Creating a Functional Soil from Fine Kimberlite Tailings and Waste Materials from the Victor Diamond Mine

By

Brent C. Rouble

Thesis submitted as partial requirement in the Bachelor of Science (B.Sc.) in Environmental Earth Science

Environmental Earth Science
Laurentian University
Ramsey Lake Road
Sudbury, Ontario
P3E2C6

April 2011

Abstract

DeBeers Victor mine is an open pit diamond mine located in a fragile ecosystem within the Hudson Bay Lowlands. Post mine closure, it is necessary to restore the area to near pre-mining conditions using stockpiled waste, including: fine processed kimberlite (FPK), coarse processed kimberlite (CPK), silt overburden, limestone pebbles, and peat. A series of experiments were done to determine what ratios of waste materials, particularly FPK, could produce a functional soil that could support the highest biomass of Kentucky Bluegrass (used as an indicator species). Plant biomass, soil moisture and soil chemistry were analyzed. It was discovered that a combination of grain sizes was necessary for optimal plant growth, and with increased peat, it is ideal to have a soil consisting of more coarse grained material than fine grained (40 – 80% coarse grained material), which allows for better root penetration. Also, high amounts of FPK can cause lower root biomass relative to shoots, likely due to too fine of grain size causing cement-like soil.

Acknowledgements

Without the following people, this paper would not have been possible:

Dr. Campbell, for his wealth of knowledge and open door. I am truly grateful to have had him as a thesis advisor and I would be honored to work with him again in the future.

Dr. Courtin, for his years of wisdom and his guidance and support. He means more to community of Laurentian than he knows.

Kathryn Bergeron, for providing data and methods.

Henri Ytilato, for allowing me access to the Laurentian Engineering Department to mix my soils.

Finally, family and friends, for keeping me sane when the work load was too much.

TABLE OF CONTENTS

Introduction

The Hudson Bay Lowland (HBL) is a vast subarctic region which has recently undergone an explosion in mineral exploration and mining. The Hudson Bay lowlands are situated in the northern most ecozone of Ontario and include approximately 25% of the province (MNR 2010), covering approximately 325 000 km^2 to the south of Hudson Bay and surrounding James Bay (Riley, 2003). The geology of the area consists of massive Palaeozoic and Mesozoic mottled limestone, shale and sandstone covered by calcareous marine clays that were deposited at the end of the Pleistocene glacial advance (Riley, 2003). The rock is typically covered >30 m silty overburden then 2-3m peat. The area has a poorly drained flat landscape dominated by extensive muskeg, and is in the region of sporadic discontinuous permafrost (AMEC 2004, De Beers Canada, 2009). The subarctic environment of the Hudson Bay lowland's if characterized by harsh winters and short summers with extreme seasonal temperature variations. This environment is known for having the largest annual temperature range on earth, with temperatures as cold as -40 °C in the winter and +30°C in the summer (MNR 2010). Outside the short growing season, biological activity, chemical weathering and leaching in the soils are reduced. Moisture builds up in the soils as it is unable to completely evaporate during the short summers, causing areas of wetland (Pettapiece, 1984).

The Hudson Bay Lowlands support 816 native vascular plant species and 98 non-native species. It is necessary to utilize native species for the restoration efforts since the ecosystem can be very sensitive.

De Beers Canada recently began production at the Victor diamond mine, which is an open pit kimberlite diamond mine that is situated within the HBL and is the first mine of its kind in Ontario. It is in a remote location that is 90 km west of the First Nation community of

Attawapiskat. Therefore, aboriginal relations must be taken into consideration during the operation and reclamation of the mine.

This type of mining involves stripping and stockpiling the overlying peat and silt, exposing the diamondiferous kimberlite and blasting and drilling to extract the kimberlite containing the diamonds. The kimberlite is then crushed, washed and screened to remove the diamonds. This process has less negative impacts on the environment than other types of mining since few chemicals are used (De Beers 2009). Tailings from this process include: fine processed kimberlite (FPK), coarse processed kimberlite (CPK), as well as silt overburden, peat, and limestone waste rock.

Reclamation is important for the mine site because it is situated in a fragile ecosystem, it is close to a First Nation community, and because it is a large open pit mine that required the excavation of a large amount of material. Revegetation of this area can be difficult because of the large scale of the disturbance, the remote situation, the subarctic environment and the fact that native plant species must be used over non-native species. To create an environment that is suitable for native plant growth with minimal external amendments, a functional soil must be created that has adequate nutrients and proper moisture retention. Stockpiled waste material will be used to create this soil, which must be able to support vegetation and withstand a harsh climate. Characteristics of this environment that make restoration difficult include: freeze/thaw cycles, needle ice, moisture, high pH of native soils, and short summers.

The general objective of the restoration efforts at De Beers Victor Mine is to create a functional soil from stockpiled waste materials with minimal external amendments that is capable of supporting vegetation, with adequate moisture retention capabilities and nutrient supply, and without being toxic to the plant. This study is concentrating on determining suitable mixes to specifically restore the fine processed kimberlite. In order to achieve this, mixtures with different ratios of minerals (with different chemistry and grain size) were mixed with different amounts of peat.

It is hypothesized that: 1- Treatments with high percentages of peat will produce the most functional soils. 2- Increasing FPK will cause toxicity problems relating to the minerals poor Ca:Mg ratio and fine grain size. 3- Limestone pebbles may not largely affect soils compared to the effect of the silt overburden, over a short time period. However, limestone pebbles may have more of an effect over a larger time period.

Methods

Description of Mining Waste Materials

Stockpiled tailings and overburden from the Victor mine include: fine processed kimberlite (FPK), coarse processed kimberlite (CPK), silt, limestone, and peat. The descriptions of the materials are presented in table 1.

Table 1. Material description (*D. Campbell and K. Bergeron* unpublished data)

Material	Texture	Grain Size	pH	CEC (cmol/kg soil)	CEC treated with HCl (cmol/kg soil)	Ca:Mg Ratio
FPK	silt	3.9-62.5um	~9	56	56	1.1
CPK	coarse sand	62.5um-2mm	8.5-9	25.66	34.41	1
Limestone	pebble	>2mm	8.4-8.8	27.53	3.99	23.1
Silt	silt	3.9-62.5um	8-8.7	28.54	30.27	6.1
Peat	organic	-	5.5-6	282.77	125.34	8.4

Preparation of Mixes

Samples of fine and coarse processed kimberlite, silt overburden, limestone, and peat were taken from DeBeers Victor mine and shipped to Sudbury, Ontario in 2009. It was observed that there was some variability in texture between shipping containers of like material and some oxidation had occurred between the containers and the moist material inside. The material affected by oxidation was removed and the usable material was then spread out in pans in a growth chamber set to normal summer conditions until the material was dry to the touch. Once dry, the FPK and silt was manually crushed using a mallet and pin roller. Large, foreign objects were manually removed from the FPK, silt, and peat in order to have a more homogeneous material for testing. Once dried and crushed, like material was mixed together, to avoid bias, for 15 min per material in a cement mixer. Soil materials were then mixed according to the desired mixture ratios (Table 1) using a cement mixer for 15 min per sample. This process yielded 5 liters of soil per soil sample, having 20 different samples. The mixed soils were divided into 5 pots per sample for replication purposes. Each pot was 10 cm in diameter and approximately 20 cm in length with five 4 mm diameter holes in the underside for drainage. each pot held approximately 1 liter of mixed soil. The individual pots of soil were oversaturated with distilled water and left to drain to field capacity.

Table 2. Soil mixtures

#	% FPK	% Silt	% Limestone	% CPK	Peat (% of total mineral mix)
1	60	-	40	-	20
2	60	40	-	-	20
3	60	-	20	20	20
4	60	20	-	20	20
5	40	20	-	40	20
6	40	-	20	40	20
7	40	20	20	20	20
8	20	20	-	60	20
9	-	20	-	80	20
10	-	100	-	-	20
11	60	-	40	-	40
12	60	40	-	-	40
13	60	-	20	20	40
14	60	20	-	20	40
15	40	20	-	40	40
16	40	-	20	40	40
17	40	20	20	20	40
18	20	20	-	60	40
19	-	20	-	80	40
20	-	100	-	-	40

Growth Chamber Experiment

One pinch of *Poa pratensis* seeds were applied around the center of each pot of soil. The seeds were then slightly pushed into the soil so they were approximately 1 mm deep or slightly embedded. This was done to prevent floating of the seeds after applications of water. The pots were placed randomly in a blocked factorial design with the 10 mineral mixes, 2 levels of peat for a total of 20 pots in each of the 5 blocks. The pots were placed in the growth chamber with 16 hours of light at 24° Celsius followed by 8 hours of dark at 14° Celsius with constant 25 – 30% humidity.

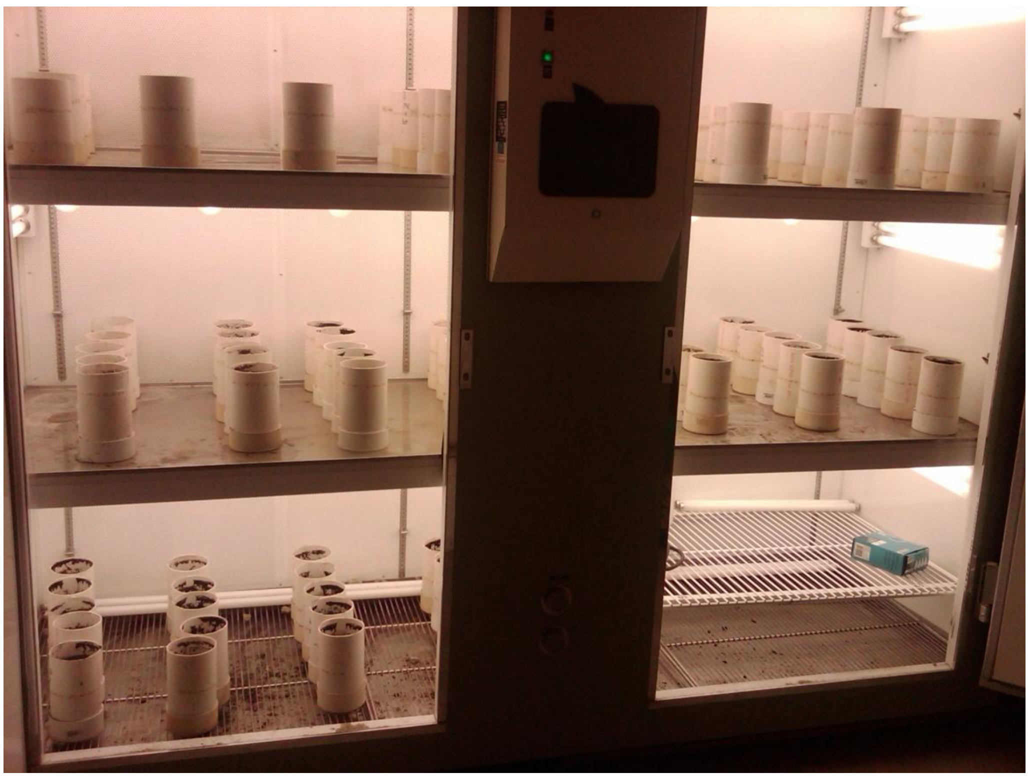

Figure 1. 100 Randomized pots of soil in 5 blocks of 20.

The randomized soil samples were watered with 60 ml of distilled water per day until germination, which was approximately seven days after seeding. Post germination, the seeds were watered 3 times per week with 50 ml of distilled water per pot. Ten days after germination and the start of regular watering, a 1% Rorison fertilizer solution was applied. A regular watering scheme of 3 times per week with 50 ml of nutrient mix per pot was used. Once there was sufficient growth, the pots were weeded using tweezers so that there was only a single blade of *Poa pratensis* in the pot, roughly in the center of the pot, to reduce edge effect and competition.

The plants were harvested seven weeks after germination by removing the column of soil from the pot and massaging the soil with running water until the roots were free of soil. When clean, the roots and shoots were separated, placed into individual envelopes, dried in a convection oven at 80°C for a minimum of 48 hours. The biomass was then weighed to 0.1mg precision. The length of the dried shoots was also recorded. Factorial ANOVA analysis was conducted using blocks, mineral mixes and peat amendments as main factors and the mineral X peat interaction only. Significant differences between mineral mixes were assessed using a Tukey's post hoc test. Significance was evaluated at a Type I error level of $P<0.05$.

Soil Moisture Content

The moisture content of the selected mixes was measured using pressure plates of soils after the harvest of soils. All samples that did not have limestone in the mixture were subjected to pressure plate testing. This is because large pebbles of rock do not hold water; therefore it was unnecessary to test the soils with large pebbles.

Mixes were air dried in the growth chamber then crushed with a rolling pin. The samples were placed in rubber rings on 1 bar and 15 bar pressure plates and soaked in distilled water for a minimum of 24 hours. The pressure plates containing the rings of soil were placed into pressure chambers and subjected to pressure experiments at -1/3 bar, -1 bar, -2 bar, and -15 bar. Triplicates of each sample were taken at each pressure. The samples remained in the pressure chambers until water ceased to be extracted from the soils, which took from 6 to 12 days. Soils were then weighed, dried in a convection oven at 105°C for a minimum of 24 hours, then weighed again. The moisture content was calculated using the following equation:

$$\text{Moisture Content (g/g dry weight)} = \frac{\text{Fresh soil weight} - \text{Dry soil weight}}{\text{Dry soil weight}}$$

Soil Chemical Analysis

After harvesting the plants, a portion of each soil was collected for lab analysis. Once air dried, all grass material was removed and the soils were placed into labeled Ziploc® bags and sent to the Elliot Lake Research Field Station at Laurentian University for pH in water, conductivity and bioavailable elements after a LiNO3 extraction. Cation exchange capacity (CEC) was also determined after an initial treatment with HCL to remove carbonates.

Results

Soil Moisture Content

Soil moisture curves were determined for treatments without limestone and with 20 – 60% FPK. All soils were subjected to pressures of: -1/3 bar, -1 bar, -2 bar, and -15 bar. There is variation amongst the different mineral mixtures, particularly those with different grain sizes (Figure 2). Soils containing a higher percentage of fine grained materials are more capable of retaining moisture at higher pressures and soils with a higher percentage of coarser grained materials are less capable. This was expected as it is well known that finer grained materials can hold water more efficiently than coarser grained materials.

When comparing peat treatments, it is evident that treatments with higher levels of peat have the ability to hold a significant amount of moisture, compared to treatments with lower amounts of peat (Figure 3).

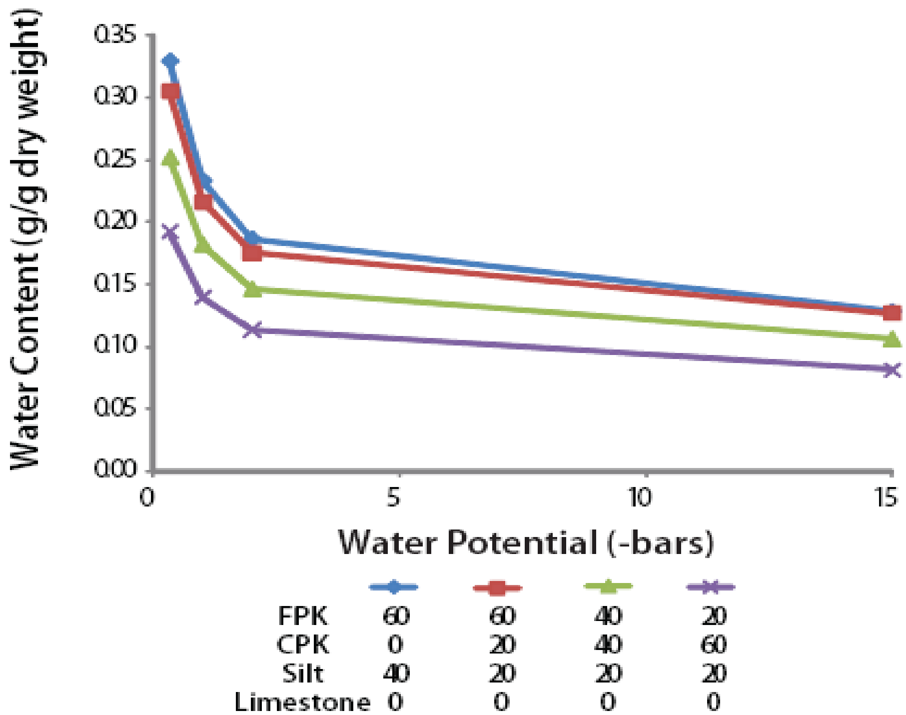

Figure 2. Soil Moisture experiments showing the comparison of the average soil moisture curves for different mineral mixtures.

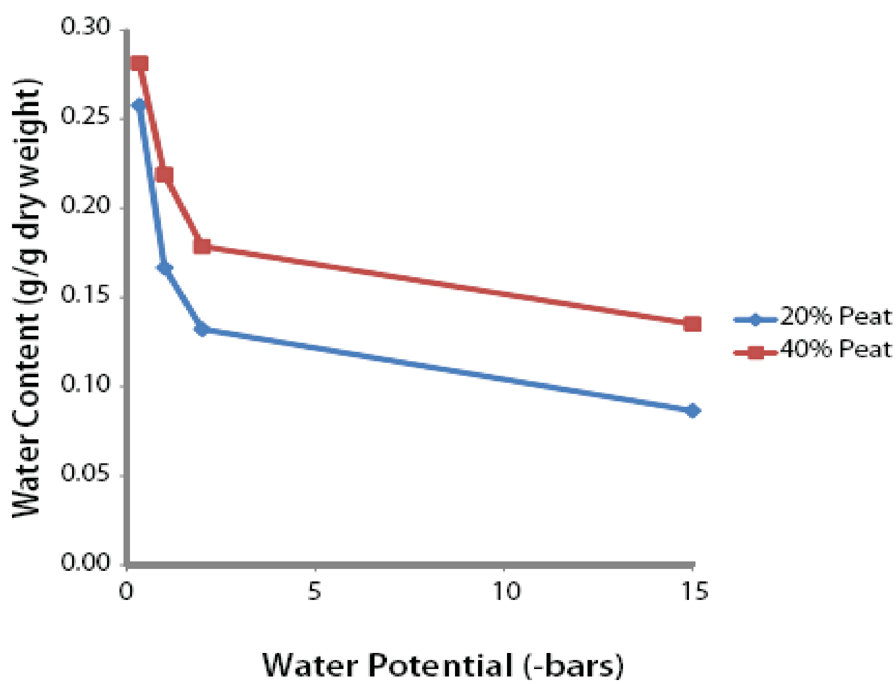

Figure 3. Soil moisture experiments showing the comparison of the average soil moisture curves for the different peat mixtures.

Soil Chemical Analysis

All mineral treatments have a pH over 8 (Figure 4) and range from moderately alkaline to strongly alkaline, according to the USDA (United States Department of Agriculture) soil classification. The amount of FPK, or any individual mineral, does not seem to strongly affect the pH of the soils. Many plants and soil life forms have a preference for either alkaline or acidic conditions, thus limiting the choice of crop or plant that can be grown within these alkaline soils.

The amount of peat had very little effect on the pH of the soils (Figure 5).

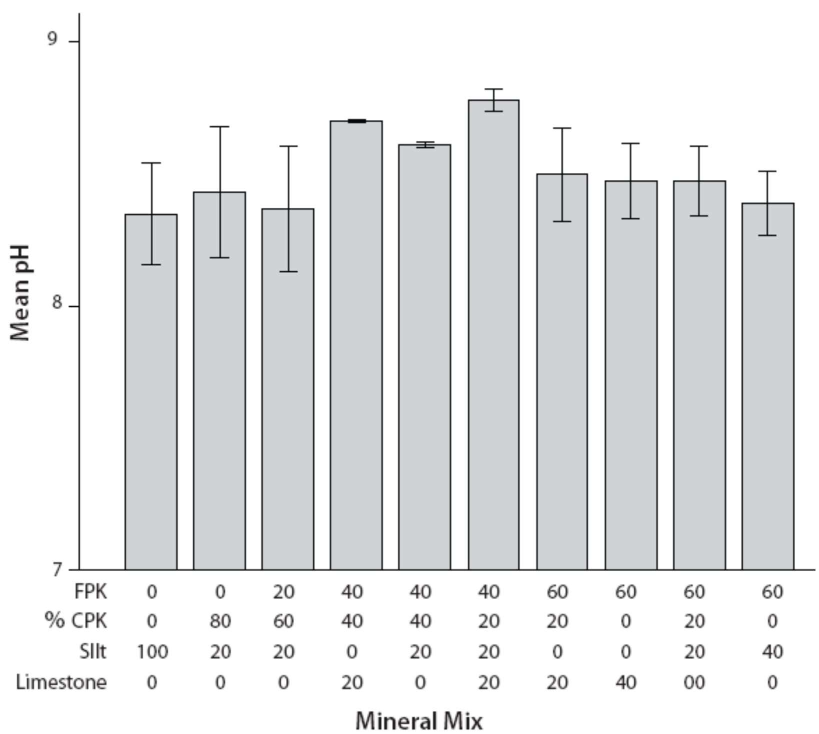

Figure 4. Soil chemical analysis showing the comparisons of pH for the different mineral mixtures.

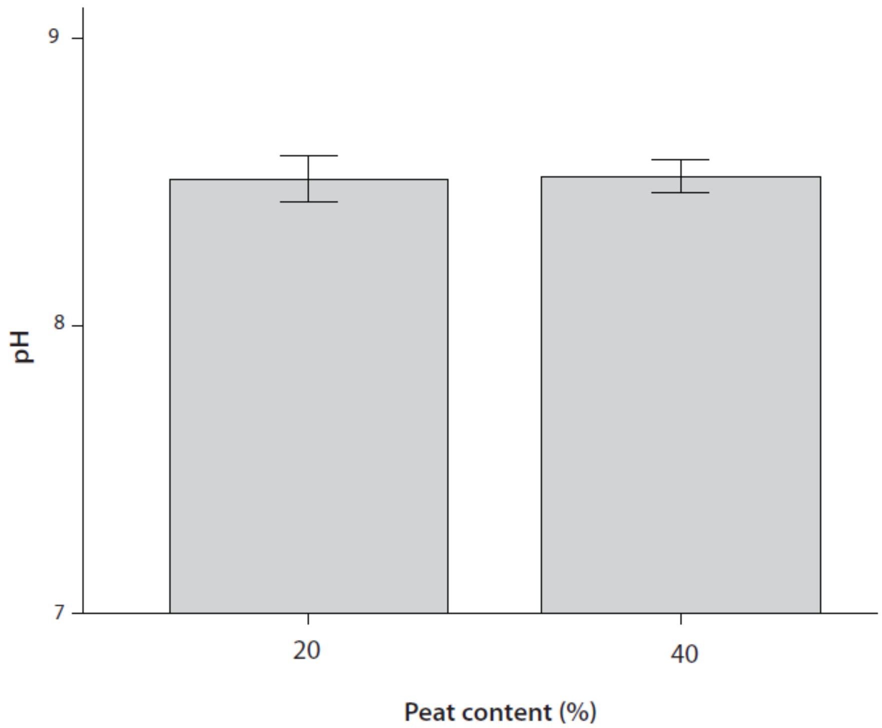

Figure 5. Soil chemical analysis showing the comparisons of pH for the different peat mixtures.

The mineral mix shows some variation in cation exchange capacity. Silt alone has a poor cation exchange capacity as well as when it is mixed with CPK and a small amount (20%) of FPK (Figure 6). Mixtures displaying the greatest cation exchange capacities contain a large percentage of FPK and limestone. This is somewhat unexpected since limestone has a very low cation exchange capacity (27.53 cmol/kg soil). However, FPK does have a higher cation exchange capacity than silt.

The treatments with 40% peat generally have a higher cation exchange capacity than the mixtures with 20% (Figure 7). This is expected because CEC is highly dependent on soil texture and organic matter content. Soils with more organic matter content usually have higher cation exchange capacities.

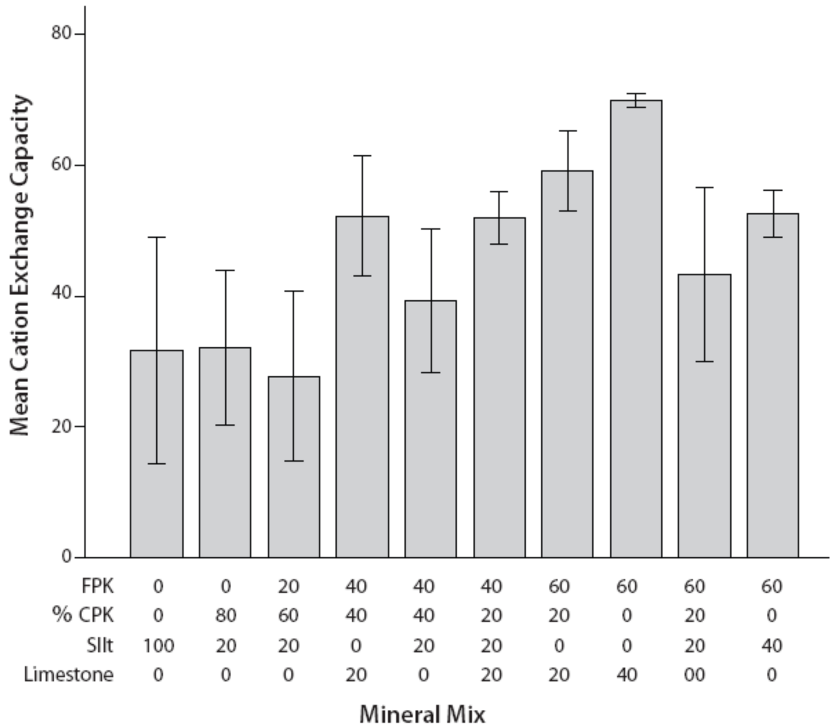

Figure 6. Soil chemical analysis showing the comparisons of cation exchange capacity for the different mineral mixtures.

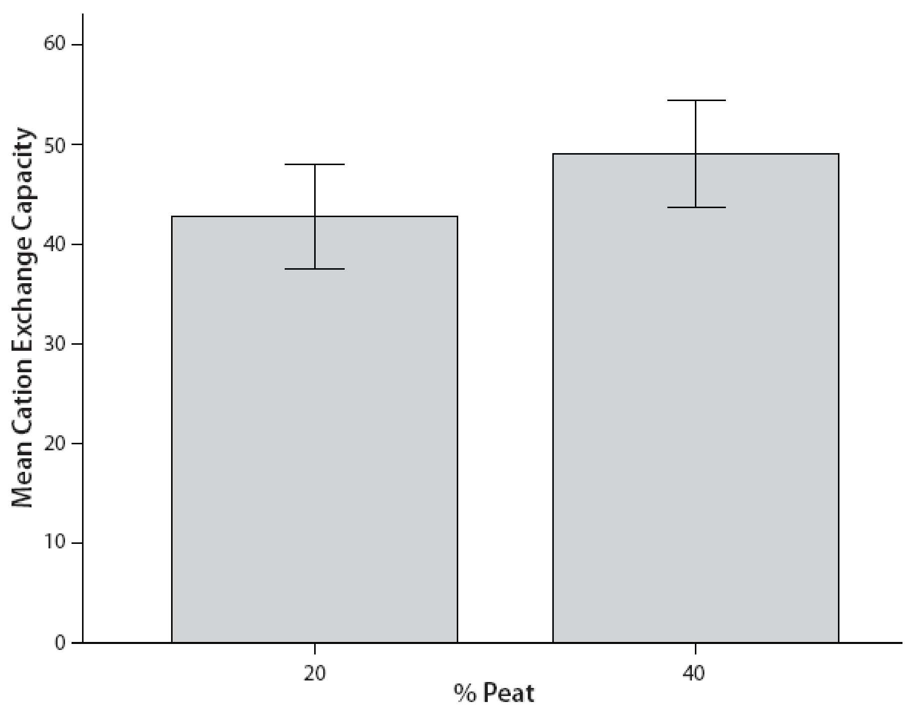

Figure 7. Soil chemical analysis showing the comparisons of cation exchange capacity for the different peat mixtures.

Growth Chamber Experiment

The mineral mixes showed significant differences in total biomass (P=0.004, Table 3, Figure 8). This was mostly a result of better growth in the treatments with a higher percentage of coarse grained material (CPK). All treatments with high amounts of FPK (40% and 60%), with the exception of one, were not significantly different from each other ($P<0.05$).

Mixes that had 40% peat did however allow plants to produce almost half of an order of magnitude more total biomass than those with only 20% peat ($P<0.001$; Table 3; Figure 9). There was no interaction between the mineral mix and the peat content (P=0.738, Table 2). Mixtures with 40% peat display a much larger total biomass than the mixtures with only 20% (Figure 3).

Table 3. ANOVA of log transformed total biomass of *Poa pratensis* in the growth chamber experiment.

Source	df	Type III Sum of Squares	Mean Square	F	Sig.
Block	4	5.990	1.498	10.936	.000
Mineral	9	3.706	.412	3.007	.004
Peat	1	3.732	3.732	27.251	.000
Mineral X Peat	9	.819	.091	.665	.738
Error	76	10.407	.137		

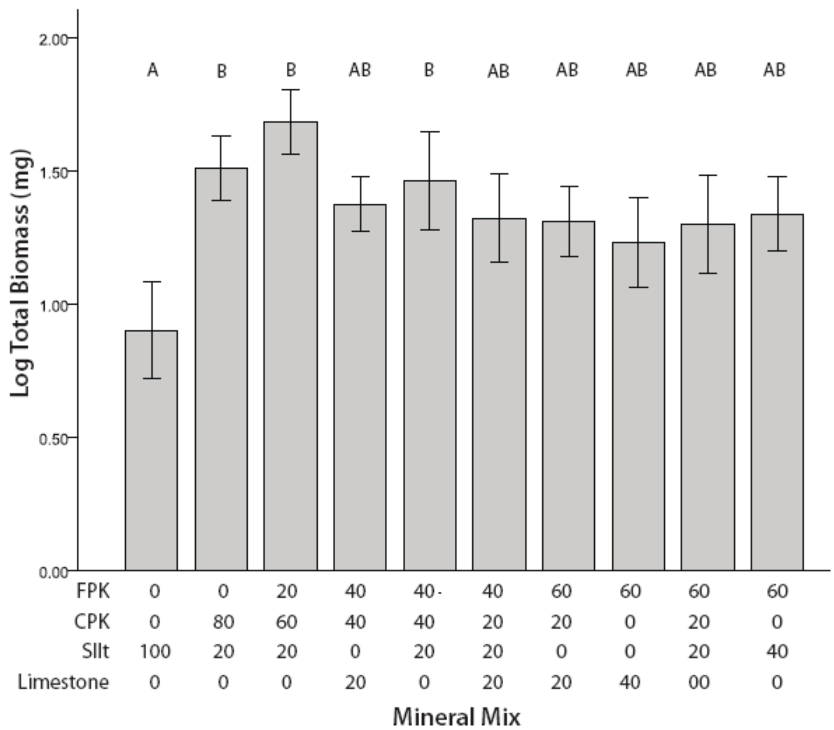

Figure 8. Growth chamber experiments showing the comparisons of the average log total biomass of *Poa prantensis*, grown in different mineral mixtures.

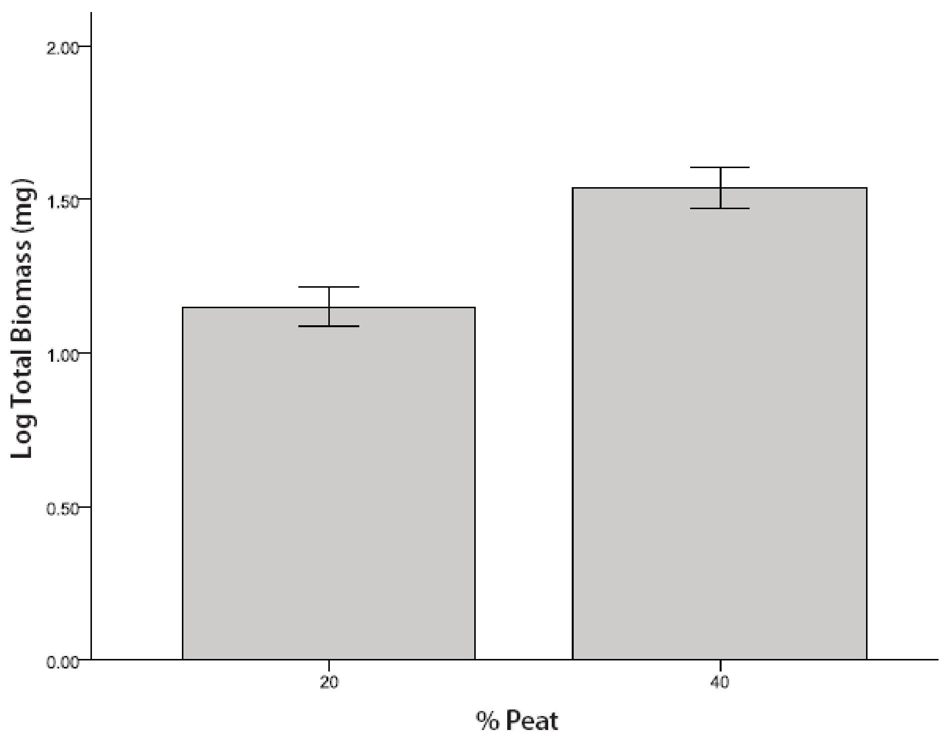

Figure 9. Growth chamber experiments showing the comparisons of average log total biomass of *Poa prantensis*, grown in different peat mixtures.

The mineral mixes showed significant differences in aboveground biomass (P<0.001, Table 4, Figure 10), but this was mostly a result of poor growth in the 100% silt control treatment. All the other treatments, including those with an increasing amount of FPK were not significantly different (*P*<0.05).

Mixes that had 40% peat did however allow plants to produce almost half of an order of magnitude more aboveground biomass than those with only 20% peat (*P*<0.001; Table 4; Figure11). There was no interaction between the mineral mix and the peat content (P<0.001, Table 4). Mixtures with 40% peat display a much larger above ground biomass than the mixtures with only 20%.

Table 4. ANOVA of log transformed above ground biomass of *Poa pratensis* in the growth chamber experiment.

Source	df	Type III Sum of Squares	Mean Square	F	Sig.
Block	4	6.683	1.671	13.034	.000
Mineral	9	5.313	.590	4.605	.000
Peat	1	4.080	4.080	31.834	.000
Mineral X Peat	9	.762	.085	.661	.741
Error	76	9.741	.128		

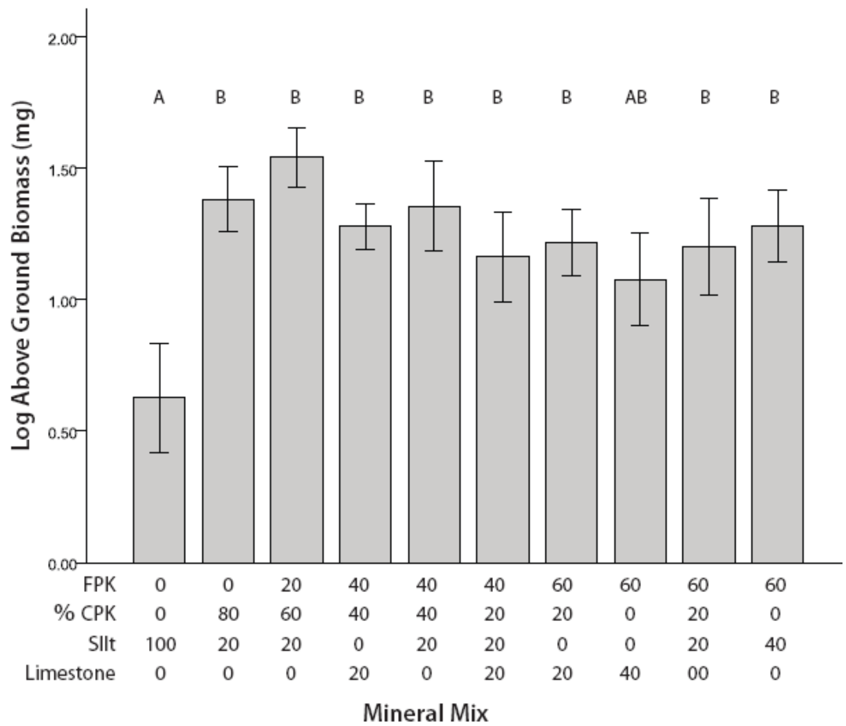

Figure 10. Growth chamber experiments showing the comparisons of the average log above ground biomass of *Poa prantensis*, grown in different mineral mixtures.

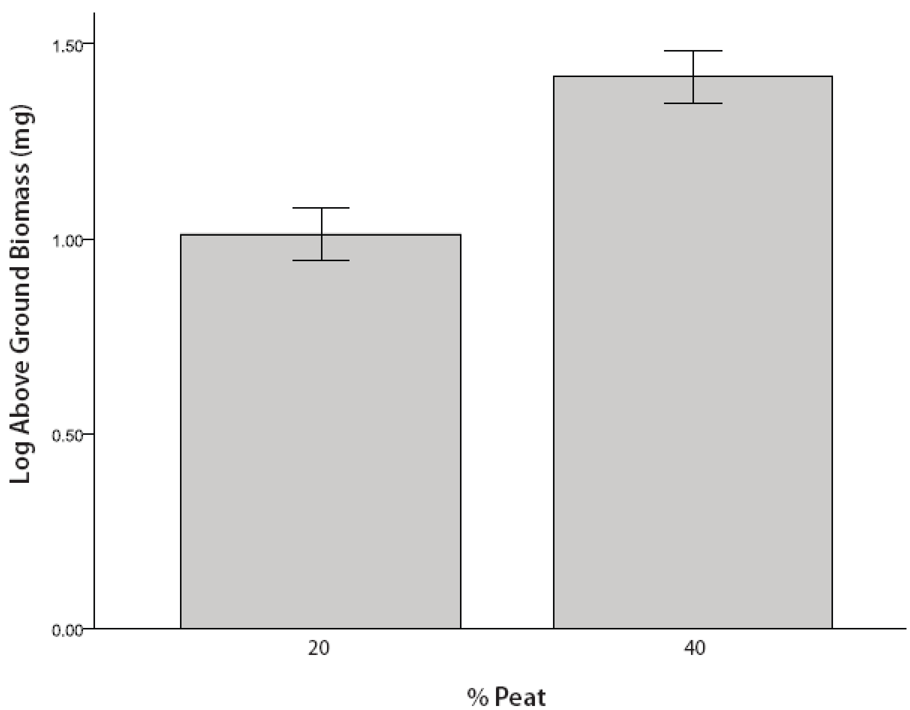

Figure 11. Growth chamber experiments showing the comparisons of average log above ground biomass of *Poa prantensis*, grown in different peat mixtures.

The mineral mixes did not show significant differences in belowground biomass (P=0.158, Table 5, Figure 12), but this was mostly a result of large variance between replicates. However, there is a decreasing trend of belowground biomass with increasing levels of FPK.

Mixes that had 40% peat allow plants to produce over half of an order of magnitude more belowground biomass than those with only 20% peat (*P*<0.001; Table 5; Figure 13). There was no interaction between the mineral mix and the peat content (P<0.001, Table 5). Mixtures with 40% peat display a much larger belowground biomass than the mixtures with only 20%.

Table 5. ANOVA of log transformed below ground biomass of *Poa pratensis* in the growth chamber experiment.

Source	df	Type III Sum of Squares	Mean Square	F	Sig.
Block	4	7.161	1.790	5.316	.001
Mineral	9	4.587	.510	1.514	.158
Peat	1	4.675	4.675	13.882	.000
Mineral X Peat	9	2.212	.246	.730	.680
Error	76	25.592	.337		

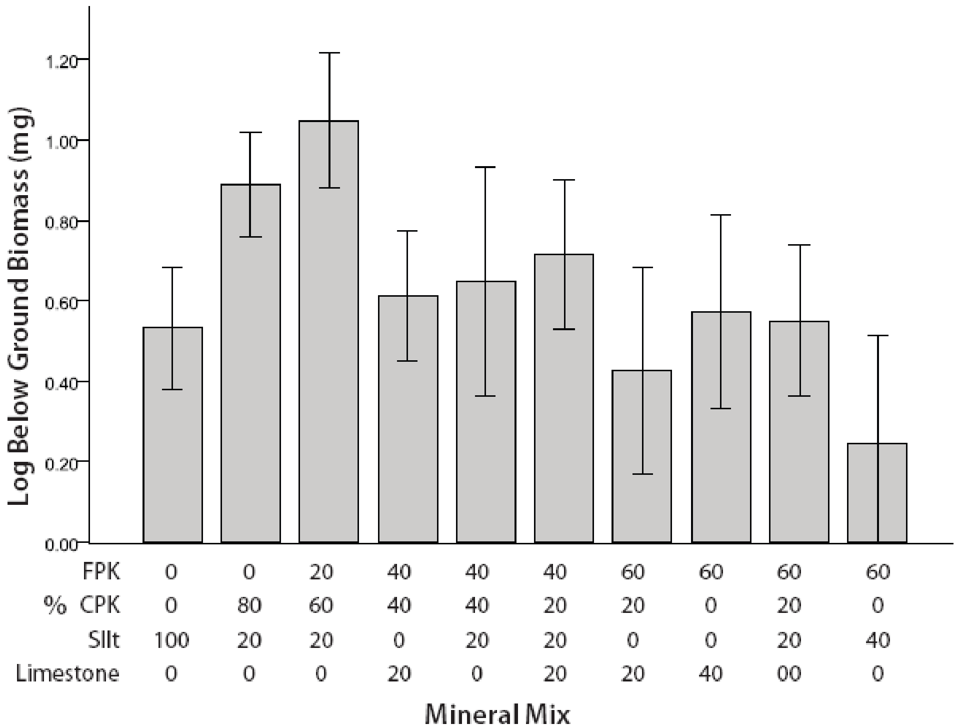

Figure 12. Growth chamber experiments showing the comparisons of the average log below ground biomass of *Poa prantensis*, grown in different mineral mixtures.

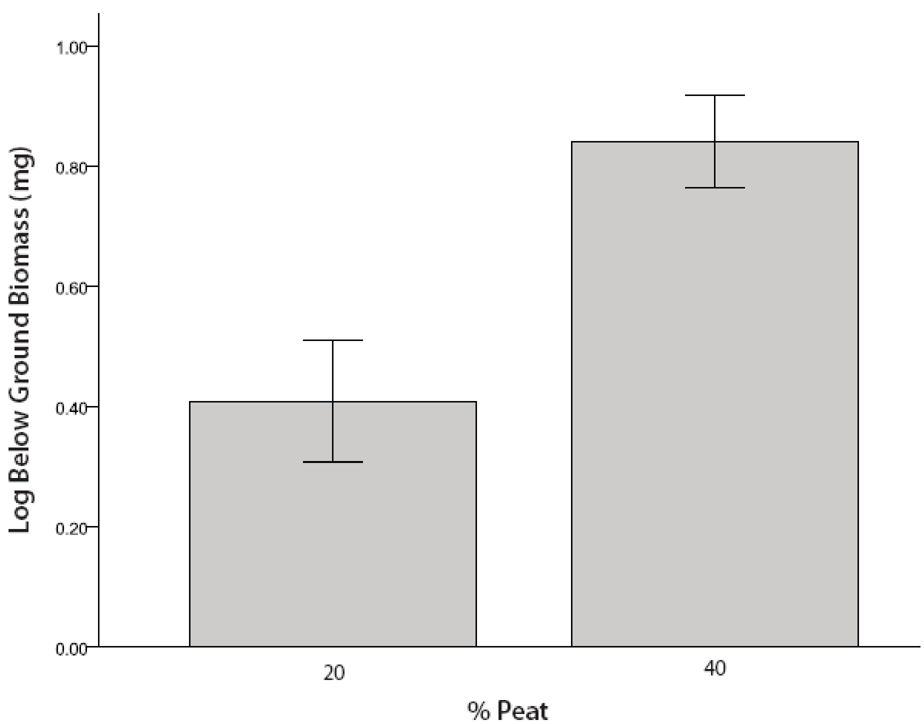

Figure 13. Growth chamber experiments showing the comparisons of average log below ground biomass of *Poa prantensis*, grown in different peat mixtures.

The mineral mixes showed significant differences in shoot to root biomass (P=0.001, Table 6, Figure 14), with an increasing trend as the percentage of FPK increases. Meaning, treatments with higher amounts of FPK displayed less root biomass compared to shoot.

Different peat mixtures did not have an effect on the shoot to root ratio (P=0.728, Table 6). There was no interaction between mineral mix and the peat content (P=0.589, Table 6).

Table 6. ANOVA of log transformed shoot to root ratio of *Poa pratensis* in the growth chamber experiment.

Source	df	Type III Sum of Squares	Mean Square	F	Sig.
Block	4	.138	.034	.209	.933
Mineral	9	5.560	.618	3.742	.001
Peat	1	.020	.020	.122	.728
Mineral X Peat	9	1.236	.137	.832	.589
Error	76	12.546	.165		

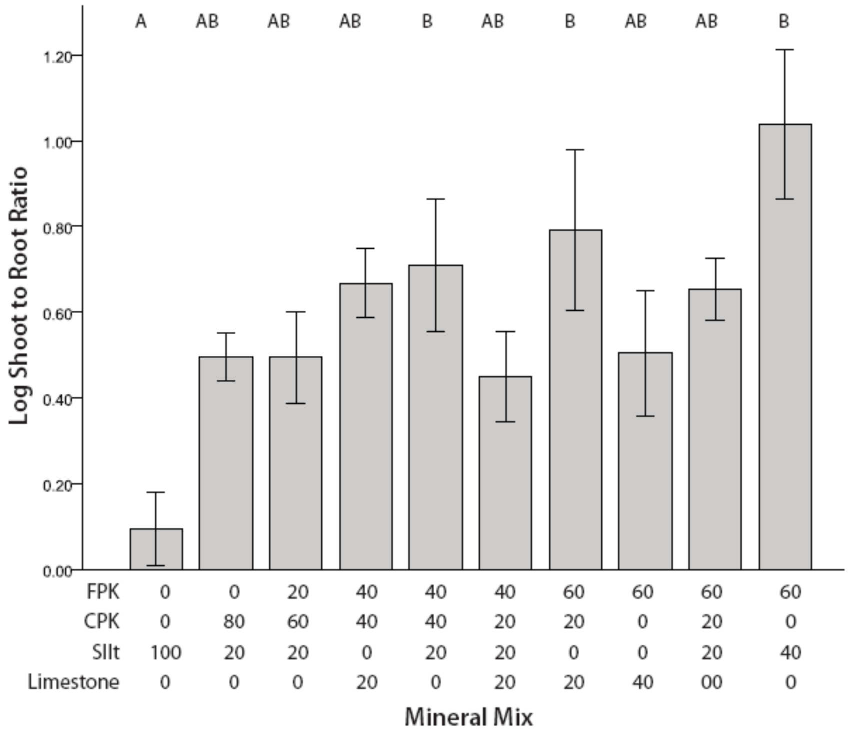

Figure 14. Growth chamber experiments showing the comparisons of the average log shoot to root ratio of *Poa prantensis*, grown in different mineral mixtures.

Discussion

The size of the particles within a soil is a primary consideration that could affect the soil. This was clear in the experiment where there was lower growth in 100% silt treatments and higher amounts of FPK in the mix as compared to those with more of the coarse textured CPK. Soil with fine grained particles are capable of holding moisture much better than soils consisting of a large percentage of coarse grained particles. Finer soil particles exhibit greater dispersion than coarser soil particles (Arcone et al., 2008). At any given matrice potential value, the heavier textured soils with more colloidal material (fine grained soils) hold more water than lighter-textured soils as sands (Salisbury et al. 1978). Fine grained soils, when subjected to dry periods, can experience hardening and mud cracking, as they are very susceptible to shrinking and swelling. Mud cracks were visible in several fine grained soil samples in this experiment after the soils dried and shrunk. This hard soil makes it difficult for roots to grow and acquire water and nutrients. Fine grained soils are also characteristic of higher cation exchange capacities (Maher 1998) and more bioavailable elements, making it easier for vegetation to obtain essential nutrients.

Coarse grained soils on the other hand, typically have lower water retention capabilities, lower cation exchange capacities, and lower bioavailable elements. However, these soils remain loose during dry periods, making it easier for roots to grow and access water and nutrients deeper within the soil. Coarse soils with the addition of peat for water retaining purposes, showed the greatest amount of biomass, as shown in Figure 8. These soils did not become too hard or crack and the roots were able to easily penetrate in between particles more easily.

Soils with more coarse grain materials and less FPK showed more biomass compared to mixtures consisting of fine grains and high amounts of FPK. The fine particles became somewhat hard between watering treatments, making it difficult for roots to extend throughout the soil column and access the moisture and nutrients. Roots could easily penetrate soils with high amounts of coarse grained materials.

Our experiment clearly shows that 40% content of peat was advantageous as compared to a 20% peat content and there is no interaction with the mineral mixes. The advantage of peat may in part be because of its ability to hold a significant amount of moisture (Figure 3). Peat has been shown to increase water retention in other kimberlite based soil mixes (Reid & Naeth, 2005). This ability of peat can be both an advantage and a disadvantage to soils of this geographic area. Adding peat to soils produces greater water retention, unless the soil becomes waterlogged. However, a high moisture content is not favourable when it comes to frost heaving and needle ice. High moisture content causes more water in an area to get incorporated into needle ice (Brink et al. 1964). Frost heaving can be severe on bare peat soils. Frost heaving and needle ice could affect the soils created in this experiment due to their high peat content (~40%). To combat frost heave, the application of straw mulch in the fall has been shown to reduce frost heaving (Groeneveld & Rochefort 2005).

Bedsides increasing the moisture content of soils, peat can also increase the cation exchange capacity and Ca:Mg ratio, and can cause looser soils. Peat's high cation exchange capacity and Ca:Mg ratio contributes to increasing that of the entire soil. Peat not only held more water and nutrients for the roots, but it also loosened the soil, making it less difficult for the roots to penetrate further into the soil. The large roots in the 40% peat mixtures allowed for better plant survival between waterings, when the soil moisture was limited.

The upland soils with low organic development in the Hudson Bay Lowland have an average pH of 7.8 (K. Garrah pers comm.). The pH of fine and coarse processed kimberlite reaches approximately 9, which is slightly higher than the pH of the silt and limestone overburden, at approximately 8-8.6. It is important to mix silt and limestone overburden and peat (with a lower pH of ~6) with the processed kimberlite in order to lower the pH of the entire mixture to pre-mining levels, so native species can once again inhabit the land. However, lowering the pH too drastically can cause minor toxicity problems from heavy metals to turn into serious problems, as is what occurs in serpentine soils from asbestos mines (Moore et al. 1977).

Although all soils in this experiment tended to have a high pH (pH>8), soils with high percentages of FPK were among the most alkaline. The addition of excess kimberlite, specifically FPK, may have adverse effects of plant root biomass, as a result of increased pH levels.

A high cation exchange capacity can play a large role in the success of a soil. CEC, the capacity of a soil for ion exchange of cations between the soil and soil solution, is typically greater in soils with a fine texture. This is due to the increased bioavailability of ions within fine grained soils, such as clay or silt. The materials used for this experiment show no exception to this generalization. Peat and FPK, had generally higher CEC. However, in this experiment higher levels of CEC did not necessarily correspond to higher levels of biomass. The poor nutrients, texture of pH of the FPK mixtures could have overshadowed the beneficial aspects of high a high CEC. A good soil must have a balance of all beneficial properties.

The experiment incorporated several treatments that compared the use of limestone fragments verse silt in order to overcome the Ca:Mg imbalance that can often reduce growth in kimberlite or similar serpentine based soils (Brady et al. 2005 & Reid et al. 2005). The main difference between silt and limestone is the size, which affects other traits of the minerals that are important to soils. Silt overburden ranged from 3.9 to 62.5 um and limestone from 2mm and up. This difference between the minerals can affect the bioavailability of nutrients, CEC, and water retention of the soils that they are in. Limestone and silt had a similar pH, however silt had better water retention, higher CEC and more bioavailable elements.

Within the growth chamber experiments, mixtures with limestone showed less, but non-significantly different total biomass when compared to mixtures with limestone substituted with silt (Figure 8). This slight effect, if real, could be because there was not enough time within the seven week experiment for the limestone pebbles to break down, releasing their nutrients and causing greater CEC and water retention. Over time, the difference between limestone and silt overburden may become less, as the limestone breaks down. Limestone could be more beneficial to soils over a greater time span, however, it was not clearly beneficial to the biomass in this experiment.

An interesting result from the experiment was the non-significant difference in belowground biomass across the mineral treatments, and the contrasting large increase in shoot to root biomass over the mineral treatments. Those with more FPK had up to an order of magnitude more aboveground biomass than belowground biomass. Roots play a vital role in the success of a plant. Roots absorb water and inorganic nutrients, anchor the plant to the ground, store food and nutrients, and prevent soil erosion. Larger roots are more beneficial to plants, as they can accomplish these functions more efficiently. In subarctic and subalpine regions, it is essential for the roots of plants to grow quickly and large in dense stands during the summer months to protect against needle ice (Brink et al. 1964). Needle ice can target seedling roots in soils such as those in question and will destroy the plant. However, steps can be taken to prevent destruction by needle ice, such as increasing the density of the stand thereby altering the microclimate at the soil surface, increase the amount fertilizer to promote root growth, and plant earlier in the season so roots may have sufficient time to grow. Needle ice can be very powerful, as it has been knows to lift rocks weighing several kilograms several centimeters. (Brink et. Al 1964).

High amounts of FPK may have stunted root growth due to inadequate nutrients within the soils as well as high amounts of fine grain sizes causing a cement-like soil. FPK and fine grain dominant soils displayed stunted root growth.

This study has shown that soil mixes containing 40% peat, moderate levels of FPK and silt overburden, and moderate to high levels of CPK should have the most potential to grow vegetation with sufficient biomass and low toxicity problems, using minimal external amendments. Further investigation is required to determine the most suitable plant species that will be grown on the soil that will be used for the reclamation, and further tests must be done to determine the effects of the soil on that species. Species can react differently to soils with different characteristics such as pH, CEC, and moisture retention. It is vital to thoroughly understand the interactions of the soil and vegetation before beginning a large scale project, such as the restoration of a large open pit mine in a fragile ecosystem.

Conclusion

A combination of grain sizes is indeed necessary for optimal plant growth. However, with increased peat, it is ideal to have a soil consisting of more coarse grained material than fine grained (40 – 80% coarse grained material), which allows for better root penetration. It is necessary to address structural and nutrient limitations when creating a soil.

Increasing the amounts of FPK causes a reduction in biomass, specifically root biomass. Possible reasons for this include the poor Ca:Mg ratio and lack of nutrients, small grain size, and other toxicity problems.

Limestone pebbles did not show a large effect on plant growth compared to silt overburden during this experiment. This could be due to the fact that the time span of the experiment was too short to breakdown the limestone pebbles so the plants could utilize their nutrients. Over a longer time period, limestone may have more of an effect on plant growth. Further research is required to determine such a hypothesis.

Recommendations

Further studies are needed in order to fully understand how the soils will react in this environment. Soil test plots at the mine site with possible reclamation species are recommended. This will allow the researcher to observe exactly how the soil will react to the environment and how the native species react to the soil. This is an important step before reclamation activities can begin.

If more growth chambers are to be undertaken, it is recommended to experiment with different levels of fertilizer and different mixtures of minerals. Increasing the humidity of the growth chamber could also simulate the Hudson Bay Lowland more appropriately.

When harvesting plants, take fresh measurements of root and shoot length to understand how deep the roots can penetrate and how large the shoots can grow.

Literature Cited

AMEC. (2004). *VICTOR DIAMOND PROJECT.* Ontario: De Beers Canada.

Arcone, S., Boitnott, G., & Bostick, B. (2008). Complex Permittivity and Clay Mineralogy of Grain-Size Fractione in a Wet Silt Soil. *Geophysics* , 3.

Brady, K. U., Kruckeberg, A. R., & Bradshaw, H. D. (2005). Evolutionary ecologyof plant adaptation to serpentine soils. . *Annual Review of Ecology Evolution and Systematics* , 36: 243-266.

Brink, V. C., Mackay, R., Freyman, S., & Pearce, D. G. (1967). Needle Ice and Seedling Establishment in Southwestern British Columbia. *Canadian Journal of Plant Science* , 5.

Bronfenbrener, L., & Bronfenbrener, R. (2010). Frost heave and phase front instability in freezing soils. *Cold Regions Science and Technology* , 20.

Consulting, S. (2003). *Summary of Geochemical Characterization and Water Quality Estimates, Victor Diamond Project.* Toronto: De Beers Canada.

De Beers Canada . (2009). Retrieved from www.debeerscanada.com

Deventer, P. W., Bloem, A. A., & Hattingh, J. M. (2008). Soil Quality as a Key Success Factors in Sustainable Rehabilitation of Kimberlite Mine Waste. *The Journal of The Southern African Institute of Mining and Metallurgy* , 7.

Groeneveld, E. V., & Rochefort, L. (2005). Polytrichum strictum as a Solution to Frost. *Restoration Ecology* , 10.

Groeneveld, E. V., Masse, A., & Rochefort, L. (2007). Polytrichum strictum as a Nurse-Plant in Peatland Restoration. *Restoration Ecology* , 12.

Maher, B. A. (1998). Magnetic properties o fmodern soils and Quaternary loessic paleosols: paleoclimatic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* , 25-54.

MNR. (2010, Janurary 11). *Ministry of Natural Resources*. Retrieved from http://www.mnr.gov.on.ca/en/Business/Biodiversity/2ColumnSubPage/STEL02_166949.html

Moore, T. R., & Zimmermann, R. C. (1977). Establishment of Vegetation on Serpentine Asbestos Mine Wastes, Southeastern Quebec, Canada. *Journal of Applied Ecology* , 12.

Outcalt, S. I. (1971). *Field Observations of Soil Temperature and Water.* Ann Arbor: Department of Geography, University of Michigan.

Reid, N. B., & Naeth, A. M. (2005). Establishment of a Vegetation Cover on Tundra. *Restoration Ecology* , 8.

Reid, N. B., & Naeth, A. M. (2005). Establishment of a Vegetation Cover on Tundra. *Restoration Ecology* , 7.

Riley, J. L. (2003). *Flora of the Hudson Bay Lowland and its Postglacial Origins.* Ottawa: NRC-CNRC Research Press.

Roach, D. A. (1984). RECOVERY OF ALPINE DISTURBANCES: EARLY GROWTH AND SURVIVAL IN POPULATIONS OF THE NATIVE SPECIES, ARENARIA GROENLANDICA, JUNCUS TRIFIDUS, AND POTENTILLA TRIDENTATA. *Arctic and Alpine Research* , 8.

Salisbury, F. B., & Ross, C. W. (1978). *Plant Physiology, Second Edition.* Belmont: Wadsworth Publiching Company, Inc.

Appendix

2010 03 09 - CEC BaCl2 Fraction K Bergeron & K Driscoll
Analysis Date: 2010 03 09
Analyst: Troy Maki

2010 03 12 - CEC NH4Cl Fraction K Bergeron & K Driscoll
Analysis Date: 2010 03 12
Analyst: Troy Maki

FINAL RESULTS (CEC)

Client	ELRFS	Total CEC (cmol/kg soil)		Individual Elemental Exchange Capacity (cmol/kg soil)						
Label	Label	Untreated	Treated	Al	Ca	Fe	K	Mg	Mn	Na
LMST1-A	KB10-1	48.46	n/a	0.670	121.877	0.0029	0.585	3.366	0.0050	0.544
LMST3-B	KB10-2	49.93	n/a	0.663	122.892	<MDL	0.590	3.231	0.0050	0.562
LMST4-B	KB10-3	5.19	3.40	0.159	11.005	0.0074	0.410	0.760	0.0007	0.082
LMST5-B	KB10-4	6.54	4.58	<MDL	14.295	0.0039	0.444	0.695	0.0019	0.069
CPK1-A	KB10-5	21.69	32.08	0.177	15.086	0.0024	0.649	30.911	<MDL	0.742
CPK8-A	KB10-6	29.28	35.42	0.003	18.672	0.0033	0.761	38.440	0.0015	0.754
CPK12-A	KB10-7	26.09	33.75	0.164	18.411	<MDL	0.786	33.303	0.0026	0.972
CPK1-B	KB10-8	30.69	37.29	<MDL	21.233	<MDL	1.222	35.333	0.0009	0.702
CPK2-B	KB10-9	30.49	37.49	0.258	23.038	<MDL	1.230	34.385	0.0007	0.777
CPK3-B	KB10-10	18.71	32.94	0.006	11.339	0.0006	0.567	25.779	0.0010	0.493
CPK4-B	KB10-11	21.03	30.37	0.123	11.898	<MDL	0.631	32.562	0.0005	0.263
CPK5-B	KB10-12	27.29	35.96	<MDL	14.072	<MDL	0.643	35.780	0.0005	0.241
CLAY1-A	KB10-13	19.32	15.05	0.403	39.002	<MDL	2.127	1.357	0.0035	0.767
CLAY3-A	KB10-14	39.94	37.15	0.562	65.425	<MDL	8.763	8.984	0.0173	2.041
CLAY4-A	KB10-15	30.24	33.85	<MDL	47.931	<MDL	8.982	10.711	0.0075	7.439
CLAY5-A	KB10-16	29.88	35.61	0.415	45.814	<MDL	10.837	13.050	0.0097	11.327
CLAY6-A	KB10-17	28.72	37.54	0.433	49.430	0.0005	7.343	12.876	0.0097	1.533
CLAY1-B	KB10-18	19.98	19.44	<MDL	51.522	<MDL	4.097	5.129	0.0046	1.471
CLAY2-B	KB10-19	21.39	20.75	0.406	50.768	<MDL	6.221	5.181	0.0168	4.305
CLAY3-B	KB10-20	24.02	23.11	<MDL	49.032	0.0011	8.000	6.178	0.0067	6.261
CLAY4-B	KB10-21	43.54	36.11	0.406	48.250	<MDL	12.033	19.790	0.0270	36.158
CLAY5-B	KB10-22	28.41	44.08	0.442	53.435	<MDL	3.475	4.469	0.0097	0.667
PEAT1-B	KB10-23	306.77	128.80	2.431	725.018	0.3046	9.164	137.455	0.4486	31.722
PEAT2-B	KB10-24	292.13	130.40	2.295	720.153	0.4086	5.781	100.419	0.7534	17.177
PEAT3-B	KB10-25	313.86	129.78	2.451	760.630	0.3500	2.964	84.492	1.0006	6.239
PEAT4-B	KB10-26	187.72	114.71	14.666	169.873	9.7318	11.239	53.959	0.3827	10.867
PEAT5-B	KB10-27	313.38	123.03	2.297	631.220	0.2150	7.596	132.305	0.6769	8.645
MFPK1-B	KB10-28	63.72	58.46	<MDL	55.620	<MDL	3.908	73.492	0.0018	17.637
MFPK2-B	KB10-29	59.80	55.61	<MDL	36.356	<MDL	1.739	63.409	0.0020	4.850
MFPK3-B	KB10-30	58.69	60.11	<MDL	35.539	<MDL	1.677	66.737	0.0017	5.011
QFPK1-B	KB10-31	48.55	54.63	0.408	39.243	<MDL	1.395	50.127	0.0004	8.035
QFPK5-B	KB10-32	49.10	54.52	0.373	39.455	<MDL	1.415	48.751	<MDL	7.109
Average Method Blank (mg/L):		<MDL		<MDL	<MDL	<MDL	<MDL	<MDL	<MDL	0.0760
Average CRM Precision:		35.4		14.6	n/a	0.3	n/a	n/a	2.6	n/a
Average Duplicate Precision:		5.4		5.3	5.1	1.3	3.4	4.5	9.8	1.8

Treated Samples were first leached with dilute HCl to disolve limestone etc...All of sample LMST1-A and LMST3-B were leached away.
Total CEC based on Ba readings.

2010 04 05 - Kathryn Bergeron's Digests

Analysis Date: 2010 04 05
Analyst: Troy Maki

FINAL RESULTS (Total Digests)

Client Labels	ELRFS Labels	Al (ug/g)	As (ug/g)	B (ug/g)	Ba (ug/g)	Ca (ug/g)	Co (ug/g)	Cr (ug/g)	Cu (ug/g)	Fe (ug/g)	K (ug/g)	Mg (ug/g)	Mn (ug/g)	Na (ug/g)	Ni (ug/g)	P (ug/g)	Pb (ug/g)
LMST1-A	KB10-1	1374	<MDL	<MDL	11	209526	0.91	<MDL	5.65	899	1119	3900	35.7	234	5.17	3.28	0.60
LMST3-B	KB10-2	1444	1.57	<MDL	11	201422	1.41	<MDL	0.57	829	1016	3876	36.6	276	10.87	<MDL	<MDL
LMST4-B	KB10-3	34270	<MDL	137	328	101032	5.45	11.5	<MDL	11654	14580	10278	200.8	14843	11.04	3.32	6.51
LMST5-B	KB10-4	31235	<MDL	322	282	102654	4.24	8.7	2.29	9622	12575	8537	165.8	14546	9.10	3.92	6.60
CPK1-A	KB10-5	5791	8.10	2901	120	37827	82.46	951.8	33.92	40713	1811	52237	796.4	4314	1223	38.28	10.44
CPK8-A	KB10-6	4528	<MDL	1264	148	57419	75.39	1218.8	34.02	38538	1034	52088	808.7	2611	1134	36.38	1.65
CPK12-A	KB10-7	5265	19.46	1854	142	48903	75.40	1012.3	33.16	39264	1343	52353	802.5	3116	1152	38.30	0.76
CPK1-B	KB10-8	6998	<MDL	2989	166	70879	72.90	1038.3	37.14	37105	2100	50558	825.0	4596	1021	39.14	1.65
CPK2-B	KB10-9	6540	<MDL	1873	234	75864	59.21	641.7	38.11	33412	1521	50888	734.0	3093	911	38.61	1.17
CPK3-B	KB10-10	5659	6.53	1549	120	46592	82.03	1075.3	31.89	39264	1255	51736	846.1	2615	1142	39.41	<MDL
CPK4-B	KB10-11	6288	21.34	2718	127	39569	76.01	877.4	31.67	38744	1903	52214	787.5	4483	1193	38.58	8.71
CPK5-B	KB10-12	7194	<MDL	3708	156	54877	73.69	948.4	30.14	36970	2614	50734	793.6	5670	1136	34.74	<MDL
CLAY1-A	KB10-13	11707	16.39	330	140	90373	1.65	2.8	1.99	4321	4563	15610	157.1	4750	4.10	0.89	2.22
CLAY3-A	KB10-14	46554	<MDL	989	375	110607	10.82	34.5	17.76	19846	22848	18982	372.4	13469	21.96	19.79	9.01
CLAY4-A	KB10-15	39755	8.92	1009	346	108858	9.41	26.5	14.43	16632	20647	20682	334.5	13413	17.59	15.09	8.27
CLAY5-A	KB10-16	38403	4.94	1221	346	111930	10.03	28.7	14.57	16882	20145	21770	350.7	13499	32.06	15.13	9.06
CLAY6-A	KB10-17	38808	<MDL	1079	341	120217	8.67	23.6	12.10	15845	19349	19612	324.2	13218	16.71	13.37	10.81
CLAY1-B	KB10-18	35598	<MDL	494	337	104670	6.87	17.5	5.74	13357	17966	19928	264.0	13855	11.44	8.18	7.31
CLAY2-B	KB10-19	35068	<MDL	554	339	107355	7.28	17.8	8.29	13360	18355	20783	267.4	13760	11.97	8.51	7.78
CLAY3-B	KB10-20	38453	<MDL	304	355	103684	8.32	20.6	8.05	14563	19484	21048	299.8	13070	15.49	10.27	7.30
CLAY4-B	KB10-21	45611	<MDL	955	375	118381	12.18	39.7	22.75	21952	22681	20204	474.8	13256	24.50	23.27	7.15
CLAY5-B	KB10-22	23081	<MDL	160	200	216201	4.90	11.9	5.59	9334	13200	17301	179.9	6480	17.10	6.33	3.76
PEAT1-B	KB10-23	1897	<MDL	583	26	25225	0.44	<MDL	<MDL	6611	563	2131	34.8	1081	0.74	2.08	<MDL
PEAT2-B	KB10-24	6191	<MDL	953	61	26351	1.62	<MDL	5.08	7804	1993	2950	67.8	2496	4.81	4.95	2.31
PEAT3-B	KB10-25	4527	<MDL	744	48	26399	0.97	<MDL	0.28	6824	1212	1667	61.7	1345	0.20	1.54	<MDL
PEAT4-B	KB10-26	14352	28.53	20846	35	5129	0.31	<MDL	<MDL	1158	6837	1167	16.3	3303	<MDL	<MDL	<MDL
PEAT5-B	KB10-27	13242	22.88	1784	125	25800	1.89	<MDL	<MDL	5522	4393	5027	76.4	4845	4.37	1.51	1.58
MFPK1-B	KB10-28	5983	<MDL	1021	191	53583	71.88	467.2	59.55	32125	1559	51167	587.3	2675	1037	54.85	2.61
MFPK2-B	KB10-29	5944	<MDL	1011	182	54058	72.77	481.1	54.26	32084	1429	51664	615.7	2406	1059	51.11	0.76
MFPK3-B	KB10-30	4660	<MDL	66	184	49276	75.70	490.7	56.18	33205	696	51244	653.2	611	1082	52.93	2.52
QFPK1-B	KB10-31	6997	1.61	2019	162	61461	68.20	515.5	48.76	32864	2077	48321	630.3	4113	1040	51.63	1.09
QFPK5-B	KB10-32	7958	1.01	3209	159	62906	66.20	509.9	50.86	32046	2540	50171	624.7	5595	1003	49.64	1.12
Average Method Blank:		<MDL	<MDL	<MDL	<MDL	<MDL	0.0002	0.0014	0.0063	0.0195	<MDL	<MDL	<MDL	0.0006	<MDL	<MDL	<MDL
Average CRM Precision:			14.9			4.1	25.1	14.2	5.4	51.3		38.7	1.4		69.6		7.6
Average Duplicate Precision:		6.2	136.0	21.2	4.9	1.8	12.8	7.9	11.0	4.1	8.8	3.4	1.3	11.0	27.3	12.8	69.5
Average Spike Recovery (%):		101.6		28.7	100.8	105.2	97.3	93.7	105.8	112.7	70.9	94.7	98.6	81.0	100.7		101.1