Oil and Gas Site Reforestation: Operational Trial

Prosperity Through Unity - Year 3

Final Report

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Abstract

With over 1,400 oil and gas wells drilled in northeast British Columbia (BC) in 2005 alone, cumulative reductions in future timber supply may occur if well sites (~1 ha in size) are not reforested. Forestry landings resemble well sites in their challenges to soil productivity and reforestation, which include adverse physical conditions (i.e., compact soils), low organic matter content, and limited nutrient supply. Previous research in BC on forest soil rehabilitation techniques has developed practical methods for ameliorating adverse soil physical, chemical, and biological conditions in forestry landings. This project aims to apply these techniques to typical abandoned well sites in the Peace River region of BC as part of achieving successful reforestation. Five abandoned well sites were selected within the Boreal White and Black Spruce biogeoclimatic zone near Fort St. John and Dawson Creek, BC. Treatments consisted of tillage, wood chip mulch, tillage + wood chip mulch, tillage + incorporated wood chips, brush mats, and a control. Treatments were implemented between Fall 2003 and Spring 2004, and sites were subsequently planted with alternating lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*). Soils at all sites were fine to medium in texture with average coarse fragment contents ranging from 3% to 10%. Soil conditions were monitored throughout the 2004 and 2005 growing seasons. Response variables include soil physical parameters (bulk density, soil strength, moisture, air-filled porosity, water retention characteristics), nutrient availability, and seedling survival and growth. Initial data indicate that growth-limiting values of soil strength occurred under dry conditions on control plots. Pine and Spruce seedling performance was measured in September 2005. Individual seedlings and treatment plots have been marked and documented in order to allow long-term assessment of the performance of these treatments.

Introduction

Reclamation of oil and gas sites is common practice in western Canada, and a large body of information is available on restoring site hydrology, soils (Larney et al. 2003), and vegetation (Sinten, 2001) to a productive state. Including reforestation as a goal in reclamation faces additional challenges, such as (1) limited experience with reforestation as an objective for reclamation, (2) additional cost, and (3) the long-term nature of forest establishment and growth, which can make planning for reforestation more complicated.

There is evidence that reclamation and reforestation of disturbance caused by forestry development (i.e. landings) can lead to establishment of young forests (Bulmer and Krzic, 2003; Plotnikoff et al. 2000). Factors affecting reforestation success included soil conditions such as bulk density and texture, along with site factors such as soil moisture regime.

This project evaluated the effectiveness of tillage, organic amendments, and vegetation control to restore soil productivity and re-establish forest vegetation on abandoned oil and gas well sites in northeast British Columbia. Our objectives were to:

1. evaluate soil conditions and tree growth on sites that were reclaimed using a combination treatments of involving tillage, organic amendments and vegetation control, and
2. evaluate the extent to which soil conditions affected regeneration success and early growth.

Materials and methods

Study Sites

Sites were selected from among those visited as part of a previously completed well site inventory project (Green et al. 2004). Sites were located in the Boreal White and Black Spruce (BWBS) biogeoclimatic zone, and only sites that had received a Certificate of Restoration (COR) were considered for study. The results of a previous study (Bulmer et al. 2003) had emphasized the importance of the soil moisture regime in determining regeneration success of planted pine, so we stratified our site selection based on the expected moisture regime. Stratification was accomplished initially by examining Canada Land Inventory maps of the area and estimating the average forest capability and moisture regime for map units of approximately 100 square km. Moisture regime and forest capability are closely related in this landscape. The actual moisture regime for candidate treatment sites was then verified by air photos, field checks, and detailed site assessments. We selected sites with mesic moisture regime, accessible by four wheel drive vehicle. Sites are described in Appendix 1.

Site Treatments

Our treatments were designed to test whether or not soil conditions on typical reclaimed (COR) well sites were suitable for the productive growth of commercial tree species (Table 1). We based our selection of soil treatments on the factors that were expected to limit productivity, based on the results of our previous research. The operationally realistic treatments were expected to address limitations arising from (a) soil physical conditions, (b) reduced site organic matter levels, and (c) competition from seeded cover crops.

Reforestation efforts were primarily designed to evaluate the performance of lodgepole pine and white spruce. We also carried out preliminary testing of a range of hardwood and shrub species to evaluate their establishment success.

Table 1. Site treatments for operational trial of well site reforestation.

Code	Decompaction	Veg Control	Organic Amendment	Application Method
U (*Control*)	none	none	none	n/a
B (*Brush Mats*)	none	brush mats	none	n/a
C (*Mulch Only*)	none	none	10 cm of wood chips	mulch
D (*Till Only*)	to 50 cm	none	none	n/a
DC (*Till + Mulch*)	to 50 cm	none	10 cm of wood chips	mulch
DCI (*Incorporated*)	to 50 cm	none	15 cm of wood chips	incorporate to 25 cm

The range of treatments were selected because (a) they were expected to alleviate growth-limiting conditions, (b) similar treatments could be applied operationally, and (c) there is a need to test low-cost options for reclamation and reforestation. Since the sites had received COR, and had already been treated to reduce compaction for establishment of the cover crop, our lowest cost option was to simply plant trees on well sites that receive no further treatment (*Control*). To alleviate the potential competition from the cover crops, which was well established on all of the well sites, we used brush mats attached to the ground with steel pins when the sites are planted (*Brush Mats*). To provide organic matter inputs, and to simulate the presence of forest floor as a rooting medium, and its ability to modify soil temperature and moisture conditions, we applied a (approx.) 10 cm layer of wood chips (*Mulch Only*). This depth is similar to the depth of forest floor on nearby undisturbed sites (*offsite*). To evaluate whether or not soil physical conditions were suitable for productive forest growth after standard reclamation techniques have been applied, we tilled the soil to a depth of 50 cm. As a further test of soil conditions, we added wood chips to the tilled soil, either as a mulch (*Till + Mulch*) or incorporated (*Incorporated*). The wood chip treatments we applied were costly because the material had to be transported to the site in a large 'shuffle deck' van. However, in operational situations, there are often large accumulations of waste logs and logging debris remaining after clearing and site development. Wood chips for use in site reclamation treatments could be obtained operationally using a satellite chipper to process these residual wastes..

The treatments were applied to 3 sites[1] (Aitken, Bernadet, Blueberry) in October and November of 2003. Decompaction was carried out using a Komatsu 30 ton excavator with a site preparation rake and/or a bucket. Two additional sites (Blackhawk, Boot) were treated in May 2004. Wood chips were obtained from the Canadian Forest Products Ltd. sawmill in Taylor BC, and were derived from coniferous logs. The wood chips had been stored at the site for some time, and were slightly discoloured. Wood chips were stockpiled adjacent to the plots by unloading the amount required from the "shuffle deck" van. Wood chips were spread across the site by the excavator after decompaction, while minimizing the need for the machine to travel over decompacted areas. In some cases, the machine was able to reach across the site and did not have to travel over treated areas. In other cases, minor amounts of machine traffic were needed, and the effects were eliminated by further treatment as the machine worked sequentially across the plot. As the excavator carried out the tillage, we were able to confirm our initial assessment of soil moisture conditions for the plots.

Some studies indicate that addition of wood chips to soil reduces the availability of nitrogen, and can reduce the growth of planted crops. In one previous study using pine trees planted on restored landings in south BC, pine trees were not affected by wood chips added without added N. The approach in this experiment was to monitor the need for supplemental N additions through soil

[1] In fact 4 sites were treated in 2003, but one (2-4-88-22) was lost to the study as it was slated for re-entry drilling.

testing and the evaluation of tree health, and add N if necessary. No supplemental N had been added to the plots as of March 2006.

Treatment plot maps and site characteristics for the 5 study sites are included in Appendix 1 of this report.

Tree planting

Trees were planted on all plots in May and June of 2004. The tree planting layout consisted of 12 rows of 12 trees per row on each plot (6 plots per site). Tree spacing was 1.7 m x 1.7 m. In each row, spruce and pine seedlings were planted in an alternating pattern. The tree planting layout allowed for measuring survival on 144 trees (72 of each species), and for long term growth measurements on 64 trees (32 of each species) in an inner plot. This layout provided two rows of buffer trees to eliminate problems caused by edge effects at the boundary of treatment plots. Trees from the buffers can if necessary be transplanted to the inner measurement plot to replace damaged or dead trees. Approximately 4500 trees were planted on the plots, evenly split between lodgepole pine (Pli seedlot number 02077) and interior spruce (Sx seedlot number 01822). Additional trees were planted on untreated portions of the well sites.

In addition to the coniferous trees planted on the sites, a variety of approaches were used to test shrub species for their ability to establish and grow on the well sites. Willow whips were planted on untreated areas of the well sites north of Fort St John in early spring, 2004. On two of the treatment plots (*Incorporated* and *Control*) at each well site, we established several rows of shrubs and deciduous species, including trembling aspen (*Populus tremuloides*), Red osier dogwood (*Cornus stolonifera*), hedge rose (*Rosa sp.*), and Red elderberry (*Sambucus racemosa*), along with approximately 400 rooted cuttings, and 200 unrooted cuttings of Walker hybrid poplar obtained from Parkland Agroforestry in Melfort, Saskatchewan. Additional poplar cuttings were planted in 2005. The survival and growth of these plants was assessed in fall 2006.

Maintenance

Site visits in July 2004 revealed a significant competition problem from previously seeded cover crops on some sites, even on plots where tillage treatments, mulches and brush blankets had been applied. This was unexpected: we had anticipated competition would affect survival on the untreated plots, and had no plans to brush them as it was considered part of the raw planting treatment, and would be compared to other more costly treatments that included soil amelioration as well as brush control. However, the need for additional measures to control herbaceous cover crops was apparent, so we carried out manual vegetation control on the treated plots on at least two occasions, and were thus able to minimize damage to establishing trees. Some mortality occurred however.

Manual vegetation control involved simply pulling back the vegetation cover near the seedlings and flattening it down with foot pressure. We do not expect any changes to soil properties have resulted from these treatments. No chemicals were applied, and the vegetation recovered quickly to reinvade the seedling growing space. Manual vegetation control was carried out throughout the rest of the experiment where conditions warranted. Vegetation on untreated plots was not controlled, as this was one of the anticipated treatment effects.

We became aware of damage caused by grazing cattle on two sites (Bernadet and Blueberry) late in the 2004 growing season. This occurred despite our discussions with the rancher in the spring and summer which led us to believe that little damage would occur because the cattle were only expected to be in the area for a short period of time. The cattle, however, showed a great interest in the treated areas, and inflicted considerable damage to planted trees and the plots in a relatively short time period (2-3 weeks). For this reason, fences were built to exclude cattle from the treated areas at Bernadet and Blueberry.

Soil sampling and Analysis

Soil sampling was carried out to obtain information on the soil physical, chemical and nutritional factors that affect seedling performance. Activities included:

- Bulk density sampling at 0-7 cm and 10-17 cm depths at five locations on each plot (320 samples collected using a 0.518 l core)
- Air-filled porosity determination using an air pycnometer (each of the 320 bulk density samples was measured following collection)
- Water retention sampling (150 samples collected using a 0.039 l core)
- Nutrient sampling (30 composite samples collected: 1 from each treatment plot as a composite of the five sampling stations within the plot)
- Proctor maximum bulk density sampling (4 samples per site = 20 samples)
- Monitoring soil mechanical resistance and water content at each of 150 stations (Sites north of Ft. St. John were monitored in May, June, July, and October, 2004; sites south of Dawson Creek were only monitored in June, July, and October due to their delayed treatment; in 2005 all plots were monitored during June, July, August and October) Soil moisture content was measured volumetrically using a Theta probe in the same soil pits used to obtain soil strength measurements using the minipenetrometer at a depth of 10 cm. The RIMIK® Cone Penetrometer (RIMIK) was inserted adjacent each location to capture the change in strength with depth. This data was intended to record the soil strengths across a range of moisture contents throughout the 2004 and 2005 growing seasons. In May 2005, a suite of Hobo® dataloggers were installed at a site south of Dawson Creek, BC (Blackhawk) and another suite at a site north of Ft St John, BC (Blueberry) to monitor soil and air temperature, soil moisture content, and relative humidity in air. The continuous climate data is expected to provide detailed and relevant information on site conditions between site visits and throughout the winter months. Soil moisture content was measured on occasion adjacent to the installation to calibrate instrumentation.

The following laboratory analyses were completed:

- <u>bulk density</u> samples were passed through a 2mm sieve then dried in an oven to determine total and fine fraction bulk density, along with contribution of organic materials
- <u>mineralization of nitrogen</u> from treated and undisturbed portions of the well sites (results of a pilot study are included in this report)
- <u>Proctor compaction</u> (WSA Engineering in Castlegar)
- <u>water retention</u> characteristics of undisturbed core samples (MoF – Victoria) Five small cores were collected from each treatment plot (three from 2 to 4 cm, two from 12 to 14 cm) and analysed for water retention characteristics. Moisture contents at the permanent wilting point (PWP) were determined using a pressure plate apparatus along with moisture contents at field capacity and other water potentials.
- <u>nutrient sample analysis</u> for C, N, P and cations Total carbon and nitrogen (%) were determined gravimetrically on 5 point composite samples collected from a 0 to 17 cm

depth range at each treatment plot. Mineralizable N (min N) and electrical conductivity (EC) was also determined from the same samples.

- texture on composite soil samples (five point) collected from each treatment plot from 0 to 17 cm for particle size analysis (<2 mm) using the pipette method. Soils samples collected from Blueberry, Boot Lake, and Blackhawk were pre-treated for carbonates (using HCl) and salts (wash and centrifuge) due to observed flocculation of soil suspensions. All soils were pre-treated with hydrogen peroxide for presence of organic matter.
- coarse fragment content was determined gravimetrically following retention of the coarse mineral fraction from the bulk density cores on a 2 mm sieve

Tree Measurements

Trees were individually tagged for identification by placing a pin flag in the ground beside each seedling and attaching a numbered aluminium tag. Each tree in the trial has a unique identifying number. Detailed information on tree measurement techniques are provided in Appendix 2 of this report.

In September 2005, tree height, survivorship, relative vigour, and relative competition from adjacent ground cover species was measured as indicators of seedling performance. Tree height was measured from the root collar to the base of the top bud on the leader. Where the leader had died, the last bud on the longest lateral was used in its place. Vigour was based on the visual condition of the tree which relied heavily on colour but also crown volume and needle size. In order to assess incremental growth in the future, it was noted for each tree if the leader was dead.

Results

Soil Conditions

Bulk density

Initial results indicate treatments involving tillage reduced bulk density at both the 0 to 7 cm and 10 to 17 cm depth ranges. The *Incorporated* treatment was also significantly different than all other treatments at the 0 to 7 cm depth range. This effect is likely in part to the inclusion of the < 2 mm organic fraction (carbon originating from the wood chips) in the analyses as well as an increase in void space associated with the incorporated chips. The treatment effect of lowered bulk density through tillage was less clear and in some instances not realized on some sites. The lack of effect in these instances may be due to the potential of higher bulk density subsoil being brought to surface at plots receiving tillage treatment, particularly where soils pre-treatment had relatively low bulk density values (i.e., Aitken). Figure A summarizes bulk density and the 95% confidence intervals for mean values at 0-7 cm depth, and Figure B is a summary of the data from the 10-17cm depth..

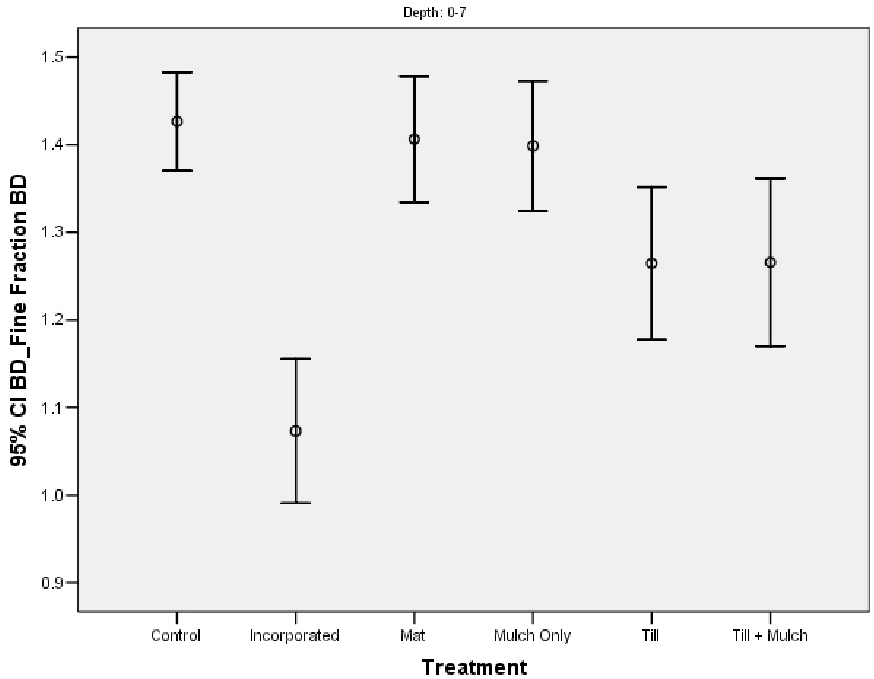

Figure A: Summary of pooled average fine fraction bulk density (0–7 cm) values by treatment

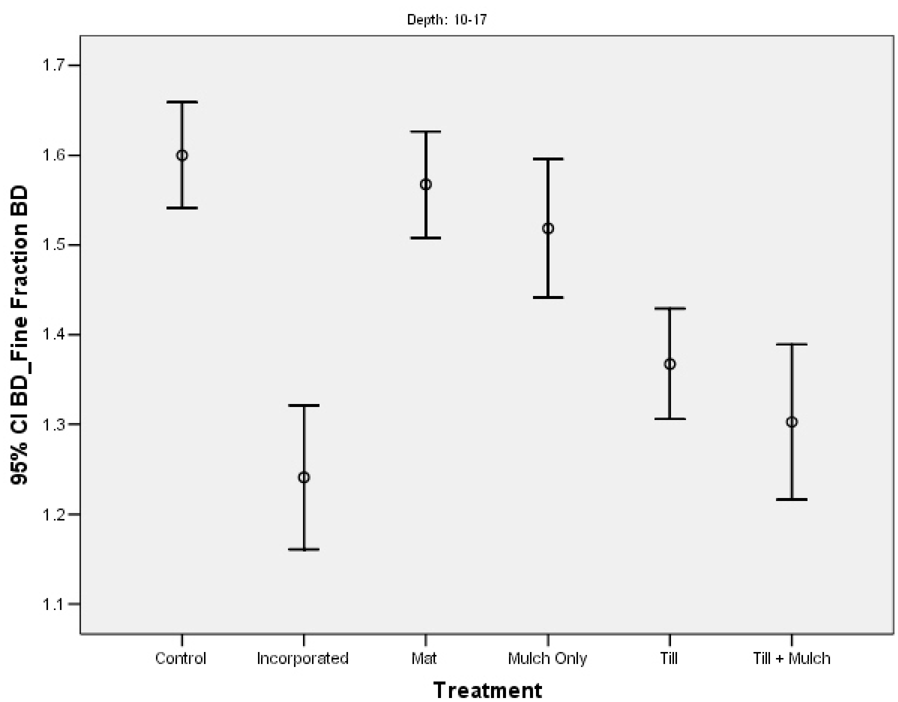

Figure B: Summary of pooled average fine fraction bulk density values (10-17 cm) by treatment

Soil particle size analysis and coarse fragments:

Soils were generally moderately fine in texture (clay loams and silty clay loams) at all sites except for Blackhawk (loam), which had higher sand contents with an average of 41% on treatment plots. The relative fractions of sand, silt, and clay, as well as the soil textural classification are provided in Table 2. Rehabilitative treatments were not anticipated to influence texture and the data supports this. With the exception of Blackhawk, offsite soils were observed to have similar or lower clay contents compared to soils collected from treatment plots. The observed eluviation of clay from the upper part of the soil profile at offsite locations was expected due to this being one of the dominant soil forming processes common to Luvisols in the general area.

Table 2. Summary of particle size analysis.

Site	Treatment	CLAY (%)	SILT (%)	SAND (%)	Texture Class
Aitken	*Control*	24.7	48.7	26.6	Loam
	Mat	29.9	45.1	25.0	Clay Loam
	Mulch Only	28.8	47.4	23.7	Clay Loam
	Till Only	30.2	46.2	23.7	Clay Loam
	Till + Mulch	28.1	48.4	23.6	Clay Loam
	Incorporated	29.1	46.7	24.2	Clay Loam
	Offsite	16.2	58.1	25.7	Silt Loam
	Degraded	32.0	45.6	22.4	Clay Loam
Blueberry	*Control*	32.2	47.0	20.8	Clay Loam
	Mat	35.7	47.8	16.5	Silty Clay Loam
	Mulch Only	27.8	43.7	28.5	Clay Loam
	Till Only	36.0	47.9	16.1	Silty Clay Loam
	Till + Mulch	36.1	48.6	15.3	Silty Clay Loam
	Incorporated	32.1	44.2	23.7	Clay Loam
	Offsite	21.9	61.5	16.6	Silt Loam
	Degraded	36.2	44.2	19.6	Silty Clay Loam
Bernadet	*Control*	29.2	52.8	17.9	Silty Clay Loam
	Mat	32.8	48.8	18.4	Silty Clay Loam
	Mulch Only	29.1	50.4	20.6	Clay Loam
	Till Only	27.9	53.0	19.1	Silty Clay Loam
	Till + Mulch	27.8	51.9	20.3	Clay Loam
	Incorporated	33.4	49.8	16.8	Silty Clay Loam
	Offsite	31.0	51.9	17.1	Silty Clay Loam
	Degraded	27.3	49.6	23.1	Clay Loam
Boot Lake	*Control*	30.6	41.4	27.9	Clay Loam
	Mat	27.6	49.7	22.7	Clay Loam
	Mulch Only	28.2	48.6	23.2	Clay Loam
	Till Only	29.8	47.6	22.5	Clay Loam
	Till + Mulch	27.1	49.2	23.7	Clay Loam
	Incorporated	25.5	50.7	23.9	Silt Loam
	Offsite	9.9	66.9	23.3	Silt Loam
	Degraded	28.0	47.3	24.7	Clay Loam
Blackhawk	*Control*	18.8	43.5	37.7	Loam
	Mat	16.7	38.7	44.6	Loam
	Mulch Only	18.8	40.6	40.5	Loam
	Till Only	16.2	37.9	45.8	Loam
	Till + Mulch	15.4	42.9	41.7	Loam
	Incorporated	21.3	43.8	34.9	Loam
	Offsite	22.1	58.2	19.7	Silt Loam
	Degraded	22.6	43.0	34.4	Loam

Coarse fragment content obtained from the soil cores (Figure C) ranged from approximately 3% (Aitken) to 9 % (Blackhawk) across sites for fragments that were smaller than approximately 5 cm. This value likely underestimates total coarse fragment content for all sizes as it excludes any fragments that would not fit into the core, and those from rocky areas that required the core to be relocated.

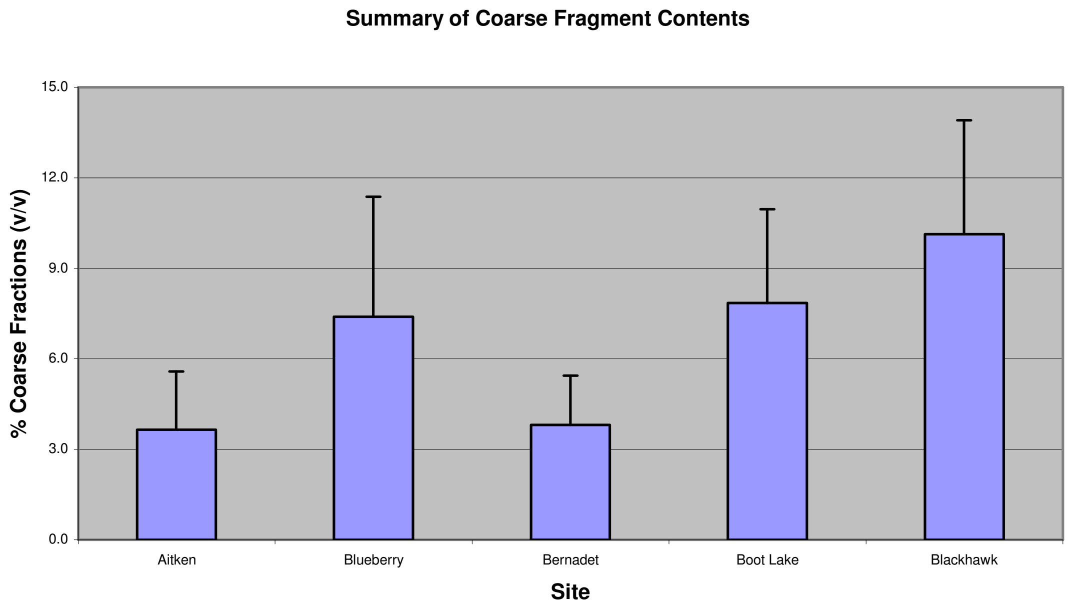

Figure C: Summary of coarse fragment determination

Soil mechanical resistance and water content:

For many of the plots, water content tended to be higher in spring and fall compared to summer measurements (Figure D) and the strength of this effect appears to have varied among treatments. For sites north of Fort St John (Aitken, Bernadet and Blueberry), elevated precipitation in the late summer was likely responsible for soils not drying as much as expected in 2005, and perhaps in 2004 as well although precipitation records for 2004 were not consulted. Figures F and G summarize the moisture contents across all sites for the *Control* and *Till Only* treatments, respectively.

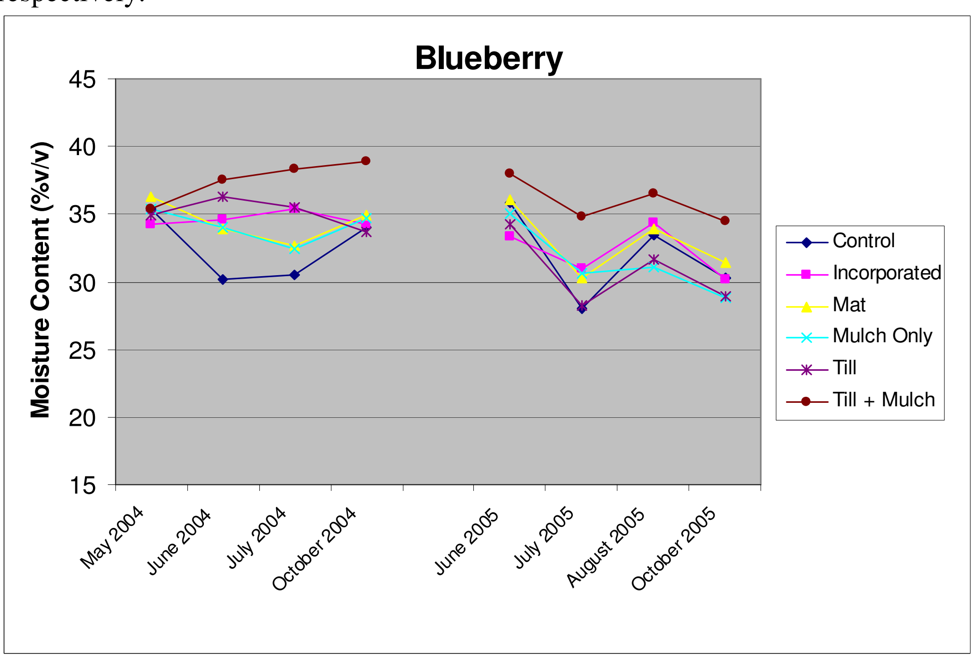

Figure D: Summary of moisture content at Blueberry: all treatments

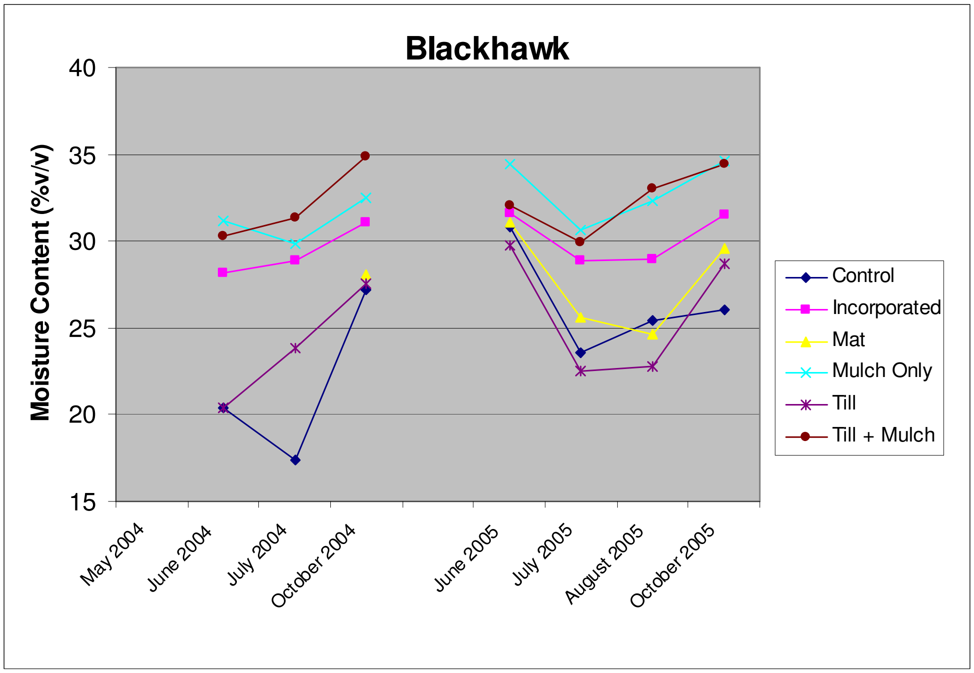

Figure E: Summary of moisture content at Blackhawk: all treatments

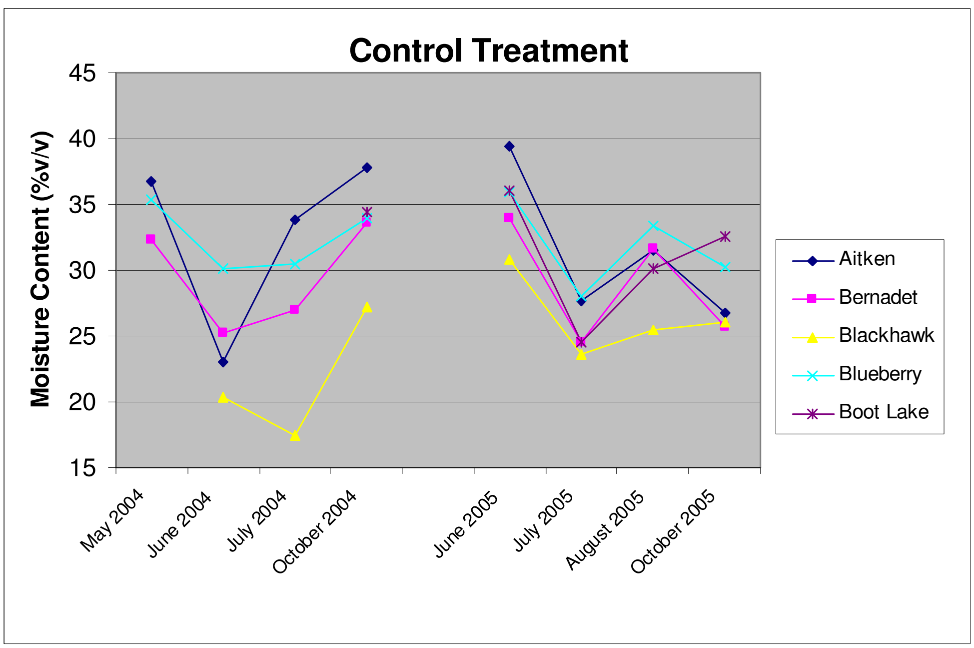

Figure F: Summary of moisture content on *Control* treatment: all sites

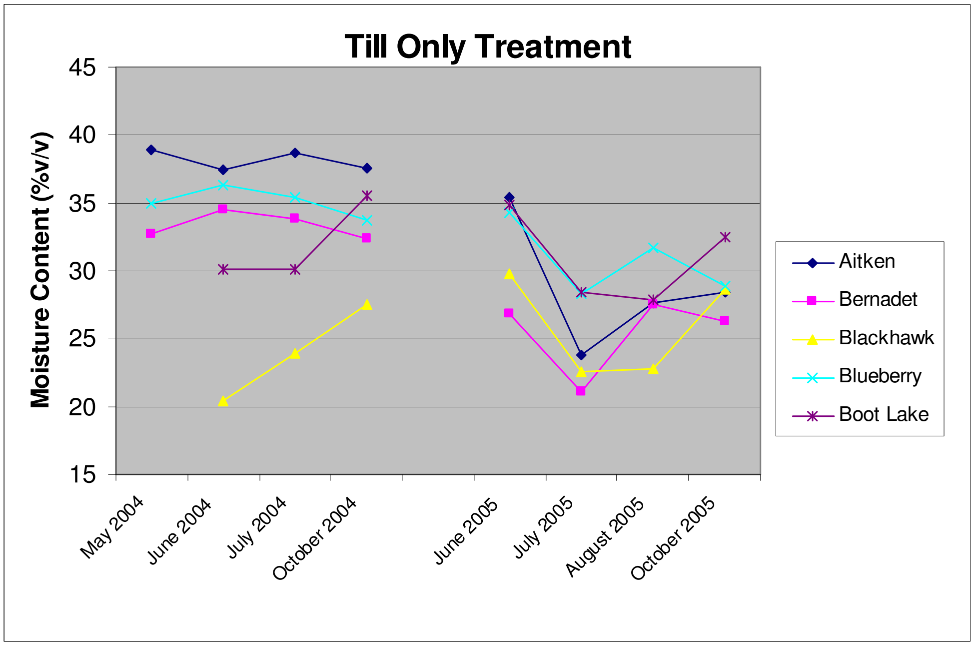

Figure G: Summary of moisture content on *Till Only* plots: all sites

Soil mechanical resistance determined with the minipenetrometer was lower in the spring and fall compared to summer measurements (Figure H). At Aitken, soil mechanical resistance for treated plots did not appear to reach growth limiting values at any time during the growing season, while soils on the control plots did experience growth-limiting values of soil mechanical resistance during June, which coincided with dry soils. Soil strength was generally higher at untilled plots, particularly, the *Control* and *Brush Mat* treatments. Treatments involving mulches generally increased moisture content, and a corresponding decrease in soil strength was observed. The *Incorporated* treatment was also typically successful in decreasing soil strength and increasing moisture content. Figure I summarizes observed soil strength across all treatments for 2004 at Aitken, which demonstrates the effect of strength on depth as well as the more robust treatment effects observed between tilled and untilled plots. The change in soil strength throughout 2004 as indicated in Figure J is a function of the changing moisture content observed at the *Control* treatment plot.

Soil mechanical resistance and water content were correlated. As expected, the higher the moisture content, the weaker the soil or less resistance encountered. Continuous soil strength determined with the RIMIK penetrometer was also monitored at each of the sampling stations throughout the 2004 season. Results from the RIMIK (Figure E) indicate generally stronger soils in untilled treatments, and an increase in soil strength with depth. This trend was common to each of the five sites.

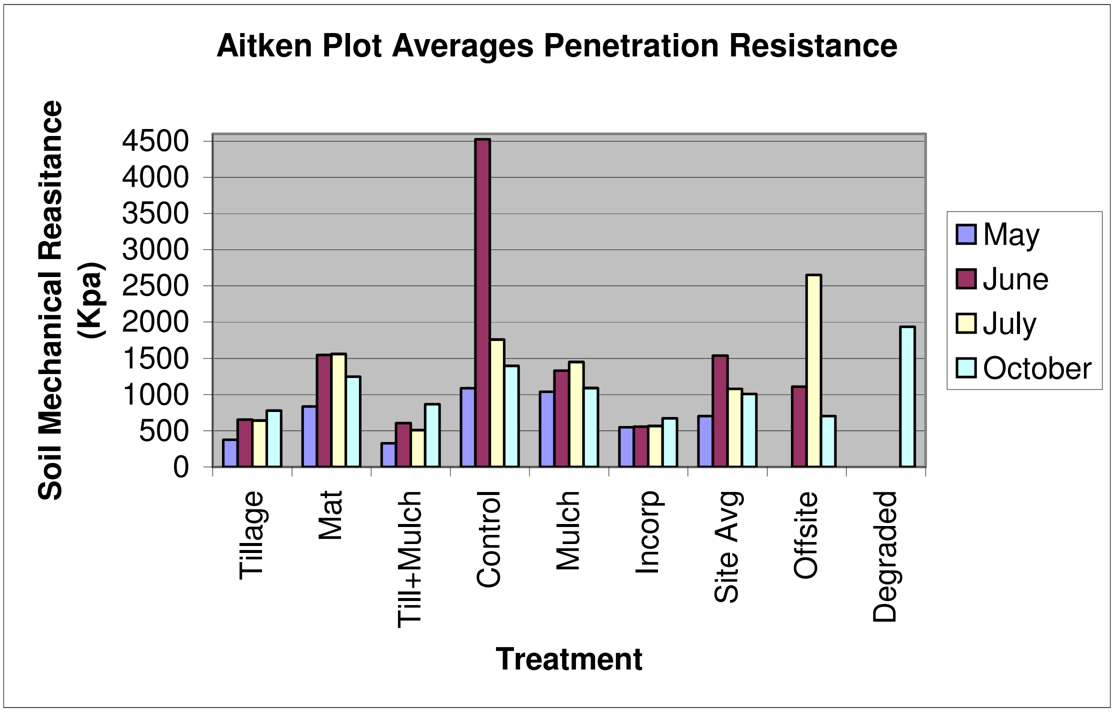

Figure H: Summary of soil mechanical resistance using minipenetrometer

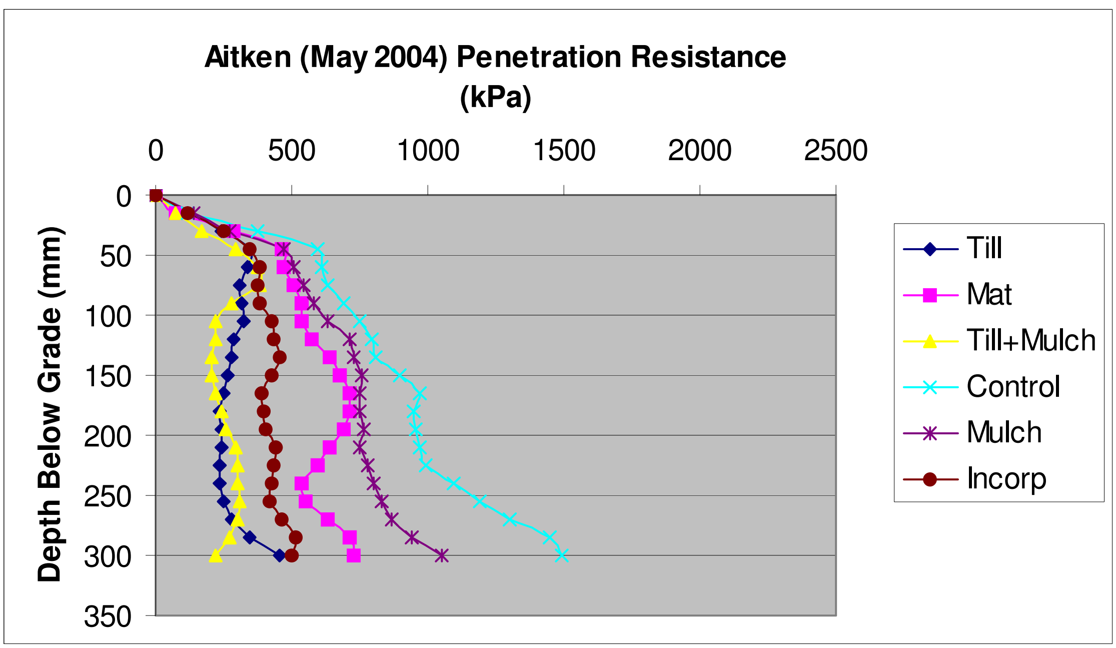

Figure I: Summary of continuous soil mechanical resistance at Aitken using RIMIK Penetrometer

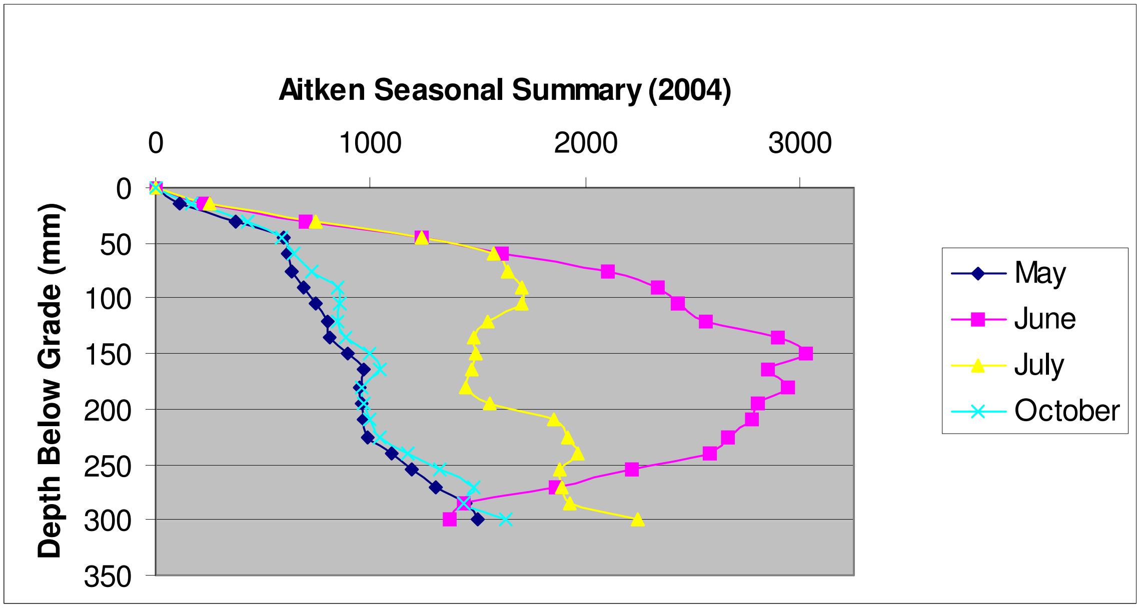

Figure J: Summary of continuous soil mechanical resistance (RIMIK) on the control plot at Aitken over the 2004 season

An exponential decay curve (eqn 1) was fitted to the graphs of soil strength and moisture on the individual treatment plot level as a means to correct soil strength for moisture. In general, Equation 1 generated an improved line of best fit for observed data (i.e., increased R^2 value) when compared to those generated using a linear model. Using the exponential model, moisture content explained 61% of the variation in soil strength for the *Control* treatments when data from all sites were pooled. Preliminary observations using this predictive model for soil strength indicated that the use of tillage may have altered the relationship between soil strength and moisture (i.e., coefficients a and/or b may be significantly different).

(Equation 1) $y = ae^{-bx}$, where y = soil strength, and x = moisture content

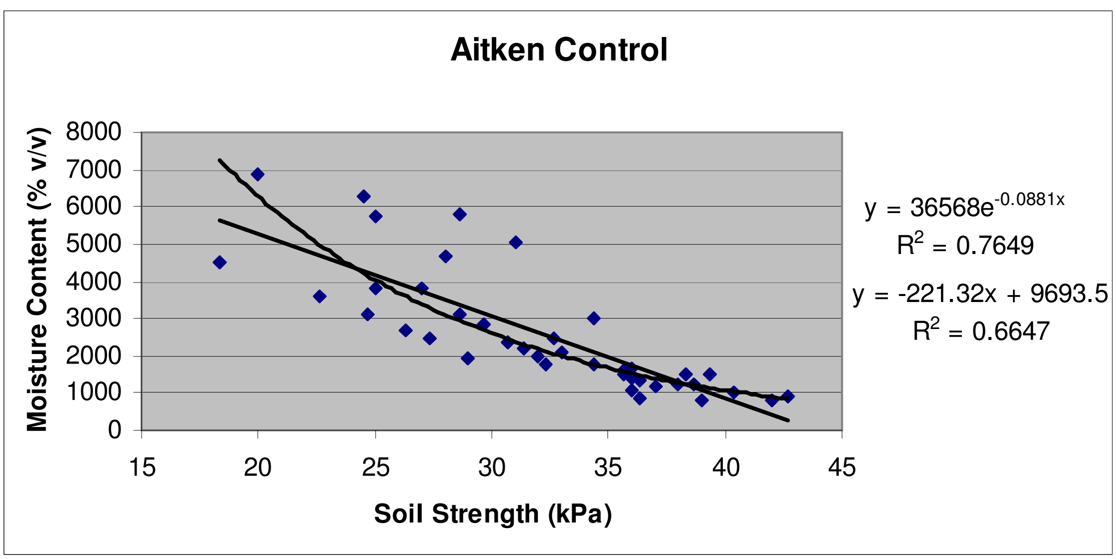

Figure K: Relationship between soil strength and moisture content at the Aitken *Control* Plot.

In general, Equation 1 generated an improved line of best fit for observed data (i.e., increased R^2 value) when compared to those generated using a linear model. Preliminary observations using this predictive model for soil strength indicated that the use of tillage may have altered the relationship between soil strength and moisture (i.e., coefficients a and/or b may be significantly different).

The exponential curve fitting described above was used to determine the moisture content at which soil strength would be expected to become growth limiting (i.e., 2,500 kPa). Figure L below summarizes these moisture contents for all of the *Control* treatment plots using data collected at a depth of 10 cm below ground.

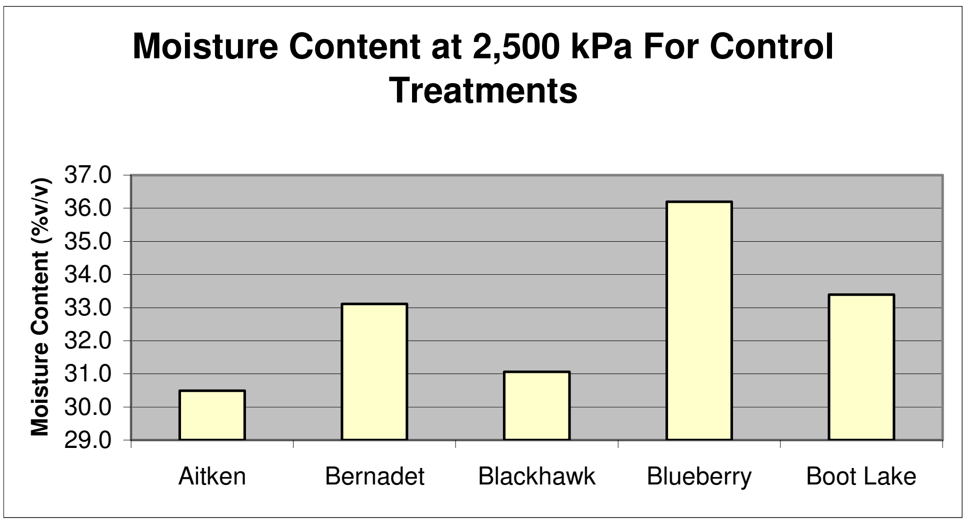

Figure L: Summary of moisture contents at 2,500 kPa for *Control* treatments

When these values are compared to the moisture contents observed throughout the 2004 and 2005 growing seasons (Figure F), it is expected that growth-limiting conditions due to soil strength were encountered on all of the *Control* treatments.

Water retention:

Average values between the two depth ranges were used in the comparison made to moisture contents at a depth of 10 cm and have been summarized in Figure M. Moisture contents at the PWP ranged from 28% at Aitken to 19% at Blackhawk. Based on the range of moisture contents observed throughout the growing season (Figure F), it is anticipated that the PWP was reached at Aitken, Boot Lake, and Blackhawk. These sites would already have been experiencing growth-limiting conditions related to soil strength (>2,500 kPa) at these moisture contents, which suggests that limitations to tree growth on these sites may be more related more to soil strength rather than water availability.

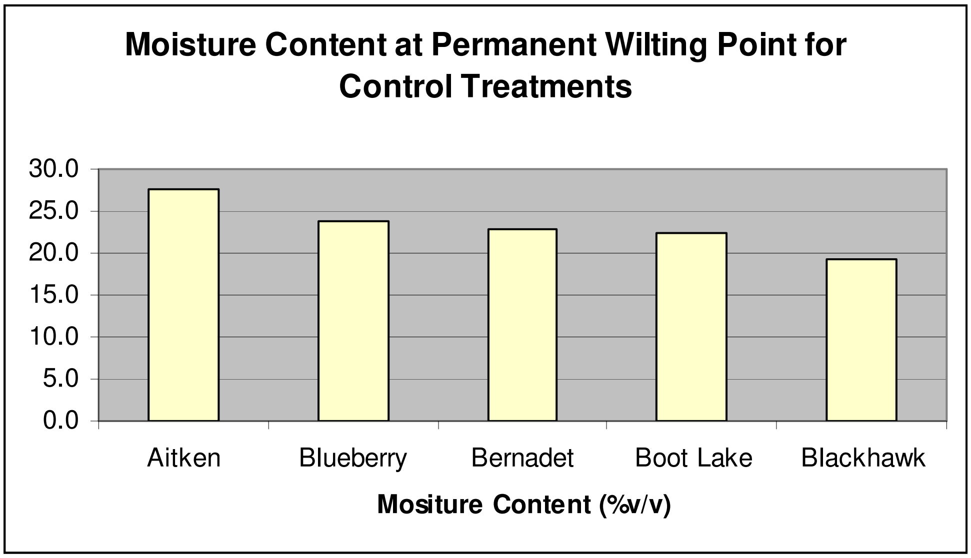

Figure M: Summary of moisture contents at the permanent wilting point (-1,500 J/kg)

Soil chemistry and nutrients:

Soil samples had relatively low EC values indicating normal salinity levels. Total C was observed to range from roughly 1% at Blackhawk to 3% at Aitken. Variability across each site was high and treatment effects unclear. As expected, Total N is highly correlated to Total C given their typical association in the soil profile. Data for Total N, Total C, and Min N are summarized below in Table 3.

Table 3: Summary of total carbon and nitrogen analyses of composite nutrient samples collected from 0 to 17 cm depth range.

	Aitken			Blueberry			Bernadet			Boot Lake			Blackhawk		
	Tot C %	Tot N %	Min N ppm	Tot C %	Tot N %	Min N ppm	Tot C %	Tot N %	Min N ppm	Tot C %	Tot N %	Min N ppm	Tot C %	Tot N %	Min N ppm
Control	2.3	0.15	62.7	1.5	0.12	7.8	2.2	0.15	27.1	1.5	0.08	4.4	1.2	0.06	3.4
Brush Mat	2.6	0.18	66.4	1.2	0.12	18.4	1.8	0.14	20.4	1.5	0.09	7.9	1.2	0.05	3.3
Mulch Only	3.3	0.21	65.6	1.9	0.12	9.7	2.4	0.17	65.3	1.8	0.10	10.5	1.2	0.05	4.5
Till Only	2.0	0.16	58.5	1.2	0.12	16.3	2.2	0.15	47.2	1.9	0.12	14.4	1.1	0.05	0.6
Till + Mulch	1.9	0.14	38.2	1.0	0.11	13.1	3.8	0.21	59.7	1.5	0.10	27.6	1.3	0.07	9.0
Incorporated	2.9	0.18	65.5	1.8	0.14	21.1	1.8	0.14	20.7	2.3	0.10	11.4	1.4	0.07	5.8
Offsite	1.1	0.10	27.4	1.4	0.11	14.7	2.8	0.18	40.4	1.6	0.08	17.8	0.9	0.08	12.7
Degraded	1.4	0.12	26.3	1.0	0.12	15.8	3.7	0.24	89.5	1.4	0.09	8.8	1.2	0.07	5.1

N immobilization often occurs subsequent to the addition of nutrient poor residues (i.e. wood chips) as microbial populations access N during decomposition of the residues. To assess the potential need for fertilization at "incorporated" plots, and also as a measure of site productivity, mineralizable N (min N) was determined as an index of N availability following a 7-day anaerobic incubation period at 40°C. The results (Table 3) indicate that min N was highly variable between sites and would be expected to affect tree performance. Due to highly variable tree growth data (as discussed below), this analysis has not yet been completed. The data was also variable between treatments, but to a lesser extent. The results suggest that N immobilization did not occur at *Incorporated* treatments to the extent where tree performance would have been affected.

<u>*Coniferous tree survival and growth:*</u>

Site observations late in 2004 indicated that incursions of domestic cattle onto treatment plots may have considerably damaged trees. In 2005, the damage was assessed visually and was determined to have had a minimal effect on seedling health and survivorship. Survivorship was considered high for both pine and spruce across all sites and treatments and ranged from approximately 70% to 90% (Figures N and O). It was determined that treatment effects were not significant for tree height (Figures P and Q). High numbers of dead trees and dead leaders were noted on a number of sites, particularly Blackhawk, where frost and/or winter desiccation are suspected to have occurred. Competition from ground cover species (i.e. clover, grasses) may also have negatively affected tree performance on some sites (i.e., Aitken). For both species, seedling height was negatively impacted by dieback of the leaders; however, damage was considered more extensive for the spruce (Figure P, Q, R and S). Pine seedlings tended to be less susceptible to the dieback of leaders.

Treatment effects were not clear based on indicators of tree performance. This is thought to be primarily a result of the short period of growth (2 growing seasons) between planting and the assessment in September 2005. The confounding effects discussed above are also thought to have obscured potential treatment effects over the short term. The tagging of trees, installation of fencing, and other measures taken will ensure it is possible to monitor tree performance well into the future.

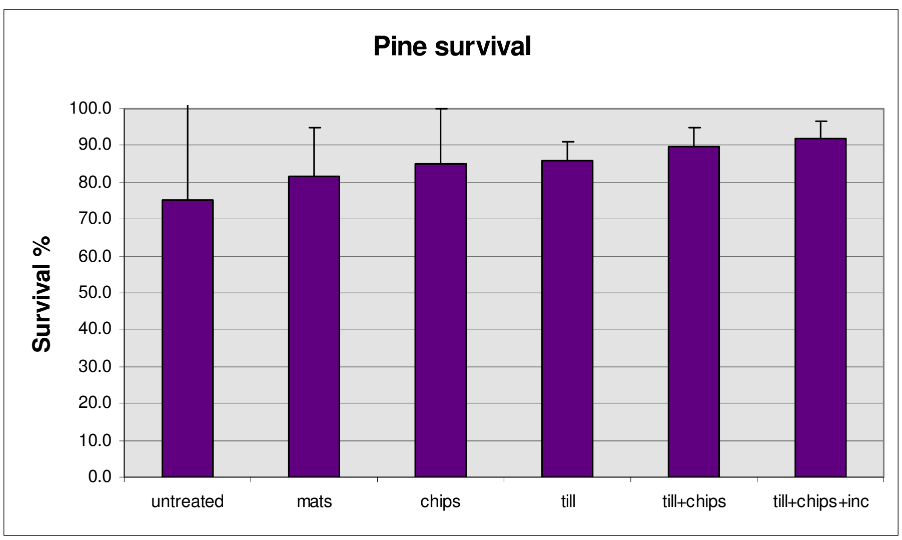

Figure N: Summary of pine survivorship

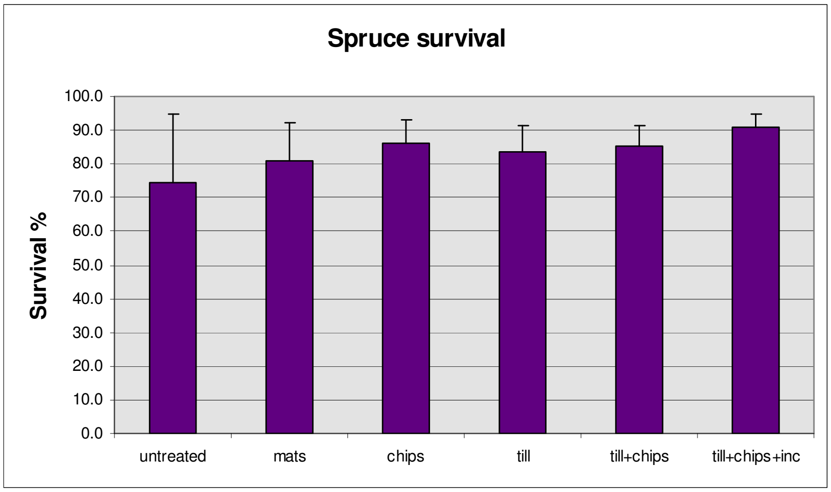

Figure O: Summary of spruce survivorship

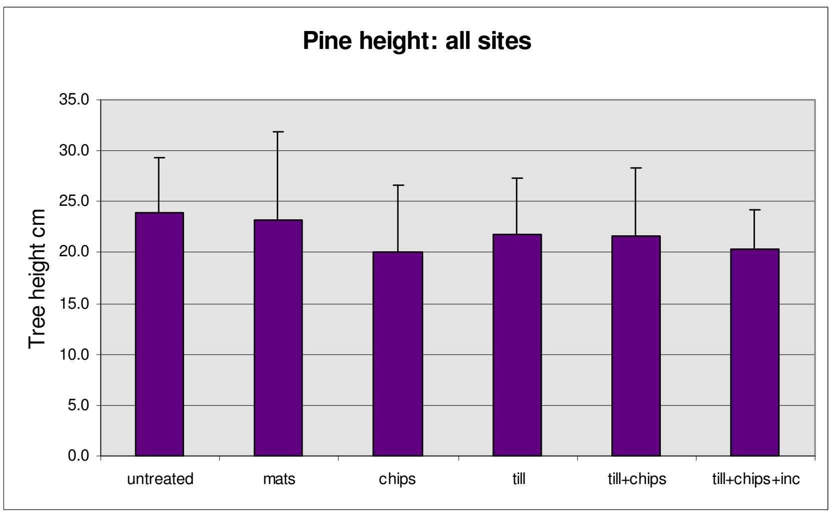

Table P: Summary of tree growth by treatment for pine

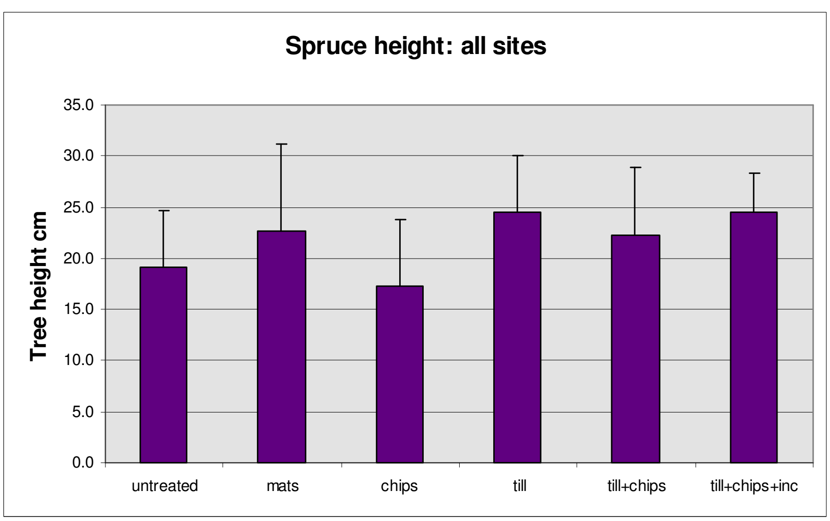

Table Q: Summary of tree growth by treatment for spruce

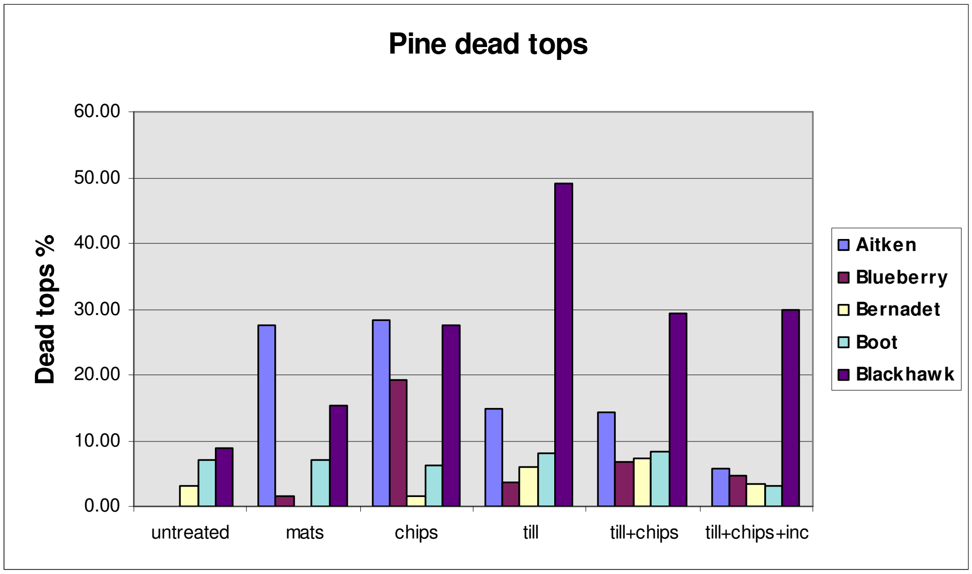

Table R: Summary of tree damage by treatment for pine

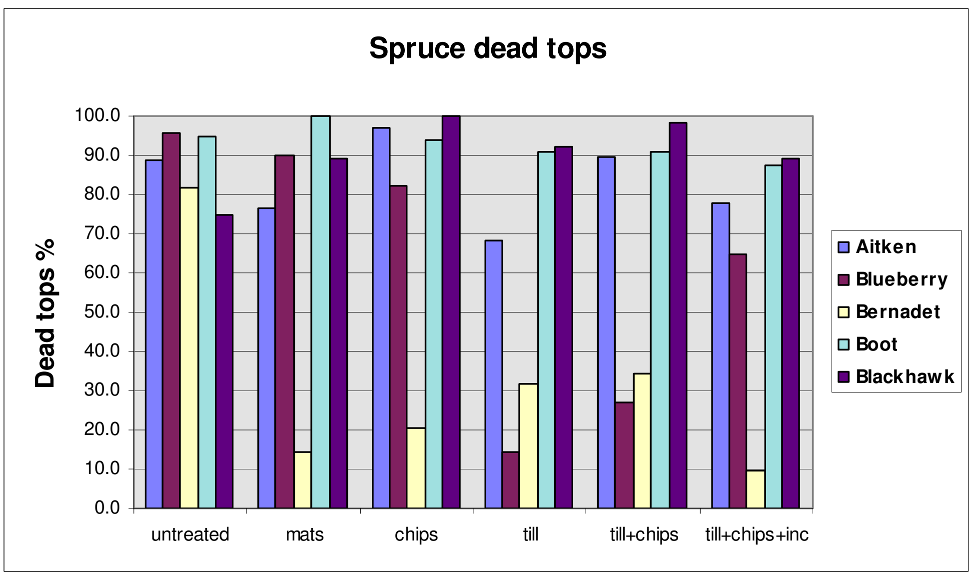

Table S: Summary of tree damage by treatment for spruce

<u>Deciduous survival and growth:</u>

Site observations late in 2004 indicated that survival and growth of the deciduous species was generally poor (Figure T, U). In particular, where the species were planted into untreated sites without vegetation control, fewer than 10 percent of planted aspen, poplar, elderberry and dogwood survived on average. Survival was better where these species were planted into plots receiving wood chips that were incorporated into surface soils. Hedge rose had the best survival and growth of any of the deciduous plantings. Despite this, where poplar cuttings survived, they often attained considerable height.

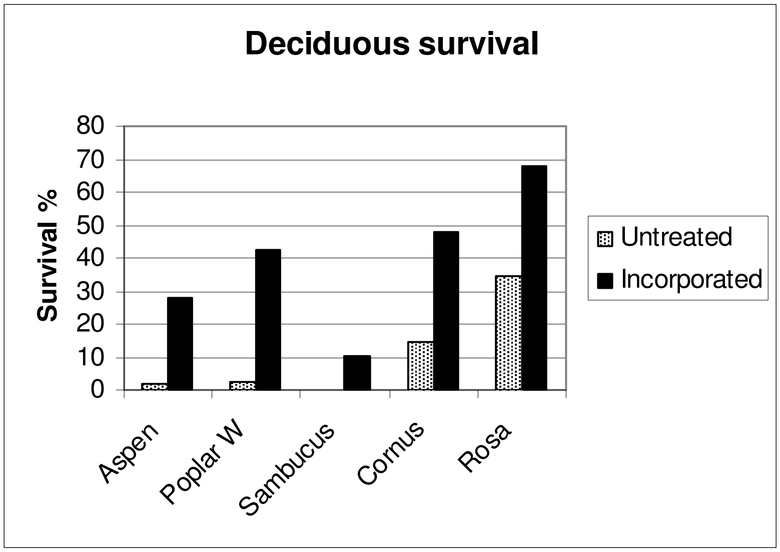

Table T: Summary of survival for deciduous plantings

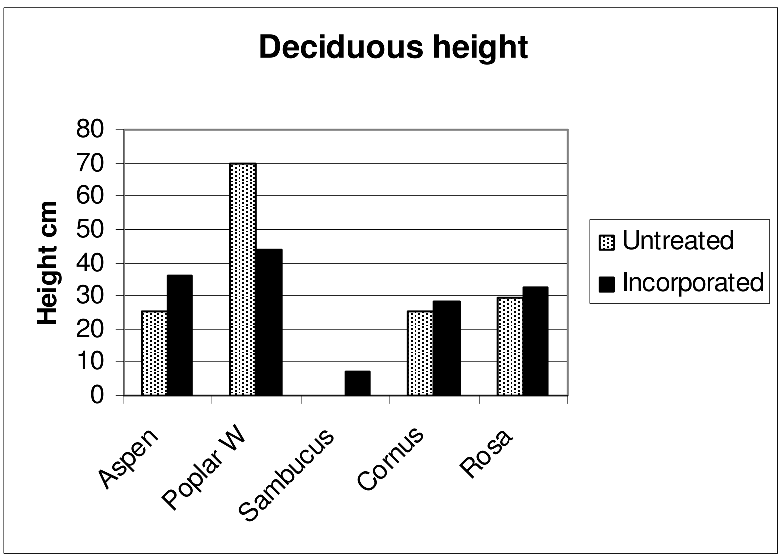

Table U: Summary of growth for deciduous plantings

Conclusion and Summary:

Soil conditions on the plots were improved by tillage and by the incorporation of organic amendments. Bulk density and soil strength tended to be reduced where tillage was used as a part of the rehabilitative treatment. Those treatment plots receiving the wood chip organic amendment (as a mulch or incorporated) were generally observed to be wetter. Nutrient status was variable across the sites, likely reflecting different amounts of fertilizer added during the initial reclamation operations. It appeared as if site differences for nutrients were more important than differences resulting from our treatments.

The results for soils suggest that, with improved planning, soil conditions on reclaimed well sites could be improved to some extent over those that we observed after operational reclamation.

Even though our soil measurements suggest that tree survival and growth should respond to such efforts, it is not clear yet from our data whether this is the case.

Coniferous tree survival was generally high for both pine and spruce across all treatments, but tree response to the soil treatments was difficult to assess because many of the trees suffered top dieback which we attributed to winter desiccation. Many of the surviving trees were reduced to a few live buds near the base of mostly a dead stem, and their ultimate fate has not been determined at this time. Deciduous survival and growth were poor, with the exception of hedge rose.

The results for tree establishment growth illustrate the challenges of reforesting oil well sites in northeast BC, and suggest that such efforts could get increasingly difficult if warm winter weather becomes more common. The top dieback we observed was common throughout the Fort St John area in the winter of 2004, and affected disturbed as well as undisturbed sites. If these problems persist in the future, it is expected that trees growing on sites where soil conditions are less conducive to seedling establishment and early growth will experience these problems to a greater extent than sites where soil conditions are more favourable.

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Appendix 1: Site locations, descriptions, and plot layout

Figure A1. Site locations. Four well sites were treated in fall 2003 (Aitken, Blueberry and Bernadet). Two sites were treated in spring 2004 (Boot Lake and Blackhawk).

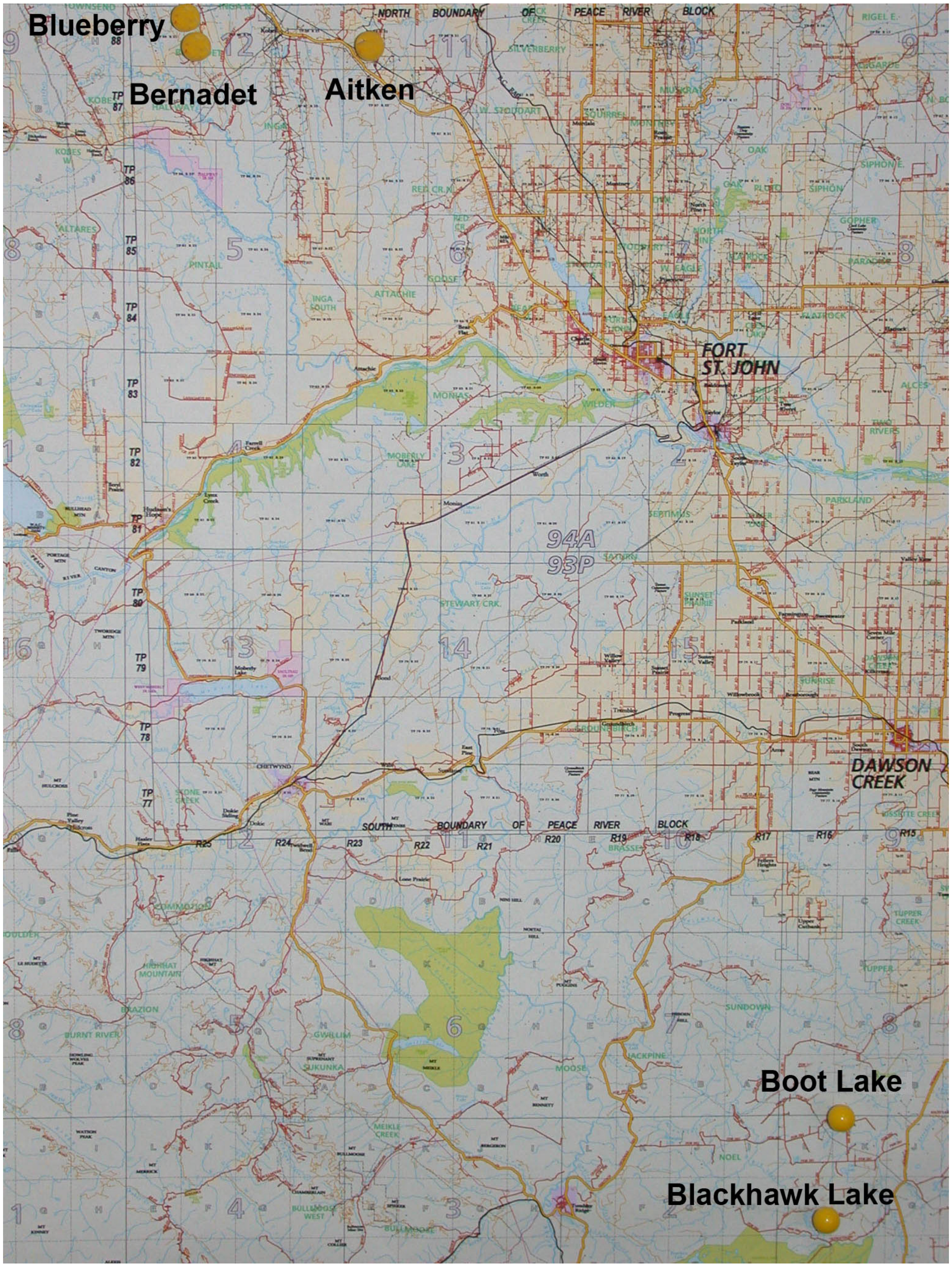
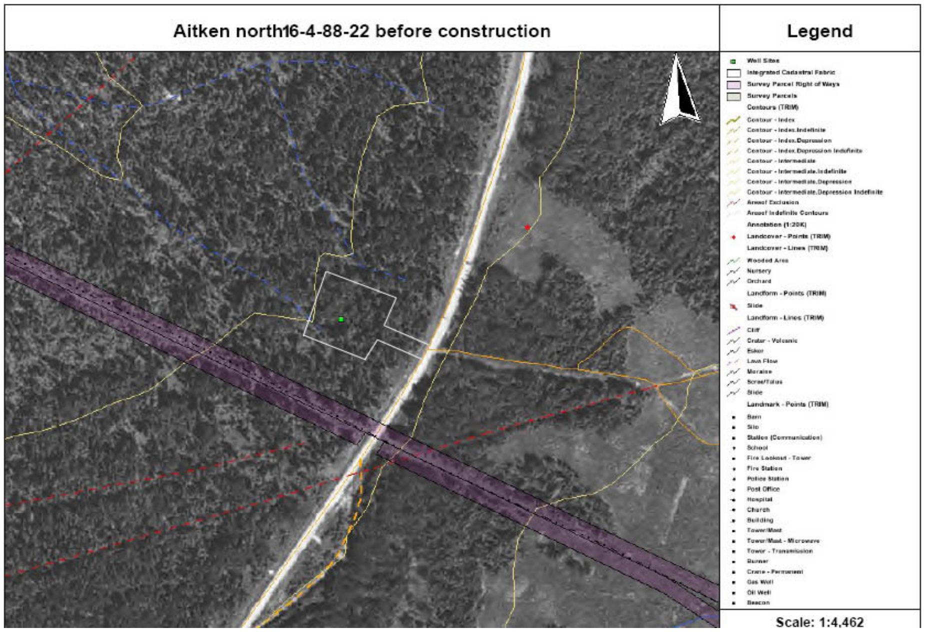


Figure A2. Orthophoto and treatment plot layout for 16-4-88-22 (Aitken).



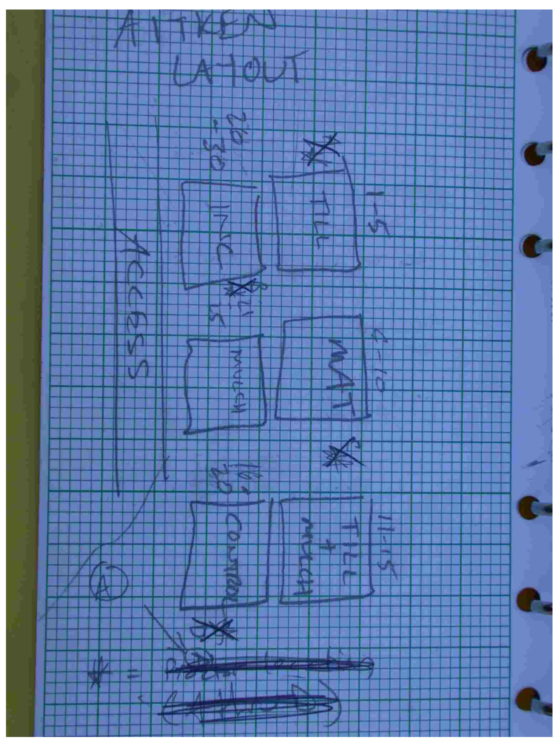
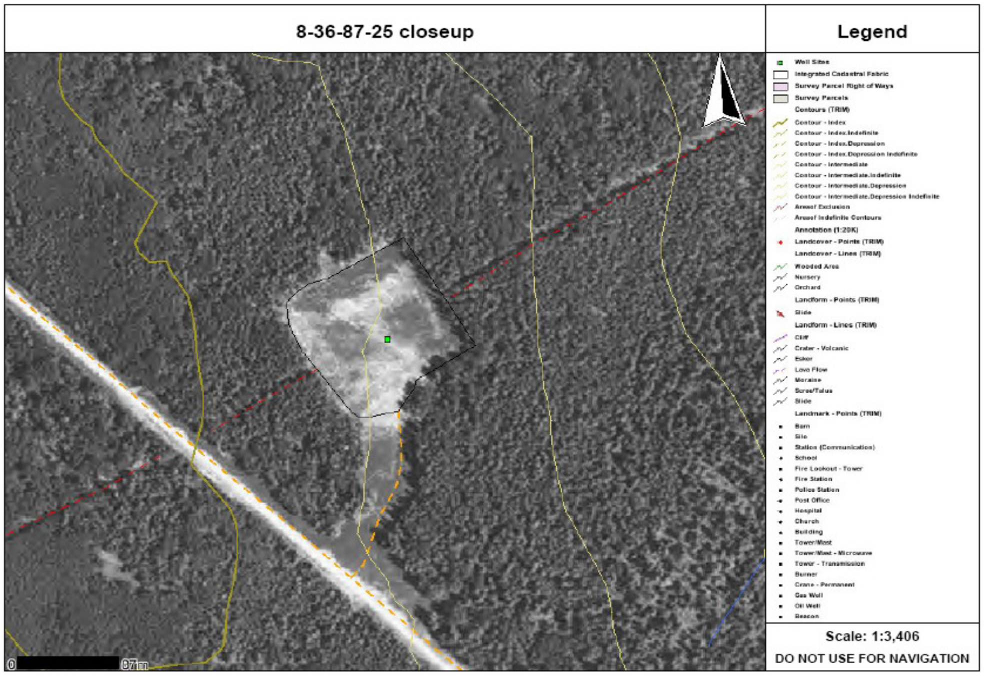


Figure A3. Orthophoto and treatment plot layout for 8-36-87-25 (Bernadet).



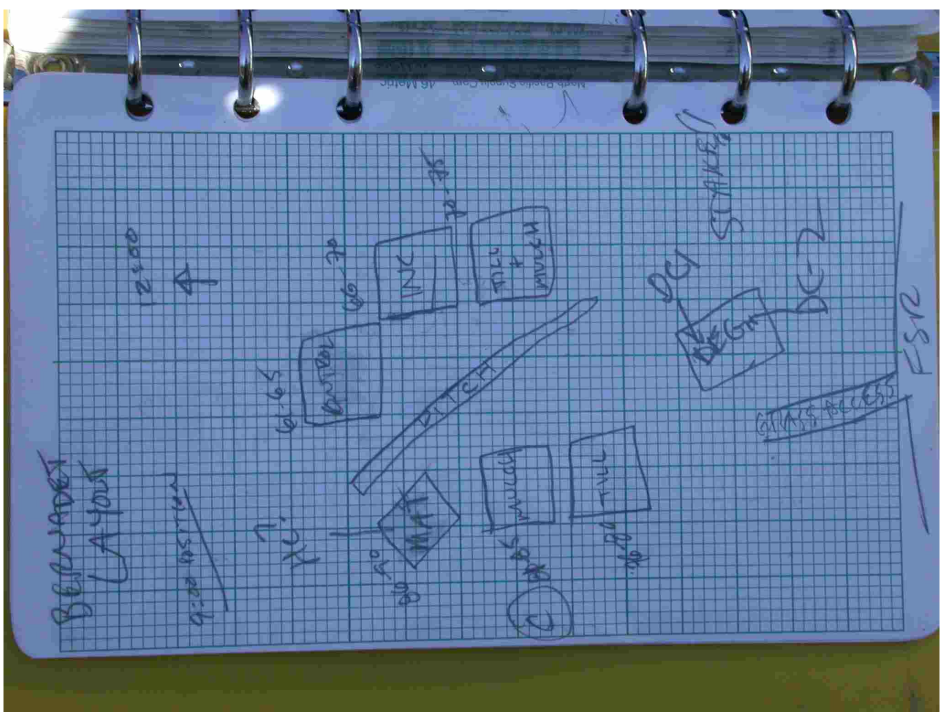
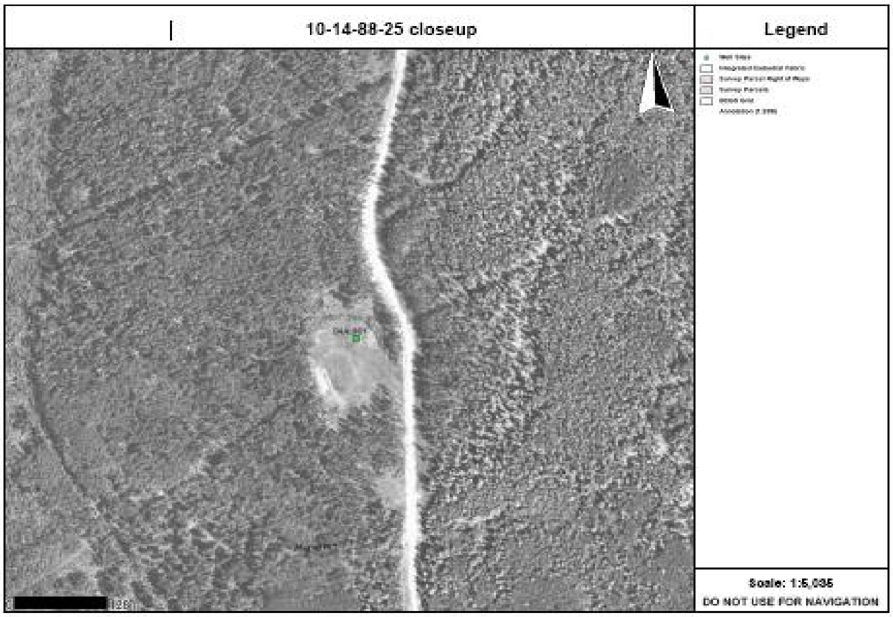


Figure A4. Orthophoto and treatment plot layout for 10-14-87-25 (Blueberry).



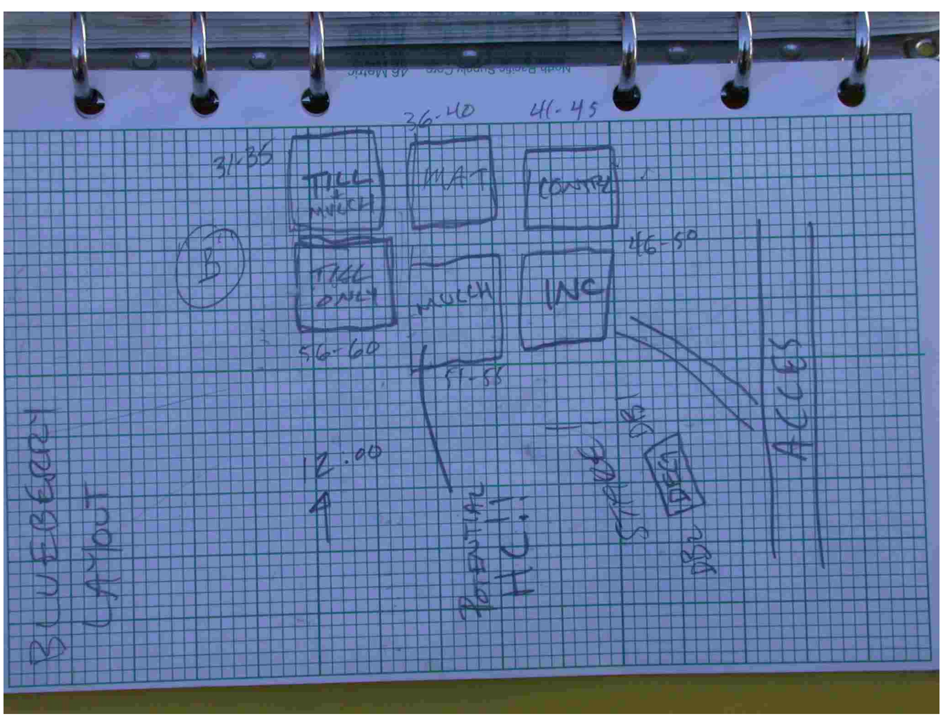


Figure A5. Orthophoto and treatment plot layout for a-1-D, 93P-8 (Boot).

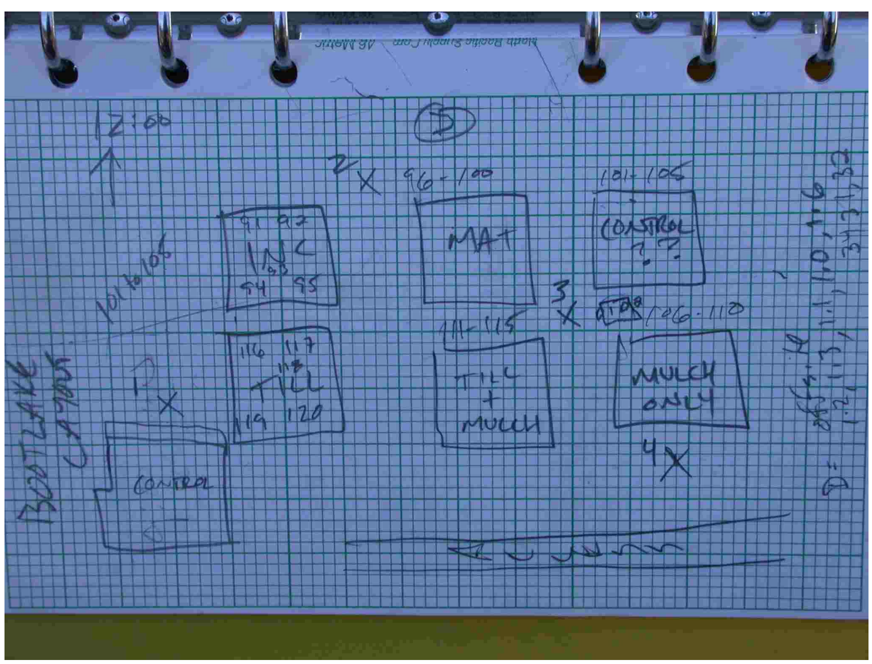
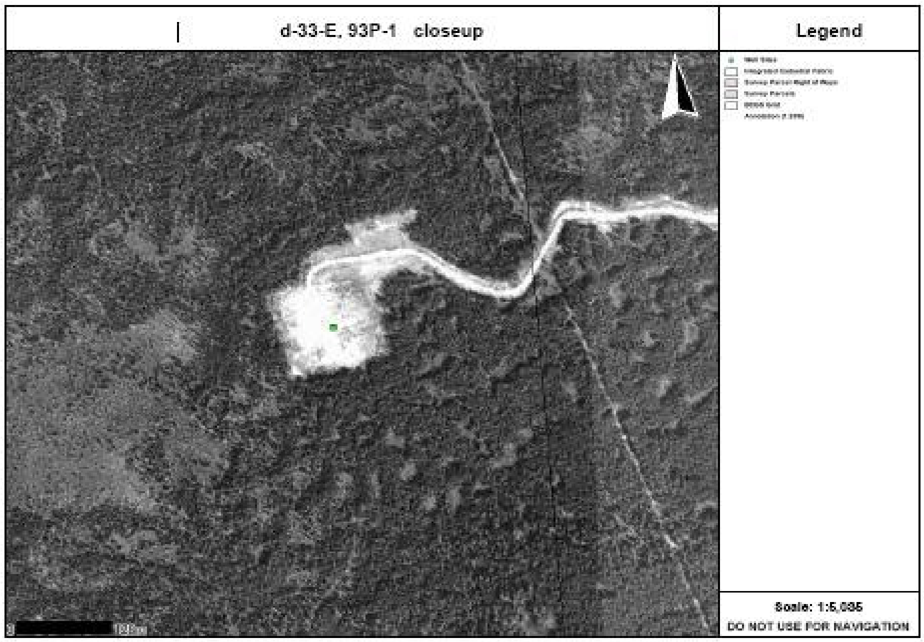


Figure A7. Orthophoto and treatment plot layout for d-33-E, 93P-1 (Blackhawk Lake).



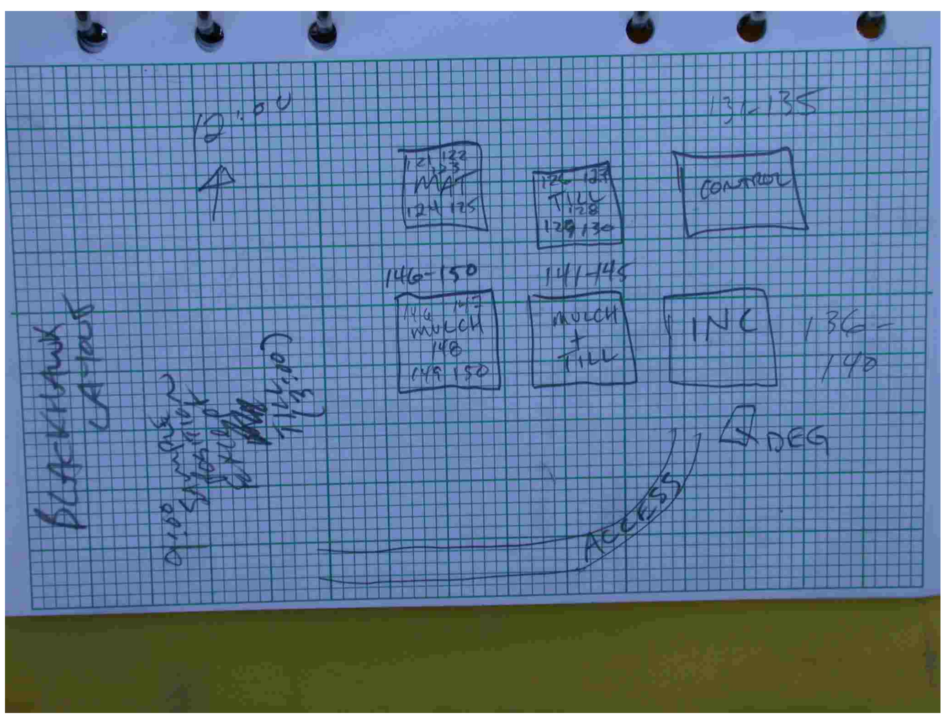


Figure A8. Tree planting and soil monitoring plot layout for mesic sites.

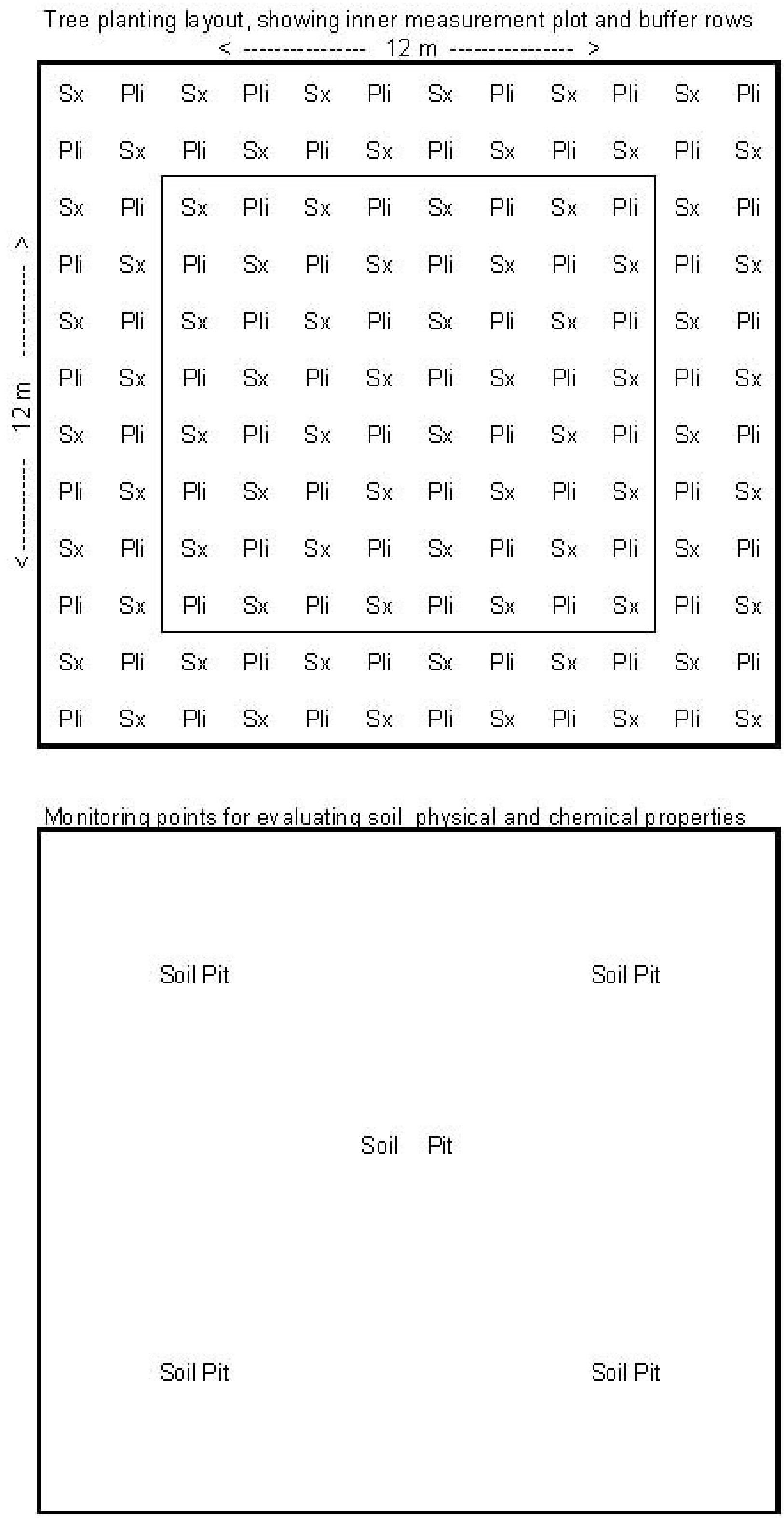


Table A1. Site descriptions

Site	Location	Rig release	Prod'n	Stake holders	Elev. (m)	Slope % / Aspect	SMR	SNR	Grass / Herb %	Tree cover %	Field Texture	Coarse frag %	Rooting depth cm	BEC
Aitken	16-4-88-22	n/a	und	n/a	860	10 / NW	mesic	med-rich	20	n/a	sil	15	18	BWBS mw1-01
Bernadet	10-14-88-25	1979	oil	grazing	875	3 / NE	mesic	med	80	20	sic	20	12	BWBS mw1-03
Blueberry	8-36-87-25	1994	und	grazing	850	7 / E	mesic	poor-med	30	n/a	sicl	15	16	BWBS mw1-03
Boot	d1A 93P8	1994	und	n/a	985	4 / SE	mesic	poor-med	80	n/a	sicl-cl	5	15	BWBS mw1-01
Blackhawk	d33A 93P1	1991	gas	n/a	970	2 / NE	mesic	med	80	5	sicl-cl	20	12	BWBS mw1-04

Appendix 2. Measurement methods

Tree measurement methods:
Trees were measured in the fall after shoot growth had stopped. Height was measured from the base of the root collar to top of bud to the nearest cm. Tree condition was recorded (poor / medium / good / no tree / dead), competition staus (high / medium / low), wildlife presence (high / medium / low), wildlife type comments, etc.

Odd numbered tags were used for pine, even for spruce, in the following pattern:

Location:

Aitken (16-4-88-22)	1-1000
Blueberry(10-14-88-25)	1001-2000
Bernadette (8-36-87-25)	2001-3000
Boot Lake (a-1-D)	3001-4000
Blackhawk Lake (d-33-E)	4001-5000

Treatment:

Untreated	1-150
Untreated with Brush Mats	151-300
Untreated With Chips	301-450
Ripped	451-600
Ripped With Chips	601-750
Ripped With Chips Incorporated	751-900

Soil measurement methods:
In the Spring of 2004, five sampling stations (denoted as "soil pit" in Figure A2.1) were laid out on each plot where all samples and measurements would be taken over the course of the season. Prior to recording soil mechanical resistance (using hand held penetrometer) and volumetric water content (using a Theta probe) at each station, a fresh face of the soil would be exposed to facilitate measurement at a depth of 10 cm. Further excavation was then completed to a depth of 18 cm where soil water content was again measured. Continuous soil mechanical resistance was also measured using a Rimik Penetrometer from 0 cm to 30 cm at each station. Prior to recording each reading, care was taken to avoid areas that had been previously measured.

In October, 2004, bulk density and water retention characteristic cores were collected at all of the plots. Cores were collected adjacent to the stations at their prescribed depths for bulk density cores (0-7 cm and 10-17 cm) and water retention characteristic cores (2-4 cm and 12-14 cm). It should be noted that due to a delay in site treatments for the Blackhawk and Boot Lake sites, the "tilled", "till + mulch", and "incorporated" plots were sampled for bulk density, water retention characteristics, and nutrients in 2005.