USE OF ORGANIC AMENDMENTS AND SNOW FENCING TO MITIGATE SUBSTRATE LIMITATIONS TO REVEGETATION ON GRAVEL-DOMINATED HUMAN-INDUCED DISTURBANCES, CHURCHILL, MANITOBA, CANADA

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ABSTRACT.

Amelioration of substrate limitations to revegetation was investigated through the addition of an organic amendment, chemical fertilizer, alteration of microrelief-and modification of the wind regime at three gravel pits and two gravel pads near Churchill, Manitoba. Treatments were assessed for the first and second growing seasons and winters. Increased amounts of nitrogen, phosphorus and potassium, were only apparent in the first growing season. The organic amendment reduced the bulk density and pH of the substrate while increasing its water-holding capacity. Inter-site differences were reduced by the organic amendment and plant responses were positive. The microrelief treatment had no discernable effect. The snow fence produced significantly more snow than areas without fencing but had no major effect on the substrate. The combination of an organic amendment to improve conditions in the short- to long-term with the fencing which will accumulate benefits in the longer-term was the best way to ameliorate the limitations to growth of gravel-dominated substrates.

Key words: Churchill, Subarctic, tundra, boreal, disturbance, gravel, organic amendment, peat moss, reclamation, revegetation, snow fence, fertilizer

INTRODUCTION

Conditions dominating substrates such as gravel pits and pads can limit revegetation on these sites (Harper and Kershaw, 1996; Kershaw, 2003; Lavrinenko *et al*., 2003). Combining these growth limiting sites with the climatic and environmental conditions of the Arctic and Subarctic (Billings, 1987) further complicates the revegetation process (Arnalds *et al*., 1987; Stonehouse, 1989; Webber and Ives, 1978). In areas where roads are present, aggregate extraction sites (gravel pits) can make up 40 % of the disturbed area (Johnson, 1987). This number is made higher by the presence of aggregate deposition sites (gravel pads), such as abandoned roads and building pads. Examples of these types of disturbances can be found in the Churchill, Manitoba area (Figure 1). Many of these are present around the Churchill Northern Studies Centre (CNSC), the site of the former Churchill Research Range. The Churchill Research Range was a rocket launch experiment and testing facility operational from the 1950s to 1980s, and briefly in the late 1990s (Coutts, 2000). Gravel is easily extracted (Groom, 2001) in the region due to the commonness of beach ridges covered with a layer of thin and easily removed soil and vegetation. The ease of access and lack of an enforced permitting process has created a collage of gravel-dominated disturbances with either no attempts at revegetation or no successful revegetation.

Churchill is located at the transition between the taiga (or boreal) and tundra biomes (Ecological Stratification Working Group, 1995; Ritchie, 1962). Sparse tree cover, the presence of low-lying tundra vegetation and proximity to roads makes these disturbances highly visible. They diminish the natural appearance of the landscape which is especially important to an ecotourism-based economy such as Churchill's. Visitors from across Canada and around the world travel to Churchill providing CAN$1 billion each year to the local economy (Manitoba Tourism, pers. comm., 2003) to see northern lights, birds, wildflowers, beluga whales and primarily, polar bears (Town of Churchill, 1997). Although some of these gravel disturbances are still active, many have not been used for decades or the usable aggregate has been exhausted. It is these abandoned sites that should be reclaimed in an effort to facilitate recovery to a more ecologically-functional state and to aesthetically blend them with the surrounding undisturbed community.

Limitations to Plant Growth

Leaving sites to naturally recover can be a long process, particularly in the Subarctic (Harper and Kershaw, 1996; Jorgenson *et al*., 2003; Kershaw, 2003) where harsh environmental conditions such as severe wind and cold temperatures are the norm for most of the year. Many plants are suited to Arctic and Subarctic conditions, however the combination of these with human-induced disturbance creating an unsuitable growth substrate, such as gravel, adds to the lengthy natural revegetation process. Gravel-dominated disturbances are nutrient poor and there are almost no soil micro-organisms to convert nutrients such as nitrogen into plant available forms (Haag, 1974). Few species can colonize this poor growth medium, and often have low seed production (Johnson, 1987). Those that are successful must also withstand increased exposure to wind year-round and wind-driven ice crystals in the winter which can easily abrade needles off trees (Scott *et al*., 1993) and destroy plants and seedlings as if they were grazed (field observation). This increased exposure is due to the gravel-dominated disturbances being windswept with the substrate completely exposed to the elements. These gravel disturbances' predisposition to being windswept is a function of their raised profile relative to the surrounding undisturbed plant community and lack of vegetation to capture snow and build up a snowpack (McKendrick *et al*., 1992). Snowpack, even as little as ten centimetres, is a valuable guard for plants. It can significantly reduce winterkill, plant death resulting from harsh winter conditions (Leep *et al.*, 2001), which is one of three major causes of seedling failure following germination. The other two major causes, drought and lack of nutrients (Vough *et al*., 1995), are also limitations of gravel-dominated disturbances (Cargill Bishop and Chapin, 1989).

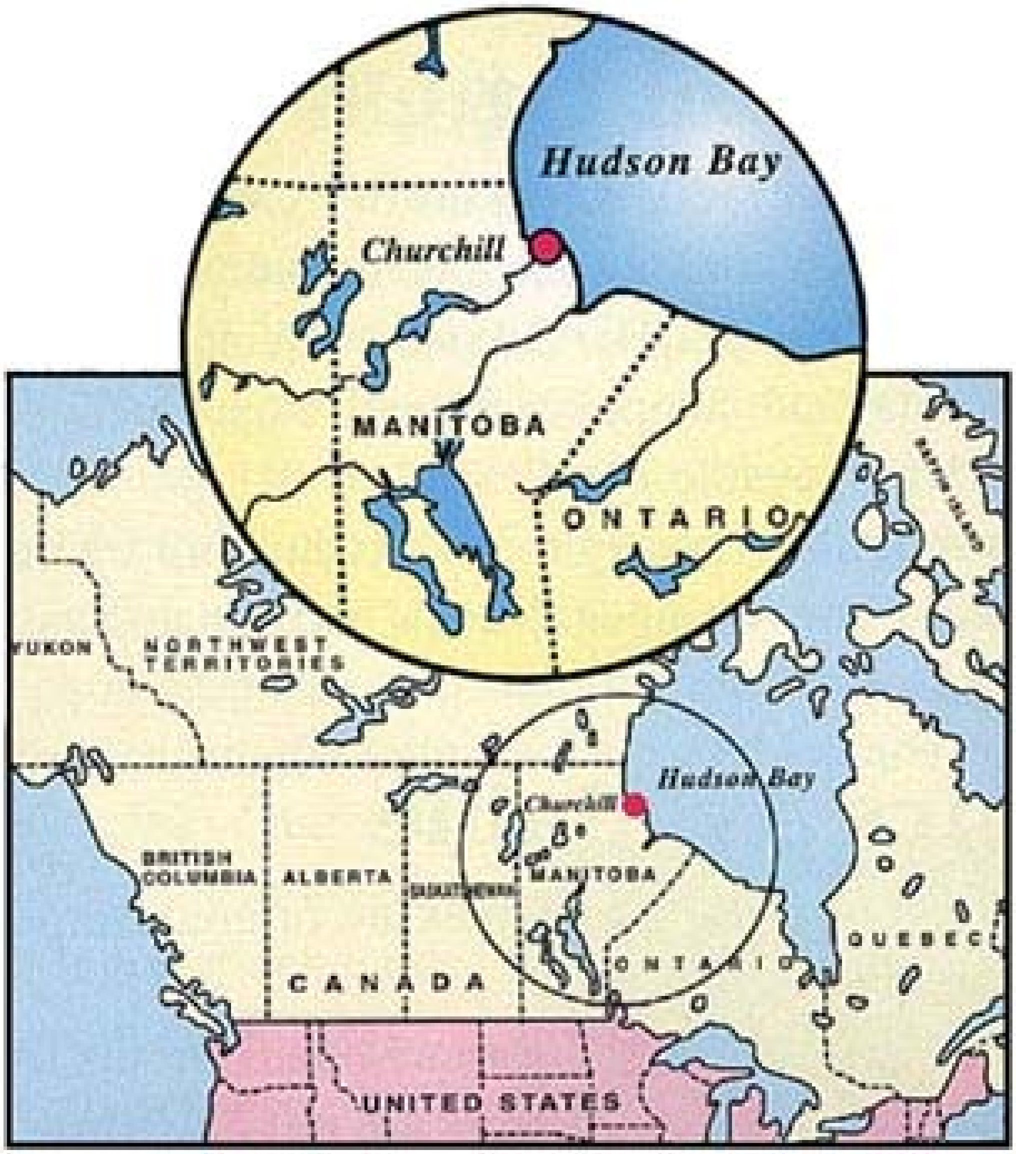

Figure 1 – Study site location: Churchill, Manitoba (GreatCanadianOutdoors.com, 2003).

Natural Revegetation

These limitations to growth are the reason natural revegetation, or allowing the surrounding plant community to naturally invade the disturbed area, is a potential method, albeit an extremely slow process (Borgegard, 1990; Firlotte, 1998; Forbes and Sumina, 1999; Jorgenson *et al.*, 2003). In addition, the naturally revegetated area after several years or decades in comparison with the undisturbed community will have large areas of bare ground with small patches of a few species, or overall low cover and low species richness (Borgegard, 1990; Cargill Bishop and Chapin, 1989; Firlotte, 1998; Jorgenson *et al.*, 2003; Kershaw, 2003). Disturbance itself is not always detrimental to plant growth and can improve species diversity (Harper and Kershaw, 1996; Vavrek *et al.*, 1999), but this is in situations where the seed bank, propagules and soil have not been entirely stripped from the disturbance. In situations of gravel extraction or deposition, natural revegetation is a cost-free and easy method of revegetating these sites. However, in the Arctic and Subarctic, the potential for invasion by non-native or exotic plant species (Staniforth and Scott, 1991), as well as the extremely long time it takes and unsatisfactory end result in terms of blending the disturbance with the surrounding landscape, makes it an unsuitable means of reclaiming these disturbances.

Substrate Modification

An easy, moderately-priced alternative to natural revegetation is modification or manipulation of the substrate. This can greatly increase the chance of revegetation success and eventual reclamation of the gravel disturbances by making the substrate more hospitable to invading natural species (Johnson, 1987). As well, substrate modifications also help support seeded species and reduce seeding rates (Johnson, 1987) which is important in northern projects where the cost of native seed can be the greatest expense. Methods of substrate manipulation include: adding an organic soil amendment; adding natural or chemical fertilizer; alteration of topography, either on a macro- or micro-scale; and erection of snow fencing.

Organic amendments are used to improve nutrient availability and provide a suitable growth medium while reducing bulk density (Land Resources Network Ltd., 1993; Logan, 1978). Organic amendments, and especially peat moss, are good at improving the water holding capacity (Cole and Spildie, 2000; Ontario Ministry of Natural Resources, 1978; Richardson and Evans, 1986) of the substrate by decreasing the pore size in coarse-textured soils (Puustjarvi and Robertson, 1975) which in turn mediates large temperature fluctuations (Addison, 1975; Hillel, 1982) and the darker colour helps warm the soil in the spring (Land Resources Network Ltd., 1993). Organic amendments can consist of the original overburden, commercially produced topsoil, wood chips, peat moss, straw mulch, sewage sludge or fly ash. In Churchill's case, use of the original overburden in reclamation projects is not possible as it was not retained from the older disturbances and is very difficult to collect in new disturbances due to the thin topsoil (Dredge, 1992; Scott, 1996). However, it has been done in at least one instance but there was only enough overburden to partly cover a portion of the disturbed pit (personal observation). Straw mulch in the Churchill area has a history of being contaminated by exotic seeds (Staniforth and Scott, 1991) and also requires infrastructure to keep the mulch from blowing away, which can be expensive (Chambers *et al.*, 1990). Wood chips decompose very slowly (Schoenholtz *et al.*, 1992), especially in cool climates, and as such would not provide a short-term amelioration of the substrate for seeds and seedlings. Locally collected peat moss was considered as a potential substrate addition but rejected due to its time consuming, work-intensive extraction process for this project's small-scale experiments, and the desire not to create any additional disturbances on the landscape. Commercial peat moss was selected over commercial topsoil as an organic amendment as it was less expensive and more readily available in sufficient quantities. Although peat moss and topsoil do not require infrastructure to keep the material in place, it is recommended that it be tilled or mixed with the gravel to prevent loss to wind erosion (Logan, 1978). McKendrick (1997a, pers. comm., 2002) found that over a space of ten years the majority of the topsoil added to plots that were not tilled, was lost due to wind erosion while the tilled plots still had appreciable amounts of organic matter. Another benefit of peat moss is that it can lower the pH of the substrate (Logan, 1978; Reid and Naeth, 2001) which can be useful in situations where the substrate is calcareous and/or alkaline (Land Resources Network Ltd., 1993). Peat also collects capillary water, the portion of soil water that cannot be removed by gravity (Hillel, 1982); of which up to 70 % is available to plants (Puustjarvi and Robertson, 1975) and retains seeds better increasing the effectiveness of substrate seeding (Gartner *et al*., 1983). Although peat moss is not a permanent soil amendment, especially if only added once, its slow decomposition due to the more resistant organic material (Allison, 1973) provides a suitable growth substrate long enough for plants to establish which then in turn improve the growing conditions (Land Resources Network Ltd., 1993).

Natural fertilizers, such as manure, are useful soil amendments in areas where they are readily available. In areas such as Churchill, where there is no agricultural activity, it would not be cost-effective to ship manure to the North. As well, the manure may also contain seeds of species not native to the Churchill area. As such, chemical fertilizer was used to increase the nutrient status of the substrate. Decomposition in the North is slow due to the lower temperatures so nutrients are not recycled as quickly as they are in southern environments (Johnson, 1987) increasing the need for additional nutrients especially in extremely well-drained substrates such as gravel pits and pads. Since decomposition is slow and arctic plants have the ability to conserve nutrients once they are obtained, fertilizer can have a long-lasting effect (Klokk and Rønning, 1987). In gravely soils leaching of nutrients from fertilizer is a common problem (Chambers *et al*., 1990; Mitchell, 1987). Use of time-released fertilizer or application of fertilizer in combination with an organic amendment can retard the rate of loss of nutrients (Logan, 1978).

Alteration of topography, both on a macro- (disturbance) and micro- (plant) scale can encourage plant growth on these disturbances. Although not a consideration for this study as all the sites were relatively flat and uniform in topography, macro-scale modification of gravel-dominated disturbances is recommended to remove steep (>22 °) and often unstable slopes which prevent vegetation from establishing (Borgegard, 1990). Micro-scale topography modifications consisting of small ridges, troughs, or generally uneven or roughed surface help to provide micro-scale wind protection, and collection of moisture in the troughs or lower-lying areas (Densmore, 1987; Johnson, 1981; Mitchell, 1987). Creation of meso-scale ridges or berms, made out of substrate can also help by providing sheltered, moist (relative to the rest of the disturbance) areas for plants to grow in. However, McKendrick *et al*. (1992) and McKendrick (pers. comm., 2002) found that berms did not work well in their revegetation experiments on Alaskan oil drilling gravel pads, but that the same principle could be duplicated using what they believed to be much more effective snow fencing.

Plastic-mesh snow fencing can be used to collect snow into drifts which can protect plants and seedlings from the wind (Scott *et al*., 1993), provide additional moisture to the site upon melt (McKendrick *et al*., 1992) and an opportunity for roots to grab soil particles being washed through with the meltwater (Walker *et al*., 2001). This spring moisture burst which can create puddles on still frozen substrate and cause seed immersion is important for water uptake of some species at low temperatures – a process critical to germination (Bell, 1975). Fencing left up year-round can also provide benefits to the site in the summer by collecting soil and plant particles, helping to reduce erosion and continuing to provide wind protection. This is very important at least until the plants have passed the establishment stage (McKendrick *et al*., 1992). McKendrick *et al*. (1992) used snow fencing that was 1.2 m high and found it collected too much snow, leaving the sites snow covered late into the growing season. Modification of the fencing height to 0.6 m in subsequent experiments was found to be the optimum (J.D. McKendrick, pers. comm. 2002) where snow was collected to the height of the fencing, but melted quickly enough in the spring so as not to shorten the growing season.

Purpose

Overall this project was designed to determine whether wind, moisture or nutrients was most restrictive to seedling germination and survival on gravel-dominated disturbances. For the purposes of this paper the differences in the abiotic factors (substrate/'soil' and snow) between treatments and sites are discussed. As plant growth and survival is dependant on the suitability of the substrate, mitigation of the limiting factors is a key part of reclaiming these disturbances.

METHODS

Site Description

Three aggregate extraction (gravel pits – Pit L, Pit N and Pit P) and two aggregate deposition (gravel pads – Pad B and Pad R) disturbances were selected for reclamation testing. Site selection was based on adequate size; lack of plant cover (<10%); accessibility; and flat, uniform topography. Sites were selected from within tundra- to boreal-dominated undisturbed plant communities. Pit N was within the predominately tundra area and was the most recently disturbed (2000/2001) after originally being abandoned prior to 1961 (Firlotte, 1998). Pit L and Pad R were adjacent sites, close to the CNSC and were remnants of the rocket range. Within the transition of tundra to forest vegetation, Pit L was lower than the adjacent surrounding plant community after being regraded in 1984. Pad R, a compacted, abandoned road, was approximately 1.5 m higher than the adjacent disturbed and undisturbed areas. Upon the rocket range closure in 1984, it was blocked off from traffic and abandoned. Pad B, the most recently created disturbance (around 1997) was a compacted gravel pad about 0.6 m higher than the surrounding undisturbed community, within an open treed area in the forest-tundra zone. Pit P was within the boreal forest. It was part of a larger pit that straddled both sides of Twin Lakes Road, one of the major roads outside of the town site. Abandoned around 1960 Pit P was the oldest of the five study sites.

Treatment Installation

To mitigate the limitations of the gravel substrate, a total of eight treatments were applied at each of the five sites. Quadrates (1 m^2) were randomly located within six 5 m^2 blocks (necessary because of the fencing treatment), with three replicates of each treatment per site (n = 24 per site, 120 total). Three of the blocks had 0.6 m of orange, plastic mesh snow fencing (F) erected along the northwest face of the block, perpendicular to the prevailing wind. The other three blocks were left exposed. Within the blocks the other treatment combinations were installed to further improve the substrate conditions or to provide a reference. Alteration of the topography on a micro-scale was simulated by microrelief (FM and M) treatments consisting of three to five hand-raked and -packed ridges and troughs ($\alpha \approx 5$ cm) perpendicular to the northwest. Addition of an organic amendment (peat moss), as well as a chemical fertilizer, was achieved with the seed mix treatment (FS and S), which also included seeds of six native plant species (Rausch, In prep., 2005). For each 1 m^2 quadrate the seed mix treatment (seed mix) consisted of removing the top 2.5 cm of gravel and spreading 2.5 cm of peat moss over the quadrate, and sprinkling most of the removed gravel back over the peat moss. The removed portion of the gravel was combined with seeds (density = 1800 seeds m^{-2}) and 30 g (300 kg ha^{-1}, same as that used by Firlotte (1998) in Churchill) of time-released fertilizer (SmartCote 12-12-12 NPK, 12 % each: nitrogen, available phosphoric acid (P_2O_5) and soluble potash (K_2O)). The mixture was added to the surface of the quadrate and packed down by lightly walking over the surface. The same process was used for the combination treatment of seed mix and microrelief (FSM and SM), except the mixture was not packed down by walking, but rather by hand during the creation of the ridges and troughs. Control, or no treatment, quadrates were placed within both block types for a baseline of no assistance, or natural revegetation (C) and fence only treatment (FC).

Disturbed and Undisturbed Areas - Year (Growing Season) 1

Five 225 cm^3 soil samples were taken from randomly-chosen locations within each pit or pad but outside of the treatment blocks after removing the surface vegetation. Another five samples were taken outside the disturbance in the undisturbed community surrounding each site. The wet weight of each soil sample was taken within 24 h of sampling. Samples were oven dried at 60 °C for a longer period of time rather than the usual 105 °C (Hillel, 1982) to prevent burning of organic matter. Samples were weighed to determine dry bulk density, gravimetric water content (mass wetness) and volumetric water content (volume wetness). Organic matter content was determined by burning a portion of each sample (loss-on-ignition, LOI) in a crucible at 475 °C for 1-1.5 h until a steady weight was obtained (Scott, 1985). A lower temperature and longer time were again used to prevent burning off of carbonates which could over-inflate the LOI results. Samples were sieved to determine the percentage of fines (particles <2 mm) and to prepare samples for testing of total nitrogen (N), phosphorus (P) and potassium (K) content. Nutrient content and pH testing was done using a Hach NPK-1 Soil Fertility Test Kit (Hach Company, Colorado, USA) according to the methodology in the test kit manual (Hach Company, 1992). The Hach NPK-1 Soil Fertility Test Kit was selected for processing the soil samples because of the lower cost (in comparison with private or university laboratory processing) and because it enabled field processing in Churchill. Samples were also tested for carbonates by adding a few drops of 10 % Hydrochloric Acid (HCl^-) to a portion of the sample and observing the presence and strength of any reaction and rating it on a scale of 0 (no reaction, <1 % $CaCO_3$), 1 (slight reaction, 1 % $CaCO_3$), 2 (moderate reaction, 2-6 % $CaCO_3$) or 3 (strong reaction, 6-40 % $CaCO_3$) (Scott, 1985; Soil Classification Working Group, 1998).

Reclamation Quadrates - Year 1 and 2

A 130 cm^3 soil sample was taken from the same grid cell in each quadrate (destructive sampling). In quadrates where the treatment included microrelief, a sample was taken from both the ridge (r) and the trough (t) in Year 1 to examine the differences between these two microenvironments. In Year 2, only one sample was taken from each quadrate, regardless of presence of a ridge or trough, and in a different grid cell from the previous year to avoid sampling an already re-disturbed area within the quadrate. Soils were processed as described in the previous section with the exception of carbonate testing which was not conducted on the reclamation quadrate soil samples. Replicates were combined to create composite samples prior to soil nutrient, percent fines, pH testing because of lack of sufficient sample material after the other tests were completed.

Snow Sampling - Winter 1 and 2

Blocks at each of the five sites were sampled in the first and second winters (February) after treatment installation. Sampling consisted of taking eleven randomly-collected depth measurements within each block, as well as three snow cores along the northwest edge of the block, using an Adirondack snow corer (Goodison, 1978) to determine snow density. The snow water equivalent (SWE) [1] (Kershaw, 2001; Pomeroy and Gray, 1995) and heat transfer coefficient (HTC) [2] (Kershaw, 1991, 2001) were calculated from the snow density and depth.

$$\text{SWE (mm)} = 0.01\, d_s\, \rho_s \qquad [1]$$

$$\text{HTC } (\text{W}\cdot\text{m}^{-2}{}^{\circ}\text{K}^{-1}) = k / d_s \qquad [2]$$

where: ρ_s = snow density ($kg\cdot m^{-3}$)
d_s = snow depth (cm)
$k = (2.94 \times 10^{-6}\ \text{W}\cdot\text{m}^{-2}{}^{\circ}\text{K}^{-1})(\rho_s)^2$

Snow cores were melted and filtered for particulate matter and the pH was determined for the filtered water.

Statistical Analysis

All data were tested for a significant difference ($p<0.05$ if not otherwise stated) using one-way and two-way analysis of variance (ANOVA), with the Holm-Sidak multiple comparison test to determine between which treatments the differences, if present, occurred. For between year comparisons the ridge and trough samples from Year 1 were averaged to make the data balanced with Year 2. If the data were not normal they were transformed by taking the natural log of each value. If that failed to make the data normal then a rank transformation, where data are arranged from smallest to largest and assigned an integer rank value, was applied. Differences between rank transformed data must be greater to be found significant (SPSS Inc., 2003).

RESULTS

Soil - Disturbed and Undisturbed Areas

Bulk density, carbonates and pH were significantly higher ($p<0.05$ and $p<0.001$) in the disturbed sites than in adjacent undisturbed sites. Gravimetric and volumetric water content, percent fines, percent organic matter, and N and P levels were significantly lower in the gravel disturbances at most sites (Table 1). A major exception was Pad R which was not different in water content, P or pH from the adjacent undisturbed area. Although the soil characteristics are listed in Table 1 with significant differences between the disturbed and undisturbed areas and among sites, it is important to mention the K values specifically. Many of the K values were similar due to the testing method where a minimum value of 77.5 mgL^{-1} had to be assigned to most of the samples because the amount present was less than that measurable by the Hach kit procedure. As the data were not normal and could not be transformed, only descriptive statistics were used, so although The only significant differences between the fence and no fence treatments were found in bulk density at Pit L (FC>C), gravimetric water content at Pits L and P (FS>S), volumetric water content at Pad R and Pit L (FS>S) and Pit P (FC>C and FS>S), percent organic matter at Pad B (FC>C) and P content at Pad R (FM>M and FC>C). Another interesting trend was that the fencing treatment seemed to further increase the differences between the seed mix and no seed mix treatments as compared to the unfenced blocks, with the seed mix having more improved conditions for plant growth.

Site differences in Year 1 were not all the same as differences in Year 2, except for Pad B and Pit L which both had higher organic matter and lower pH in both years. Pit L also had constantly higher gravimetric water content. Pit P on the other hand had high bulk density and low organic matter in both years and Pad R had high and Pad B low, percent fine material (Table 2).

K values, as previously mentioned were not normal and could not be transformed for ANOVA comparison. However, in Year 1 samples that had a K value greater than 77.5 mg L^{-1} (the lowest measurable value) were those that included the seed mix (and thus fertilizer). Pit N also had the highest number (4 out of 24) of K values greater than 77.5 mg L^{-1}, and Pad R and Pit L the lowest numbers (1 out of 24 at each site) but by Year 2, no values above the minimum testable were recorded (Table 2).

Ridge and trough sample (only obtained for Year 1) differences were fewer than expected. Of the few soil characteristics that had a significant difference, all but one fit the predicted pattern of the trough samples being more favourable to plant growth. The volumetric water content of the FSMt and SMt treatment types were moister than the ridge equivalents. The same was true for N content. The FMt and Mt treatments collected more fine soil material than the FMr and Mr treatments.

SITE / SOIL	Pad B		Pad R		Pit L		Pit N		Pit P	
	D	U	D	U	D	U	D	U	D	U
bulk density ($g \cdot cm^{-3}$)	1.60 (0.10)	0.43 (0.26)	1.31 (0.12)	0.91 * (0.33)	1.30 (0.20)	0.15 (0.06)	1.57 (0.19)	0.44 (0.40)	1.87 * (0.10)	0.34 (0.35)
grav. water content (%)	9.72 (4.16)	217.04 (202.36)	5.33 (1.96)	15.71 ^ (12.75)	6.84 (1.43)	288.21 (119.99)	6.42 (3.54)	198.32 (150.58)	5.67 (3.54)	240.69 (235.26)
vol. water content (%)	15.20 (5.62)	52.90 (20.10)	6.98 (2.72)	11.00 ^ (4.94)	8.72 (1.34)	38.80 (17.90)	9.57 (4.42)	43.20 (26.40)	10.70 (6.84)	29.40 (19.20)
fines (%)	38.57 ^ (3.73)	62.63 (29.30)	50.31 (11.14)	46.49 ^ (7.98)	55.58 (12.42)	88.03 (26.48)	50.84 (9.21)	83.80 (19.46)	42.30 (1.73)	93.36 (0.16)
organic matter (%)	0.87 (0.21)	35.50 (30.98)	0.45 (0.20)	4.21 ^ (3.56)	1.02 (0.37)	69.09 (33.27)	1.13 (1.36)	44.24 (39.04)	0.34 (0.14)	56.64 (37.30)
N ($mg \cdot L^{-1}$)	6.80 ** (1.59)	4.00 (1.81)	4.52 (0.48)	4.50 (1.00)	3.30 (0.70)	3.20 (1.40)	3.64 (0.76)	4.90 (2.11)	1.20 (1.55)	1.28 ^ (0.34)
P ($mg \cdot L^{-1}$)	1.17 (1.22)	17.58 (6.35)	4.29 (2.58)	8.34 (4.41)	2.88 (1.93)	9.92 (5.81)	9.39 ** (2.33)	23.94 ** (7.86)	3.21 (2.54)	32.82 ** (8.92)
K ($mg \cdot L^{-1}$)	77.50 (0.00)	77.50 (0.00)	77.50 (0.00)	77.50 (0.00)	77.50 (0.00)	77.50 (0.00)	77.50 (0.00)	78.42 (1.60)	77.50 (0.00)	175.20 (169.22)
pH	8.03 (0.34)	6.94 (0.64)	8.00 (0.10)	7.92 (0.44)	8.57 ** (0.18)	6.79 (1.08)	8.42 ** (0.26)	7.34 (0.46)	8.48 ** (0.08)	6.60 (0.70)
carbonates (ranked scale)	2.6 (0.55)	0.2 (0.45)	2.8 (0.45)	1.2 (0.45)	2.4 (0.55)	0.6 (1.34)	1.6 (0.89)	0.2 (0.45)	2.4 (0.55)	0.0 (0.0)

Table 1 - Pre-treatment soil attributes at five reclamation sites. Samples were taken from within the disturbance outside the reclamation quadrates (D), and from the undisturbed area adjacent the disturbances (U). The values are given as the average (standard deviation). Shading denotes a significant difference (light $p<0.05$; dark $p<0.001$) between fence and no fence treatment blocks for that soil parameter. * / ** represents a significantly higher and ^/^^ a significantly lower (*/^ $p<0.05$; **/^^ $p<0.001$) value between sites for that year and soil parameter, or for the "Between Years" column a significant increase or decrease between years.

Snow – Reclamation Blocks

On a whole the fenced blocks had significantly greater snow depth (1-14 times deeper in Winter 1, 3-15 times deeper in Winter 2) and SWE, and lower pH than the unfenced blocks. Pit P was an exception for all three parameters. Density was only different between treatments at Pit N where the snow on the fenced blocks was denser. HTC was greater on the unfenced blocks at Pit L in Winter 1 and at Pad B and Pit N in Winter 2. The fences collected more particulate matter at Pit P in Winter 1 and at Pad R in Winter 2. Winter to winter comparison found a significant increase in pH at three of the five sites and a decrease at Pit P, and an increase in density at Pad R (Table 3).

SOIL	SITE	Year 1 (2002) S / NS^{1}	Year 2 (2003) S/ NS^{1}	Between Years
bulk density (g·cm^{-3})	Pad B	0.63 / 1.16 ^	0.58 / 1.15	
	Pit L	0.66 / 1.03 ^	0.66 / 1.03	
	Pit N	0.75 / 1.24 *	0.69 / 1.14	
	Pit P	0.66 / 1.27 *	0.82 / 1.35 *	*
	Pad R	0.78 / 1.21 *	0.76 / 1.01	
grav. water content (%)	Pad B	11.36 / 3.03	30.18 / 3.93	**
	Pit L	16.61 / 3.98 **	28.00 / 6.03 **	*
	Pit N	9.17 / 2.31	19.33 / 3.03	*
	Pit P	12.39 / 1.63	8.37 / 1.29 ^^	^
	Pad R	19.33 / 5.66 **	14.78 / 4.01	^
vol. water content (%)	Pad B	6.59 / 3.40	12.26 / 4.52 **	*
	Pit L	8.20 / 4.04	12.67 / 6.11 **	*
	Pit N	6.20 / 2.78	10.86 / 3.46	*
	Pit P	7.10 / 1.93	6.04 / 1.74 ^^	
	Pad R	11.46 / 6.78 **	8.56 / 4.01	^^
fines (%)	Pad B	36.38 / 27.32 ^^	39.58 / 25.99 ^	
	Pit L	48.17 / 41.07	44.07 / 45.09	
	Pit N	42.28 / 38.26	45.04 / 32.14	
	Pit P	52.12 / 31.86	53.25 / 54.29 *	
	Pad R	57.49 / 55.46 **	52.40 / 48.20 *	
organic matter (%)	Pad B	11.60 / 0.90 *	18.54 / 0.88 **	
	Pit L	14.34 / 1.03 *	12.18 / 1.15 **	
	Pit N	11.08 / 0.76	10.98 / 0.65	
	Pit P	11.38 / 0.55 ^	6.87 / 0.23 ^^	^
	Pad R	10.02 / 0.54 ^	10.51 / 0.41	
N (mg·L^{-1})	Pad B	50.31 / 18.87	3.47 / 1.78 *	^^
	Pit L	46.14 / 25.30	3.48 / 1.00	^^
	Pit N	60.40 / 10.30	6.55 / 2.62 *	^^
	Pit P	60.87 / 13.60	1.07 / 0.50	^^
	Pad R	55.32 / 20.58	3.50 / 3.50 *	^
P (mg·L^{-1})	Pad B	42.17 / 18.63	11.22 / 5.64	
	Pit L	62.79 / 21.16	11.39 / 6.66	
	Pit N	24.11 / 8.01	9.21 / 5.36	
	Pit P	31.74 / 4.42	3.41 / 3.77 ^^	^
	Pad R	17.55 / 24.16	50.02 / 49.14 **	*
K^{2} (mg·L^{-1})	Pad B	2 109.55 / 77.50	0 77.50 / 77.50	
	Pit L	1 101.42 / 77.50	0 77.50 / 77.50	
	Pit N	4 113.27 / 78.28	0 77.50 / 77.50	
	Pit P	2 86.28 / 77.50	0 77.50 / 77.50	
	Pad R	1 84.62 / 77.50	0 77.50 / 77.50	
pH	Pad B	6.63 / 8.02 ^	6.45 / 8.45 ^	
	Pit L	6.85 / 8.07 ^	6.93 / 8.28 ^	
	Pit N	6.75 / 8.58	6.68 / 8.73	
	Pit P	6.53 / 8.53	6.83 / 8.78 *	
	Pad R	7.07 / 8.18	7.48 / 8.53 *	

Table 2 - Significant differences on the reclamation quadrates between the seed mix (S) and no seed mix (NS) treatments, sites and years. ^{1}Average seed mix quadrates value on the left and average no seed mix quadrates value

on the right (average seed mix / average no seed mix). ^{2}Descriptive statistics only. The number of quadrates (out of 24) for each site with a value greater than minimum testable are given. All were seed mix quadrates. Shading denotes a significant difference (light p<0.05; dark p<0.001) between seed mix and no seed mix treatments for that year and soil parameter. * / ** represents a significantly higher and ^/^^ a significantly lower (*/^ p<0.05; **/^^ p<0.001) value between sites for that year and soil parameter, or for the "Between Years" column a significant increase or decrease between years.

		Winter 1 (2003)		Winter 2 (2004)		Between Winters	
SNOW	SITE	F	NF	F	NF	F	NF
density (kg·m^{-3})	Pad B	230.89	174.97	275.37	233.17 *		
	Pit L	197.59	223.70 *	185.54	134.06		^
	Pit N	243.27	135.08	258.57	138.96		
	Pit P	149.99 *	146.23	178.50	161.16		
	Pad R	202.89	179.16	135.09 ^	107.51	^	^
depth (cm)	Pad B	31.40	4.74	35.00	3.73		
	Pit L	32.96	4.98	26.06	7.82		
	Pit N	56.39 *	4.02	39.73	2.64		
	Pit P	22.08	20.03 *	35.97	41.05 *		
	Pad R	26.17	4.63	29.73	9.82		
SWE (mm)	Pad B	77.76	9.43	102.25 *	9.50		
	Pit L	48.99	8.15	59.77	10.77		
	Pit N	85.54	6.62	82.09	4.08		
	Pit P	54.59	40.75 *	79.83	76.49 **		
	Pad R	58.32	7.64	40.73 ^	12.24		
HTC (W·m^{-2}°K^{-1})	Pad B	0.50	1.88	0.61 *	4.76 *		
	Pit L	0.49	8.42 *	0.33	1.10		
	Pit N	0.69	1.33	0.73 *	4.52 *		
	Pit P	0.25	0.34	0.23	0.18		
	Pad R	0.57	2.79	0.19	0.42		
particulate matter (mg)	Pad B	15.39	10.37	13.46	4.66		
	Pit L	11.93	37.93 *	9.52	3.66		
	Pit N	9.99	6.67	14.27	12.50		
	Pit P	11.84	4.10	4.19	5.36	^	
	Pad R	7.16	7.89	8.83	3.38		
pH	Pad B	6.38	6.85	7.09	7.44	*	*
	Pit L	6.47	6.91	7.12	6.88	*	
	Pit N	6.29	6.72	7.37 *	7.31	**	
	Pit P	6.81 *	6.69	6.20 ^^	6.15 ^		^
	Pad R	7.13 *	nd	7.09	7.13		nd

Table 3 - Significant differences on fenced (F) and no fence (NF) blocks in Winters 1 and 2, between fencing treatments, sites and years. Shading denotes a significant difference (light p<0.05; dark p<0.001) between the fence and no fence treatments for that year and snow parameter. * / ** represents a significantly higher and ^/^^ a significantly lower (*/^ p<0.05; **/^^ p<0.001) value between sites for that year and snow parameter, or for "Between Winters" column a significant increase/decrease between Winters 1 and 2. nd indicates no data.

DISCUSSION

Although the baseline soil characteristics between sites were different, by treating areas of the disturbances (reclamation quadrates) with a peat moss, fertilizer and seed mixture (either alone or in combination with fencing and microrelief alteration) these site differences were evened out and became less important than treatment differences. Thus, with regards to the soil characteristics of these gravel disturbances; the organic amendment was the main factor controlling substrate improvements for plant growth.

Disturbed and Undisturbed Areas

The disturbed areas prior to any treatment were significantly less suited to plant growth than the undisturbed areas. The higher bulk density makes it harder for roots to penetrate the substrate, while the porous, loosely packed peat moss of the undisturbed areas provides little resistance to rooting and also provides more soil structure and surfaces for roots to latch on to for stabilizing an individual seedling or plant (Goss, 1985; Juma, 2004). Pit L had the lowest bulk density. It also had the greatest percentage of fine material and although the rest of the particles sizes were not sorted, the remainder of the aggregate was also smaller in comparison with the other sites (field observation). However, Pit P had the sandiest substrate (field observation) which probably accounted for its higher bulk density. The small soil sampling container collected the smaller-grained samples at Pit P more easily than at the other sites with larger particles, some bigger than the sampling container, which interfered with the precision of sample collection. Why the gravel pads did not have the highest bulk densities as expected, could be due to the sampling container height. The dense layer or layers can be at least 10 cm below the surface (Addison, 1975) and the sampling tin height was less than that (about 5 cm).

pH was higher in the disturbed areas as compared to the undisturbed. This may have been due to the higher carbonate content of the substrate in the disturbed areas. pH is higher in soil with a lot of calcium carbonate ($CaCO_3$) where free carbonates from $CaCO_3$ dissociation are present. The free carbonates combine with free hydrogen ions and form highly soluble hydrogen carbonate (HCO_{3-}). The carbonates are then easily leached into the lower levels of the soil profile(Briggs *et al*., 1993; Yaalon, 1954). Although measuring pH in carbonate rich soils is often problematic in that the partial pressure of CO_2 must be controlled during the testing (Turner and Clark, 1956). It was not in this study as in most field situations, so the pH values must be considered with this in mind.

Pad B had the highest N levels while Pit N had very high P values. This may be because P is highly soluble in calcareous soil as the soil to water ratio increases (Olsen *et al*., 1960). Since there is little water available and the substrate is highly calcareous, the P was retained. As well, although not significant, there was more organic matter naturally present in the substrate at Pit N which could have further increased the P present in the samples and P levels can be higher than N in upland tundra communities (Haag, 1974).

Water content and percent organic matter were not very different among sites. This explains why the seed mix treatment which mainly influenced the percent organic and water content of the substrate, was also similar across sites. Pit L was unusual in that there were more wet areas within the disturbance (possibly from a higher water table) but this was not reflected in the water content of the samples which may have been a result of the shallow sampling container.

The undisturbed areas had high water content, fine materials and organic matter from naturally accumulated peat moss, roots and decomposing plant material. Plant cover was 100 % (Rausch, In prep., 2005) reflecting the suitability of the undisturbed area substrate for plant growth. The undisturbed area adjacent to Pit L and Pad R had less phosphorus than the other sites. Pit P, surrounded by boreal forest, had low N, from low quality organic matter (Vance and Chapin, 2001) and high P levels possibly from greater amounts of decomposing plant litter (Shiels and Sanford Jr., 2001). The undisturbed area next to Pad R was the most different from the others. This was mainly due to poor sample site selection. The ditch areas adjacent to Pad R (a former road) had naturally revegetated to a point where field personnel mistook these areas, with their underlying gravel-dominated substrate to be the 'undisturbed' areas. Sample collection beyond the previously disturbed ditches would have yielded results similar to that of the Pit L undisturbed areas as these sites were immediately adjacent and surrounded by the same undisturbed plant community. Low P values for the undisturbed area surrounding Pit L could also be due to poor sample site selection as there was a buffer of re-established vegetation surrounding the pit that was more advanced than that adjacent to Pad R, that could have been sampled in error.

Reclamation Quadrates – Effects of the Seed Mix Treatment (Peat and Fertilizer)

The addition of the peat, fertilizer and seed mix (seed mix) was the main factor in the improvement of substrate characteristics for plant growth. It lowered the pH and bulk density and increased the water-holding capacity, amount of fine material and organic matter. The decreased bulk density and increased amount of fine material (and thus decreased average particle size) improves the soil bed (Bateman and Chanasyk, 2001) and germination potential (Down, 1974). As well, in the first year the seed mix treatments contained more nutrients (N, P and K). Year differences were mainly restricted to soil nutrients. Loss of nutrients though leaching, use by seedlings and volatilization resulted in decreased N and K at all sites, and of P at all sites except Pad R. Natural N or ammonium is usually not lost to leaching, but the highly soluble nitrate from fertilizer additions is easily leached (Hach Company, 1993). The seed mix quadrates had more nutrients than the non-seed mix quadrates in Year 1 but by Year 2 any significant differences between the seed and non-seed mix treatments with respect to nutrients had disappeared. Thus the fertilizer only provided additional nutrients in the first growing season. Subsequent additions of fertilizer would have been needed to maintain or increase the level of soil nutrients in the seed mix quadrates. Other studies found it necessary to fertilize in both the first and second years in order to compensate for the major loss of nutrients in coarse-grained substrates through leaching (Mitchell, 1987). Hernandez (1974) and Gartner *et al.* (1983) found N and P contributed most to growth in the first year. However, by the second and third years the effect from the fertilizer was lost because what ever was not immediately assimilated by the plants was quickly lost to immobilization, and/or leaching (Babb and Bliss, 1974; Densmore *et al*., 1987). While the nutrients only provided improvement to the substrate in the first growing season the benefits from the peat moss were longer lasting. In addition, the benefits to growth from increased moisture far exceed those of increased nutrients (Jorgenson *et al*., 2003). Soil water content was different between years but this was likely due to differing weather and soil moisture conditions at the time of sampling rather than a reduction in the water-holding capacity.

Pads B and R and Pit N had higher N contents than the other sites. However, these disturbances had naturally higher levels to begin with, so this difference could still be expressing itself despite the treatments. Overall substrate improvements were greatest at Pad B and Pit L. Organic matter and soil moisture were higher and bulk density lower than at the other sites. As well, pH was lower due to the commercial peat moss (Bateman and Chanasyk, 2001; Land Resources Network Ltd., 1993) which normally has a pH between 3.8-5.5 (Land Resources Network Ltd., 1993) which in cases of carbonate-rich soil where nutrients are being made unavailable, is a useful side-effect of using peat moss as an organic amendment. The main exception to Pad B and Pit L being the best suited to growth was percent fines where Pad B had low levels in both years while Pad R and Pit P had more fine-grained material. This increased amount of fines may have been associated with the increased water holding capacity at Pad R but this was not seen at Pit P, and the fine material did not seem to improve nutrient retention or organic matter content. Pit P was also not as suited to growth despite the higher fines content, with high bulk density (again as with the disturbed/undisturbed area samples perhaps due to the smaller overall particle size), higher pH and low water content. Pit P was the oldest and most sheltered by trees but the most limiting for plants. Organic additions did raise levels to values comparable to the seed mix treatments on the other sites. However, the extremely low pre-treatment values out-weighed the benefits of the seed mix treatments in overall site comparisons. Pit N had low soil moisture and percent fines, but its moderate bulk density, percent organic matter and relatively high-to-moderate soil nutrient content made up for these growth deficiencies.

The lack of significant differences between the ridge and trough samples was surprising, especially when field observations one week after treatment installation confirmed obvious visible differences in moisture and amount of fine material. This obvious difference was also observed by Jorgenson *et al.* (1993) but they did not sample and test these areas separately. The troughs were darker and full of small-grained sand and gravel while the ridges were much lighter in colour and had mainly large gravel and rocks along the crest. The presence of the peat moss could have helped to retain the fertilizer (Logan, 1978) and moisture on the ridges particularly as the ridges were hand-formed after the peat was added creating ridges comprised mainly of peat rather than gravel ridges with a layer of peat. This is supported by the fact that the ridges were less defined in the seed mix quadrates in Year 2 than those on the non-seed mix quadrates after peat erosion and/or settling during the winter and spring. It also helps explain why some of the FSMr quadrates had more organic matter than the FSMt quadrates. The increased moisture in the seed mix troughs (FSMt, SMt) as compared to the seed mix ridges (FSMr, SMr), was likely because the peat moss better retained the water in the troughs and wind more easily dried the more exposed peat on the ridges. On the non-seed mix quadrates, although differences between ridge and trough were visible immediately after installation eventually the water drained or evaporated away from both micro-sites. Thus, although the water was lost on different time frames, the end result was the same – they were dry.

Reclamation Quadrates - Effects of the Fencing Treatment

The most obvious and significant difference due to the snow fencing treatment was snow depth. Unfenced treatments in Alaska had snow-free periods but averaged <13 cm of snow (McKendrick *et al*., 1992). In our study average snow depth on the unfenced blocks was 7.7 cm in Winter 1 and 13.0 cm in Winter 2 when on the fenced blocks it averaged just over 33 cm in both years.

SWE, a theoretical value of how much water would be released from the snowpack if it were to all melt (Kershaw, 2001; Pomeroy and Gray, 1995), was significantly higher on the fenced blocks at all sites except Pit P. The average SWE for the fenced blocks was 65.0 mm in Winter 1 and 72.9 mm in Winter 2 while the unfenced blocks had much smaller SWE values of 14.5 mm and 22.6 mm in Winters 1 and 2 respectively. The fenced blocks did not have near as high SWE values as McKendrick *et al*. (1992) where the fences trapped about 420 mm SWE and the unfenced 0-<130 mm SWE, however their fences were twice as high as those in this experiment. If we were to take the square root of the SWE from McKendrick *et al*. (1992) study as the snowpack volume is proportional to the squared height of the fence (Pomeroy and Brun, 2001), then the results are comparable and almost identical (this paper versus McKendrick *et al*. (1992): fenced, ~69 mm vs. 65 mm; unfenced, ~19 mm vs. 0-<36 mm).

HTC is a measure of the heat loss from the snowpack (Kershaw, 1991) where a low value (<1.00 $W \cdot m^{-2} {}^{\circ}K^{-1}$) indicates good snowpack insulation and a high value (>2.00 $W \cdot m^{-2} {}^{\circ}K^{-1}$) increased heat conductivity from the ground to the air. Thus if the snowpack has a low HTC, from low density, deep snow (Kershaw, 1991), there is likely pukak, or depth hoar because of the large temperature gradient between the ground surface and the air temperature. Plants and roots would have increased temperature protection from extreme winter temperatures and fluctuations in a snowpack with a low HTC. The HTC was only significantly higher on the unfenced blocks at three of the sites, Pit L in Winter 1 and Pad B and Pit N in Winter 2. Since Pad B (raised from surrounding area) and Pit N (tundra) are so exposed to wind, it was not surprising that there was a difference in the HTC values when the snowpack was dense and shallow on the unfenced blocks. Even between site comparisons of both the fenced and then unfenced blocks found Pad B and Pit N to have the highest HTCs and highest densities as compared to all the other sites. The wind was able to pack the snow particles tighter together creating a denser snowpack. The density of the snow must be the main factor influencing these differences since the depths were not significantly different between sites for the same block treatment (fenced or unfenced). Although Pit L is relatively sheltered, it had a very high unfenced snowpack density. This was probably the result of an icy ground layer which would have had a greater chance of forming on the unfenced blocks from increased freezing and thawing because of the shallow snowpack and more exposed surface longer into the winter. Other snow studies spanning several winters at Churchill found HTCs in the undisturbed forest to range from 0.12-0.17 and those on the tundra from 2.49-4.35 (G.P. Kershaw, unpublished data, 2004). So the fences made the HTC of the snowpack closer to that of the forest rather than its previous tundra-like values.

The pH of the snow at the sites was inconsistent between the two winters. The significantly higher pH of the snow on Pad R and Pit P in Winter 1 matched with the higher pH of the substrate at these sites. However in Winter 2, the pH was significantly higher at Pit N and significantly lower at Pit P. The low pH at Pit P can be attributed to the surrounding coniferous trees of which the needles may have lowered the pH (Kahkonen *et al*., 2002; Vance and Chapin, 2001). Pit N has large gravel spoil piles surrounding it from all directions; especially from the NW (prevailing wind direction) which could explain the higher pH. The increased carbonate-rich dust blown and deposited onto Pit N could have increased the pH of the snow since these piles are not snow covered in the winter. At the other sites, any spoil piles present are located on the down-wind side of the site.

Although differences in the soil characteristics between the fenced and unfenced blocks were not significant at all sites and for all treatments, slight improvements to the growth conditions of the soil were found. This was noticeable for water content in some of the seed mix treatments, where the additional moisture provided by the snow trapped behind the fence upon melt was retained better retained by the organic amendment (peat moss) than on the unfenced seed mix quadrates. This may be because the organic amendment could better retain the additional moisture collected by the fencing in the form of snow (Jorgenson *et al*., 1993), or that the fencing provided protection from wind desiccation. Differences between the fenced and unfenced control quadrates were also found at four of the five sites, although for different soil characteristics. Again the fencing alone provided improved plant growth conditions with increased soil moisture, organic material and P. However, greater bulk density on the FC quadrates as compared with the C quadrates was found at Pit L. This may be because the bulk density on the C quadrates at Pit L was significantly lower than all the other sites and that the greater bulk density of the FC treatment at Pit L is representative of the differences in the placement of the blocks within the pit rather than true treatment differences. This hypothesis is also confirmed by the samples collected from within the pit but outside the reclamation quadrates, where the standard deviation in bulk density at Pit L was the largest ($\sigma = 0.20$) among the disturbance samples.

The fencing treatment made the seed mix versus no seed mix groupings more tight and different in terms of suitability for growth. This may be because the fencing made the effect of the seed mix treatment greater so that differences were more likely to be significant amongst the fenced treatments. The fencing enabled the peat moss to collect additional moisture and provided a wind-break so less organic matter and fine material were lost to aeolian transport. Most snowpack meltwater is lost to through-flow and runoff in spring and only remains around for three to ten days (Jorgenson and Joyce, 1994) unless there is an organic or topsoil amendment to increase the storage capacity of the soil and retain some of this moisture (Kershaw, 1995). Input of moisture from melt water can be almost as much as that from summer precipitation (Jorgenson and Joyce, 1994). Retaining as much of this melt water as possible through use of absorbents, or organic amendments is critical (Jorgenson and Joyce, 1994). Increased snowmelt is useful to plants but it is not as important as storage capacity of the substrate to retain some of this snowmelt (Jorgenson *et al*., 1993). As well, the spring moisture burst can aid decomposition which rarely occurs on dry sites except in moist micro-sites (Wein and Bliss, 1974).

The snowpack traps mineral and organic particles such as plant debris. Much of this is lost with melt water, but some is retained by the substrate especially if plant roots can trap these tiny particles (Walker *et al*., 2001). It was surprising that a greater difference in the amount of particulate matter in the soil was not found, however as the plant roots were removed from the soil samples and not carefully brushed off, much of this fine and organic material would not have been captured in the fines/organic matter content sample analysis. In addition, measures of the particulate matter in the snowpack were also not that different where only the high density, shallow snowpack of the unfenced blocks at Pit L and Pit N (although not significantly more) collected more particulate matter than all the other sites and blocks. It may be that the frequent redistribution of snow particles (and organic particulate matter) is not captured by the snowpack unless certain conditions are present. As well any amounts of particulate matter collected by the snowpack would take a long time to accumulate in the substrate and impact the substrate properties. Unlike McKendrick (1999) there was no significant loss of fines on unfenced plots. However he applied the fine material over a much larger area, so the smaller scale application of fine and organic material in this experiment provided a less obvious or measurable opportunity for loss.

Since snow provides six-times better insulation than the same depth of soil (Pomeroy and Brun, 2001), although there may not be many differences in the soil characteristics from the snow fencing, this continued insulation will probably have an effect on plant growth, especially once the plants become taller than the average snowpack on the unfenced blocks. Plants taller than the snowpack will be scoured by wind (Scott *et al*., 1993). While not captured in the snow sampling on these sites pukak was present on all the fenced blocks and not on the unfenced (field observations). This signifies that there was a larger temperature gradient between the air and ground surface on the fenced blocks with the snowpack providing a more moderate temperature at the ground surface and root zone (Kershaw, 1991) which will further affect plant growth in the long-term. It is expected that the snow fences, while not creating obvious differences in the soil characteristics in the short-term, will further improve the growing conditions on the blocks in the long-term (see also Jorgenson *et al*., 1993; McKendrick, 1991, 1997b; McKendrick *et al*., 1993).

CONCLUDING REMARKS

Although fertilizer was useful in the first year, and the fencing treatment will likely be beneficial to plant growth in the long-term, the addition of an organic amendment to the gravel-dominated substrate of these disturbances was the most valuable improvement to the growth potential. The organic amendment (peat moss) provided an improved growth medium in the short-term, and due to its slow decomposition, will continue to maintain this improvement for plants in the long(er)-term. Ease of application and its uncomplicated, relatively cost-effective commercial availability also makes peat moss a beneficial organic amendment for use in the Churchill area and other areas of the North.

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