RECLAMATION OF DISTURBED SITES

AT THE STAR-ORION DIAMOND PROJECT IN SASKATCHEWAN

PRELIMINARY GREENHOUSE RESEARCH

FINAL REPORT

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1. BACKGROUND

Diamond mining is an important industry in Canada, with active mines in the Northwest Territories and northern Ontario and with potential for development in other regions including northern Saskatchewan. The Canadian diamond mining industry has the challenge to reclaim mining disturbances and the opportunity to develop innovative, cost effective and environmentally sustainable reclamation methods. Successful reclamation involves substrate development with re-establishment of soil processes and revegetation to support trajectories towards appropriate plant communities. Sites to be reclaimed vary with mine sites, but generally they include gravel roads, gravel pads, waste rock and till stockpiles and considerable amount of processed kimberlite tailings.

Shore Gold's Star-Orion South Diamond Project is located in Fort a la Corne Provincial forest, at the southern edge of the boreal forest in central Saskatchewan. The region receives more precipitation and has a longer growing season than arctic regions, where diamond mine reclamation research has mainly focused to date. Lack of soil organic matter, poor water holding capacity and low nutrients of available substrates are significant obstacles on disturbed sites in the arctic and in northern Saskatchewan. Thus the research conducted in the arctic sites can be a good starting point for reclamation of the Star-Orion South Diamond Project. The main potential end land uses for mined sites in northern Saskatchewan include forestry and native plant communities.

Processed kimberlite is a waste material from diamond mining that has potential reclamation uses. Reclamation research on processed kimberlite at various mine sites in the Canadian north has shown that amendments are required to enhance physical structure and chemistry of the tailings (Reid and Naeth 2005a, 2005b; Drozdowski, Naeth and Wilkinson 2011; Naeth and Wilkinson 2011). Without amelioration of both structural and chemical components, establishment of vegetation is extremely poor and not sustainable. Chemistry and structure of processed kimberlites differ depending on geologic parent material. Processed kimberlite properties and local availability affects selection of appropriate amendments for reclamation.

In this study, three types of processed kimberlite were investigated to determine their potential, alone and amended, as substrates for successful reclamation on disturbed sites at the Star-Orion South Diamond Project in northern Saskatchewan. This greenhouse research was designed to facilitate narrowing the list of potential amendments and plant species prior to field research on the mine site.

2. RESEARCH OBJECTIVES

The research goal is to identify effective and economical methods for using waste materials to reclaim disturbed sites at the Star-Orion South Diamond Project in Saskatchewan. Specific research objectives of this greenhouse study are as follows.

- To assess processed kimberlite materials as potential substrates for plant establishment, development and growth.
- To assess select amendments to enhance processed kimberlite properties.
- To assess whether select plant species can establish and survive on processed kimberlite.
- To determine potential uses of processed kimberlite in agriculture and forestry operations.

3. MATERIALS AND METHODS

3.1 Experimental Design and Treatments

A completely randomized design greenhouse experiment was established at the University of Alberta in June 2010. The experiment ran for 12 weeks.

Three potential reclamation substrates from the Star-Orion South Diamond Project that require reclamation were provided by Shore Gold Inc. for the greenhouse experiment. Substrates used were fine processed kimberlite from the Star deposit, fine processed kimberlite from the Orion South deposit and a mix of coarse processed kimberlites from Star and Orion South. These were common materials likely to be used for reclamation after mining.

Five soil amendments were selected to enhance physical and chemical properties of the reclamation substrates based on results of prior research in other reclamation scenarios and availability. Amendments were native sandy soil from Fort a la Corne Provincial Forest, agricultural soil from immediately north of the Fort a la Corne Forest, inorganic nitrogen phosphorus fertilizer (11-52-0 applied at 28 kg ha^{-1} nitrogen) and biosolids and yard composts from the City of Prince Albert Compost Facility. Amendments were mixed with reclamation substrates at a 50 % by volume ratio. As this is the first study to be conducted using processed kimberlite from the Star-Orion South Diamond Project, a 50:50 application rate was considered an appropriate starting point from which to assess the interaction of physical and chemical properties of the materials and determine application rates more specific to each amendment based on preliminary results.

The reclamation goal for the Star-Orion South Diamond Project is to return the site to a productive vegetation community similar to other areas within the Fort a la Corne Provincial Forest. Potential plant species for use in reclamation include native and agronomic grasses, legumes and agricultural crops or trees.

Seven plant species were selected for greenhouse research. They were four native grasses, *Agropyron trachycaulum* (Linke) Malte (slender wheat grass), *Elymus innovatus* Beal (hairy wild rye grass), *Festuca saximontana* Rydb. (rocky mountain fescue) and *Koeleria macrantha* (Ledeb.) J.A. Schultes. f. (june grass); two agronomic forages, *Hordeum vulgare* L. (barley) and *Bromus elatior* (l.) Koeler (meadow brome grass); and one tree species, *Populus tremuloides* Michx. (trembling aspen).

Grasses were obtained from Brett Young Seeds in Calmar, Alberta. Aspen seed was obtained from Shand Greenhouses in Estevan, Saskatchewan. Single species were sown per pot at a rate of 10 to 15 seeds depending on documented germination for each species. *Hordeum vulgare* and *Bromus elatior* densities were reduced to five plants per pot two to three weeks following seeding to prevent crowding and a non-treatment induced reduction in plant health.

Substrates and amendments were thoroughly mixed in the appropriate proportions prior to filling five inch diameter pots with the final treatment mix. Each combination of substrate-amendment-species was replicated five times. Controls consisted of each substrate unamended and commercial potting soil. Greenhouse temperature was set at 21 ^{o}C during the day (16 h) and 15 ^{o}C at night (8 h) and pots were watered to maintain approximate field capacity.

3.2 Soil and Vegetation Measurements

Prior to starting the greenhouse experiment, five composite samples of each of the substrates and amendments were submitted to a commercial laboratory and analyzed for pH, sodium adsorption ratio, electrical conductivity, total carbon, total nitrogen, major and minor nutrients, cation exchange capacity, particle size and major and trace metals. Three composite samples of each treatment were submitted to the laboratory for the same analyses.

Germination (via plant emergence) was monitored every three to four days for the first two weeks and density and health were measured every week for twelve weeks. Health was evaluated using a five point scale; a rating of five for healthy and vigorously growing plants, four for mostly healthy (could have brown tips on all or a few plants), three for 50 % healthy and 50 % dying or in poor health, two for mostly dying and one for dead.

In the final week, height of three representative plants in each pot was measured and a mean height per pot calculated. Above ground biomass in each pot was clipped, oven dried at 80 ^{o}C for 48 h and weighed. In three *Agropyron trachycaulum* pots of each treatment, below ground biomass was separated from the soil, washed, oven dried at 80 ^{o}C for 48 h and weighed.

3.3 Statistical Analyses

Mean height, percent germination and percent plant establishment were calculated for each pot. Data were tested for normality and homogeneity of variance prior to statistical analyses. Parametric methods were employed for soil data and non-parametric methods for plant response data due to heteroscedasticity. Two way analysis of variance (ANOVA) was conducted, with processed kimberlite type and amendment as fixed factors, to determine if there were differences in soil and plant response. If the overall test was significant, post hoc LSD tests (parametric) or Mann Whitney U tests (non-parametric) were conducted.

Due to differences in growth form and phenology among plant species, a separate ANOVA was conducted for each species. General comparisons between species were based on means and standard errors. A p value of 0.05 was used for all tests. In results and discussion, the word significant is used to denote analyses that were statistically significant.

4. RESULTS AND DISCUSSION

4.1 Characterization of Processed Kimberlite

The fine processed kimberlite from Orion and Star ore bodies were classified as sandy loam texture while the mix of coarse processed kimberlite from both ore bodies was classified as sand (Table 1). Sand content was highest in the mixed processed kimberlite. Clay content differed among processed kimberlite types from greatest to least as Orion > Star > Mix.

The lower clay content was expected based on the mix being of coarse Star and Orion processed kimberlites. The clay contents between the coarse and fine processed kimberlites are different enough to potentially impact their performances as substrates. These clay contents could impact physical, chemical and biological properties of the substrates as related to water holding capacity, percolation and infiltration rates and cation exchange capacity, which in turn could affect nutrient and water availability to plants.

All processed kimberlites were alkaline with similar pH from 8.6 to 9.3 (Table 1). These values would be considered poor for reclamation substrates and may affect pH sensitive plant species. Above pH 8, some plant nutrients may be deficient for some species.

Electrical conductivities were 3.2, 3.5 and 5.3 dS m^{-1} for Star, Orion and mixed processed kimberlite, respectively (Table 1). These values are unlikely to be limiting for most plant species. Electrical conductivities greater than 4 dS m^{-1} are considered slightly saline by agricultural standards and may impact salt sensitive plants. Electrical conductivities between 4 and 8 dS m^{-1} are considered poor for reclamation soil quality. The mixed processed kimberlite is in the lower range of these vales with potential for impact on salt sensitive species.

Sodium adsorption ratios were wide ranging, with Star processed kimberlite having the lowest 17.8) and mixed processed kimberlite having the highest (95.9) (Table 1). Ratios greater than 12 are considered unsuitable for reclamation substrates and can seriously limit plant growth for many species. Ratios between 12 and 15 can significantly impact soil physical properties, potentially restricting water and nutrient uptake by plants. The large concentration of sodium in the mixed processed kimberlite could lead to potential soil physical property issues, particularly as related to dispersion of clay particles affecting water and nutrient movement. While dispersion caused by high sodium adsorption ratios is a more serious concern in clay soil than sandy soils (Miller and Donahue 1995), it is an issue to be addressed with amendments.

Cation exchange capacity varied, being significantly highest in mixed processed kimberlite (40.7 meq 100 g^{-1}) and significantly lowest in Star processed kimberlite (5.3 meq 100 g^{-1}) (Table 1). Cation exchange capacity is usually higher in materials with higher clay content, so it is interesting that the mixed processed kimberlite, with the least amount of clay content has the highest values. Orion and Star processed kimberlite have quite different mineralogical compositions, which likely affected the cation exchange capacity. Montmorillonite, which is associated with a high cation exchange capacity, is most dominant in Orion processed kimberlite and does not occur in Star processed kimberlite. The coarser mix likely had high montmorillonite from the Orion component of the mix. Since primary minerals are reduced with weathering, the more weathered fine processed kimberlites would also have lower cation exchange capacity.

Larger cation exchange capacities indicate that a soil has a greater capacity to hold cations. Therefore, it requires higher rates of fertilizer or lime to change a high cation exchange capacity soil, but can offer a large nutrient reserve. Low cation exchange capacity soils hold fewer nutrients, and may be subject to leaching of mobile anion nutrients. These soils may benefit from split applications of several nutrients.

Total carbon and nitrogen were low in all processed kimberlite types (Table 2). Star processed kimberlite had less total carbon then the other two types, although values are similar from a biological perspective. The mixed processed kimberlite had highest total sodium and calcium concentrations while Star processed kimberlite had highest total magnesium and potassium concentrations. All processed kimberlite types were very low in available phosphorus; Orion and Star were also very low in available nitrogen. Available sulphur and potassium concentrations were high, with highest concentrations in mixed and lowest in Star processed kimberlite. Thus plant nutrient availability will likely vary considerably depending on the substrate material used and this will need to be supplemented with amendments. Available micro nutrients copper, zinc, manganese and iron were similar in the types of processed kimberlites, except for lower manganese in Star and lower iron in mixed processed kimberlites (Table 2).

Nickel and chromium and cobalt exceeded Canadian Council of Ministers of the Environment soil quality guidelines in all three processed kimberlite types (Table 3). Exceedances were very high for nickel and chromium in all three processed kimberlites. This is comparable to processed kimberlite from other mine sites (Baker 2001, Reid and Naeth 2005a, 2005b, Drozdowski et al. 2011). Soils developed from ultrabasic rocks are usually enriched in chromium, cobalt, nickel and zinc (Anderson et al. 1973, Adriano 2001); therefore, soils derived from kimberlite will be elevated in these elements. Although elements such as chromium, cobalt, nickel and zinc are considered essential micro nutrients in low concentrations, at high concentrations they can be toxic to plants, animals and humans. Chromium has been found in kimberlite materials at other mine sites and was not taken up by plants or leached (Stevens 2006), therefore elevated concentrations are not likely to limit plant growth or result in negative environmental impacts. The low organic matter in processed kimberlite could increase metal mobilization, although the high pH would likely reduce toxicity potential. Orion processed kimberlite had highest concentrations of arsenic, chromium and copper; Star processed kimberlite had highest concentrations of nickel; the mixed processed kimberlite had highest concentrations of barium.

4.2 Effect of Amendments

The native sand, agricultural soil, yard compost and biosolids compost amendments each had potential to improve physical and chemical properties of the three processed kimberlite types.

They were specifically expected to lower pH, electrical conductivity and sodium adsorption ratio and to increase available nitrogen and phosphorus.

Agricultural soil was loamy sand textured with good chemical properties (Table 4). Native sand had potential to enhance soil structure and reduce pH, electrical conductivity and sodium adsorption ratio. Yard compost had highest electrical conductivities at 10.7 dS m^{-1}; biosolids compost had electrical conductivities of 6 dS m^{-1}. These values may be high enough to affect salt sensitive plant species. Amendment pH and sodium adsorption ratios for all amendments were within ranges to provide no problems for vegetation.

Agricultural soil had good available nitrogen and phosphorus (Table 5). Native sand had low available nutrients. Both composts had high available nutrients although concentrations in yard compost were significantly greater than those in biosolids compost. Sulphate and phosphate concentrations in yard compost and potassium in both yard and biosolids composts may be high enough to be detrimental to some plants. Yard compost had significantly more total carbon and total nitrogen than other amendments including biosolids compost.

Metal concentrations in agricultural soil and native sand were well below any soil quality guidelines and therefore not a concern (Table 6). Metal concentrations in both composts were acceptable according to Canadian Council of Ministers of the Environment Guidelines for Compost Quality for Category B compost; however, molybdenum, selenium and mercury were above acceptable concentrations for Category A compost (Canadian Council of Ministers of the Environment 2005).

For most soil properties the interaction of processed kimberlite type and amendment was statistically significant. Amendments, with the exception of compost, significantly decreased silt content of Orion and Star processed kimberlite (Table 7). Agricultural soil and sand increased silt content in mixed processed kimberlite. Sand amendment significantly increased sand content of Orion and Star processed kimberlite, but not mixed processed kimberlite. Orion processed kimberlite had significantly more clay than when amended, while Star processed kimberlite had significantly more clay than when amended with agricultural soil and sand. Soil texture in all cases was acceptable for reclamation, although the high sand contents in the mixed processed kimberlite, with any of the amendments, have potential to limit water and nutrient retention.

All amendments significantly decreased pH of processed kimberlite (Table 8). Although pH was lower with amendment, it was not always sufficiently lowered to have much of an impact on vegetation. Most biologically significant reductions occurred with yard compost amendment of Orion and mixed processed kimberlite, and any amendment of Star processed kimberlite.

Sand significantly decreased electrical conductivity in Orion and mixed processed kimberlite, but not Star processed kimberlite (Table 8). Yard compost significantly increased electrical conductivity in all three types and biosolids compost increased electrical conductivity of Orion and Star processed kimberlites. Electrical conductivity was only high enough to be of concern for vegetation in compost amended processed kimberlite. However, electrical conductivity tends to decrease very quickly as salts leach from the composts. So these higher values would not preclude use of composts for reclamation.

All amendments significantly decreased sodium adsorption ratio of all processed kimberlites (Table 8). Values were still very high in most amended Orion and mixed processed kimberlites, but relatively better in amended Star processed kimberlites.

All amendments except yard compost significantly decreased cation exchange capacity of mixed and Orion processed kimberlite (Table 8). Yard and biosolids composts significantly increased cation exchange capacity of Star processed kimberlite. This illustrates the value of compost in amending kimberlites, even with the higher short term electrical conductivities.

Amendments impacted total, available and micro nutrients (Tables 9, 10, 11). Regardless of processed kimberlite type, yard and biosolids composts significantly increased total carbon and nitrogen, while sand significantly decreased both relative to unamended. Treatments where agricultural soil was added were not significantly different from unamended processed kimberlite. Adding yard compost to mixed and Orion processed kimberlite resulted in significantly greater available nitrate than in all other amended treatments. Yard and biosolids compost significantly increased available potassium, total carbon and total nitrogen. Sand significantly decreased available sulphate in Orion and mixed processed kimberlite and biosolids compost in mixed processed kimberlite only. Biosolids compost increased sulphate in Orion and Star processed kimberlite. Sand decreased sodium in mixed and Orion processed kimberlite. The two composts significantly increased total calcium, potassium and magnesium cations in each processed kimberlite type. Biosolids compost significantly decreased sodium in mixed processed kimberlite, while yard compost increased concentrations in all three types. Agricultural soil had little effect on the nutrient status of the three processed kimberlite types. In general nutrient status was most enhanced by composts. Yard and biosolids compost significantly increased manganese concentrations and biosolids compost increased iron concentrations when added to each processed kimberlite type. Thus nutrient status was affected by amendments but the effect varied with processed kimberlite and amendments.

Amendments significantly reduced cobalt, nickel and vanadium concentrations in each processed kimberlite (Tables 12a, 12b and 12c). Yard compost amended processed kimberlite had significantly greater concentrations of these metals than with other amendments. Nickel concentrations in all treatments were greater than Canadian Council of Ministers of the Environment soil quality guidelines (Canadian Council of Ministers of the Environment 2007). Amendment with agricultural soil or sand decreased cobalt concentrations in Orion and mixed processed kimberlite so they were below guidelines; cobalt remained at or above Canadian Council of Ministers of the Environment guidelines in all Star processed kimberlite treatments. Processed kimberlite alone had significantly higher barium and chromium concentrations than amended treatments, and significantly greater copper and lead than agricultural soil or sand amended treatments. Yard compost significantly increased copper and lead compared to other treatments. Chromium concentrations were above Canadian Council of Ministers of the Environment guidelines for soil quality in all treatments and copper concentrations in compost amended treatments (Canadian Council of Ministers of the Environment 2007). Barium and lead concentrations were well below soil quality guidelines.

4.3 Response of Agronomic Forages

Germination of *Bromus elatior* was lower in unamended Orion (62 %) and mixed (64 %) processed kimberlites than in Star (84 %) processed kimberlite (Tables 13, 14, 15). Germination for *Hordeum vulgare* was similar in all three unamended processed kimberlites (84 to 90 %). Germination in the reference potting soil for each species averaged 80 and 90 %, respectively.

None of the amendments in this study improved *Bromus elatior* germination in Star processed kimberlites, but germination rate dropped by 8 to 28 % relative to the unamended processed kimberlite (Tables 13, 14, 15). In Orion and mixed processed kimberlites, amendment with agricultural soil or native sand increased germination rate by 10 to 20 %. Amending Orion processed kimberlite with fertilizer, yard composts and biosolids compost had little impact, dropping germination slightly. In mixed processed kimberlites these three amendments dropped germination significantly. *Hordeum vulgare* germination increased slightly with amendment with agricultural soil in Orion and mixed processed kimberlites and decreased by 10 % in Star processed kimberlites. Native sand amendment increased germination in all processed kimberlites. Fertilizer and compost decreased germination *Hordeum vulgare* in Star and mixed processed kimberlites, while fertilizer increased germination in Orion processed kimberlite and biosolids compost had no effect.

Establishment of *Bromus elatior* was relatively unaffected by amendment in all processed kimberlites, except it was reduced by biosolids compost in mixed processed kimberlite (Tables 13, 14, 15). Establishment of *Hordeum vulgare* increased in all processed kimberlites with compost amendment; native sand and fertilizer had less impact and agricultural soil decreased germination in Star processed kimberlite.

Hordeum vulgare is relatively salt tolerant while *Bromus elatior* is more sensitive to salts. This likely contributed to the different responses of the two plant species to processed kimberlites and amendments. Germination was more impacted by processed kimberlite type and amendment than establishment. Age can be a significant factor in salt tolerance, explaining the more dramatic responses of germination than establishment.

Bromus elatior and *Hordeum vulgare* plants had significantly greater density, height and biomass in Star processed kimberlite than in Orion or mixed processed kimberlite (Tables 16, 17, 18). In Orion processed kimberlite with fertilizer and agricultural soil had no effect on *Hordeum vulgare* density, while composts and sand significantly increased density. Amendment had no effect on *Bromus elatior* density. Plants were taller when amendments were added. All amendments increased above ground biomass considerably compared to the unamended processed kimberlites. Biomass was most increased with composts in all three processed kimberlites for both plant species.

Health of *Hordeum vulgare* plants declined at 8 weeks as plants became root bound in the pot, not related to impacts of processed kimberlite or amendments. At 8 weeks, plants were healthy and vigourous; by week 12 the mean health rating ranged from 1.8 in unamended processed kimberlite to 3.3 in yard compost and processed kimberlite. Leaves gradually developed brown tips, which then yellowed in colour. Plants in all treatments set seed around week 9 regardless of declining health. Mean health rating for *Bromus elatior* was 3.0 in unamended processed kimberlite and 4.3 in biosolids compost. None set seed.

4.4 Response of Native Grasses

Germination for native grass species in unamended processed kimberlite was 77 to 88 % for *Agropyron trachycaulum* (81 % in reference potting soil), 34 to 70 % *Elymus innovatus* (56 % in reference potting soil), 17 to 41 % *Festuca saximontana* (63 % in reference potting soil) and 3 to

29 % for *Koeleria macrantha* (57 % in reference potting soil) (Tables 13, 14, 15). The interaction between processed kimberlite type and amendment significantly influenced most of the species.

Agropyron trachycaulum germination was most affected by yard compost in Orion, fertilizer and composts in Star and all amendments in mixed processed kimberlites (Tables 13, 14, 15). Germination of *Elymus innovatus* was most affected by yard compost in Orion and fertilizer in mixed processed kimberlites. Germination of *Festuca saximontana* was reduiced by all amendments in Star processed kimberlite and most increased by biosolids compost in Orion and by all but the composts in mixed processed kimberlite. Germination of *Koeleria macrantha* increased with all amendments in Orion processed kimberlite and decreased with fertilizer and composts in Star processed kimberlite. In mixed processed kimberlite germination increased with agricultural soil and native sand and decreased with composts.

Establishment of native grasses was affected by amendments and processed kimberlites (Tables 13, 14, 15). Establishment was high for *Agropyron trachycaulum* and relatively unaffected by amendment. This is not unexpected for this robust and tolerant species. Establishment of *Elymus innovatus* increased with sand, fertilizer and composts in Orion and Star processed kimberlites; it decreased with agricultural soil and fertilizer and increased with sand and composts in mixed processed kimberlite. Establishment of *Festuca saximontana* increased with agricultural soil, fertilizer and composts in Orion processed kimberlite. It decreased with all amendments in Star processed kimberlite and increased with all but fertilizer in mixed processed kimberlite. Establishment of *Koeleria macrantha* was improved with all amendments in Orion and mixed processed kimberlites, but only with sand and fertilizer in Star processed kimberlite. Establishment rates, like germination, were very low for *Koeleria macrantha* suggesting soil conditions were not favourable for this species.

The effect of processed kimberlite type and amendment on above ground biomass, height and density varied greatly with plant species (Tables 16, 17, 18). *Agropyron trachycaulum* density declined with yard compost in Orion and fertilizer and biosolids compost in mixed processed kimberlites. Height increased in all but fertilizer amended mixed processed kimberlite. Amendments alone, particularly composts, significantly increased *Agropyron trachycaulum* biomass. Processed kimberlite type and amendments impacted *Elymus innovatus* height, density and biomass. All amendments increased height and biomass, except biomass in fertilized mixed processed kimberlite. *Festuca saximontana* density varied considerably with amendments and processed kimberlites. Height increased with all amendments, except native sand in Orion and fertilizer in mixed processed kimberlites. Biomass increased with amendments, except for native sand and fertilizer in Orion, and fertilizer in mixed processed kimberlites. *Koeleria macrantha* density increased with all amendments in Orion, decreased with all amendments except native sand in Star and decreased with all amendments except agricultural soil and native sand in mixed processed kimberlite. Height increased with all amendments except fertilizer in Orion, and only increased with native sand in Star and agricultural soil in mixed processed kimberlites.

Only below ground biomass from *Agropyron trachycaulum* was sampled and weighed. Mean biomass in the unamended treatments was 0.410 g, 0.549 g and 0.580 g for Orion, Star and mixed processed kimberlite, respectively. Type of processed kimberlite did not affect below ground biomass. Amendments increased below ground biomass, although only yard compost (0.823 g), biosoilds compost (0.838 g) and sand (0.455 g) did so significantly.

Agropyron trachycaulum was the only species to set seed at around 10 weeks. In general health ratings slightly declined at 8 to 10 weeks. Tips of plants browned and some leaves yellowed, particularly in the unamended treatment (Photos 1 to 4). These morphological changes, however, were not detrimental to plant survival.

4.5 Response of Native Trees

Populus tremuloides was selected as a potential species for reclamation due to its high germination, rapid growth and dominance in forests surrounding the mine site. In germination tests, 100 % of the seed germinated within 48 hours. In the greenhouse, germination was lower than expected even in the reference potting soil (31.1 %). Of the reclamation treatments, germination was greatest in Orion processed kimberlite amended with agricultural soil (24.0 %), followed by Star processed kimberlite amended with biosolids compost (17.3 %) and agricultural soil (10.7 %). In reclamation treatments seedlings died within 2 weeks. Seedlings survived the 12 week experiment in potting soil with a mean density of 4.7 plants per pot and mean height of 20.7 cm. The mean health rating was 3.75 and was reduced slightly as seedlings became pot bound. This low success with this species will need to be investigated to determine if greenhouse conditions were not favourable, since even the potting soil control did not do well.

4.6 Reclamation of Processed Kimberlites

In general, and not unexpectedly, plant species performance in each of the three processed kimberlite types was relatively unique. To assess reclamation potential and amendment needs of each of the three processed kimberlites, some overall trends must be interpreted. One can assume that for effective revegetation, germination, establishment and biomass production are the plant parameters of general importance. Evaluating these within and between processed kimberlites and amendments will provide a general trend for reclamation treatments most likely to be effective.

Differences in physical properties among processed kimberlite types likely had a considerable impact on plant response. Mixed processed kimberlite, which had high sand and low clay content, resulted in lowest germination and plant densities for agronomic and most native species and Star processed kimberlite, which had moderate sand and clay, the highest. Sandy loam to loamy sand textures of Orion and Star processed kimberlites would improve nutrient and water retention over sand textured mixed processed kimberlite. Mixed processed kimberlite had high available nitrogen and cation exchange capacity, theoretically providing good conditions for plant growth, however, the physical and chemical limitations such as extreme sodium adsorption ratio and high electrical conductivity likley negated some of these potential benefits. If coarse processed kimberlites were to be used for reclamation substrates they would benefit from mixing with finer processed kimberlites and more heavy amendment applications.

For the mixture of coarse processed kimberlite, germination and final plant performance was greatest in sand amended treatments. Agricultural soil also improved germination of most species, with the exception of *Agropyron trachycaulum* and *Elymus innovatus*, and increased the final density of *Festuca saximontana* and *Koeleria macrantha*. Final density of *Hordeum vulgare* was greatest in compost amended treatments. Fertilizer amendment was detrimental to germination and establishment of *Agropyron trachycaulum*, *Bromus elatior* and *Elymus innovatus*; had no effect on *Koeleria macrantha*; and increased germination but not final density of *Festuca saximontana*. Yard compost resulted in highest above ground biomass for *Agropyron trachycaulum*. Highest biomass of *Elymus innovatus* and *Festuca saximontana* was produced in biosolids compost and *Koeleria macrantha* in treatments amended with agricultural soil.

While cation exchange capacity and total carbon were low in Star processed kimberlite, its physical composition and lower sodium adsorption ratio were more suitable for plant growth. Star and Orion processed kimberlites had significantly elevated concentrations of certain metals compared to mixed processed kimberlite, but these do not seem to have inhibited plant growth.

Revegetation of fine processed kimberlite in the Northwest Territories was not successful without amendment (Reid and Naeth 2005a, 2005b; Naeth and Wilkinson unpublished) and even then plant densities were lower than other reclamation treatments and declined over a five year period (Naeth and Wilkinson unpublished). These tailings had similar nutrient and metal limitations to Shore Gold processed kimberlite, although sodium adsorption ratio and electrical conductivities were more amenable for plant growth. In this greenhouse study, the addition of amendments improved plant response for Orion and mixed processed kimberlite types but in general not Star processed kimberlite.

When amending fine processed kimberlite from the Orion deposit, sand significantly enhanced germination and final plant densities of *Agropyron trachycaulum, Bromus elatior* and *Koeleria macrantha*. Sand also enhanced germination of *Elymus innovatus*, however, the unamended treatment provided similar final densities as sand, fertilizer or biosolids compost. Agricultural soil also enhanced *Bromus elatior* and *Hordeum vulgure* germination. For above ground biomass production, there was agreement among species in their response. Reclamation treatments had the following order for biomass, biosolids compost > yard compost > agricultural soil.

Amendments did not always improve plant response in Star processed kimberlite. The unamended treatment had the highest, or similar to other treatments, germination and density. Mean plant heights and aboveground biomass were greater in biosolids compost and yard compost treatment with the exception of *Koeleria macrantha*, where sand treatments resulted in the tallest plants and greatest biomass. High amounts of biomass were also obtained in fertilizer treatments for *Hordeum vulgare* and *Koeleria macrantha*, sand for *Elymus innovatus* and *Festuca saximontana* and agricultural soil for *Agropryon trachycaulum* and *Bromus elatior*.

4.7 Species Selection for Reclamation

Species growth form appears to impact plant response to reclamation treatments. Short, tufted species, *Festuca saximontana* and *Koeleria macrantha*, often responded in the same way to a particular processed kimberlite type or amendment. *Hordeum vulgare*, an agronomic forage developed for optimum production in an agricultural setting, was able to tolerate the poor chemical conditions of treatments more readily than the native species. While *Bromus elatior* is also an agronomic forage, it responded more similarly to *Agropyron trachycaulum* than *Hordeum vulgare*. *Agropyron trachycaulum*, a native bunch grass, is known to be fairly tolerant of saline and low nutrient conditions compared to other native species. *Elymus innovatus*, also a native bunch grass, responded similarly to *Agropyron trachycaulum* for many parameters measured, however, overall it had much lower germination, density and biomass, reflecting a lower tolerance to poor growing conditions. Including a diversity of plant species in a seed mix, increases community species richness. Even if reclamation sites are initially dominated by a few species, the increased species richness may in time improve soil and site conditions and overall reclamation success.

5. CONCLUSIONS

Based on this initial greenhouse study, the following can be reported:

- Agronomic and native plant species will establish in unamended fine processed kimberlite from the Star and Orion-South deposits and a mix of coarse processed kimberlite from both deposits.
- The three processed kimberlites tested had different physical and chemical compositions which affected plant response.
- Star fine processed kimberlite unamended had higher germination and plant densities than Orion fine processed kimberlite or the mix of coarse processed kimberlites. The mix of coarse processed kimberlites consistently had the lowest plant response.
- Reclamation treatments that resulted in the tallest plants and greatest aboveground biomass were not the same ones that provide the highest germination or final plant densities.
- The addition of native sand or agricultural soil enhanced germination and final plant density.
- The addition of yard compost or biosolids compost increased aboveground biomass in each type of processed kimberlite.
- *Koeleria macrantha* had the poorest performance of the plant species tested. *Festuca saximontana*, a reclamation species that does well on many disturbed sites, also did not perform well in treatments.

6. FUTURE RESEARCH

Further research is justified based on results from this preliminary greenhouse study. Differences in plant response to processed kimberlite types are not fully understood and will ultimately affect reclamation success. Potential benefits of adding multiple amendments should be investigated to determine optimal techniques to address physical and chemical limitations while enhancing beneficial properties of various processed kimberlites. The most likely end land use will be native boreal forest, similar to that currently found surrounding the Star Orion-South Diamond Project, and therefore woody species including boreal trees and shrubs should be tested for establishment and survive in amended processed kimberlite substrates.

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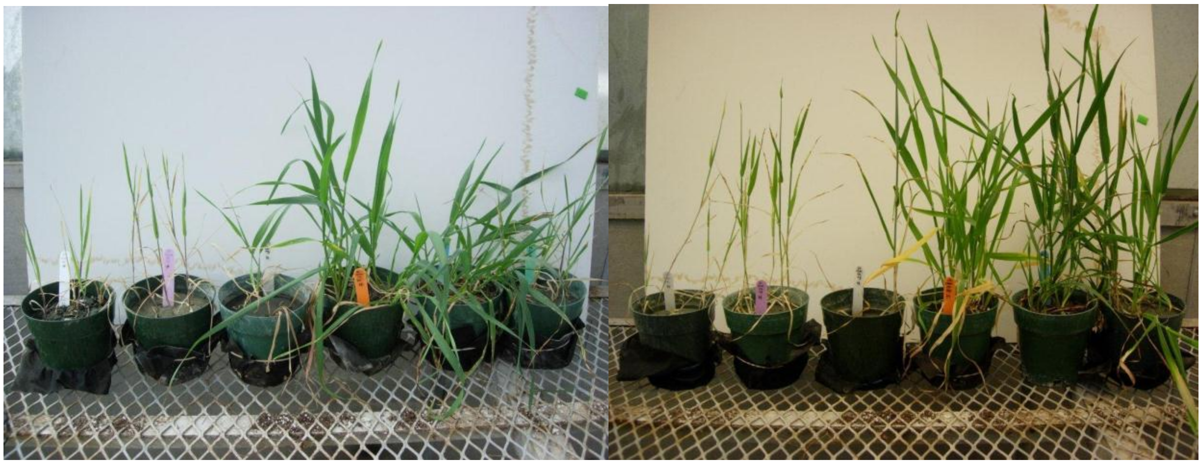

Photo 1. *Hordeum vulgare* (barley) grown in Orion (left) and Star (right) fine processed kimberlites. Treatments in each photo, from left to right are unamended, sand amended, agricultural soil, biosolids compost, yard compost, inorganic fertilizer.

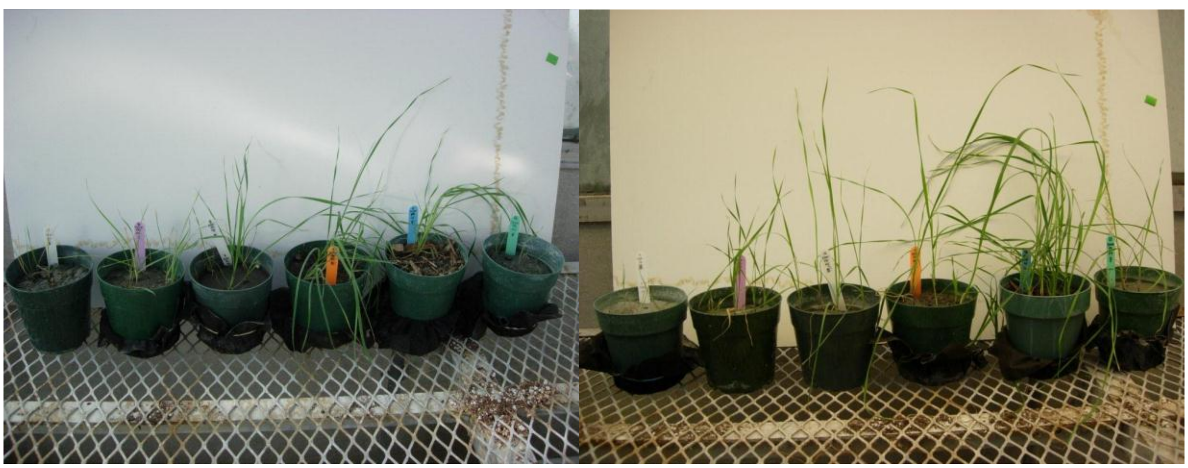

Photo 2. *Bromus elatior* (meadow brome) grown in Orion (left) and Star (right) fine processed kimberlites. Treatments from left to right in each photo are unamended, sand amended, agricultural soil, biosolids compost, yard compost, inorganic fertilizer.

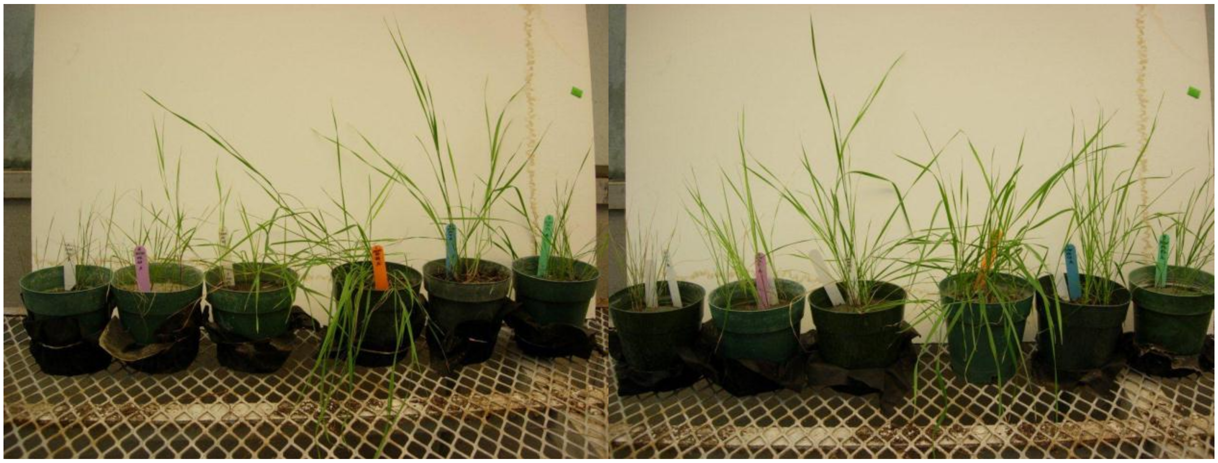

Photo 3. *Agropyron trachycaulum* (slender wheatgrass) grown in Orion (left) and Star (right) fine processed kimberlites. Treatments from left to right in each photo are unamended, sand amended, agricultural soil, biosolids compost, yard compost, inorganic fertilizer.

Photo 4. *Elymus innovatus* (hairy wild rye) grown in Orion (left) and Star (right) fine processed kimberlites. Treatments from left to right in each photo are unamended, sand amended, agricultural soil, biosolids compost, yard compost, inorganic fertilizer.

Table 1. Physical and chemical properties of unamended processed kimberlites.

Parameter	Orion Fine	Star Fine	Orion Star Mixed Coarse
Sand (%)	66.2 (2.7)	70.0 (1.3)	90.9 (0.3)
Silt (%)	20.2 (1.1)	20.7 (1.3)	4.9 (0.2)
Clay (%)	13.6 (1.7)	9.8 (0.3)	4.2 (0.2)
Texture	Sandy loam	Sandy loam	Sand
Hydrogen Ion Concentration (pH)	9.1 (0.1)	8.6 (0.0)*	9.3 (0.0)*
Electrical Conductivity (dS m^{-1})	3.5 (0.2)	3.2 (0.2)	5.8 (0.4)
Sodium Adsorption Ratio	74.4 (16.7)	17.8 (0.9)	95.9 (2.1)
Cation Exchange Capacity (meq 100 g^{-1})	22.1 (2.3)	5.3 (0.2)	40.7 (0.7)
Saturation (%)	80.2 (11.5)	46.6 (1.7)	38.4 (0.7)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

Table 2. Macro and micro nutrient properties of unamended processed kimberlites.

Parameter	Orion Fine	Star Fine	Orion Star Mixed Coarse
Total Carbon (%)	1.2 (0.1)	0.9 (0.0)*	1.0 (0.1)
Total Nitrogen (%)	0.0* (0.0)	0.0* (0.0)	0.0* (0.0)
Total Calcium (mg L^{-1})	3.6 (0.7)	12.5 (0.8)	13.6 (2.5)
Total Magnesium (mg L^{-1})	5.0 (1.9)	42.7 (2.3)	3.0 (0.5)
Total Potassium (mg L^{-1})	19.8 (1.6)	32.1 (1.6)	23.2 (1.7)
Total Sodium (mg L^{-1})	823.8 (56.9)	591.8 (44.1)	1254.0 (87.8)
Available Nitrate (mg kg^{-1})	6.7 (0.6)	1.7 (0.5)	55.6 (5.2)
Available Phosphate (mg kg^{-1})	1.0 (0.0)	1.0 (0.0)	1.2 (0.2)
Available Potassium (mg kg^{-1})	206.4 (12.2)	119.8 (3.1)	307.0 (4.8)
Available Sulfate (mg kg^{-1})	121.7 (9.4)	93.2 (7.0)	202.8 (22.9)
Available Copper (mg kg^{-1})	1.8 (0.1)	1.3 (0.0)*	1.2 (0.1)
Available Zinc (mg kg^{-1})	1.3 (0.1)	0.9 (0.0)*	1.1 (0.1)
Available Manganese (mg kg^{-1})	4.3 (0.6)	1.5 (0.1)	4.7 (0.2)
Available Iron (mg kg^{-1})	31.6 (1.8)	33.3 (1.0)	9.1 (0.5)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

Table 3. Total metal and selenium concentrations in processed kimberlites.

Parameter	Orion Fine	Star Fine	Orion Star Mixed Coarse
Antimony (mg kg^{-1})	0.1 (0.0)*	0.1 (0.0)	0.1 (0.0)
Arsenic (mg kg^{-1})	3.2 (0.6)	2.0 (0.1)	0.8 (0.0)*
Barium (mg kg^{-1})	211.8 (11.6)	209.6 (7.5)	268.8 (13.8)
Cadmium (mg kg^{-1})	0.3 (0.0)	0.0* (0.0)	0.0* (0.0)
Chromium (mg kg^{-1})	546.4 (41.6)	398.4 (13.8)	350.8 (26.0)
Cobalt (mg kg^{-1})	76.0 (6.0)	70.9 (1.0)	48.8 (1.3)
Copper (mg kg^{-1})	59.5 (7.0)	42.8 (2.6)	28.6 (1.8)
Lead (mg kg^{-1})	6.9 (0.4)	6.9 (0.2)	7.9 (0.3)
Molybdenum (mg kg^{-1})	3.1 (0.7)	1.4 (0.2)	0.5 (0.0)
Mercury (mg kg^{-1})	0.0* (0.0)*	0.0* (0.0)	0.0* (0.0)
Nickel (mg kg^{-1})	986.2 (76.6)	1346.0 (60.1)	670.8 (15.4)
Selenium (mg kg^{-1})	0.3 (0.0)	0.3 (0.0)	0.2 (0.0)
Silver (mg kg^{-1})	0.5 (0.0)	0.5 (0.0)	0.5 (0.0)
Tin (mg kg^{-1})	2.5 (0.0)	2.5 (0.0)	2.5 (0.0)
Uranium (mg kg^{-1})	1.0 (0.0)	1.0 (0.0)	1.6 (0.4)
Vanadium (mg kg^{-1})	74.8 (7.6)	50.0 (1.7)	49.2 (0.9)
Zinc (mg kg^{-1})	46.8 (2.5)	46.6 (1.3)	41.8 (1.0)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

Table 4. Physical and chemical properties of soil amendments.

Parameter	Agricultural Soil	Native Sand	Yard Compost	Biosolids Compost
% Sand	85.1 (0.9)	94.5 (0.2)	69.0 (5.5)	84.6 (1.0)
% Silt	10.9 (1.2)	2.6 (0.3)	27.9 (5.0)	11.4 (0.8)
% Clay	4.1 (0.3)	2.9 (0.3)	3.1 (0.8)	4.0 (0.3)
Texture	Loamy sand	Sand	Sandy loam	Loamy sand
Hydrogen Ion Concentration (pH)	7.0 (0.0)*	7.3 (0.0)*	6.5 (0.1)	7.6 (0.0)*
Electrical Conductivity (dS m^{-1})	1.0 (0.1)	0.1 (0.0)*	10.7 (0.5)	6.0 (0.1)
Sodium Adsorption Ratio	0.2 (0.1)	0.6 (0.0)*	1.5 (0.1)	0.6 (0.0)*
Cation Exchange Capacity (meq 100 g^{-1})	5.9 (0.3)	2.2 (0.1)	30.8 (2.4)	11.4 (0.7)
Saturation (%)	29.9 (0.5)	27.0 (0.6)	234.8 (4.9)	58.2 (1.1)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

Table 5. Macro and micro nutrient properties of soil amendments.

Parameter	Agricultural Soil	Native Sand	Yard Compost	Biosolids Compost
Total Carbon (%)	1.0 (0.0)	0.2 (0.0)*	16.9 (0.2)	3.9 (0.1)
Total Nitrogen (%)	0.1 (0.0)*	0.0* (0.0)	1.9 (0.0)*	0.4 (0.0)*
Total Calcium (mg L^{-1})	129.2 (8.9)	11.9 (0.6)	166.4 (17.3)	251.0 (3.4)
Total Magnesium (mg L^{-1})	23.5 (1.4)	3.3 (0.2)	203.6 (34.1)	115.0 (1.8)
Total Potassium (mg L^{-1})	35.2 (2.3)	3.6 (0.1)	547.6 (22.9)	1154.0 (40.6)
Total Sodium (mg L^{-1})	5.1 (0.4)	8.4 (0.8)	123.2 (5.2)	48.2 (0.9)
Available Nitrate (mg kg^{-1})	26.3 (2.0)	1.0 (0.0)*	734.6 (69.2)	196.8 (6.1)
Available Phosphate (mg kg^{-1})	52.4 (3.1)	12.8 (0.7)	6566.0 (217.3)	277.2 (12.0)
Available Potassium (mg kg^{-1})	157.6 (4.8)	38.2 (0.6)	2448.0 (84.5)	1996.0 (39.4)
Available Sulfate (mg kg^{-1})	3.4 (0.2)	1.7 (1.7)	1374.0 (10.3)	43.42 (2.0)
Available Copper (mg kg^{-1})	0.2 (0.0)*	0.1 (0.0)*	62.7 (0.6)	0.7 (0.0)*
Available Zinc (mg kg^{-1})	0.4 (0.0)*	0.2 (0.0)*	79.1 (0.9)	6.0 (0.2)
Available Manganese (mg kg^{-1})	2.7 (0.1)	1.3 (0.0)*	72.4 (1.3)	8.5 (0.9)
Available Iron (mg kg^{-1})	15.5 (0.3)	15.8 (0.4)	149.5 (10.3)	58.5 (3.0)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

Table 6. Metal and selenium concentrations in soil amendments.

Parameter	Agricultural Soil	Native Sand	Yard Compost	Biosolids Compost
Antimony (mg kg^{-1})	0.1 (0.0)*	0.1 (0.0)	2.0 (0.1)	0.6 (0.4)
Arsenic (mg kg^{-1})	2.4 (0.0)*	3.3 (0.1)	3.2 (0.1)	3.2 (0.1)
Barium (mg kg^{-1})	46.0 (0.9)	45.1 (1.5)	218.0 (7.0)	72.0 (2.2)
Cadmium (mg kg^{-1})	0.0* (0.0)	0.0* (0.0)	1.0 (0.0)*	0.0* (0.0)
Chromium (mg kg^{-1})	6.3 (0.9)	5.6 (0.1)	20.4 (0.7)	7.9 (0.6)
Cobalt (mg kg^{-1})	2.9 (0.1)	3.6 (0.1)	3.5 (0.1)	3.6 (0.2)
Copper (mg kg^{-1})	4.1 (0.2)	2.8 (0.1)	312.8 (12.8)	10.6 (0.3)
Lead (mg kg^{-1})	2.5 (0.0)	2.5 (0.0)	24.5 (1.1)	55.6 (49.1)
Molybdenum (mg kg^{-1})	0.5 (0.0)	0.5 (0.0)	6.3 (0.3)	0.5 (0.0)
Mercury (mg kg^{-1})	0.0* (0.0)	0.0* (0.0)*	1.0 (0.1)	0.0* (0.0)
Nickel (mg kg^{-1})	5.4 (0.1)	9.0 (0.7)	15.9 (0.6)	8.9 (0.4)
Selenium (mg kg^{-1})	0.3 (0.0)	0.3 (0.0)	2.1 (0.1)	0.3 (0.0)
Silver (mg kg^{-1})	0.5 (0.0)	0.5 (0.0)	6.3 (0.3)	0.5 (0.0)
Tin (mg kg^{-1})	2.5 (0.0)	2.5 (0.0)	14.0 (0.5)	2.5 (0.0)
Uranium (mg kg^{-1})	1.0 (0.0)	1.0 (0.0)	6.8 (0.3)	1.0 (0.0)
Vanadium (mg kg^{-1})	10.6 (0.1)	8.6 (0.3)	13.7 (0.3)	11.7 (0.5)
Zinc (mg kg^{-1})	19.6 (1.0)	307.8 (12.7)	48.0 (1.3)	18.2 (2.7)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

Table 7. Textural properties of processed kimberlite reclamation treatments.

Reclamation Treatment	% Sand	% Silt	% Clay	Texture
Orion PK	66.2 (2.7)	20.2 (1.1)	13.6 (1.7)	Sandy loam
Orion PK, Agricultural Soil	82.8 (2.1)	11.7 (0.7)	5.5 (1.5)	Loamy sand
Orion PK, Native Sand	88.0 (0.7)	7.1 (0.3)	4.9 (0.4)	Sand
Orion PK, Yard Compost	70.4 (0.2)	18.4 (0.3)	11.2 (0.1)	Sandy loam
Orion PK, Biosolids Compost	76.8 (0.4)	15.0 (0.6)	8.2 (0.2)	Sandy loam
Star PK	69.6 (1.3)	20.7 (1.3)	9.8 (0.3)	Sandy loam
Star PK, Agricultural Soil	78.7 (0.7)	13.8 (0.6)	7.5 (0.2)	Loamy sand
Star PK, Native Sand	83.9 (0.4)	9.7 (0.3)	6.4 (2.7)	Loamy sand
Star PK, Yard Compost	69.7 (0.6)	20.0 (0.5)	10.3 (0.2)	Sandy loam
Star PK, Biosolids Compost	73.1 (1.1)	17.6 (0.2)	9.4 (0.8)	Sandy loam
Mix PK	90.9 (0.3)	4.9 (0.2)	4.2 (0.2)	Sand
Mix PK, Agricultural Soil	88.6 (0.8)	7.9 (0.5)	3.5 (0.3)	Sand
Mix PK, Native Sand	92.8 (0.2)	3.8 (0.2)	3.4 (0.1)	Sand
Mix PK, Yard Compost	90.5 (0.1)	5.9 (0.2)	3.6 (0.2)	Sand
Mix PK, Biosolids Compost	88.8 (0.6)	7.9 (0.4)	3.3 (0.3)	Sand

Numbers in brackets are standard errors of mean.

PK = processed kimberlite

Table 8. Chemical properties of processed kimberlite reclamation treatments.

Reclamation Treatment	Hydrogen Ion Concentration (pH)	Electrical Conductivity (dS m^{-1})	Sodium Adsorption Ratio	Cation Exchange Capacity (meq 100 g^{-1})	% Saturation
Orion PK	9.1 (0.1)	3.5 (0.2)	74.4 (16.7)	22.1 (2.3)	80.2 (11.5)
Orion PK, Agricultural Soil	8.9 (0.0)	3.0 (0.1)	54.1 (7.9)	8.2 (0.4)	33.5 (0.5)
Orion PK, Native Sand	8.9 (0.0)	2.2 (0.1)	34.4 (1.1)	6.8 (1.0)	30.5 (1.2)
Orion PK, Yard Compost	8.4 (0.1)	8.2 (0.2)	32.4 (3.7)	23.9 (0.1)	80.2 (11.5)
Orion PK, Biosolids Compost	8.7 (0.0)	5.9 (0.1)	32.7 (0.3)	16.1 (0.4)	48.2 (0.5)
Star PK	8.6 (0.0)	3.2 (0.2)	17.9 (0.9)	5.3 (0.2)	46.6 (1.7)
Star PK, Agricultural Soil	8.1 (0.1)	3.6 (0.3)	11.5 (1.3)	5.5 (0.2)	32.9 (1.0)
Star PK, Native Sand	8.3 (0.0)	3.6 (0.1)	14.9 (0.3)	3.4 (0.2)	30.5 (1.2)
Star PK, Yard Compost	7.6 (0.1)	12.2 (0.4)	8.1 (0.6)	11.3 (1.1)	50.8 (2.3)
Star PK ,Biosolids Compost	8.2 (0.0)	7.6 (0.2)	11.8 (0.9)	9.5 (0.5)	42.4 (1.2)
Mix PK	9.3 (0.1)	5.9 (0.4)	95.9 (2.1)	40.7 (0.7)	38.4 (0.7)
Mix PK, Agricultural Soil	8.9 (0.0)	5.2 (0.1)	79.8 (2.9)	22.6 (1.2)	34.0 (1.3)
Mix PK, Native Sand	8.9 (0.0)	4.2 (0.3)	84.4 (2.8)	21.0 (1.3)	33.3 (0.3)
Mix PK, Yard Compost	8.0 (0.0)*	10.9 (0.3)	61.9 (1.6)	42.8 (0.9)	69.1 (2.3)
Mix PK, Biosolids Compost	8.7 (0.1)	5.4 (0.2)	31.6 (0.3)	20.8 (0.2)	47.6 (1.0)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

PK = processed kimberlite

Table 9. Total nutrients in processed kimberlite reclamation treatments.

Reclamation Treatment	Carbon (%)	Nitrogen (%)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Potassium (mg L^{-1})	Sodium (mg L^{-1})
Orion PK	1.2 (0.1)	0.0* (0.0)	3.6 (0.7)	5.0 (1.9)	19.8 (1.6)	823.8 (56.9)
Orion PK, Agricultural Soil	1.1 (0.0)	0.0* (0.0)*	5.8 (0.3)	4.8 (1.2)	18.0 (1.0)	643.0 (29.8)
Orion PK, Native Sand	0.4 (0.0)*	0.0* (0.0)	5.3 (0.8)	4.5 (0.3)	8.3 (0.6)	443.0 (21.8)
Orion PK, Yard Compost	3.9 (0.7)	0.3 (0.1)	51.0 (9.5)	78.8 (11.3)	183.7 (28.2)	1567.7 (97.0)
Orion PK, Biosolids compost	2.7 (0.1)	0.2 (0.0)*	28.2 (0.3)	36.3 (0.5)	294.0 (6.2)	1116.7 (18.6)
Star PK	0.9 (0.0)*	0.0* (0.0)	12.5 (0.8)	42.7 (2.3)	32.1 (1.6)	591.8 (44.1)
Star PK, Agricultural Soil	1.0 (0.0)	0.1 (0.0)*	71.8 (6.3)	67.6 (3.1)	34.1 (1.0)	562.7 (62.3)
Star PK, Native Sand	0.5 (0.0)*	0.0* (0.0)	36.1 (0.6)	53.9 (1.4)	17.1 (0.5)	605.33 (16.0)
Star PK, Yard Compost	2.6 (0.2)	0.2 (0.0)*	348.7 (35.1)	604.7 (34.8)	334.3 (29.9)	1078.7 (47.1)
Star PK, Biosolids Compost	2.2 (0.2)	0.1 (0.0)*	115.7 (5.2)	176.3 (6.7)	541.7 (35.9)	865.3 (66.0)
Mix PK	1.0 (0.1)	0.0* (0.0)	13.6 (2.5)	3.0 (0.5)	23.2 (1.7)	1254.0 (87.8)
Mix PK, Agricultural Soil	1.0 (0.0)*	0.0* (0.0)*	19.1 (1.9)	2.5 (0.0)	23.3 (0.9)	1256.7 (23.3)
Mix PK, Native Sand	0.4 (0.0)*	0.0* (0.0)	9.6 (0.7)	2.5 (0.0)	15.0 (2.1)	950.0 (66.8)
Mix PK, Yard Compost	3.5 (0.2)	0.3 (0.0)*	78.7 (7.1)	31.0 (3.8)	121.3 (2.7)	2550.0 (85.4)
Mix PK, Biosolids Compost	2.8 (0.1)	0.2 (0.0)*	50.6 (3.9)	24.3 (1.7)	181.7 (16.6)	1090.0 (34.6)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

PK = processed kimberlite

Table 10. Available nutrients of processed kimberlite reclamation treatments.

Reclamation Treatment	Nitrogen (mg kg^{-1})	Phosphorus (mg kg^{-1})	Potassium (mg kg^{-1})	Sulfur (mg kg^{-1})
Orion PK	6.7 (0.5)	1.0 (0.0)	206.4 (12.2)	121.7 (9.4)
Orion PK, Agricultural Soil	18.7 (0.6)	7.9 (0.4)	159.7 (4.8)	84.7 (7.1)
Orion PK, Native Sand	3.6 (0.2)	5.1 (0.3)	90.0 (5.3)	60.6 (2.1)
Orion PK, Yard Compost	219.7 (32.6)	657.3 (241.3)	844.7 (177.7)	453.3 (47.3)
Orion PK, Biosolids Compost	95.3 (2.5)	61.0 (1.2)	1260.0 (28.5)	150.3 (0.9)
Star PK	1.7 (0.5)	1.0 (0.0)	119.8 (3.1)	93.2 (7.0)
Star PK, Agricultural Soil	14.0 (1.5)	12.3 (3.4)	149.3 (1.8)	84.5 (7.7)
Star PK, Native Sand	2.1 (0.7)	2.0 (0.5)	71.3 (3.4)	76.5 (1.3)
Star PK, Yard Compost	786.7 (336.9)	171.2 (47.0)	477.7 (38.7)	369.7 (19.7)
Star PK, Biosolids Compost	34.0 (4.8)	2.2 (0.2)	1035.0 (70.8)	173.0 (5.3)
Mix PK	55.6 (5.2)	1.2 (0.2)	307.0 (4.8)	202.8 (22.9)
Mix PK, Agricultural Soil	26.4 (1.1)	18.4 (0.8)	229.7 (1.2)	124.0 (8.7)
Mix PK, Native Sand	15.0 (0.2)	4.9 (0.8)	163.7 (6.6)	107.7 (2.0)
Mix PK, Yard Compost	375.0 (29.0)	1004.3 (63.9)	777.3 (42.3)	514.0 (18.2)
Mix PK, Biosolids Compost	92.3 (5.7)	104.3 (1.8)	1013.0 (47.0)	106.0 (2.5)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

PK = processed kimberlite

Table 11. Available micro nutrients of processed kimberlite reclamation treatments.

Reclamation Treatment	Copper (mg kg^{-1})	Zinc (mg kg^{-1})	Manganese (mg kg^{-1})	Iron (mg kg^{-1})
Orion PK	1.8 (0.1)	1.3 (0.1)	4.3 (0.6)	31.6 (1.8)
Orion PK, Agricultural Soil	1.0 (0.0)*	2.4 (0.3)	3.0 (0.0)*	30.3 (0.7)
Orion PK, Native Sand	0.7 (0.0)*	0.5 (0.0)*	2.5 (0.1)	21.8 (0.4)
Orion PK, Yard Compost	9.4 (2.0)	8.8 (2.4)	16.8 (2.5)	8.8 (2.4)
Orion PK, Biosolids Compost	1.8 (0.0)*	16.7 (2.8)	7.7 (0.0)*	59.4 (1.0)
Star PK	1.3 (0.0)*	0.9 (0.0)*	1.5 (0.1)	33.3 (1.0)
Star PK, Agricultural Soil	0.7 (0.1)	12.9 (5.0)	2.5 (0.1)	27.6 (0.7)
Star PK, Native Sand	0.6 (0.1)	0.5 (0.0)*	1.8 (0.1)	25.9 (1.1)
Star PK, Yard Compost	5.5 (0.5)	6.1 (0.5)	9.6 (0.9)	32.7 (1.2)
Star PK, Biosolids Compost	1.2 (0.1)	7.1 (0.3)	4.4 (0.1)	42.3 (1.0)
Mix PK	1.2 (0.1)	1.1 (0.1)	4.7 (0.2)	9.1 (0.5)
Mix PK, Agricultural Soil	1.0 (0.0)*	1.1 (0.2)	5.1 (0.1)	15.3 (0.2)
Mix PK, Native Sand	0.8 (0.0)*	0.6 (0.0)*	4.3 (0.2)	14.1 (0.0)*
Mix PK, Yard Compost	9.6 (0.4)	13.9 (1.0)	20.7 (0.5)	20.9 (0.6)
Mix PK, Biosolids Compost	1.2 (0.0)*	4.1 (0.1)	8.8 (0.1)	57.5 (2.1)

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

PK = processed kimberlite

Table 12a. Metal concentrations in processed kimberlite reclamation treatments.

Reclamation Treatment	Antimony (mg kg^{-1})	Arsenic (mg kg^{-1})	Barium (mg kg^{-1})	Cadmium (mg kg^{-1})	Chromium (mg kg^{-1})	Cobalt (mg kg^{-1})
Orion PK	0.1 (0.0)*	3.2 (0.6)	211.8 (11.6)	0.0* (0.0)	546.4 (41.6)	76.0 (6.0)
Orion PK, Agricultural Soil	0.1 (0.0)	2.0 (0.1)	110.8 (10.4)	0.0* (0.0)	258.7 (40.3)	29.0 (4.1)
Orion PK, Native Sand	0.1 (0.0)	2.7 (0.1)	112.0 (3.1)	0.0* (0.0)	212.7 (5.4)	26.9 (1.2)
Orion PK, Yard Compost	0.4 (0.1)	1.8 (0.1)	214.7 (2.0)	1.8 (0.1)	386.7 (14.0)	57.7 (4.1)
Orion PK, Biosolids Compost	0.1 (0.0)*	2.2 (0.1)	134.3 (7.4)	4.3 (4.3)	263.3 (18.2)	34.9 (2.5)
Star PK	0.1 (0.0)	2.0 (0.1)	209.6 (7.5)	0.0* (0.0)	398.4 (13.8)	70.9 (1.0)
Star PK, Agricultural Soil	0.1 (0.0)	1.8 (0.1)	113.1 (14.0)	0.0* (0.0)	193.3 (34.1)	37.5 (7.7)
Star PK, Native Sand	0.1 (0.0)	2.5 (0.1)	125.7 (10.5)	0.0* (0.0)	191.7 (24.9)	39.2 (5.1)
Star PK, Yard Compost	0.4 (0.1)	1.7 (0.1)	165.3 (5.8)	0.0* (0.0)	316.3 (6.1)	58.9 (1.7)
Star PK, Biosolids Compost	0.1 (0.0)	2.0 (0.1)	124.3 (7.7)	0.0* (0.0)	238.0 (28.7)	43.1 (5.2)
Mix PK	0.1 (0.0)	0.8 (0.0)*	268.8 (13.8)	0.0 (0.0)	350.8 (26.0)	47.8 (1.3)
Mix PK, Agricultural Soil	0.1 (0.0)	1.3 (0.1)	212.0 (16.8)	0.0* (0.0)	190.7 (7.8)	31.3 (1.5)
Mix PK, Native Sand	0.1 (0.0)	2.2 (0.4)	154.4 (30.6)	0.0* (0.0)	155.1 (36.5)	23.3 (5.4)
Mix PK, Yard Compost	0.3 (0.0)*	1.2 (0.0)*	255.0 (16.5)	0.0* (0.0)	278.0 (52.5)	37.0 (1.7)
Mix PK, Biosolids Compost	0.1 (0.0)	1.7 (0.1)	169.0 (14.0)	0.0* (0.0)	222.3 (52.5)	40.8 (4.1)
CCME Guidelines	-	12	500	1.4	64	40

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

PK = processed kimberlite

Table 12b. Metal and selenium concentrations in processed kimberlite reclamation treatments.

Reclamation Treatment	Copper (mg kg^{-1})	Lead (mg kg^{-1})	Molybdenum (mg kg^{-1})	Selenium (mg kg^{-1})	Silver (mg kg^{-1})	Tin (mg kg^{-1})
Orion PK	59.5 (7.0)	6.9 (0.4)	3.1 (0.7)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
Orion PK, Agricultural Soil	22.4 (2.6)	2.5 (0.0)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
Orion PK, Native Sand	20.4 (1.2)	3.5 (1.0)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
Orion PK, Yard Compost	84.0 (13.5)	9.4 (0.9)	1.9 (0.3)	0.5 (0.1)	0.9 (0.4)	3.7 (1.2)
Orion PK, Biosolids Compost	27.1 (1.5)	6.5 (0.3)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
Star PK	42.8 (2.7)	6.9 (0.2)	1.4 (0.2)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
Star PK, Agricultural Soil	24.1 (4.2)	4.5 (1.0)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	4.7 (2.2)
Star PK, Native Sand	20.3 (2.4)	4.6 (1.0)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
Star PK, Yard Compost	75.8 (11.6)	9.5 (0.7)	1.6 (0.3)	0.5 (0.1)	0.9 (0.2)	2.5 (0.0)
Star PK, Biosolids Compost	24.8 (2.8)	6.7 (0.2)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
Mix PK	28.6 (1.8)	7.9 (0.3)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
Mix PK, Agricultural Soil	23.8 (5.4)	6.4 (0.4)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	2.5 (1.0)
Mix PK, Native Sand	15.5 (3.0)	4.6 (1.0)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
Mix PK, Yard Compost	66.4 (3.9)	10.8 (0.3)	1.1 (0.1)	0.6 (0.0)*	0.8 (0.3)	2.5 (0.0)
Mix PK, Biosolids Compost	24.0 (1.9)	6.5 (0.2)	0.5 (0.0)	0.3 (0.0)	0.5 (0.0)	2.5 (0.0)
CCME Guidelines	63	70	-	1	-	-

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

PK = processed kimberlite

Table 12c. Metal concentrations in processed kimberlite reclamation treatments.

Reclamation Treatment	Uranium (mg kg^{-1})	Nickel (mg kg^{-1})	Vanadium (mg kg^{-1})	Zinc (mg kg^{-1})
Orion PK	1.0 (0.0)	986.2 (76.6)	74.8 (7.7)	46.8 (2.5)
Orion PK, Agricultural Soil	1.0 (0.0)	379.7 (58.0)	35.8 (3.8)	36.3 (1.8)
Orion PK, Native Sand	1.0 (0.0)	341.7 (14.1)	30.5 (1.6)	26.3 (0.7)
Orion PK, Yard Compost	2.0 (0.6)	785.7 (54.9)	52.2 (1.2)	90.7 (14.2)
Orion PK, Biosolids Compost	1.0 (0.0)	458.3 (36.9)	37.1 (2.2)	88.7 (11.8)
Star PK	1.0 (0.0)	1346.0 (60.1)	50.0 (1.7)	46.6 (1.3)
Star PK, Agricultural Soil	1.0 (0.0)	605.3 (138.1)	28.1 (3.0)	54.3 (9.3)
Star PK, Native Sand	1.0 (0.0)	606.7 (85.7)	27.4 (1.8)	32.7 (2.0)
Star PK, Yard Compost	2.0 (0.6)	1038.7 (120.9)	39.5 (0.2)	90.3 (10.7)
Star PK, Biosolids Compost	1.0 (0.0)	695.0 (96.5)	31.9 (2.6)	55.0 (2.3)
Mix PK	1.6 (0.4)	670.8 (15.4)	49.2 (0.9)	41.8 (1.0)
Mix PK, Agricultural Soil	1.0 (0.0)	445.0 (18.9)	34.4 (1.1)	60.0 (24.5)
Mix PK, Native Sand	1.0 (0.0)	311.3 (88.2)	26.8 (4.6)	28.0 (3.8)
Mix PK, Yard Compost	2.4 (0.2)	565.3 (39.3)	41.0 (1.5)	131.3 (17.8)
Mix PK, Biosolids Compost	1.4 (0.4)	631.7 (76.1)	32.5 (3.3)	44.0 (1.0)
CCME Guidelines	23	50	130	200

Numbers in brackets are standard errors.

* Trace amounts less than 0.04.

PK = processed kimberlite

Table 13. Seed germination and establishment in Orion processed kimberlite at 12 weeks.

Amendment		*Agropyron trachycaulum*	*Bromus elatior*	*Elymus innovatus*	*Festuca saximontana*	*Hordeum vulgare*	*Koeleria macrantha*
Unamended	Germination	79 (7)	62 (7)	70 (7)	20 (2)	84 (4)	3 (2)
	Establishment	96.9 (6.1)	100.0 (0.0)	65.6 (17.8)	53.3 (16.2)	72.1 (8.2)	20.0 (20.0)
Agricultural Soil	Germination	73 (6)	82 (9)	56 (5)	28 (5)	94 (2)	27 (7)
	Establishment	84.5 (6.9)	97.5 (2.5)	58.9 (9.4)	82.7 (7.5)	77.1 (10.6)	82.7 (12.9)
Native Sand	Germination	84 (3)	72 (7)	74 (4)	25 (9)	98 (2)	45 (7)
	Establishment	100.0 (0.0)	100.0 (0.0)	70.9 (10.0)	53.3 (16.2)	96.0 (2.4)	70.1 (13.1)
Fertilizer	Germination	75 (7)	54 (10)	58 (7)	17 (6)	94 (2)	12 (2)
	Establishment	98.3 (1.7)	100.0 (0.0)	93.8 (3.8)	63.0 (19.2)	70.5 (9.0)	50.0 (22.4)
Yard Compost	Germination	41 (5)	48 (9)	24 (7)	17 (5)	66 (9)	9 (3)
	Establishment	100 (0.0)	100.0 (0.0)	80.0 (20.0)	80.0 (20.0)	100.0 (0.0)	60.0 (24.5)
Biosolids Compost	Germination	81 (3)	62 (11)	52 (4)	33 (6)	82 (6)	24 (2)
	Establishment	100 (0.0)	100.0 (0.0)	96.7 (3.3)	87.1 (9.7)	100.0 (0.0)	73.3 (13.8)

Numbers in brackets are standard errors.

* Trace amounts less than 0.4.

Table 14. Seed germination and establishment in Star processed kimberlite at 12 weeks.

Amendment		*Agropyron trachycaulum*	*Bromus elatior*	*Elymus innovatus*	*Festuca saximontana*	*Hordeum vulgare*	*Koeleria macrantha*
Unamended	Germination	88 (4)	84 (5)	34 (9)	41 (9)	90 (7)	29 (7)
	Establishment	97.0 (1.9)	100.0 (0.0)	77.1 (19.5)	80.5 (7.0)	90.1 (6.1)	79.8 (8.2)
Agricultural Soil	Germination	84 (5)	68 (13)	38 (7)	19 (7)	80 (18)	21 (2)
	Establishment	97.1 (2.9)	98.0 (2.0)	81.7 (14.5)	28.3 (17.4)	91.6 (4.1)	53.3 (22.6)
Native Sand	Germination	87 (2)	76 (7)	44 (7)	35 (7)	92 (5)	40 (6)
	Establishment	100.0 (0.0)	100.0 (0.0)	92.1 (5.1)	75.3 (8.0)	98.0 (2.0)	92.5 (5.0)
Fertilizer	Germination	69 (9)	56 (5)	40 (5)	16 (5)	86 (5)	9 (3)
	Establishment	98.3 (1.7)	100.0 (0.0)	80.0 (20.0)	70.0 (20.0)	100.0 (0.0)	80.0 (20.0)
Yard Compost	Germination	67 (6)	64 (4)	42 (10)	17 (6)	72 (6)	15 (8)
	Establishment	96.2 (2.3)	100.0 (0.0)	79.2 (6.4)	50.0 (21.1)	100.0 (0.0)	42.7 (23.5)
Biosolids Compost	Germination	69 (3)	60 (7)	40 (10)	24 (8)	86 (5)	13 (6)
	Establishment	100.0 (0.0)	100.0 (0.0)	96.7 (3.3)	62.5 (15.8)	100.0 (0.0)	57.3 (20.5)

Numbers in brackets are standard errors.

* Trace amounts less than 0.4.

Table 15. Seed germination and establishment in mixed coarse processed kimberlite at 12 weeks.

Amendment		*Agropyron trachycaulum*	*Bromus elatior*	*Elymus innovatus*	*Festuca saximontana*	*Hordeum vulgare*	*Koeleria macrantha*
Unamended	Germination	77 (5)	64 (5)	62 (12)	17 (3)	84 (10)	15 (6)
	Establishment	100.0 (0.0)	96.7 (3.3)	73.1 (18.7)	20.0 (20.0)	76.0 (11.2)	34.7 (18.3)
Agricultural Soil	Germination	78 (11)	84 (7)	52 (7)	52 (6)	96 (2)	39 (5)
	Establishment	91.7 (8.3)	100.0 (0.0)	45.1 (13.3)	74.1 (8.7)	68.9 (7.3)	69.1 (11.8)
Native Sand	Germination	91 (5)	84 (9)	74 (4)	44 (8)	100 (0)	35 (5)
	Establishment	89.9 (7.1)	98.0 (2.0)	92.5 (7.5)	54.9 (6.4)	80.0 (7.1)	58.3 (5.3)
Fertilizer	Germination	49 (7)	18 (4)	16 (7)	27 (12)	78 (7)	11 (4)
	Establishment	93.3 (2.8)	100.0 (0.0)	20.0 (12.2)	14.0 (11.7)	83.6 (10.1)	40.0 (19.4)
Yard Compost	Germination	69 (5)	46 (12)	38 (8)	15 (4)	72 (4)	7 (5)
	Establishment	98.2 (1.8)	100.0 (0.0)	96.0 (4.0)	73.3 (19.4)	100.0 (0.0)	41.7 (25.0)
Biosolids Compost	Germination	43 (7)	28 (11)	30 (5)	17 (5)	64 (7)	9 (5)
	Establishment	98.0 (2.0)	80.0 (20.0)	88.3 (7.3)	95.0 (5.5)	100.0 (0.0)	35.0 (21.8)

Numbers in brackets are standard errors.

* Trace amounts less than 0.4.

Table 16. Plant response in Orion processed kimberlite at 12 weeks.

Amendment		*Agropyron trachycaulum*	*Bromus elatior*	*Elymus innovatus*	*Festuca saximontana*	*Hordeum vulgare*	*Koeleria macrantha*
Unamended	Density	11 (1)	5 (1)	5 (2)	2 (1)	1 (1)	0* (0)*
	Height (cm)	16 (2)	8 (1)	4 (1)	2 (1)	11 (6)	1 (1)
	Biomass	0.19 (0.05)	0.07 (0.01)	0.02 (0.01)	0.00* (0.00)*	0.33 (0.14)	0.00 (0.00)
Agricultural Soil	Density	9 (1)	4 (1)	3 (1)	3 (1)	2 (1)	3 (1)
	Height (cm)	33 (3)	33 (4)	14 (2)	7 (2)	21 (9)	5 (1)
	Biomass	0.87 (0.14)	0.58 (0.12)	0.10 (0.02)	0.02 (0.00)*	0.98 (0.38)	0.01 (0.01)
Native Sand	Density	13 (0)*	6 (1)	5 (1)	3 (1)	4 (0)*	5 (1)
	Height (cm)	23 (3)	13 (1)	9 (1)	2 (1)	33 (3)	2 (1)
	Biomass	0.48 (0.08)	0.16 (0.03)	0.06 (0.01)	0.00* (0.00)*	0.92 (0.11)	0.01 (0.00)*
Fertilizer	Density	11 (1)	4 (1)	5 (1)	2 (1)	2 (1)	1 (0)*
	Height (cm)	30 (1)	10 (2)	9 (3)	3 (1)	13 (6)	2 (0)*
	Biomass	0.70 (0.11)	0.10 (0.04)	0.06 (0.02)	0.00* (0.00)*	0.45 (0.11)	0.00 (0.00)
Yard Compost	Density	6 (1)	4 (1)	2 (1)	3 (1)	6 (1)	1 (1)
	Height (cm)	32 (4)	56 (5)	28 (7)	8 (3)	44 (1)	5 (2)
	Biomass	1.78 (0.35)	2.02 (0.37)	0.55 (0.22)	0.03 (0.02)	5.62 (0.62)	0.01 (0.00)*
Biosolids Compost	Density	12 (1)	5 (1)	5 (0)*	4 (1)	5 (0)*	3 (1)
	Height (cm)	39 (3)	56 (1)	37 (2)	16 (4)	56 (1)	11 (2)
	Biomass	3.18 (0.52)	2.14 (0.35)	1.32 (0.34)	0.32 (0.14)	5.65 (4.22)	0.06 (0.02)

Numbers in brackets are standard errors.

* Trace amounts less than 0.4.

Table 17. Plant response in Star processed kimberlite at 12 weeks.

Amendment		*Agropyron trachycaulum*	*Bromus elatior*	*Elymus innovatus*	*Festuca saximontana*	*Hordeum vulgare*	*Koeleria macrantha*
Unamended	Density	13 (1)	6 (1)	3 (1)	5 (1)	4 (1)	4 (1)
	Height (cm)	20 (3)	13 (1)	11 (2)	3 (1)	29 (1)	2 (0)*
	Biomass	0.38 (0.14)	0.13 (0.02)	0.02 (0.01)	0.01 (0.00)*	0.80 (0.12)	0.00* (0.00)*
Agricultural Soil	Density	12 (1)	4 (1)	3 (1)	1 (1)	3 (1)	2 (1)
	Height (cm)	31 (2)	42 (3)	21 (3)	7 (4)	36 (3)	4 (2)
	Biomass	1.06 (0.11)	0.68 (0.12)	0.12 (0.03)	0.08 (0.07)	1.22 (0.16)	0.00* (0.00)*
Native Sand	Density	13 (0)*	5 (0)*	4 (1)	4 (1)	5 (0)*	6 (1)
	Height (cm)	27 (2)	24 (2)	24 (2)	7 (3)	38 (2)	8 (1)
	Biomass	0.67 (0.12)	0.38 (0.03)	0.21 (0.04)	0.04 (0.02)	1.52 (0.28)	0.04 (0.01)
Fertilizer	Density	10 (1)	5 (1)	3 (1)	2 (1)	5 (0)*	1 (0)*
	Height (cm)	33 (3)	34 (3)	20 (3)	5 (2)	43 (2)	3 (1)
	Biomass	0.92 (0.16)	0.53 (0.17)	0.18 (0.07)	0.02 (0.01)	2.81 (0.66)	0.00* (0.00)*
Yard Compost	Density	10 (1)	6 (1)	3 (1)	2 (1)	6 (0)*	1 (0)*
	Height (cm)	35 (4)	62 (3)	34 (3)	7 (4)	49 (4)	3 (1)
	Biomass	3.56 (0.83)	3.81 (0.15)	1.34 (0.64)	0.09 (0.07)	6.42 (0.69)	0.00* (0.00)
Biosolids Compost	Density	10 (1)	6 (1)	4 (1)	2 (1)	5 (0)*	1 (0)*
	Height (cm)	38 (1)	48 (2)	36 (4)	11 (4)	53 (2)	3 (1)
	Biomass	2.42 (0.40)	1.56 (0.15)	0.99 (0.35)	0.03 (0.02)	4.91 (0.80)	0.00* (0.00)*

Numbers in brackets are standard errors.

* Trace amounts less than 0.4.

Table 18. Plant response in mixed coarse processed kimberlite at 12 weeks.

Amendment		*Agropyron trachycaulum*	*Bromus elatior*	*Elymus innovatus*	*Festuca saximontana*	*Hordeum vulgare*	*Koeleria macrantha*
Unamended	Density	12	4	5	0*	2	1
		(1)	(1)	(2)	(0)*	(1)	(0)*
	Height (cm)	22	9.0	3	1	10	1
		(6)	(1)	(1)	(1)	(6)	(1)
	Biomass	0.72	0.05	0.01	0.00	0.40	0.00*
		(0.45)	(0.01)	(0.00)*	(0.00)	(0.12)	(0.00)
Agricultural Soil	Density	11	6	2	6	2	4
		(2)	(1)	(1)	(1)	(1)	(1)
	Height (cm)	34	21	12	6	19	6
		(3)	(3)	(3)	(4)	(5)	(1)
	Biomass	1.78	0.36	0.06	0.07	0.44	0.03
		(0.13)	(0.07)	(0.02)	(0.04)	(0.05)	(0.00)*
Native Sand	Density	12	5	7	4	3	3
		(1)	(0)*	(1)	(1)	(1)	(1)
	Height (cm)	27	12	9	7	30	2
		(2)	(1)	(0)*	(2)	(1)	(1)
	Biomass	0.87	0.17	0.07	0.02	0.88	0.00*
		(0.08)	(0.01)	(0.01)	(0.00)*	(0.06)	(0.00)*
Fertilizer	Density	7	1	0*	1	3	1
		(1)	(0)*	(0)*	(1)	(2)	(0)*
	Height (cm)	19	16	18	1	16	2
		(5)	(3)	(2)	(1)	(7)	(1)
	Biomass	0.28	0.05	0.00*	0.00*	0.46	0.00
		(0.15)	(0.04)	(0.00)*	(0.00)*	(0.08)	(0.00)
Yard Compost	Density	10	4	4	2	6	1
		(1)	(1)	(1)	(1)	(1)	(1)
	Height (cm)	42	53	25	6	43	2
		(2)	(7)	(5)	(2)	(4)	(2)
	Biomass	3.36	1.80	0.41	0.01	7.77	0.00*
		(0.68)	(0.63)	(0.18)	(0.00)*	(0.89)	(0.00)*
Biosolids Compost	Density	6	3	3	2	5	1
		(1)	(1)	(1)	(1)	(1)	(1)
	Height (cm)	34	40	40	16	50	2
		(5)	(11)	(5)	(4)	(3)	(1)
	Biomass	1.94	1.06	0.73	0.14	4.50	0.00*
		(0.52)	(0.52)	(0.28)	(0.06)	(0.39)	(0.00)

Numbers in brackets are standard errors.

* Trace amounts less than 0.4.

Table 19. Overall plant response to processed kimberlite reclamation treatments.

	Orion	Star	Mixed	Mean
Germination				
Unamended	53	61	53	56
Agricultural Soil	60	52	67	60
Native Sand	66	62	71	66
Fertilizer	52	46	33	44
Yard Compost	34	46	41	40
Biosolids Compost	56	49	32	46
Establishment				
Unamended	68	87	67	74
Agricultural Soil	81	75	75	77
Native Sand	82	93	79	85
Fertilizer	79	88	58	75
Yard Compost	87	78	85	83
Biosolids Compost	93	86	83	87
Biomass				
Unamended	0.1017	0.2233	0.1967	0.1739
Agricultural Soil	0.4267	0.5367	0.4567	0.4734
Native Sand	0.2717	0.4767	0.3350	0.6945
Fertilizer	0.2183	0.7433	0.1317	0.3644
Yard Compost	1.6683	2.5367	2.2250	2.1433
Biosoilds Compost	2.1117	1.6517	1.3950	1.7195

Table 19. Comparisons of processed kimberlite reclamation treatments.

Treatment	Recommend for Field Research	Justification	Operational Applicability	Potential Limitations
Orion Fine PK	Yes	• Adequate establishment and growth of most species. • *Elymus innovatus* performed best compared to other unamended treatments.	• Single material, easy to apply.	• High SAR, Cr and Co and low N and P may inhibit plant growth in longer term.
Star Fine PK	Yes	• Lowest pH, EC and SAR. • Texture most ideal for plant growth. • Unamended provided best results for most species.	• Single material, easy to apply.	• High Cr and Co and low N and P may inhibit plant growth in longer term.
Orion Star Mix Coarse PK	Yes	• Available N high. • Adequate establishment and growth of most species. • *Agropyron trachycaulum* performed best compared to other unamended treatments.	• Homogeneous mix more difficult to create and apply than a single material.	• High SAR, Cr and low P may inhibit plant growth in longer term. • Coarse texture may reduce nutrient and water retention.
Agricultural Soil	Yes	• Enhanced establishment of some species. • Increased biomass production though not as much as composts.	• Locally available. Stability of source unknown.	
Native Sand	Yes	• Enhances germination and final plant densities. • *Koeleria macrantha* performed best in these treatments. • Biomass of *Elymus innovatus* and *Festuca saximontana* increased when added to Star PK.	• Locally available. Stability of source unknown.	• Reduced available N.
	Yes / No	• No significant increase in plant response compared to unamended PK. • Detrimental to *Agropyron trachycaulum*, *Bromus elatior*, *Elymus innovatus* when added to Mix PK. • Increased N and P may assist plant growth most in the longer term.	• Readily available and easy to apply to large areas. • Benefits in conjunction with other amendments should be tested.	• Native and agronomic species may have different nutrient requirements. • Nutrients may be leached without additional organic amendments.

Yard Compost	Yes	• Increases total C, total and available N, available P. • Increases plant height and aboveground biomass.	• Locally available. • Variation in feed stocks may alter chemical properties.	• Reduced germination but produced larger plants. • Excessive P and S may be detrimental to plant growth. • Increased Mn, Pb, Cu, and EC.
Biosolids Compost	Yes	• Increases total C, total and available N, available K. • Increases plant height and aboveground biomass	• Locally available. • Government regulations in place which may limit its use on agricultural lands.	• Reduced germination but produced larger plants. • Excessive K may be detrimental to plant growth • Increased Mn and EC
Native Forages	Yes	• Consistently good germination, establishment and production. • *Hordeum vulgare* has rapid growth and high biomass production.	• Seed available and inexpensive.	
Native Grasses	Yes	• Good germination, establishment and production. • Specific results species dependent. • Native species may be more tolerant of poor soil conditions than agronomics.	• Seed available.	• Germination rates variable; need to sow accordingly.
Native Trees	No	• Seedlings did not survive more than two weeks in any treatment	• Trees required depending on end land use. • Investigate other reclamation substrates and species. • Seed not readily available.	