely high 59.76 mS/cm when comparing to

0.34 mS/cm parent material. The lowest maximum electrical conductivity was observed with the 5cm LFH on the surface of the 80% OM Technosol at 0.16 mS/cm. When comparing the leachate from the treated Technosols to the parent material 80% OM Technosol, the pH remained relatively stable with applications of treatments (7.0-7.4).

Plant Nutrients

A composite soil sample of each treatment was analyzed for routine soil fertility parameters at A&L Laboratories (London, Ontario) in order to measure the impact of the individual amendments on the extractable soil nutrient levels. The two rates of N-Rich® (17 t ha^{-1} and 34 t ha^{-1}) showed the greatest overall available nutrient increase when compared to the rest of the treatments, with the higher rate of N-Rich® (34 t ha^{-1}) obtaining the highest overall increase of nutrient levels and the N-Rich® 17 t ha^{-1} having the second highest increase in overall available nutrient concentrations for 10 out of the 15 tested soil nutrients. N-Rich® 34 t ha^{-1} had the greatest increase in overall available nutrient concentrations in 12 out of the 15 tested nutrients measured in the Technosol samples. Both N-Rich® amendments, however, had a decrease in the extractable Manganese. Overall, the N-Rich® treatments showed the greatest increase in soil nutrients out of the treatments.

Phosphorus (P) and sulphur (S), two key nutrients in soils, were added to the 80% OM Technosol through the N-Rich® and the Sulphur Prill amendments, respectively. Both N-Rich® treatments displayed the greatest increase of phosphorus and sulphur. Copper (Cu) and zinc (Zn) were added at measurable levels in both and Wood Ash treatments, with the largest increase in copper (Cu) being observed with the N-Rich® treatments. The highest increases in extractable zinc was observed for Wood Ash 80 t ha^{-1} and N-Rich® 34 t ha^{-1}, with the greatest increase with the higher Wood Ash application rate. Magnesium (Mg) and calcium (Ca), both being major nutrient elements, were added in higher amounts in the N-Rich® treatments than in the Wood Ash treatments. Both N-Rich® treatments had the greatest increase in both nutrient levels, with the higher rate of N-Rich® 34 t ha^{-1} having the greatest increase. Magnesium (Mg) and Calcium (Ca) were both added in larger amounts in the N-Rich® treatments, as well as in significant levels by the Wood Ash and Sulphur Prill treatments. Magnesium, critical for chlorophyll production in photosynthesis, plays an essential role in carbohydrate metabolism and serves as an activator of the enzymes involved in the synthesis of nucleic acids (Davis and Jamieson, 1983). Calcium is essential for cell division, cell elongation and cell structure (Mahler, 2004).

Nutrient concentrations in vegetation were also analyzed; major and minor nutrients that play key roles in healthy vegetative growth were examined. Boron, Iron, Manganese, Zinc and Copper are minor nutrients that play key roles in plant health. In the shoots, the greatest increase in Zinc was found in Wood Ash 80 t ha^{-1}, the greatest increase in Manganese was found in LFH on surface, Boron had the greatest increase in Sulphur Prills 40 kg ha^{-1}, Iron had the greatest increase with the 10% Natural Soil application. In the roots, the greatest increase in Zinc was found in Wood Ash 80 t ha^{-1} application and the greatest increase in Boron was found in Sulphur Prills 100 kg ha^{-1}. In the shoots, the greatest increase Potassium, Calcium and Phosphorus in the shoots was found in the N-Rich® applications. The greatest increase in Potassium, Calcium, Phosphorus and Magnesium in the roots was also found in the N-Rich® applications.

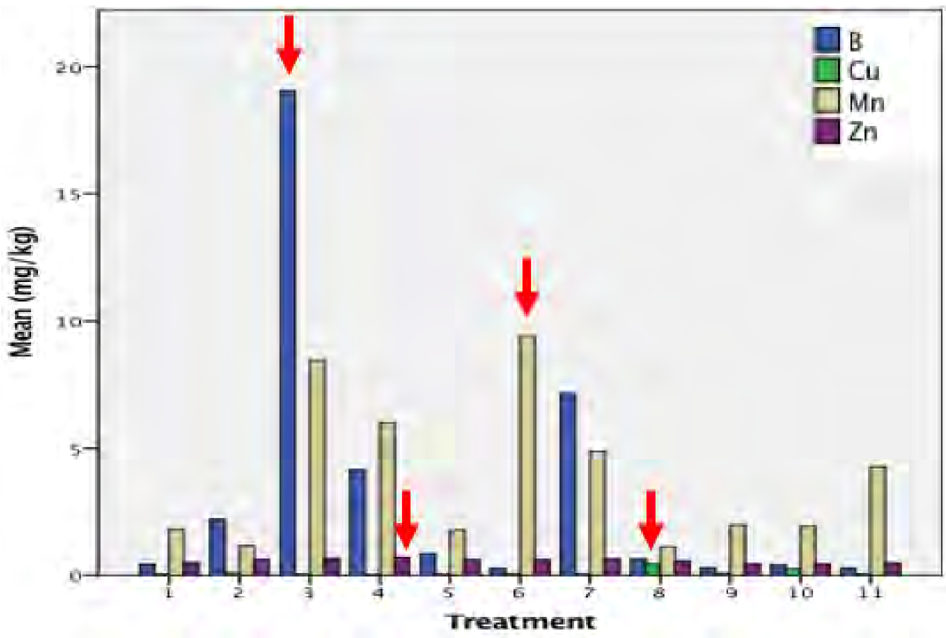

Figure 6. Soil mixtures bioavailable micronutrients

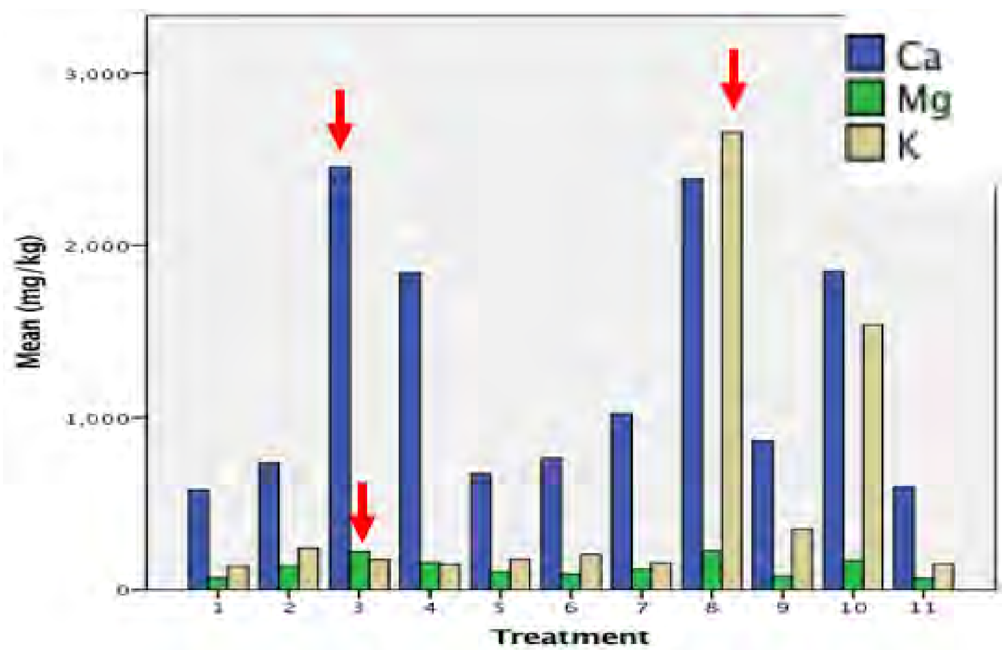

Figure 7. Soil mixtures bioavailable macronutrients.

Discussion

Mine land reclamation is not only environmentally and socially responsible, it is mandated by the government of Ontario (Mining Act, 2012). The Mine Rehabilitation Code (Ontario Mining Act (2012) states that all disturbed sites shall be revegetated and the proponent shall restore their site to its former use or condition (Mining Act, 2012). Annual ryegrass, a short lived grass often used in reclamation, was used in this study to stabilize newly placed soils (Watkinson *et al.*, 2014). Previous studies have used this short lived grass and found successful results for reclamation purposes under different growth conditions (Baker *et al*., 2011)

The increase in shoot biomass and measured root length with the application of Sulphur Prills at 100 kg ha^{-1}) suggests this treatment has a positive effect on plant growth. Thus, the increase in shoot biomass suggests Sulphur Prills 100 kg ha^{-1} is a suitable growth promoting amendment for the 80% OM Technosol manufactured from woody residuals and crushed mine rock to enhance successful plant growth. Even though there was no significant difference found in the root biomass of the ryegrass throughout the treatments, there was an observable difference in root architecture in Wood Ash 40 t ha^{-1}, Sulphur Prills 100 kg ha^{-1} and 10% Stockpiled Humic Gleysol treatments. The root system observed in these specific treatments was a lot thicker, and a lot more developed when compared to the other treated Technosols (see Plate ??).

Additions of specific amendments successfully elevated bioavailable nutrient levels in the 80% OM Technosol to levels more suitable for successful plant growth. Wastes produced by industry, municipalities and households (woody residuals, paper sludge and pulp, sewage sludge, and municipal solid wastes) can contain a substantial amount of organic material that can be used to return essential plant nutrients to soil (Nason *et al.,* 2007). Extractable phosphorus (P) and sulphur (S) are two key components in the amended soils added at measurable levels through different amendments; the different rates of Sulphur prills provided sulphur (S) to the 80% OM Technosol, and the different rates of N-Rich® provided additional phosphorus (P) to the 80% OM Technosol. Both of these nutrients provide important components to the soil for successful plant growth, with P playing an essential role in healthy plant production as a component of key molecules such as nucleic acids, phospholipids and ATP energy requiring processes in plant metabolism (Schachtman *et al.,* 1998; Grant *et al.*, 2001). Sulphur (S) also plays an essential role in plant growth, such as in plant defense against biotic and abiotic stress and for the overall quality of the crops. Sulphur (S), a macronutrient for plants, is a component of some amino acids that form proteins, and is a core component of plant protoplasts and enzymes (Mahler, 2004). Although micronutrients are required by plants in smaller amounts, certain elements such as Al, Mn, Cu, Zn and Pb can severely limit plant growth when found in high concentrations in solution (Bradshaw and Chadwick, 1980). Copper (Cu) and zinc (Zn) are nutrients added in measurable amounts in the N-Rich® and Wood Ash treatments, with the greatest increases in Cu being observed in the N-Rich® treatments. Wood ash (80 t ha^{-1}) and N-Rich® (34 t ha^{-1}) promoted the highest increase in extractable zinc (Zn) levels. Micronutrients such as copper (Cu) and zinc (Zn) are required for successful plant growth (Davis and Jamieson, 1983). Copper plays an important role in enzymes (phenolases and ascorbic acid oxidase) and may function in photosynthesis (Davis and Jamieson, 1983) Zinc (Zn) plays a role in protein synthesis; it is also involved in metabolism of plants as an activator of several enzymes (Davis and Jamieson, 1983).

The amendments added to the Technosol enhanced soil nutrient availability, providing components needed to produce a viable soil medium for successful plant growth, with specific amendments having a greater effect on increases of nutrients in the soil. The N-Rich®

applications generally increased available nutrient levels the most in the Technosol being tested in this study. These results suggest that, when handled and mixed correctly, organic wastes could be diverted from the landfill to improve the manufacture soils for use as cover soils or growth media to help restore ecosystems on post-industrial sites (Watkinson *et al.*, 2014).

Conclusion

The blending of mine waste products such as the crushed mine rock produced in open pit mining activities with lumber mill waste products as organic matter (woody residuals) can manufacture a soil for use to promote successful plant growth for the mine site reclamation process. Different treatments provide different positive effects to the Technosol. For example, one amendment can increase available nutrients in the Technosol and another can stabilize the pH. The use of regional waste products eliminates potential disturbances to surrounding healthy ecosystems, thus minimizing the devastation of healthy land through storage of waste products which promotes the leaching of materials potentially harmful to the environment. By obtaining most of the components needed for a manufactured Technosol in close proximity to the mine site, the Carbon Footprint could also be reduced. This research project has provided further information on how to improve manufactured soils in an environmentally sustainable way and also contributed to current information on land reclamation techniques to prepare for future reclamation initiatives.

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