FIRST YEAR PERFORMANCE AND ROOT EGRESS OF WHITE SPRUCE (*PICEA GLAUCA* (MOENCH) VOSS) AND LODGEPOLE PINE (*PINUS CONTORTA* DOUGL.) SEEDLINGS IN MECHANICALLY PREPARED AND UNTREATED PLANTING SPOTS IN NORTH CENTRAL BRITISH COLUMBIA.

by

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First year performance and root egress of white spruce (*Picea glauca* (Moench) Voss) and lodgepole pine (*Pinus contorta* Dougl.) seedlings in mechanically prepared and untreated planting spots in north central British Columbia.

Abstract

Root zone temperature and root egress were studied during the first growing season on white spruce and lodgepole pine seedlings planted in various forms of mechanically prepared microsites. Mounded microsites had higher summer soil temperatures and greater diurnal ranges, at a depth of 10 cm, than the patch and control treatments. Mounded microsites, however, showed the greatest response to changes in weather and decreasing solar radiation inputs in the fall, being the first to record soil temperatures below freezing.

Seedlings planted in the deep mineral soil over inverted humus mounds created by the Ministry Mounder had significantly greater numbers of new roots greater than 1 cm long than did seedlings planted in patch and control treatments at 45 and 70 days after planting. Seedlings planted in other mound and plowing treatments had high to intermediate numbers of new roots. At 95 days after planting, seedlings planted on all mounded treatments generally had higher root area indices, root dry weights and total dry weights than did seedlings on other treatments. Variation in treatment results over the three spruce sites studied reflect differences in site conditions, primarily soil moisture regimes. High and fluctuating water tables negatively affected seedlings planted in patch and control treatments.

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List of Abbreviations

Abbreviation	Full Text
RGC	root growth capacity
n/a	data not available
LT	less than
GT	greater than
min. m.	Ministry mounder
bracke m.	Bräcke mounder
br. plow	breaking plow
sink. m.	Sinkkilä mounder
D-180	Donaren 180
N conc.	foliar N concentration
P conc.	foliar P concentration
UNTRT	untreated control
LG INV MND	large inverted mound
SML INV MND	small inverted mound
MIN MND	mineral soil mound

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1 Introduction

Backlog NSR (Not Satisfactorily Restocked land) is a major problem in the northern interior of British Columbia. Failure of conifer plantations, primarily white spruce, has been most common on wetter, brush-prone ecosystems. Low soil temperature and vegetation competition have been cited as the major cause of these plantation failures (Butt 1986, Macadam 1986, McMinn 1982). Butt (1986) stated that "it was generally understood that slow warming of the mineral soil in the early summer restricted root egress of both white spruce and lodgepole pine, and therefore contributed to 'growth check' and/or poor performance". Dobbs (1972) reported that white spruce is well known to exhibit 'planting check' whereby the growth of the out-planted seedlings is nil or exceedingly slow, and that check was found to reduce leader length by about 50% in the first year after outplanting and have some negative effect for 10 years or more. Burdett et al. (1984) stated that planting check of one or several seasons has little direct effect on plantation productivity. Indirectly, however, planting check can have a major impact on yield by putting stock at a disadvantage in the competition with other vegetation.

In his report to the Ministry of Forests and Lands (now Ministry of Forests, MOF), Butt (1986) stated that as of October 31, 1986 just under 500,000 ha were classified as NSR in the northern interior, with about 70 percent or 345,166 ha located in the Sub-Boreal Spruce (SBS) zone and 144,088 ha in the Boreal White and Black Spruce (BWBS) zone. Mechanical site preparation will play an important role in the rehabilitation of these sites (Bedford 1986).

Mechanical site preparation treatments to rehabilitate backlog areas for planting must be site specific. Prescription decisions can be assisted by the use of ecological classification systems (Corns 1984, Corns and Annas 1984, Stahl 1984). Coates and Haeussler (1984) present such a handbook to assist field silviculturists in north central British Columbia in making ecologically-based prescriptions for mechanical site preparation treatments. The guide, based on the British Columbia biogeoclimatic zone classification system, describes 15 types of mechanical site preparation equipment. It contains comparisons of equipment capabilities based on physical site factors and a section on ecosystem interpretation. Such a guide, however, needs continuous, ongoing updating as experience is gained and new treatments and implements are tested. A second edition (MacKinnon et al. 1987) has already been printed. The need for a standardized, systematic approach to equipment assessment is crucial if valid comparisons are to be made, but only recently has a standard procedure been introduced and used (Sutherland 1986). The need for follow-up biological assessment is obvious (Sutherland 1987). Bedford (1986) states that "while the biological effectiveness of machines for preparing planting spots can be judged on the basis of experience, the measurement of seedling performance under comparable conditions is needed to verify such judgements". Smith (1984) reviews the history of mechanical site preparation development in Canada, and states that "biological research is generally long-term in nature and is often preceded by technical advancement".

Under the Canada-British Columbia Forest Resource Development Agreement (FRDA) 1985-90 Backlog Reforestation Program, a project was undertaken to test the operational and biological effectiveness of current site preparation equipment (FRDA Project 1.10). Objectives of the program are:

1) to evaluate the relative operational and biological effectiveness of site preparation machines for backlog rehabilitation;

2) to assist where appropriate in the modification of existing site preparation equipment and systems; and,

3) to assist where appropriate the development of promising new site preparation machines or systems.

Ecosystem association and soil type were identified as part of site selection, and comparative plots have been established in several different years to discount year-to- year climate differences and stock variation (Bedford 1986). As part of the initial assessment of the biological effectiveness of the various treatments a study on root egress was mounted (FRDA 1.24, von der Gönna and Lavender 1987). This thesis presents a summary of the first year results of this study.

1.1 Literature Review

1.1.1 Introduction

Mechanical site preparation is one treatment forest managers can use to effect the establishment, survival and early growth of plantation seedlings. The favourable response of seedlings to various forms of mechanical site preparation has been shown in numerous trials throughout the boreal forest and has been documented by many authors (Hunt 1987).

Mechanical site preparation affects seedling growth by altering the planting microsite. Various studies have monitored changes in soil temperature and moisture regimes as a result of mechanical site preparation treatments (Ballard et al. 1977, Orlander 1986, Herring and Letchford 1987, Spittlehouse 1988, Macadam 1988). These changes are specific to each treatment and are the result of changes made to various soil properties.

Plant physiologists have studied seedling response to various microsite conditions. Cold soil temperature has been shown to affect seedling root growth, water potential, stomatal conductance, and nutrient uptake. The effects of soil moisture, various depths of water table, and periods of flooding on seedling physiology have also been studied.

1.1.2 Site Preparation and Seedling Growth and Survival

Mechanical site preparation to alter the planting microsite has been shown to improve seedling root growth, establishment, and performance. Much of the pioneering work in site preparation research has been carried out in Scandinavia.

Edlund (1979) reported on the increased interest in mounding treatments in Sweden during the 1970's. One year old container lodgepole pine seedlings were planted on deep patch, mineral mound, humus mound, scarified patch, and untreated microsites. Results after 2 growing seasons showed significantly higher survival of all treatments over no treatment and greatest leader growth and total seedling height in the humus mound treatment.

Edlund and Jonsson (1986) reported the results of mounding trials established in the mid-1970's in Sweden. Results of *Pinus contorta* and *Pinus sylvestris* plantations show mounding to produce trees 50% taller on the average than patch treatments 6 to 9 years after planting.

Soderstrom (1981) reported the results of trials of 2-0 bare-root *Pinus sylvestris* seedlings, planted in unscarified, patch and patch scarified/heap microsites in Sweden. The number of non-lignified white roots 35 days after planting was over twelvefold and sixfold that of unscarified seedlings for patch/heap and patch seedlings, respectively. Height growth was similar for patch and patch/heap seedlings 7 growing seasons after planting, but survival was only 55% for patch seedlings compared with 90% for patch/heap seedlings.

Similar studies conducted in Canada have shown comparable results. On sandy soils in Ontario, Armson (1958) reported better growth of white spruce in plowed ridges.

Sutton (1984) reported on trials of manually-created mineral soil over inverted humus mounds on well-drained coarse textured soils, typical of jack pine sites in Ontario. He found that patch scarification generally gave better survival and height development than mounds. Diameter increment was promoted in mounds in some cases. Seedlings on mineral soil mounds with intact capillary contact fared better than seedlings on mineral soil on inverted humus mounds.

Van Damme (1987) reported on trials in which bare-root planted black spruce and jack pine were tested for their growth response to manually mounded Bräcke microsites across seven locations in north western Ontario, over three years. Assessments five years after planting showed pine responded favourably to mound treatments with increased basal diameters and related tree volume; however, height growth differences were very small. Pine showed high levels of mortality on inverted humus mounds in one replication. Spruce showed very limited response to microsite effects, possibly due to its small size or large ecological amplitude. Planting either species in the bottom of the patch resulted in poor growth, similar to unscarified ground.

McMinn (1982) reported on the performance of planted white spruce in British Columbia, in trials established on sites with high potential for competing vegetation. In medium- to moderately coarse-textured soils, where root growth was not impeded by compact subsurface soil structure, scalping increased root-zone soil temperature, more than compensating for the reduction in soil fertility. On a site with a gravelly loam soil and high vegetation competition, scalped spots were superior to no treatment, but were poorer than spots formed by blade scarification. Patch size and trench width appeared to be too small to adequately protect seedlings from adverse effects of competing vegetation. Results from a wet site showed that even the sloping margins of scalped patches were unsatisfactory for seedling survival and growth. Performance of seedlings planted on mounds formed by material dug from scalped patches was better despite greater vegetation competition on these mounds compared to the scalped hollows.

McMinn (1985a) stated that "judicious mechanical site preparation can produce impressive improvement in survival and growth of interior spruce seedlings. Each of three basic methods, screefing, mixing, and inverting, may be biologically satisfactory under appropriate site conditions." Results

10 years after planting showed that mixing, which incorporated surface organic matter into the subsurface mineral soil, increased seedling growth over no treatment. Seedlings planted in inverted patches were found to grow faster than seedlings in screefed areas.

McMinn (1985b) tested the effect of various depths of mineral soil cappings on the performance of white spruce seedlings planted in inverted humus mounds. Four years after planting seedling survival was lowest in untreated areas but did not differ among the mound types or between mounds and blade scarified areas. Stem volumes calculated from annual height and diameter measurements showed that seedlings grow best in mounds with the deepest mineral soil capping. Seedling growth in mounds with all depths of capping was better than in blade scarified and untreated areas. The mass of fine roots (less than 1 mm in diameter) of sample seedlings excavated at the end of the second growing season was likewise greatest for seedlings in mounds with the deepest capping. Seedlings in untreated areas had little root growth.

The biological goals of site preparation must be defined, however, if successful results are to be achieved. These goals can vary based on different site and soil conditions. McMinn (1982) stated that "appropriate site preparation methods can ameliorate factors adversely affecting seedling survival and growth, however, prescriptions must be site specific because site factors unfavourable in one ecosystem may be satisfactory in others". Sutton (1975) warned that "the biological aspects of silviculture are all-pervading, and they determine not only what is possible but how readily it may be achieved".

1.1.3 Site Preparation and Microsite Conditions

Mechanical site preparation treatments affect seedling performance by changing various properties of the planting microsite to meet seedling requirements. Factors limiting seedling growth on one site may not be limiting on another, therefore, treatments must be site specific and the limiting factors identified before treatment prescription.

Fryk (1986) explained how one management system, based on this principle, could be applied to treatment prescription in Sweden. In adopting this adapted site preparation management system it is initially necessary to define the biological requirements desired under various site conditions, and then clarify what kind of microclimate condition there is to be expected from different site preparation treatments. Important site properties one must consider are temperature and precipitation climate, water supply, and availability of nutrients. Of all the seedlings' requirements, Fryk (1986) stated that soil moisture and soil temperature are the most important during the establishment phase.

Mechanical site preparation has been shown to alter soil temperature regimes by altering microsite soil properties. McMinn (1985b) reported that field studies in which soil temperatures have been monitored over a range of mechanical site preparation treatments have shown that exposure of mineral soil by scalping, plowing, mixing or mounding can significantly increase soil root zone temperature over no treatment. The extent of the effect is limited by the amount and depth of soil moisture (Ballard et al. 1977), and mounding or plowing are particularly effective where a high, or periodically high water table causes patches to remain relatively cool (McMinn 1982, Hunt 1987).

Ballard et al. (1977) measured summer daytime energy balances and temperature profiles at three clearcut surfaces: slashburned, exposed mineral soil, and undisturbed forest floor. Exposure of mineral soil increased soil and latent heat fluxes and decreased sensible heat flux. Surface temperature was lowest and temperature at a depth of 30 cm was highest where mineral soil was exposed, primarily effected by increases in thermal admittance and diffusivity, respectively, of material near the surface.

Herring and Letchford (1987) summarized the important thermal properties of the soil as follows. Heat capacity is the amount of heat required to raise the temperature of 1 cc of soil material by 1 degree C and it increases with increasing moisture content. Thermal conductivity is the amount of heat flowing per unit time through a unit area of unit thickness with a unit temperature difference. It increases with decreasing porosity, increasing moisture content, and decreasing organic matter content. The ratio of thermal conductivity to heat capacity indicates the facility with which a soil will undergo a temperature change and is called the thermal diffusivity. Surface heat is transmitted downward in waves which decrease in amplitude with soil depth. The effects of incoming solar radiation on soil temperature can be altered by a surface insulating layer such as a mulch or vegetation; by changing the absorptivity of the surface; or, by changing the diffusivity. Also, the litter layer acts as an insulating mulch resulting in lower soil temperatures beneath. A mineral soil surface, although having a lower absorptivity, will have a higher diffusivity, if not too porous, and will generate warmer temperatures below the surface.

Herring and Letchford (1987) monitored soil temperature at 5, 15 and 30 cm depths, for three years, as part of a major backlog rehabilitation project, 50 km west of Dawson Creek, British Columbia. Temperature differences observed were attributed to differences in the thermal properties of the soil as affected by each treatment. Summer temperature regimes were rationalized by examining the characteristics of the site treatments. Initially the plowing treatment recorded the highest temperatures, followed by discing, fall clearing, and winter clearing, respectively, in descending order. As temperatures warmed during the summer the ranking was maintained and enhanced. An isothermal period in the fall was followed by winter temperatures in the reverse order.

The absence of a surface organic layer distinguished plowed plots from the others. Plowing enabled the sun's energy to directly reach the mineral soil without losses due to the insulating effect of organic matter and vegetation. Unless soil moisture is excessive, plowed plots will be the warmest throughout the summer months. However, this treatment will also show the greatest fluctuation in temperature response to weather changes as was shown by comparison with the air temperature observations. Plowing also changed the microtopography of the site by introducing improved drainage and increasing the surface area of the mineral soil. This latter effect, however, increased night- time radiation, thereby more rapidly lowering soil temperature. Similarly, in the late summer plowed sites will cool more rapidly as radiation input declines. Winter sheared plots were the coolest because the organic layer was virtually intact and the soil surface was shaded by vegetation. Fall clearing and discing treatments were quite similar, but the additional disturbance of the discing action permitted more warm air and radiation to penetrate the soil surface, thereby allowing disced plots to warm further.

Spittlehouse (1988) presented data summaries of continuously monitored soil and atmosphere conditions from summer 1983 to winter 1986/87, for a variety of microsite treatments. Soil temperature was continually measured at the 0.005, 0.05, 0.1, 0.2 and 0.5 m depth in 1984, and at 0.005, 0.1 and 0.2 m depths in 1985 and 1986.

At the time of planting in 1984, the mound and organic mat treatments averaged 5 to 7 degrees C, while the control treatments averaged 4 to 5 degrees C. After planting the mounds and mat rapidly warmed in the partially cloudy conditions, reaching an average temperature of 10 degrees C at 0.1 m by June 5. The diurnal range was 5 to 10 degrees C. The controls averaged only 6 to 7 degrees C at this time with a diurnal range of 1 to 2 degrees C. By late June, daily 0.1 m temperature in the mound treatment was varying from a maximum of over 20 degrees C to a minimum of about 9 degrees C. Similar temperatures were obtained in the organic mat treatments, while the diurnal swing in the control treatment was in the order of 1 degree C. The 0.005 and 0.1 m temperatures averaged, respectively, 10 and 7 degrees C greater in the mound than the control.

The 0.1 m temperatures in the controls reached an average of 10 degrees C on July 26, 41 days after the mounds. The 0.2 m temperatures in the control lagged that of the 0.1 m and did not reach 10 degrees C until August 10. At this time the mound 0.2 m average temperature was 16 degrees C.

Soil temperatures started to decrease in mid August. By late September, the average temperature in the top 0.2 m of the mound, mat and control treatments had dropped to 5 degrees C. This resulted in total growing degree days (5 degrees C base) of 860, 800 and 470 in the mound, mat and control treatments, respectively. The mound soil temperatures reached 0 degrees C on October 18. The control treatment was at 2 degrees C.

Conditions similar to those in 1984 prevailed during 1985 and 1986. The increase in shading of the mound and organic mat treatments had somewhat reduced their temperatures in mid-summer, however, they still averaged 3 to 6 degrees C above the temperatures in the control treatment. A comparison of the soil temperatures at 0.1 m in the various sizes of mounds and other treatments was made in 1985 and 1986. Increased temperatures at 0.1 m were found with increased mound size.

Similar temperature regime patterns of other comparative site preparation trials have been reported by Macadam (1988) and Orlander (1986). Macadam (1988) monitored soil temperature, 10 cm from the soil surface, hourly from late May to late October, 1987, in manually created mounding, plowing, and scalping treatments on mesic, subhygric, and hygric portions of an area in north central British Columbia. Inverted mounds consistently exhibited the most extreme differences between night and day temperatures in all site types, followed by mineral mounds, plowed, scalped, and untreated spots. For July the diurnal variation in hygric plots averaged 12 degrees C for small inverted mounds and 2 degrees C for untreated spots. From late May to early September in the hygric plot, minimum temperatures in the inverted mounds generally remained higher than those recorded in untreated and scalped spots and from September to October 31, minimum temperatures were similar in all treatments within 1 - 2 degrees C. Inverted mounds in the mesic plots tended to be more responsive to low air temperatures. From September to October daily minima were consistently lower in mounds and by October 8 had dropped below 0 degrees C, followed closely by mineral mounds and plowed spots, while scalped and untreated spots remained above 1 degree C and 2 degrees C, respectively up to the end of October.

Summed degree hours for seedling root zone temperatures greater than 10 degrees C showed significant treatment differences, and were summarized in four distinct periods:

1) an 'early' phase from mid-May to June 24, during which only the mounded treatments achieved the base temperature for significant periods;

2) a 'warm' phase from June 25 to August 9, during which total degree hours greater than 10 degrees C were at a maximum for all treatments and the differences among treatments the greatest;

3) a 'late' phase from August 10 to September 9, during which total degree hours declined from maximum but remained higher than 'early' phase levels and significant differences among treatments persisted; and,

4) a 'post-growing-season' phase beginning September 10, after which the occurrence of temperatures greater than 10 degrees C declined substantially in all treatments and differences among treatments diminished sharply.

As Fryk (1986) explained, we can use the knowledge that mechanical site preparation can affect root zone soil temperature and moisture positively, only if we know how these factors limit seedling performance.

1.1.4 Microsite Conditions and Seedling Response

1.1.4.1 Soil Temperature

Many lab studies have shown that low soil temperature negatively affects conifer seedling root growth. Carlson (1986) used bare-root, one-year old loblolly pine seedlings in a variety of pot tests to emphasize the importance of the root system to seedling performance. Hydraulic conductivity was affected by root volume prior to new root growth and was even more strongly affected by new root growth, presumably due to unsuberized roots being more conductive than suberized roots. Root growth in the field was found to follow the rise in temperature. Potted seedlings with soil temperatures held at 10, 15 and 20 degrees C showed the greatest numbers of new roots greater than 1 cm at 20 degrees C, after 28 days. Root growth was minimal at 10 degrees C.

Seedling establishment was separated into three phases:

1) post-planting but preroot-elongation, in which the seedling is dependent on the planted root system for water and nutrient uptake;

2) rapid root development, which begins when soil temperatures exceed 10 degrees C; and,

3) rapid shoot elongation and leaf area expansion, which is a function of environmental conditions, but may be delayed if moisture stress accumulates over phases 1 and 2.

Andersen et al. (1986) grew two-year old red pine seedlings in pots with soil temperatures maintained at 8, 12, 16, and 20 degrees C for 27 days. Root tip initiation was initially slowed by temperatures below 20 degrees C, but after 4 weeks, the total number of roots initiated was similar for 12, 16 and 20 degrees C. After 27 days, seedlings at 16 degrees C produced the greatest number of new root tips, while seedlings at 8, 12 and 20 degrees C did not differ significantly. The decrease in total number of new root tips from 16 to 20 degrees C may reflect increased utilization of carbohydrates for elongation at the expense of new tip development at 20 degrees C. Root elongation increased with increasing temperature with the greatest number of new roots 0.5 cm and longer at 20 degrees C, at all sampling dates. The decrease in the ratio of new tips greater than 0.5 cm and longer at lower temperatures suggests that root elongation was suppressed more than tip initiation.

Lopushinsky and Kaufmann (1984) planted two-year old, bare-root Douglas-fir seedlings in plastic pots, at soil temperatures of 1.3 and 20.2 degrees C. Transpiration rate declined linearly with decreasing soil temperature, and at 1.3 degrees C was only 18.8% of the rate at 20.2 degrees C. Xylem pressure potential of seedlings exposed to a moderate evaporative demand averaged -15.4 bars, compared to -11.1 bars for seedlings in warm soil. Seedlings exposed to a high evaporative demand averaged -20.0 bars in cold soil, compared to -13.4 bars in warm soil. Stomatal conductance of seedlings in cold soil was 50% or less of seedlings in warm soil. Low soil temperature delayed bud burst, reduced shoot growth, and completely prevented root growth.

Dobbs and McMinn (1977) grew white spruce germinants in growth chambers for 17 weeks at constant soil temperatures of 10, 15, 20, 25 and 30 degrees C, in favourable aerial conditions. At the conclusion of the experiment, heights, basal diameters of shoots, and ovendry shoot and root weights were recorded. Best growth in respect to all measured parameters was registered by seedlings grown in 20 degrees C soil; next best treatments in descending order were 25, 15, 30 and 10 degrees C. The differences between the 10 and 15 degrees C treatments were so great as to suggest a physiological threshold between these soil treatments.

Bowen (1970) studied the effects of soil temperature on root growth and on phosphate uptake along *Pinus radiata* roots. Increasing soil temperature from 15 to 25 degrees C approximately doubled total root length of 3-week seedlings; primary root length was increased but the main effect was due to a marked increase in the number and length of lateral roots. Lateral root growth of the 3-week seedlings was almost completely suppressed in the soil at 11 degrees C.

Heninger and White (1974) investigated the effect of soil temperature on shoot and root development of three conifers and two broadleaved species. Plants were raised from seed through two 8-week stages in environmental chambers with soil temperatures of 15, 19, 23, 27 and 31 degrees C. White spruce and tree-of-heaven had optimal shoot and root growth at 19 degrees C. Jack pine growth was maximum at 27 degrees C. Douglas-fir seedlings developed well between 15 and 27 degrees C. Paper birch grew well between 19 and 31 degrees C with best shoot development at 31 degrees C, whereas root development was favoured at 23 degrees C.

The findings of these studies support those of Soderstrom (1981) who states that "for spruce, the optimum soil temperature is about 20 degrees C, and for pines as high as 25 - 30 degrees C". Other studies suggest 5 to 10 degrees C as a minimum threshold temperature for root growth (Binder et al. 1987, Macadam 1988). Low soil temperature not only affects root growth but reduces water uptake by reducing cell membrane permeability and increasing the viscosity of water (Kramer and Kozlowski 1979).

Running and Reid (1980) studied soil temperature influences on the root resistance of two-year old lodgepole pine seedlings. Short term measurements of leaf conductance, leaf water potential and tritiated water movement were taken at root temperatures, from 22 degrees C down to 0 degrees C. Root resistance was calculated to be 67% of total plant resistance at 7 degrees C and 93% at 0 degrees C. An abrupt change in root resistance below 6 degrees C suggests significant change with temperature in the membrane pathway in the root water uptake system and may be a result of phase transition of lipids in these membranes.

Grossnickle and Blake (1985) planted cold-stored jack pine and white spruce seedlings in a controlled environmental chamber providing an air temperature of 22 degrees C, soil temperatures of 22, 16 or 10 degrees C, and soil moisture near field capacity. After 21 days, root growth for white spruce was limited at all soil temperatures, whereas jack pine showed limited root growth at a soil temperature of 10 degrees C but extensive root growth at 22 degrees C. During the 21 days of observation after removal from cold storage, stomatal response patterns changed during the transition phase from darkness to first light. Jack pine seedlings showed increasing stomatal opening for seedlings in the 22 degrees C root temperature treatment, while all white spruce seedlings exhibited a greater stomatal closure during darkness. In both species, seedlings at lower soil temperatures experienced greater initial water stress than seedlings at higher soil temperatures, the difference being associated with greater water-flow resistance through the soil-plant-atmosphere continuum (SPAC). In both species, xylem pressure potentials increased with time at all temperatures, a change attributable to a decline in water-flow resistance through the SPAC. This decline was possibly due to either a change in permeability of older suberized roots or, as in the case of jack pine at the higher soil temperature, a significantly greater development of new unsuberized white roots.

Grossnickle (1988) planted bare-root 2+0 jack pine seedlings and 1 1/2 + 1 1/2 white spruce transplants in 8 cm diameter pots held at approximately 22 degrees C for 7 and 28 days. These, together with trees fresh from cold storage, were placed in aerated water maintained at 0, 6, 14, 15, or 22 degrees C. After 18 hours, water relations measurements were made.

Seedlings were also planted in mineral soil on a site- prepared area in northeastern Ontario on four dates between May 6 and June 5, during which soil temperature at a depth of 15 cm increased from 0 to 18 degrees C. On each planting date, additional seedlings were placed with roots in aerated water in buckets set in the ground.

After 28 days in the greenhouse, both species had produced many new unsuberized roots. Needle conductance of cold stored seedlings was measured one day after plants were transferred from cold storage to a warm greenhouse where they were placed with their roots in aerated water at a controlled temperature (1-day plants). There was little diurnal variation, but in both species conductance decreased with root temperature. In both species xylem pressure potential also decreased with decreasing root temperature, both in plants in the greenhouse in aerated water and in field-planted trees the day after planting, with the latter having generally lower values.

Needle conductance of jack pine seedlings grown in pots for 28 days before being placed in aerated water decreased with root temperature although the values were higher throughout the day than for 1-day seedlings. Xylem pressure potentials of the 28-day jack pine were similar, however, to those of 1-day seedlings. For 28-day white spruce, needle conductances were higher than those of the 1-day plants early in the day but declined by the afternoon to values as low as or lower than those of the 1-day plants. Xylem pressure potential, however, was higher than the 1-day plants throughout the day.

Seedlings of both species grown in the greenhouse for 1 or 7 days showed an increase in water flow resistance in the soil-plant-atmosphere continuum (RSPAC) as root temperature decreased from 22 to 0 degrees C. The RSPAC of plants grown for 28 days was approximately half that of the 1-day plants. Compared with 1-day greenhouse plants in aerated water, trees planted in the field in mineral soil had higher RSPAC values at temperatures from 6 to 14 degrees C, but slightly lower values at 2 degrees C. Relative resistance of 1- and 7-day plants increased with decreasing temperature in both species, although the rise in resistance below 5 degrees C was much sharper for jack pine than in white spruce. In both species the increase in relative resistance was greater than the increase in the relative viscosity of water over the same temperature range. Relative plant water flow resistances of 28-day plants of both species increased with decrease in root temperature, although they were lower than in 1- and 7-day seedlings, and for white spruce were no greater than the increase in the relative viscosity of water.

Although the decline in needle conductance was accompanied by a decline in xylem pressure potential, even at lower root temperatures, xylem water potential rarely fell below the reported turgor loss point of stock freshly removed from cold storage, thus indicating the operation of a mechanism that curtails water loss with decreasing root temperature before severe water stress develops. The increase in plant resistance to water flow with decreasing soil temperature is attributed to the combined effects of the increased viscosity of water and reduced root permeability. However, 28-day spruce seedlings with many new, unsuberized roots showed markedly decreased plant water flow resistance particularly at low temperatures, indicating that trees may be more susceptible to water stress induced by low soil temperature when first planted than later on.

This supports the results of post-planting studies of white spruce carried out by Binder et al. (1987). Physiological evidence suggested that the condition traditionally called "growth check" in white spruce may actually be a resulting consequence of an inelastic physiological drought avoidance mechanism in this species. White spruce apparently maintains an early growth season daytime operational xylem pressure potential (xpp) of approximately -1.6 MPa. If replacement, by the roots, of water lost through transpiration cannot maintain this deficit stomates close up shutting photosynthesis down in under 20 minutes. Once stomates are closed they do not reopen that day. The amount of time stomates open the next day depends on the amount of water recharge during the dark period. If predawn xpp is below -1.0 MPa this time period may be very short. The osmotic adjustment to about -2.0 MPa therefore allows physiological function during summer drying and is most likely a natural consequence of frost hardiness induction. If this hypothesis is correct "growth check", because of its survival value, can never be and should never be cured. Its negative affect on growth may be greatly reduced by providing favourable microsite conditions through well-founded silvicultural practices. The most important of these include:

1) providing soil temperatures above 15 degrees C at planting;

2) reducing vapour pressure deficit; and,

3) reducing background radiation levels about 30-35% yet insuring light intensity levels above 600 uE m^{-2} s^{-1}.

Grossnickle and Blake (1987) studied the water relations and morphological development of bare-root jack pine and white spruce seedlings planted on a boreal cut-over site in northern Ontario. Comparison of morphological development between the two species showed jack pine seedlings had greater new root development and a lower new shoot/new root ratio, while white spruce seedlings had greater new shoot development. Seasonal water relation patterns showed white spruce seedlings to have a greater decrease in xylem pressure potential (xpp) per unit increase in transpirational flux density in comparison to jack pine seedlings. These results suggest that the greater resistance to water flow through the soil-plant-atmosphere continuum in white spruce seedlings compared to jack pine seedlings may be due to the relative lack of new root development in white spruce. Stomatal response of the seedlings showed that as absolute humidity deficit between needles and air (AHD) increased, needle conductance decreased in both species, but at very low AHD levels white spruce had needle conductance approximately 35% higher than jack pine. For white spruce seedlings, needle conductance decreased as xpp became more negative in a predictable curvilinear manner, while that of jack pine seedlings responded to xpp with a threshold closure phenomenon at approximately -1.75 MPa. Tissue water potential components for jack pine and white spruce seedlings at the beginning and end of the growing season showed jack pine to reach turgor loss at 76% relative water content while white spruce reached turgor loss at 88% relative water content. White spruce seedlings showed osmotic adjustment over the growing season, with osmotic potentials at turgor loss of -1.27 MPa and -1.92 MPa at the beginning and end of the growing season, respectively. Jack pine did not show any osmotic adjustment over the growing season.

The consequence of jack pine stomatal response to changes in xpp is that the threshold phenomenon allows for normal diurnal variation in xpp but does not cause stomatal closure, while white spruce exhibited a negative feedback system which resulted in immediate stomatal closure as xpp decreased. This suggests that the stomatal response of jack pine would allow growth to occur over a wider range of field conditions, while white spruce stomata are more restrictive over the range of field conditions they can tolerate.

Microclimate data collected by Binder et al. (1987) indicated that weather conditions severe enough to retard photosynthetic rate through reduced stomatal conductance might occur over as much as half the growing season.

1.1.4.2 Soil Moisture

Constant high water tables have also been shown to limit root growth. Lieffers and Rothwell (1986) studied the effects of depth of water table and substrate temperature on root and top growth of *Picea mariana* and *Larix laricina* seedlings. Three-week old seedlings were planted in thermally insulated tanks, with one half receiving a cooling treatment and the other an ambient treatment (9 and 18 degrees C at 10 cm depth, respectively). Water table levels of the tanks were maintained at 4, 10 and 25 cm below the substrate surface. After 90 days, there were highly significant differences in seedling size among water table treatments, for both species. Mean root biomass for black spruce in the 25 cm versus the 4 cm tank was 0.027 and 0.006 g, respectively. Mean shoot biomass of black spruce seedlings was 0.180 and 0.034 g in the 25 and 4 cm tanks, respectively, and for tamarack 0.666 and 0.083 g, respectively. For both species maximum rooting depth of seedlings and maximum root length were significantly longer in the 25 cm tank. Few roots penetrated below the water table in any of the tanks, and roots near the water table were usually blackened and some had necrotic tips. Root orientation was more horizontal in the 10 and 4 cm tanks. There were important interactions between temperature and water level treatments. With above ground size the ambient half of the 25 cm tank had larger seedlings than the cooled half; in contrast, the cooled half of the 4 cm tank had larger seedlings than the ambient half. The same was true for rooting depth, root length, and root:shoot ratio. These factors were depressed by cooling in the 25 cm tank but were increased by cooling in the 4 cm tank.

Periodic flooding of variable duration has resulted in root mortality and plant moisture stress. Levan and Riha (1986) studied the response of root systems of four conifer species to flooding. Two- to four-year old nursery transplants of white pine, red pine, white spruce and black spruce were removed from cold storage, root pruned to 15 cm below the root-shoot junction, potted, and placed in a growth chamber at a temperature of 23 degrees C. Treatments were begun after bud break and needle elongation were complete and root systems had initiated new growth. A sub-sample of seedlings was subjected to a fixed water table 25 cm below the soil surface and root penetration measured for 30 days, until all had reached a maximum. Within each species, roots that had grown into the water table were compared with above water table roots to determine whether an obvious increase in internal pore space had occurred. A second sub-sample of seedlings was subjected to a similar water table flooding for periods of 1, 3, 5, and 7 days. Following drainage roots were observed for signs of recovery: either apical or lateral, or no recovery. Transpiration was monitored for all treatments.

Penetration into the water table by white pine, red pine, and black spruce was similar, with most roots confined to the surface 5 cm and the deepest roots at 8 to 10 cm. White spruce showed exceptionally poor growth into the flooded soil, with roots penetrating to only 2 cm in this 30-day period. There was no sign of pore space in either the cortex or the stele of any of the conifer roots that had grown into the water table. The conifer root growth that did occur may have been supported by oxygen diffusing through the intercellular spaces of the cortex. Water table penetration may have been compressed by the relatively high experimental soil temperature.

In both red and white pine, many of the flooded root apices survived flooding and resumed growth after drainage, even in the 7-day flooding treatment. Combined apical and lateral recovery by the pine root systems averaged 85% over all treatments. When flooded for only 1 day, the response of the spruces was like that of the pines. Both apical and lateral recovery occurred, with lateral emergence relatively delayed. Flooding for longer than 1 day killed all flooded root tips of both white and black spruce. In the 3-, 5- and 7-day flooding treatments, post drainage root systems consisted entirely of replacement laterals that emerged between the 6th and 20th day after drainage. Recovery averaged 65% over all treatments.

Transpiration response to flooding was similar for all species and all lengths of flooding treatments. Beginning with the first day of flooding, transpiration tended to be depressed below control levels; by the 5th to 7th day of flooding, transpiration rates had declined to 50-60% of controls, but recovered to control rates quickly after drainage. The transpiration recovery was equally fast in the spruces and the pines, even though the spruces had no growing tips present until after transpiration had recovered. Thus, either growing tips are not necessary for the recovery in transpiration or the few growing roots that were present in the unflooded soil were adequate for the resumption of normal water uptake. Laboratory data from Binder et al. (1987) indicated that white spruce requires approximately 6 new roots greater than 1 cm to maintain proper water balance, flush and remain healthy under well watered, growth room conditions.

Grossnickle (1987) studied the influence of flooding and soil temperature on the water relations and morphological development of cold-stored black spruce and white spruce seedlings. Seedlings were planted in a controlled environment chamber with an air temperature of 20 degrees C, and soil temperatures of 10 or 20 degrees C. Root development was sampled for: extended nonflooded treatment (42 days); 14 day nonflooded - 14 day flooded - 14 day nonflooded treatment (nfld-fld-nfld); and, 28 day flooded treatments. On the first day after planting and at 3 to 4 day intervals until the 28th day, measurements of xylem pressure potential, stomatal conductance, and transpirational flux density were made.

Black spruce seedling morphological development was influenced by flooding and soil temperature treatments. At both soil temperatures, nonflooded seedlings had greater shoot development and root development compared with other treatments. Flooded seedlings showed the least shoot growth and produced no new roots over the 28 day study period. Seedlings flooded for 14 days and then released from flooding were just beginning to show signs of root development after a further 14 days. Released seedlings had white root tips while flooded seedlings had no white root tips. Nonflooded seedlings in the 20 degrees C soil treatment showed greater shoot and root development compared with nonflooded seedlings at the 10 degrees C soil treatment.

Shoot development of white spruce seedlings was not influenced by flooding or soil temperature treatments. At both soil temperatures, seedlings in the flooded and flooded/released treatments showed no root development. Nonflooded seedlings in both soil temperature treatments showed root development, but greater root development occurred in the 20 degrees C soil temperature treatment.

Black spruce seedlings, in both soil temperature treatments, had continued root development during flooding if allowed 14 days out of cold storage before given a 14 day flooding treatment. However, root development was reduced in comparison with seedlings in the nonflooded treatment. In both the control and nfld-fld-nfld treatments, root development was greater in the 20 degrees C soil temperature treatment. Seedlings flooded for 28 days showed very little or no root development.

White spruce seedling root development was suppressed for seedlings in the nfld-fld-nfld treatment compared with control seedlings. The flooding treatment for nfld-fld-nfld seedlings resulted in no new root development during day 28 to day 42 in the nonflooded soil treatment. Root development was nonexistent at day 28 in seedlings that were flooded for 28 days right after removal from cold storage.

Stomatal conductance of seedlings just removed from cold storage was reduced in both flooded and nonflooded treatments. However, the longer the seedlings were exposed to the soil treatment after removal from cold storage, the greater the difference in diurnal stomatal conductance. Nonflooded seedlings of both species showed an increase in diurnal stomatal conductance patterns until 14 days out of cold storage. Diurnal stomatal conductance of both flooded black spruce and white spruce seedlings was greatly reduced compared with nonflooded seedlings. After white spruce seedlings were released from flooding there was a gradual increase in the diurnal stomatal conductance to levels greater than nonflooded seedlings. This response was possibly due to stomatal damage, which reduced the seedling's ability to control water loss during daytime hours.

Diurnal xylem pressure potential (xpp) for flooded and nonflooded seedlings showed flooded seedlings for both species to have more negative diurnal xpp just after removal from cold storage. Flooded white spruce seedlings continued to have more negative xpp over the length of the study. Flooded black spruce seedlings did not show this daytime xpp pattern. In both species, predawn xpp measurements indicated that flooded seedlings had more negative xpp than nonflooded seedlings at the beginning of each day. Thus, flooded seedlings did not have the ability to take up a comparable amount of soil moisture as nonflooded seedlings during the dark period, presumably because of reduced root system hydraulic conductivity.

Seedlings of both species at all soil temperature - flooded treatment combinations showed a high resistance to water flow through the soil-plant-atmosphere continuum (RSPAC) 1 day out of cold storage. Changes in water flow characteristics occurred for nonflooded seedlings of both species at both soil temperatures over the course of this experiment. By day 21 white spruce seedlings showed a large RSPAC difference between soil temperature treatments, whereas black spruce did not show a large RSPAC difference between seedlings at 10 and 20 degrees C soil temperature. This indicates that white spruce seedlings are more sensitive to soil temperature than black spruce seedlings. Continued flooding resulted in higher RSPAC at 21 days compared to nonflooded seedlings of both species, thus indicating that flooded seedling root systems were less efficient at taking up water to meet the seedling transpirational demand.

1.1.5 Summary

Mechanical site preparation treatments have been shown to positively affect seedling performance. However, differences in seedling response have been found between and among species, site, and treatment combinations, indicating the need for site specific prescriptions. Soil temperature and soil moisture have been identified as the edaphic factors most important in the establishment phase. Mechanical site preparation treatments have been shown to alter soil temperature regimes by affecting changes in soil thermal admittance and diffusivity. Treatments which expose mineral soil make the planting microsite more responsive to changes in diurnal and seasonal climate.

The importance of stimulating root growth was stressed by many authors. Both low soil temperature and high soil moisture were shown to negatively affect seedling root growth. Optimal root zone soil temperature was stated as approximately 20 degrees C for spruces and 25 to 30 degrees C for pines. A low threshold temperature of approximately 5 to 10 degrees C was shown to impede root growth and affect seedling moisture status by increasing root resistance to water flow. White spruce showed the least penetration, of a fixed water table, of any of the conifer species studied by Levan and Riha (1986), and was also the most intolerant of any length of periodic flooding.

The importance of rapid root initiation to maintain seedling water balance was stressed. Growth check in white spruce was hypothesised as being a physiological response to low xylem pressure potential, and can only be overcome by maintaining good seedling water balance. The increased susceptibility of seedlings fresh out of cold storage was shown and emphasized the need for rapid achievement of optimum root zone temperatures.

1.2 Objectives

The objectives of this thesis are:

1) to provide a summary of first year results of the root egress study; and,

2) to correlate root egress data with other data collected under the FRDA 1.10 study.

Based on the literature review it was hypothesised that:

1) root egress would be a good, early indicator of site preparation treatment suitability and success;

2) numbers of new roots greater than 1 cm in length would be greatest on treatments with the warmest root zone temperatures;

3) root initiation would primarily occur from the end of the root plug, at least initially, but continued root development would differ between the two species;

4) little root growth would occur until root zone temperatures warmed to levels above 10 degrees C;

5) there would be little difference in the first year morphological response to the different treatments;

6) there would be little difference in the first year foliar analysis data, however, N concentration would be monitored for any dilution effect caused by rapid growth and P concentration monitored for deficiency due to increased available N in any treatment.

2 Materials and Methods

2.1 Site Selection

Site selection was assumed by the British Columbia Ministry of Forests (MOF) and Forestry Canada. Four locations were chosen for site preparation during the summer of 1986, and were considered representative of major backlog types where stand establishment has been hampered by cold moist soils and vegetative competition (Hedin 1987). Ecosystem association and soil type were also identified as part of site selection (Bedford 1986). The study site locations were near Fort St. John, Dawson Creek, Mackenzie, and Vanderhoof, and are shown in Figure 1.

2.2 Site Description

The ecological classification and soil characteristics of the sites are summarized in Table 1. A detailed description of soil texture and humus depth/form is presented in Appendix A.

2.2.1 Iron Creek

The Iron Creek site was located approximately 120 km northwest of Fort St. John (56°N 122°W). The site is in the Halfway River Moist Cold Southern Boreal White and Black Spruce variant (BWBSd2). The soil is fine-textured, silty clay loam and clay loam. The area was selectively logged in 1966; clearcut in 1974; and windrow scarified in winter 1985. Study plots were located between the windrows and mechanically site prepared in summer 1986.

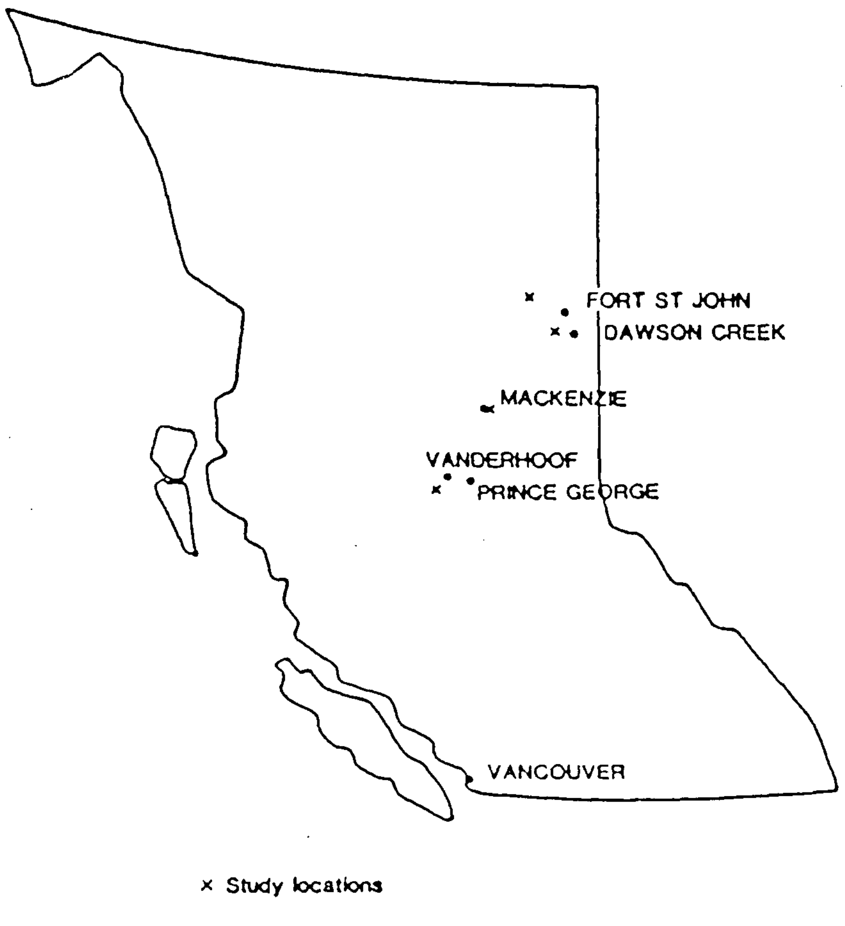

Figure 1. Location of study sites (from Hedin 1987).

Table 1. Characteristics of treatment sites as summarized from control plot descriptions, at each location, by MOFL (from Hedin 1987).

Location	Ecological classification	Humus form[a]	Humus depth (cm)	Soil texture	Soil moisture	Coarse fragments
Fort St. John	Moist Cold Southern Boreal White and Black Spruce BWBSd2 variant 06 Association - White Spruce - Horsetail (05 Assocation - Highbush-cranberry - Tall Bluebells)	moder (mor)	11-14 (7)	silty clay loam (clay loam)	subhygric (hygric, mesic)	<5%
Dawson Creek	Moist Cool SouthernBoreal White and Black Spruce BWBSc1 variant 05 Association - Highbush-cranberry - Oak Fern (06 Association - Highbush-cranberry - Tall Bluebells) (07 Association - Spruce - Horsetail)	moder	14-18 (8)	sandy loam, clay loam	subhygric (hygric)	<2%
Mackenzie	Moist Cool Central Sub-Boreal Spruce SBSj2 variant 01 Association - Black Gooseberry - Oak Fern 03 Association - Black Huckleberry - Bunchberry (04 Association - Devil's Club - Oak Fern)	mor (moder)	1-2 (10,16)	sandy silt, silty sand (silt loam)	mesic (submesic) subhygric)	<2%
Vanderhoof	Moist Cold Central Sub-Boreal Spruce SBSi subzone 01 Association - Prickly Rose - Colt's-foot	mor (moder)	2-8	silt loam	mesic	10% (20%, 30%)

[a] Bracketed descriptions are minor components of the site.

2.2.2 Stewart Lake

The Stewart Lake site was located approximately 50 km west of Dawson Creek (56°N 121°W). The site is in the Dawson Creek Moist Cool Southern Boreal White and Black Spruce variant (BWBSc1). Soils are somewhat coarser textured than in Iron Creek, with sandy and clay loams. The area had been selectively logged several times in the past 30 years and was burned in the mid-1960's and in 1971. The aspen on the area had been sheared and windrowed during April 1986. Study plots were located between the windrows and mechanically site prepared in summer 1986.

2.2.3 Mackenzie

The Mackenzie site was located approximately 5 km east of Mackenzie (55°N 123°W). The area is variable, within the Fraser Basin Moist Cool Central Sub-Boreal Spruce variant (SBSj2), but composed of three associations within that. Soils ranged from sandy silt to silty loam with humus depth and rooting depth variable. The area had been logged in winter 1977 and chain-dragged in 1978. The brush, grass, and aspen on this site were more typical of a post-logging situation than the brush-bladed Iron Creek and Stewart Lake sites. Study plots were located and mechanically site prepared in summer/fall 1986.

2.2.4 Kluskus Road

The Kluskus Road site was located approximately 75 km southwest of Vanderhoof, off the Kluskus Forest Access Road (54°N 125°W). The site is within the Moist Cold Central Sub- Boreal Spruce subzone (SBSi). The soils are very compact, with 5-30% coarse fragments. Humus depth is 2-8 cm, and rooting depth ranged from 7 to 15 cm. This shallow rooting depth was likely a result of the compact features of the soil (Hedin 1987). The area had been summer and winter logged in 1977 with a full-tree feller-buncher/grapple-skidder system. Study plots were located and mechanically site prepared in summer 1986.

2.3 Experimental Layout

The experimental layout followed that of FRDA Project 1.10. Each site had 30 x 40 m study plots established in a randomized complete block design; each with 5 blocks, each treatment represented once per block. FRDA 1.10 plots followed the 'mini-stand' approach outlined in McMinn (1984) in which seedlings were planted such that one treatment plot, consisting of 8 rows of 10 seedlings, would eventually form a stand of trees all exposed to the same treatment. Seedlings for the root egress study were planted, with care not to disturb the FRDA 1.10 seedlings, on or directly adjacent to these plots in surplus microsites judged to be representative of the study treatments. Figures 2 - 5 show plot layout and assignment of treatments for each site. Note, not all treatments are represented on all sites, and not all treatments shown are incorporated in this study.

2.4 Site Preparation Treatments

The site preparation treatments used in this study reflect current and future systems used in backlog rehabilitation. For more information on specific equipment see MacKinnon et al. (1987) and Coates and Haeussler (1984). This study was meant to provide an initial biological assessment of these systems, and the microsites each system produces, under "operational" field conditions. Microsites selected for this study reflect the actual, as opposed to the theoretical, microsites each system or implement produces. Each microsite and planting position is represented in Figure 6.

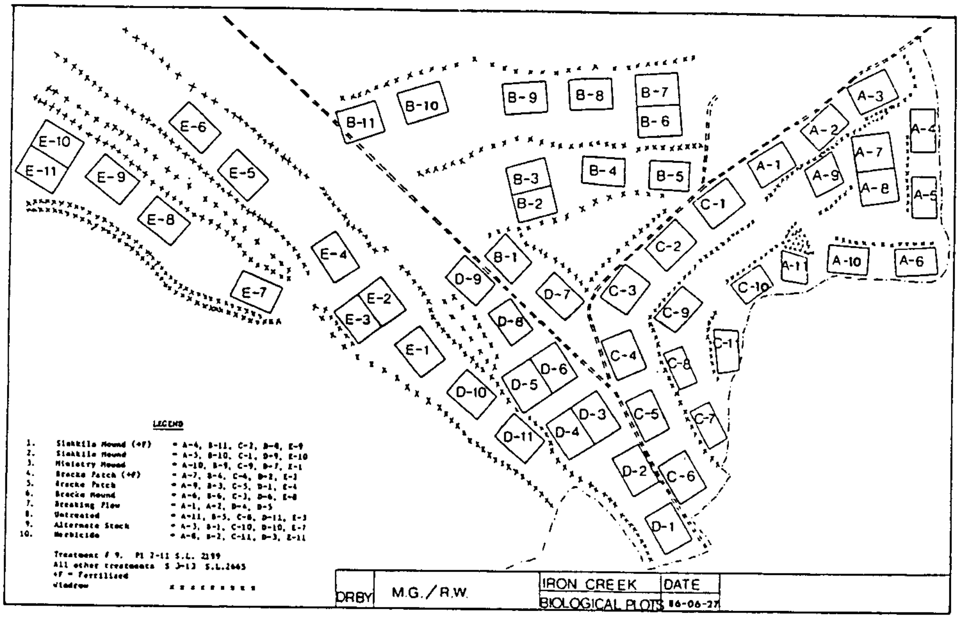

Figure 2. Plot layout and assignment of treatments, Iron Creek site.

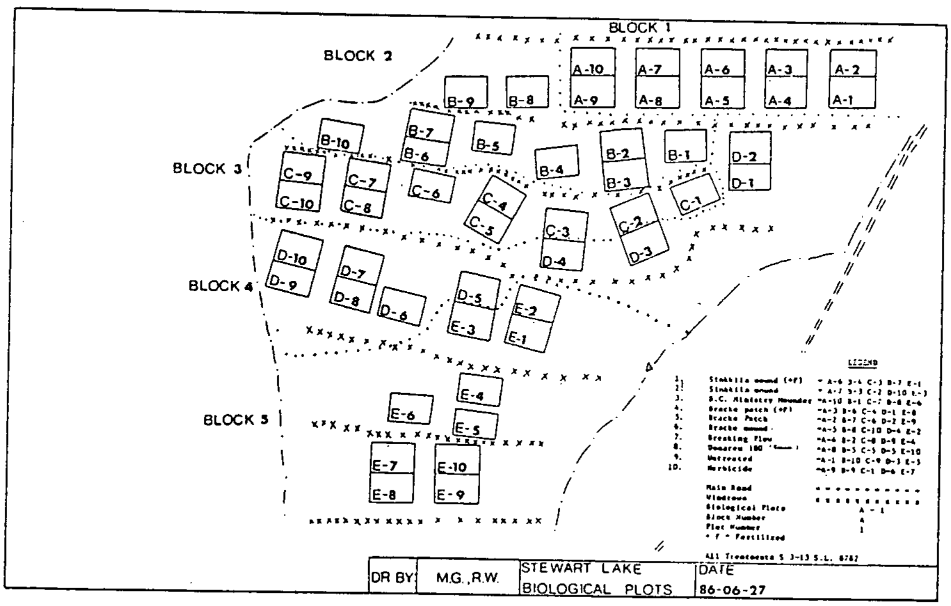

Figure 3. Plot layout and assignment of treatments, Stewart Lake site.

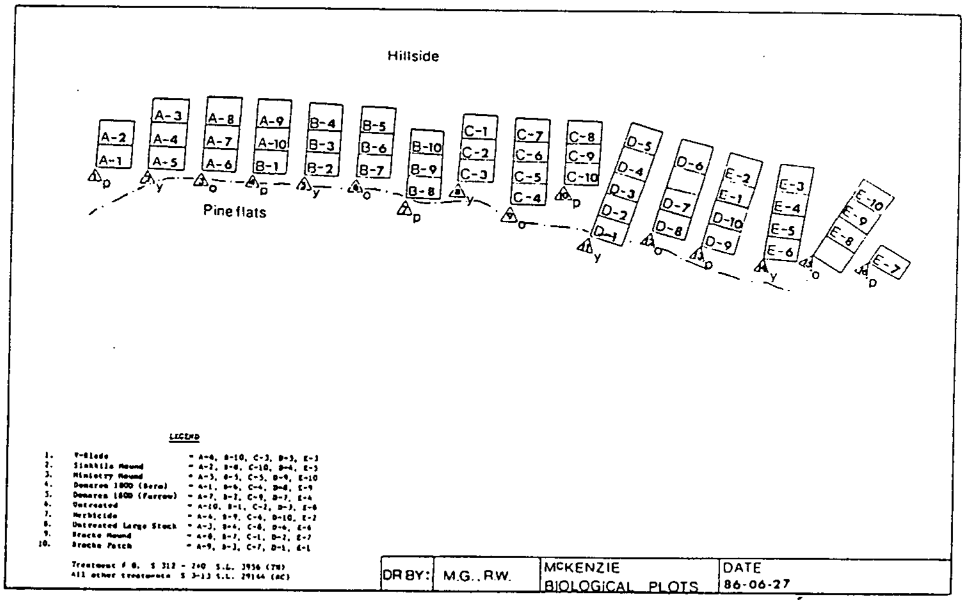

Figure 4. Plot layout and assignment of treatments, Mackenzie site.

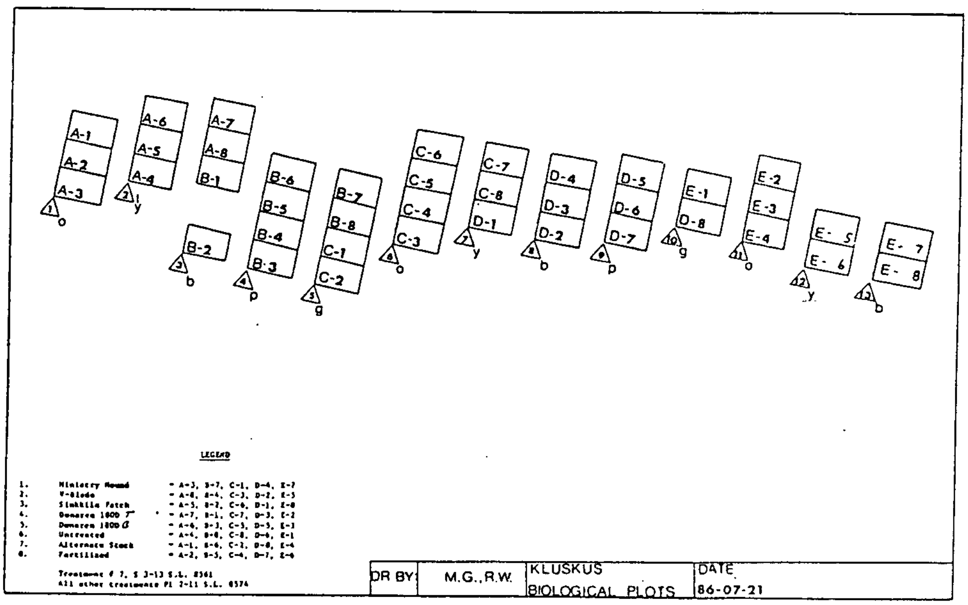

Figure 5. Plot layout and assignment of treatment, Kluskus Road site.

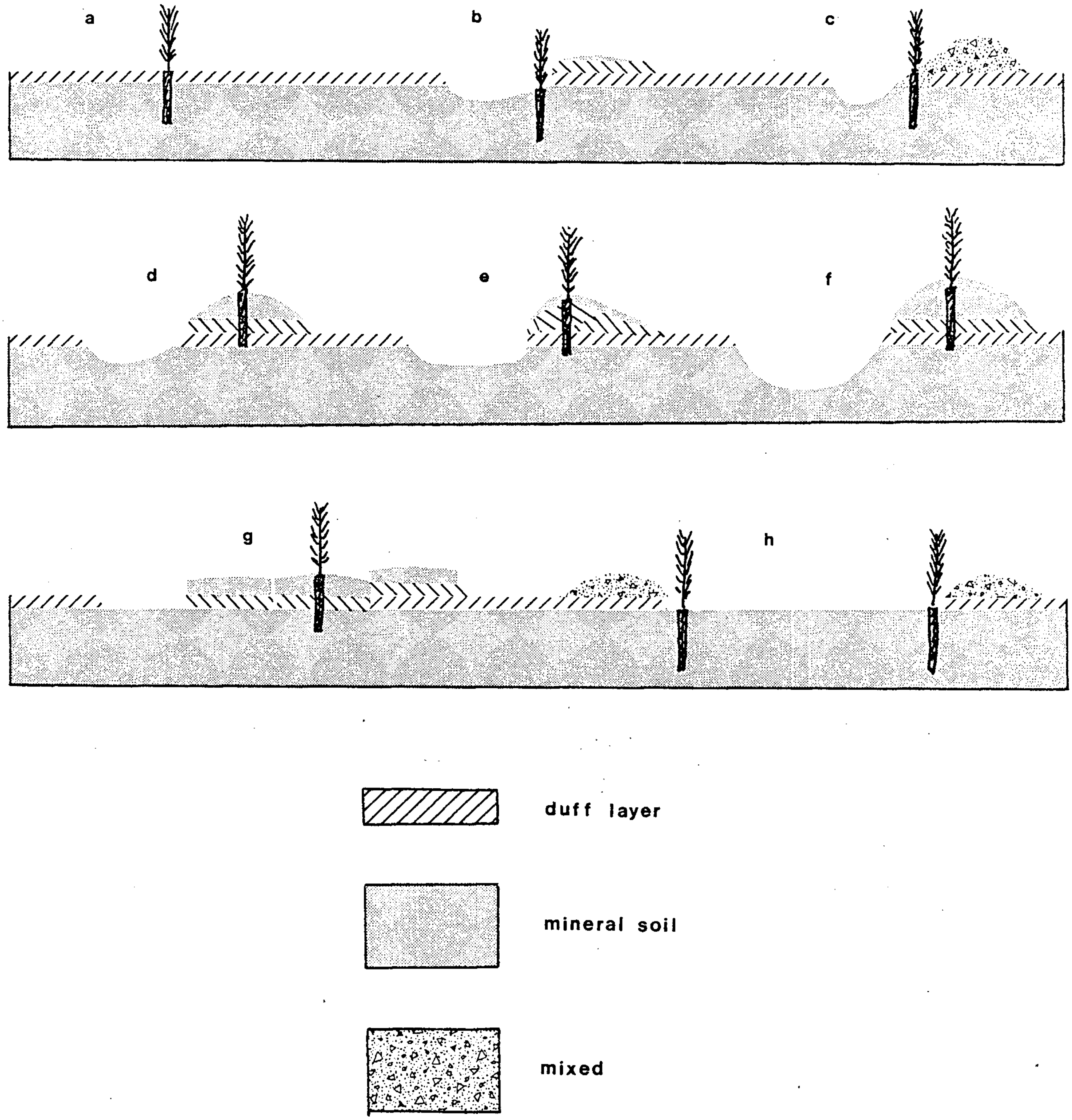

Figure 6. Diagram of (a) control, (b) patch, (c) Donaren trench, (d) Bräcke mound, (e) Sinkkilä mound, (f) Ministry mound, (g) breaking plow, and, (h) V-blade treatment microsites, and planting positions studied.

Hedin (1987) conducted field assessments of the inverted humus mounds produced by the Ministry Mounder, Sinkkilä HMF Scarifier/Mounder, and Bräcke Mounder, as part of the FRDA 1.10 Project. Mound configuration (mineral soil capping, height, length, and width) was measured in September 1986.

2.4.1 The Ministry Mounder

The Ministry Mounder was developed by the Silviculture and Engineering Branches of MOF over a 6 year period. Operational trials of an early prototype are summarized in Parolin et al. (1981). The prototype used in this study was mounted on a Cat D7E crawler, equipped with floatation tracks and a V-blade. Digging buckets are mounted on the ripper parallelogram of the machine on the rear of the crawler. Hydraulic pressure is used to drive the buckets into the ground while the machine is moving forward. The buckets are raised and then flipped to produce an overturned mineral mound over inverted organic material. The hydraulic pressure can be adjusted to suit soil conditions and the desired mound configuration, and digging cycle and spacing are adjusted using onboard computer controls.

The Ministry Mounder was the only mounder used on the Kluskus Road site as it was the only implement judged to be able to form successful mounds in these compact and stony soils (Hedin 1987).

2.4.2 The Sinkkilä HMF Scarifier/Mounder

The Sinkkilä HMF Scarifier/Mounder is a modified version of earlier machines used in Finland for patch scarification. The machine was mounted on the rear of a John Deere 740 skidder and consists of two scarifier units, 2 m apart, each with four pairs of ripper tines. As the machine is pulled forward a hydraulic brake is applied to the ripper wheel and the tines are drawn through the organic material and into the mineral soil. When the brake is released the ripper rotates, and the organic/mineral soil accumulation overturns forming a mound. Depending upon the angle of the ripper and the hydraulic braking applied to it, mounds, scalps, or continuous shallow furrows can be produced.

The unit was used at the Kluskus Road site to produce the patch treatment. The scarification action is similar to that described above but the tines are held at a less aggressive angle and only penetrate and overturn the organic/duff layer.

2.4.3 The Bräcke Mounder/Patch Scarifier

The Bräcke Mounder is an adaptation of the Bräcke cultivator used in Scandinavia and Canada for patch scarifying. It consists of two units housed in box frames mounted on a drawbar frame. Each unit consists of a rubber tire and tined mattock wheel linked by a chain mechanism through a gearbox. As the unit is pulled forward the mattock wheel rotates, at a slower speed, and the mattock tines move through the soil to produce a scalp and inverted accumulation. A mineral soil cap is produced by a tined shovel mounted behind the mattock wheel which digs into the scalp and deposits additional mineral soil on the inverted accumulation as the shovel lifts. The shovel is hydraulically powered by an auxiliary engine mounted on the frame. The Bräcke unit was mounted behind a Clark 668 skidder for this trial.

The Bräcke unit was used on the Iron Creek, Stewart Lake, and Mackenzie sites for both mounding and patch treatments. To create patches the cycle is as above except the tined shovel is not activated.

2.4.4 The Breaking Plow

The Breaking Plow used for this study consisted of three long plow shares mounted on an angled frame. The unit was mounted to the rear of a crawler tractor. The unit is pulled forward with the plows cutting through the mineral soil below the duff layer. The continuous mineral soil/organic clod is inverted as part of the plow action to produce a continuous inverted mineral over humus ridge. The two inside ridges are placed on the mineral soil exposed by the adjacent plow, with the outside ridge placed directly on the undisturbed humus layer. On a continuously plowed site the outside ridge would be placed on the exposed mineral soil of the adjacent pass.

2.4.5 The V-Blade

The V-Blade used for this study (Beale's V-blade) was mounted on the front of a D7 crawler tractor and consisted of a large shearing blade formed into a "V" shape. As the unit moves forward the forward shearing edge cuts along the organic, rootmat/mineral soil interface and removes any debris, slash, or vegetative competition, thus forming a wide, screefed corridor of exposed mineral soil.

2.4.6 The Donaren 180

The Donaren 180 is a powered disc trencher designed to produce continuous furrows of exposed mineral soil. The unit was mounted on the rear of a large skidder, and consists of two tined discs mounted on adjustable arms held at an angle to machine travel. The arms are supplied with hydraulic down pressure and the discs are hydraulically powered to rotate in the same direction as that of machine travel. As the unit is pulled forward the discs cut through the organic layer to the mineral soil, forming a furrow. The organic material and mineral soil removed are placed to one side of the furrow forming a loose berm of material.

Penetration of the discs is controlled by adjusting hydraulic down pressure to the arms. Unfortunately, preparation of the Mackenzie site was delayed till late in the fall, and penetration was limited by the frozen soil. Penetration was also limited on the Kluskus Road site by the very hard soil and the large number of rocks.

2.4.7 Untreated Control

The control treatment for this study was a microsite in which the seedlings were planted directly into undisturbed duff-covered mineral soil. Some light boot-screefing was done by the planters.

2.5 Planting Stock

All seedlings planted were grown in styroblocks, fall/winter 1986 lifted, and cold stored till time of planting. Table 2 summarizes seedling stock information. Several days prior to planting, bundles were removed from their boxes and unwrapped. Seedlings were individually inspected. Twenty to twenty-five percent were culled for any of the following reasons: seedlings abnormally large or small, root plug damaged, seedling chlorotic, heavy mold, multiple seedling per plug, multiple leader, and leader broken or damaged. Seedlings for the Stewart Lake site were heavily infested by grey mold. Bundles were re-wrapped and placed back in their boxes. Inspections were carried out inside the reefers and exposure of the root plugs kept to a minimum. Upon commencement of planting the boxes of seedlings were cached on or near the study site, or removed from the reefer on a daily basis where convenient. A sub- sample of approximately 50 seedlings per seedlot was taken at random during the plant and sent to the MOF Red Rock Research Station for morphological measurement and root growth capacity (RGC) testing, following Simpson (1985) and Hooge (1987). Unfortunately, the sample from Mackenzie was misplaced and not tested. Results are summarized in Table 3.

Table 2. Summary of seedling stock information

Site	Species	Stock Type	Seedlot	Lifting Date	Percent Culled
Iron Creek	White spruce	1+0 PSB 313	2665	n/a	24
Stewart Lake	White spruce	2+0 PSB 313	8782	n/s	20
Mackenzie	White spruce	1+0 PSB 313	29144	5 Dec 86	22
Kluskus Road	Lodgepole pine	1+0 PSB 211	8574	17 Nov 86	24

Table 3. Summary of morphological measurements and RGC testing.

Site	Seedlot	RGC Class	Shoot Length (mm)	Root Collar Diameter (mm)	Shoot Mass (g)	Root Mass (g)
Iron Creek	2665	2.69	175	2.7	1.5	0.8
Stewart Lake	8782	1.44	212	4.1	2.9	1.5
Mackenzie	29144	n/a	n/a	n/a	n/a	n/a
Kluskus Road	8574	4.56	171	2.2	0.7	0.4

2.6 Planting

All planting was carried out in spring 1987 by two contract planters. Table 4 lists planting dates for the four sites. Seedlings were planted

Table 4. Planting dates by site.

Site	Planting Date
Kluskus Road	May 12 - 18, 1987
Stewart Lake	May 20 - 26, 1987
Iron Creek	May 28 - June 2, 1987
Mackenzie	June 4 - 10, 1987

using modified planting shovels and the "slit method" (Robertson and Young 1988). Planting spots were flagged prior to planting in all but the control,

Donaren 180, Sinkkilä mound, and breaking plow treatments. Final microsite selection was, however, left up to the planters' discretion. The planters were instructed prior to planting each treatment what the desired, representative microsite was. This was done in consultation with R. G. McMinn.

For the untreated control treatment, seedlings were planted directly into the undisturbed, duff-covered mineral soil. For the patch treatment, seedlings were planted on the shoulder of the patch near the hinge of inverted organic/mineral soil. For the Donaren 180 treatment, seedlings were planted on the shoulder of the furrow adjacent to the berm of mixed organic/mineral soil. For the V-blade treatment, seedlings were planted in the exposed mineral soil of the screefed corridors approximately 25 cm from the berm of cleared, mixed debris, duff and mineral soil. For the breaking plow treatment seedlings were planted only on the ridges of inverted mineral soil/organic overlaying mineral soil. For all mound treatments seedlings were planted directly into the mineral mound over inverted humus. Planting position is shown in Figure 6.

For the breaking plow and mound treatments, seedlings were planted such that part of the root plug extended through the inverted humus layer, even though this resulted in the root collar being buried up to 12 cm on deep mounds. Experience in Scandinavia suggests that this would not reduce survival (McMinn, pers. comm.). Studies have shown that the duff layer causes capillary discontinuity, which interrupts the upward movement of soil moisture, trapping it below the discontinuity (Hunt 1987). Seedlings planted J- rooted within the mineral soil cap do not reach the continuous supply of moisture beneath the duff. Deprived of soil moisture during drought periods, such seedlings may die or become stunted by drought (McMinn 1988). While this alters seedling shoot:root ratio in relation to other treatments studied, it was felt that this provided the only chance for seedling survival on these microsites. Development and operational testing of container seedlings with a longer root plug is ongoing.

Depending upon the level of destructive sampling anticipated, either 30 or 50 seedlings were planted on each plot. Thus, 150 or 250 seedlings per treatment per site were planted.

2.7 Biological Assessment

Sample seedlings were carefully excavated at approximately 45, 70 and 95 days after planting. Due to the logistics of the study only selected treatments were sampled for all three periods. The remaining treatments were sampled for the 95 day assessment only. Table 5 lists the treatments studied and sampling intensity at each location. For each assessment date 10 seedlings in each of 5 replications per treatment per site were sampled. Seedlings were placed in plastic bags and taken to the Red Rock Research Station for immediate examination. Seedlings for the 95 day assessment were refrigerated and cold stored in plastic bags at Red Rock until they could be transported to UBC for examination.

Table 5. Treatments studied and sampling intensity at each location.

Site	Treatments Studied	Sampling Intensity
Iron Creek	Deep mound, Ministry mounder	45, 70, 95 day
	Shallow mound, Bracke mounder	
	Patch, Bracke	
	untreated control	
	Sinkkila mound	95 day only
	Breaking plow, invert	
Stewart Lake	Deep mound, Ministry mounder	45, 70, 95 day
	Shallow mound, Bracke mounder	
	Breaking plow, invert	
	Patch, Brake	
	untreated control	
	Donaren 180, shoulder	95 day only
	Sinkkila mound	
Mackenzie	Deep mound, Ministry mounder	45, 70, 95 day
	Shallow mound, Bracke mounder	
	Patch, Bracke	
	untreated control	
	Donaren 180, shoulder	95 day only
	Sinkkila mound	
Kluskus Road	Deep mound, Ministry mounder**	45, 70, 95 day
	Patch, Sinkkila	
	untreated control	
	Donaren 180, shoulder	95 day only
	V-plow, screefed	

** Initially this treatment was separated into deep and shallow mound treatments, however, after the 45 day assessment they were combined due to heavy mortality on this site.

The roots of sampled seedlings were examined for egress of new roots from the root mass developed during the growth of seedlings in styroblocks. The root systems were carefully washed and the numbers of all unsuberized, white root tips tallied for the 45 and 70 day assessments. New roots which had grown from the initial root mass but were already suberized were not included in the tally. Initially only the number of white root tips was tallied, regardless of length or location. However, this provided only limited information. The 45-day assessment for the Kluskus Road site was the only assessment done this way. For the remaining assessments the tally was broken into four groups based on whether the new root was growing from the side or bottom of the plug (Figure 7), or was greater or less than 1 cm in length.

Root egress for the 95 day assessment was measured for root area index using a Delta-T area meter (Figure 8). This device utilizes a video system to automatically quantify a projected, two-dimensional representation of the seedling's root system. The washed root system is cut, separated, and placed in a glass-bottomed root tray in a root box, over a light source. Care is taken to minimize overlap of the roots. A video camera is focused on the root system and projects this onto a standard video monitor. One scan of the video camera consists of approximately 250 individual scan lines, and is completed in 1/60 second. The area meter consists of a comparator and a counter, and is set to measure the fraction of each scan line that has a brightness above or below a user determined threshold. The device is then calibrated using an object of known area. In this case, a small piece of paper of known dimension was shredded and floated in shallow water in the root tray to simulate the root samples and allow for overlap. This method

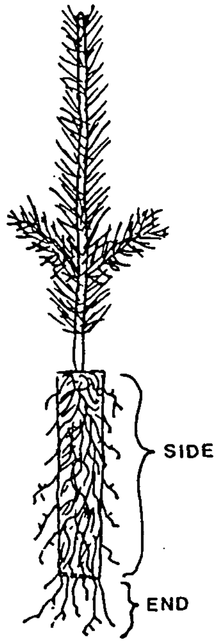

Figure 7. Diagram showing how the tally of root egress was broken into groups based on whether the new root was growing from the side or bottom of the root plug.

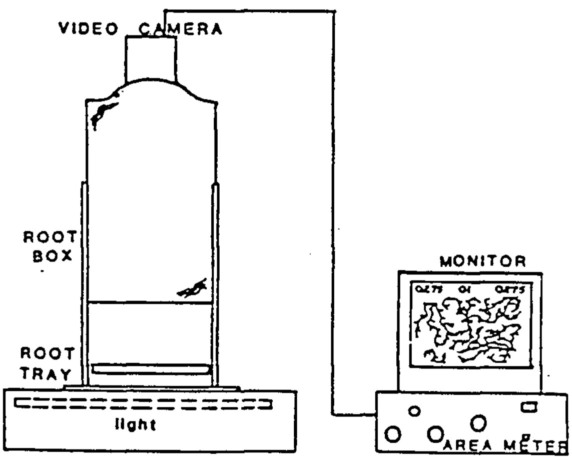

Figure 8. Schematic diagram of root box, video system, and area meter used to measure root area index for the 95 day assessment of root egress (from Delta T Operator's Manual).

proved effective. Thus root area index values are a measure of the two-dimensional projected root system surface area in cm^2 and can easily be converted to total root surface area by multiplying by Pi.

The total seedling height, root collar diameter and 1987 leader growth were measured for all 95 day seedlings. A sub-sample of two seedlings per plot was taken for measurement of root and shoot dry weight, shoot:root ratio, nitrogen and phosphorus content of 1987 seedling foliage, and dry weight of 100 needles of 1987 foliage. All samples were kiln dried for 48 hours at 70 degrees C. Needles from the top 5 cm of the apical leaders of the two seedlings were bulked and used for the nutrient determinations. Mr. M. Tse, Faculty of Forestry, UBC, carried out the foliar chemical analysis.

2.8 Analysis

Analysis of variance, followed by Duncan's mean separation test where warranted, was performed on the biological assessment data using the SAS statistical package (SAS Institute Inc. 1985).

2.9 Environmental Monitoring Study (FRDA 1.25)

An environmental monitoring study was undertaken as a subproject of FRDA 1.10 by the MOF, Prince George Region. Layout, monitoring setup and measurement is outlined in McLeod and Osberg (1986). Root zone temperature and site climatic conditions were monitored for all three spruce sites.

2.10 Vegetation Ingrowth Assessment (FRDA 1.10)

Vegetation assessments of ingrowth following site preparation and the development of vegetation on untreated plots was measured, in the second and third weeks of August 1987, by MOF personnel as part of the FRDA 1.10 project

(McMinn and Bedford 1988). Ten seedling-centred plots were sampled in each of the 5 replicates of the representative treatments being assessed, making a total of 50 sample plots, 2000 cm^2 in area, per treatment. Tree seedlings in the centre of each plot were 25 cm from the circumference of the plot. Sample plot size was chosen to reflect the presence of competing vegetation within close proximity of tree seedlings. Additionally, tests have shown that plots of this size can be assessed with greater repeatability than larger plots (McMinn and Bedford 1988).

The following estimates and measurements were made for each plot:

1) total percent cover of non-crop vegetation greater than 20 cm in height (i.e. taller than the seedling and therefore likely to compete with it for light);

2) names and cover of up to 3 species greater than 20 cm in height;

3) total percent cover of non-crop vegetation less than 20 cm in height;

4) average height of non-crop vegetation; and,

5) distance of nearest vegetation from the tree seedling.

A simple competition index was calculated as the percent cover of vegetation multiplied by the average height of vegetation divided by the distance of the nearest vegetation to the seedling (McMinn and Bedford 1988).

2.11 Survival and Frost Damage

Survival and number of seedlings damaged by frost were tallied by MOF personnel in late August as part of the FRDA 1.10 Project. All FRDA 1.10 seedlings were examined.

3 Results

3.1 Field Assessment of Mound Configuration (Hedin 1987)

Table 6 summarizes the performance of the three mounding implements. A more detailed summary is presented in Appendix B.

Overall, the Ministry Mounder had the greatest success in producing inverted humus mounds on all four locations. It had the highest percentage of acceptable mounds of the three machines (79 - 95%), and mineral soil capping was consistently greater than 10 cm.

The Sinkkilä Mounder was inconsistent in its results. It performed well at Stewart Lake (80% acceptable mounds), but poorly at Mackenzie (44% acceptable mounds). The unsatisfactory performance at Mackenzie was due in part to mechanical malfunction.

The Bräcke Mounder was consistent in its overall performance on all three locations, with 70 - 80% acceptable mounds. However, the ability of the machine to prepare mounds greater than 10 cm mineral soil capping was definitely dependent on, and limited by, the site.

3.2 Environmental Monitoring

The period of study began approximately 1 week into August and terminated at the end of October.

On all three sites solar radiation varied between 5 to 23 $MJ/m^2/day$ initially but generally tended to decrease to levels between 5 to 10 $MJ/m^2/day$ into October. Daytime, maximum air temperature on all sites varied between 10 to 25 degrees C throughout the study period. Nighttime minimum air temperatures first dropped below freezing at the Iron Creek and Stewart Lake sites on September 12 and October 5 respectively. The Mackenzie site

Table 6. Summary of the performance of the three mounding implements (from Hedin 1987).

	% Acceptable mounds			
	Fort St. John	Dawson Creek	Mackenzie	Vanderhoof
Sinkkilä				
Mineral capping ≥10 cm	21.5	52.5	3.8	N/A
Other acceptable mounds	60.5	27.0	40.5	N/A
Total acceptable mounds	82.0	79.5	44.3	N/A
Ministry mounder				
Mineral capping ≥10 cm	62.0	89.3	78.5	64.5
Other acceptable mounds	17.0	5.6	14.5	27.0
Total acceptable mounds	79.0	94.9	93.0	91.5
Bräcke mounder				
Mineral capping ≥10 cm	6.4	41.0	18.2	N/A
Other acceptable mounds	65.0	38.5	52.2	N/A
Total acceptable mounds	71.4	79.5	70.4	N/A

was located in a frost pocket and nighttime temperatures frequently dropped below freezing throughout the monitoring period.

3.2.1 Root Zone Temperatures

On the Iron Creek site, soil temperature at a depth of 10 cm reached the highest temperatures in the Ministry Mounder microsites. This treatment showed the greatest diurnal fluctuation of all treatments, with diurnal ranges up to 15 degrees C. It also showed the most response to changes in air temperature, precipitation and solar radiation.

These two characteristics are illustrated in Figure 9. The gradual decline in incoming solar radiation over the monitoring period is accompanied

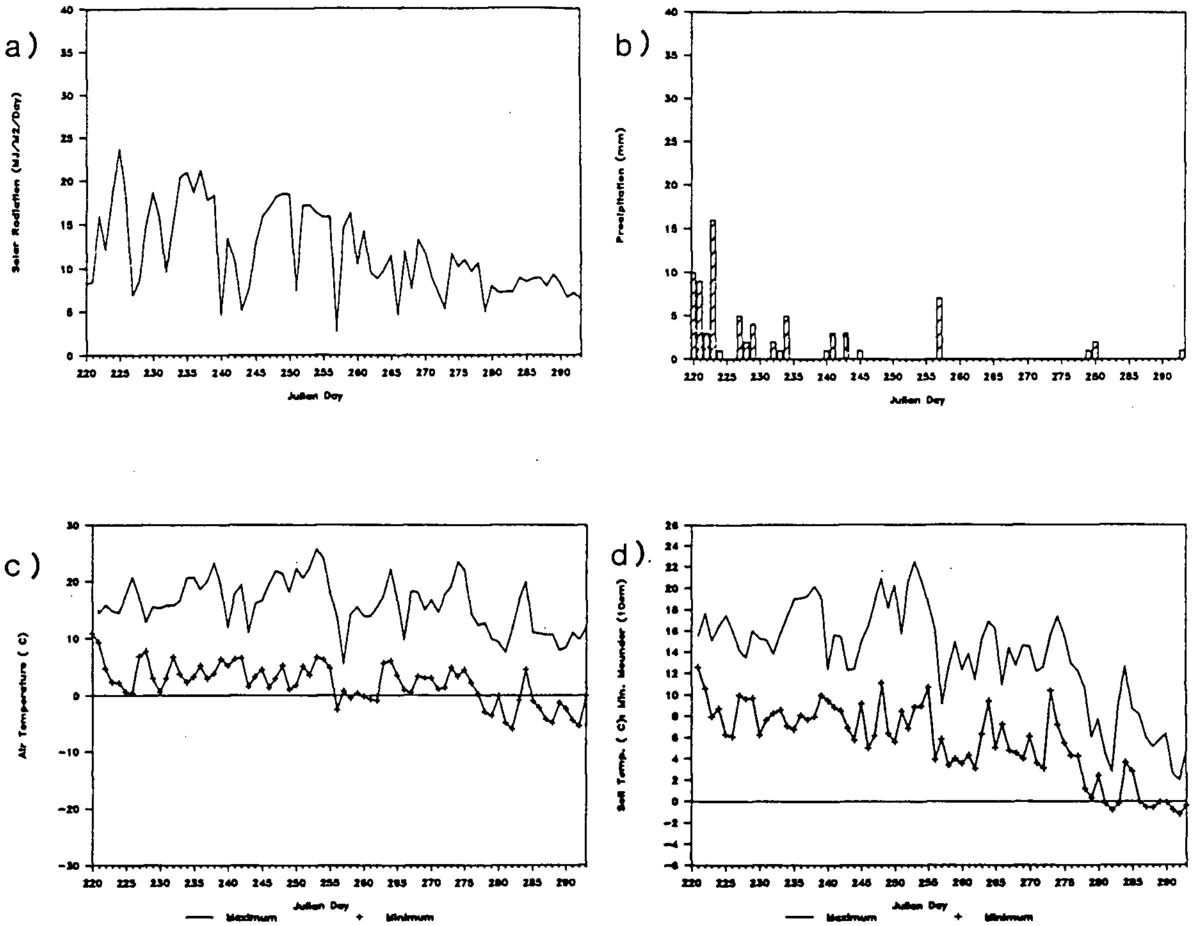

Figure 9. Plots of (a) solar radiation, (b) precipitation, (c) air temperature, and (d) root zone temperature in a mound microsite, monitored on the Iron Creek site (courtesy FRDA 1.25).

by a matching decline in average mound root-zone temperatures. A period of relatively high incoming solar radiation, air temperatures, and no precipitation between Julian days 246 and 255 results in matching high microsite temperatures. A decline in solar radiation on Julian day 251 is matched by decreased microsite temperature. The combined effect of a large precipitation event and decreased solar radiation on Julian day 257 rapidly lowers air and microsite temperatures.

Generally this treatment had many periods of daily maxima greater than 15 degrees C well into September and some peaks greater than 20 degrees C. Its minima were lower than all the other treatments and dropped below freezing first.

Soil temperature at a depth of 10 cm in the Bräcke Mounder microsite followed a similar pattern to that of the Ministry Mounder microsite, however, it had slightly less diurnal variation and never achieved temperatures in excess of 20 degrees C. It had periods of daily maxima greater than 10 degrees C well into September and some peaks greater than 15 degrees C. Soil temperature at a depth of 10 cm for the patch and control treatments was quite similar. Both showed only 2-3 degrees C of diurnal variation and a declining trend over the monitoring period from approximately 12 degrees C initially to 5 degrees C. Soil temperatures at the humus/mineral interface for the control, Ministry and Bräcke Mounder treatments followed the same trend with a diurnal variation of about only 1 degree C.

At the Stewart Lake site the thermal regimes of the different microsites each followed the same general pattern as their counterparts in Iron Creek, however, the differences between the Ministry and Bräcke Mounder microsites were somewhat less. Soil temperatures greater than 15 degrees C were seldom achieved for any significant period of time in either treatment. The patch and control treatments again had similar trends; however, the patch treatment showed a diurnal variation of about 2 degrees C whereas there was little diurnal variation for the control treatment. The control treatment also had the highest temperature at the end of the study period, at 5-6 degrees C, whereas the patch treatment had dropped to about 4 degrees C.

At the Mackenzie site, the soil thermal regimes were again typical for the various microsites, however, the Bräcke Mounder showed higher maxima and greater diurnal variation than did the Ministry Mounder. Soil temperatures at 10 cm depth had maxima greater than 15 degrees C for significant periods well into September in the Bräcke Mounder treatment. Temperatures in both treatments approached freezing by the end of the study period. Temperatures in the Ministry Mounder treatment at 20 cm depth, Bräcke Mounder humus/mineral interface, and patch treatment 10 cm depth, all had similar patterns with a decreasing trend from about 14 degrees C to 4 degrees C and a diurnal range of 2-3 degrees C. Soil temperature at 10 cm depth in the control microsite dropped from 11 degrees C to 6 degrees C over the monitoring period with little diurnal variation.

The results of the environmental monitoring project for all three spruce sites are summarized in Appendix C.

3.3 Biological

Analysis of the biological data proved quite challenging. Initially, analysis of variance testing included all three spruce sites, with treatment and block effects being tested within sites, and the Kluskus Road pine site tested separately. However, a significant treatment x site interaction was found. This is readily explained by the different climatic conditions each site experienced; especially the periodic high water tables, the Stewart Lake and Iron Creek seedlings experienced. This appeared to have the greatest impact on seedlings planted in the patch and control treatments.

Heavy, late moisture inputs from precipitation on the Iron Creek site appeared to help seedlings planted in the Sinkkilä Mounder treatment. The Sinkkilä Mounder treatment was the most inconsistent of all the treatments. This is in part explained by mechanical malfunction which varied from site to site (Hedin 1987). Differences in stock type, seedlot, and vigor (as shown in RGC testing) also added to the confusion.

Analysis proceeded on a site by site basis; however, complications still arose. As mentioned earlier, experimental layout followed the randomized complete block design of FRDA 1.10. Blocking, however, does not seem to follow any stratified set of conditions and appears to be merely systematic labelling as far as parameters affecting seedling performance are concerned. This is easily seen by viewing site soil texture and humus depth/form information presented in Appendix A in relation to block layout. This suggests that experimental layout should have followed a completely randomized design and that blocking only served to increase the estimate of the standard error by losing 1 degree of freedom. Thus, mean separation tests based on this overestimated standard error will be overly cautious, and means tested as not significantly different may in fact be significantly different.

Block x treatment interaction was also a problem, but could be readily explained by site conditions, which varied over the blocks and in the microsites ability to overcome the constraint (i.e. patch treatments were more susceptible to plots with a high water table than mounded treatments).

3.3.1 Root Growth

The 45 day assessment of root egress is summarized in Table 7 and Figures 10, 11, and 12. On all three spruce sites, seedlings planted in the deep mineral soil over inverted humus mounds created by the Ministry Mounder had significantly greater numbers of new roots longer than 1 cm than did seedlings planted in patch or control treatments. This was also the case for the breaking plow treatment on the Stewart Lake site (not shown in Figure 11). Seedlings planted in the shallower mounds created by the Bräcke Mounder had generally greater numbers of new roots greater than 1 cm than did patch or control seedlings, however, this was not always a significant difference.

Mounded seedlings also had greater numbers of new roots less than 1 cm on the Stewart Lake site. Seedlings for all treatments on the Iron Creek and Mackenzie sites had similar numbers of new roots less than 1 cm. Generally, spruce seedlings in all 4 treatments, on all three sites, had greater numbers of new root tips greater than 1 cm in length growing from the end of the root plug than from the sides. Equal numbers of new root tips less than 1 cm were generally found on the ends and sides of the root plugs.

Pine seedlings on the Kluskus Road site generally had significantly more root tips on control treatment seedlings than patch or shallow mound treatment seedlings. Deep mound treatment seedlings were intermediate and not significantly different from any of the other treatment seedlings.

The 70 day assessment of root egress is summarized in Table 8 and Figures 13 to 16. On the Iron Creek site both the Ministry and Bräcke mound treatment seedlings had significantly greater numbers of new roots greater and less than 1 cm than did the control and patch treatment seedlings. On the Stewart Lake site the Ministry Mounder treatment seedlings had significantly greater numbers of new roots in all categories than did the Bräcke Mounder

Table 7. Mean number of new roots growing from the root plug, 45 days after planting. Means in a group followed by the same letter do not differ significantly as determined by a Duncan's mean separation test (P 0.05).

	White spruce						Lodgepole pine	
	Iron Creek		Stewart Lake		Mackenzie		Kluskus Road	
Root Catagory	Mean	Treatment	Mean	Treatment	Mean	Treatment	Mean**	Treatment
Side, LT 1 cm	11.06 a	control	20.52 a	min. m.	26.16 a	patch	22.04 a	control
	9.70 ab	min. m.	12.22 b	br. plow	25.20 a	min. m.	17.16 ab	deep m.
	9.62 ab	bracke m.	11.92 b	bracke m.	16.76 b	bracke m.	15.44 b	patch
	7.80 b	patch	8.18 bc	patch	15.70 b	control	15.38 b	shal. m.
			6.63 c	control				
Side, GT 1 cm	7.04 a	min. m.	5.76 a	min. m.	11.32 a	min. m.		
	3.63 b	bracke m.	4.86 ab	br. plow	8.00 b	bracke m.		
	3.26 b	control	4.04 b	bracke m.	7.00 b	control		
	3.04 b	patch	2.26 c	patch	6.34 b	patch		
			2.18 c	control				
End, LT 1 cm	15.14 a	bracke m.	19.73 a	min. m.	15.64 a	patch		
	10.64 b	min. m.	15.46 b	br. plow	14.70 a	control		
	10.40 b	control	12.32 b	bracke m.	13.36 a	min. m.		
	9.40 b	patch	8.53 c	control	12.54 a	bracke m.		
			7.03 c	patch				
End, GT 1 cm	19.64 a	min. m.	8.36 a	min. m.	29.32 a	min. m.		
	15.60 a	bracke m.	8.26 a	br. plow	19.03 b	bracke m.		
	9.72 b	patch	4.40 b	bracke m.	15.02 b	patch		
	7.83 b	control	2.42 bc	control	12.26 b	control		
			1.26 c	patch				

** means for this site represent the total number of root tips as groupings based on size and location were not made.

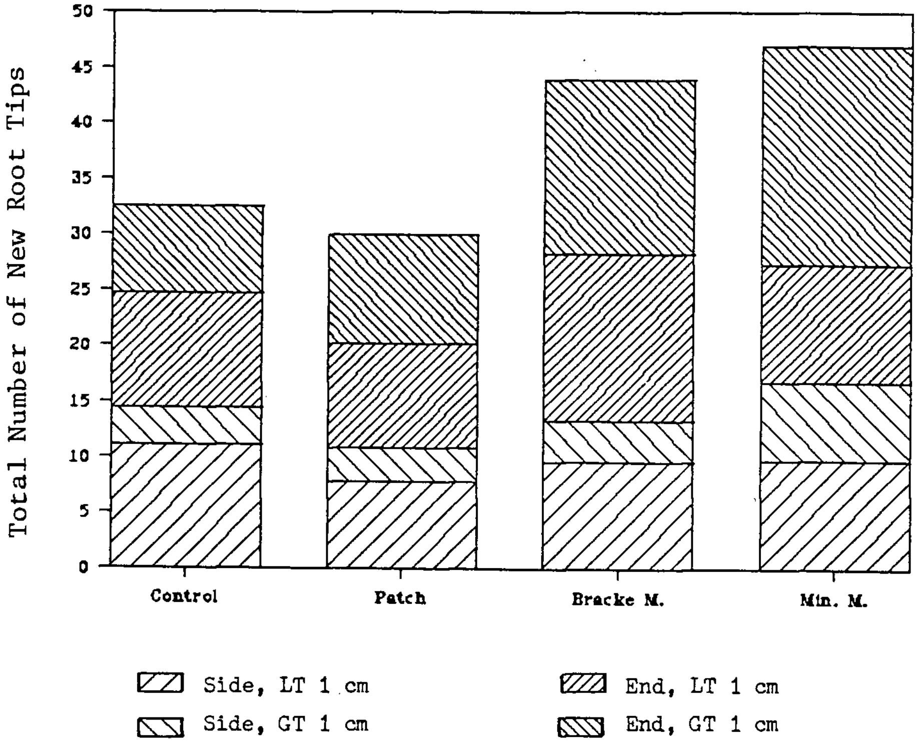

Figure 10. Total root egress 45 days after planting, Iron Creek spruce site.

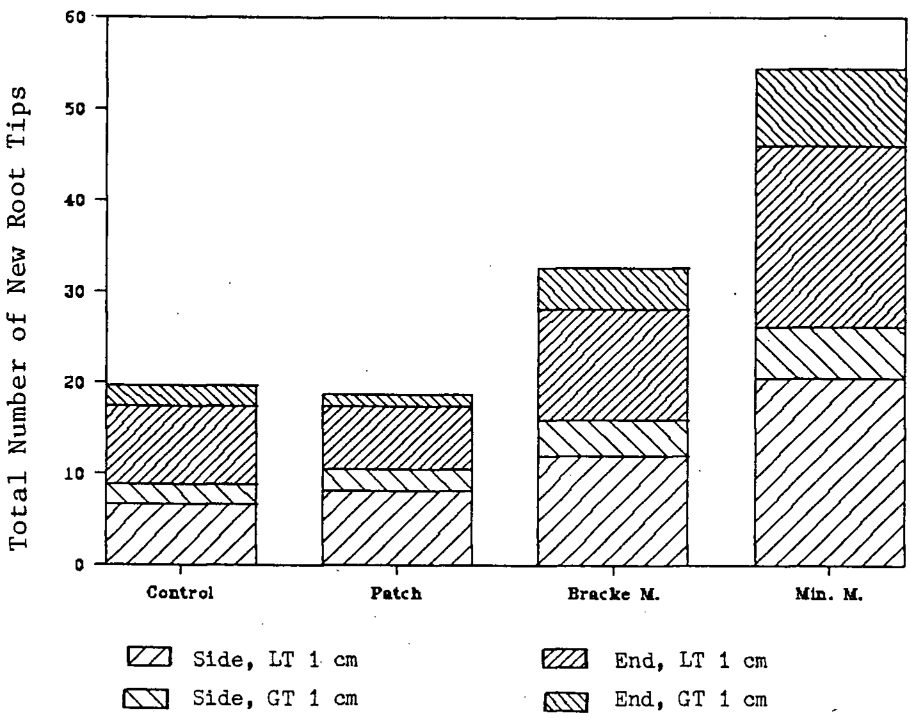

Figure 11. Total root egress 45 days after planting, Stewart Lake spruce site.

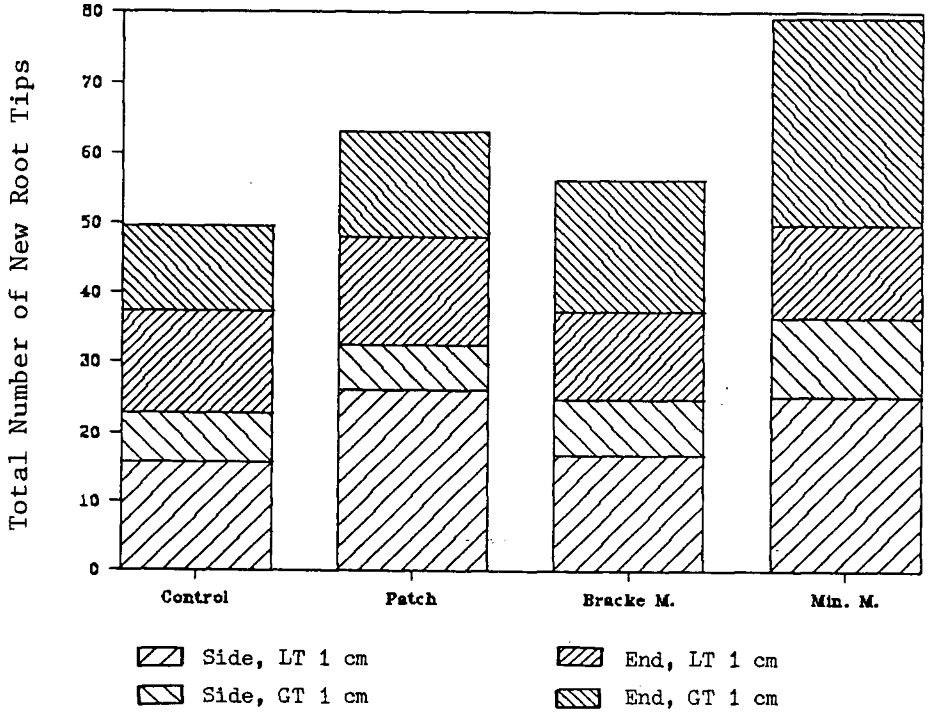

Figure 12. Total root egress 45 days after planting, Mackenzie spruce site.

Table 8. Mean number of new roots growing from the root plug, 70 days after planting. Means in a group followed by the same letter do not differ significantly as determined by a Duncan's mean separation test (P 0.05).

	White spruce						Lodgepole pine	
	Iron Creek		Stewart Lake		Mackenzie		Kluskus Road	
Root Catagory	Mean	Treatment	Mean	Treatment	Mean	Treatment	Mean	Treatment
Side, LT 1 cm	47.70 a	min. m.	64.58 a	min. m.	108.40 a	min. m.	11.80 a	patch
	42.24 a	bracke m.	47.16 b	bracke m.	87.10 b	bracke m.	11.00 a	control
	32.38 b	control	41.26 b	br. plow	73.94 bc	patch	8.66 a	min. m.
	21.38 c	patch	28.98 c	control	57.46 c	control		
			15.96 d	patch				
Side, GT 1 cm	19.60 a	bracke m.	23.46 a	min. m.	31.00 a	min. m.	2.38 a	patch
	18.62 a	min. m.	16.34 b	bracke m.	21.30 b	bracke m.	2.14 a	min. m.
	11.40 b	control	12.96 b	br. plow	18.02 bc	patch	1.92 a	control
	6.36 c	patch	8.16 c	control	15.28 c	control		
			4.98 c	patch				
End, LT 1 cm	24.52 a	bracke m.	20.94 a	min. m.	48.34 a	min. m.	4.94 a	min. m.
	22.88 a	min. m.	17.80 ab	bracke m.	31.14 b	bracke m.	4.40 a	control
	5.90 b	control	17.18 b	br. plow	20.46 c	control	3.88 a	patch
	5.54 b	patch	13.20 c	control	18.72 c	patch		
			7.08 d	patch				
End, GT 1 cm	42.18 a	bracke m.	20.66 a	min. m.	37.78 a	min. m.	11.30 a	control
	31.26 b	min. m.	15.94 b	bracke m.	27.24 b	bracke m.	6.88 b	min. m.
	10.02 c	control	13.48 b	br. plow	21.26 b	patch	6.74 b	patch
	7.78 c	patch	9.58 c	control	20.88 b	control		
			3.48 d	patch				

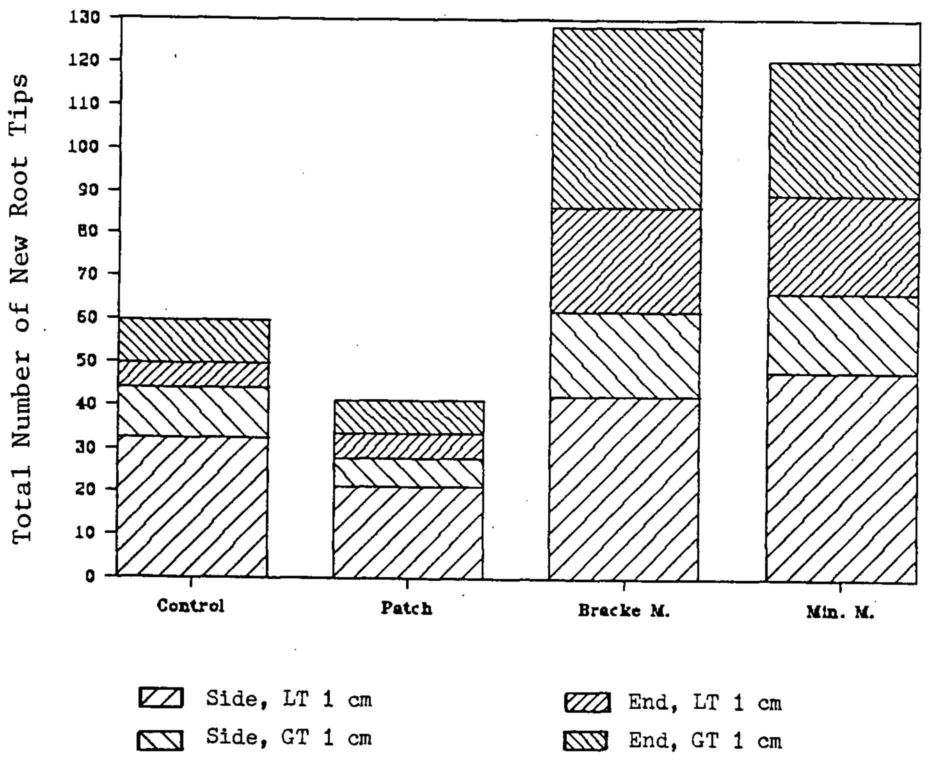

Figure 13. Total root egress 70 days after planting, Iron Creek spruce site.

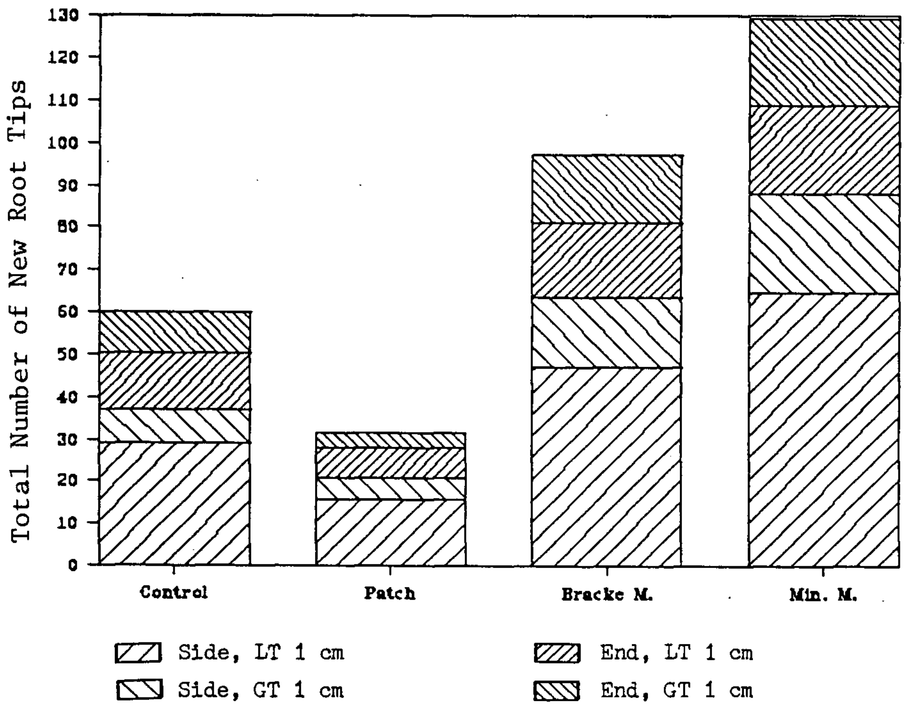

Figure 14. Total root egress 70 days after planting, Stewart Lake spruce site.

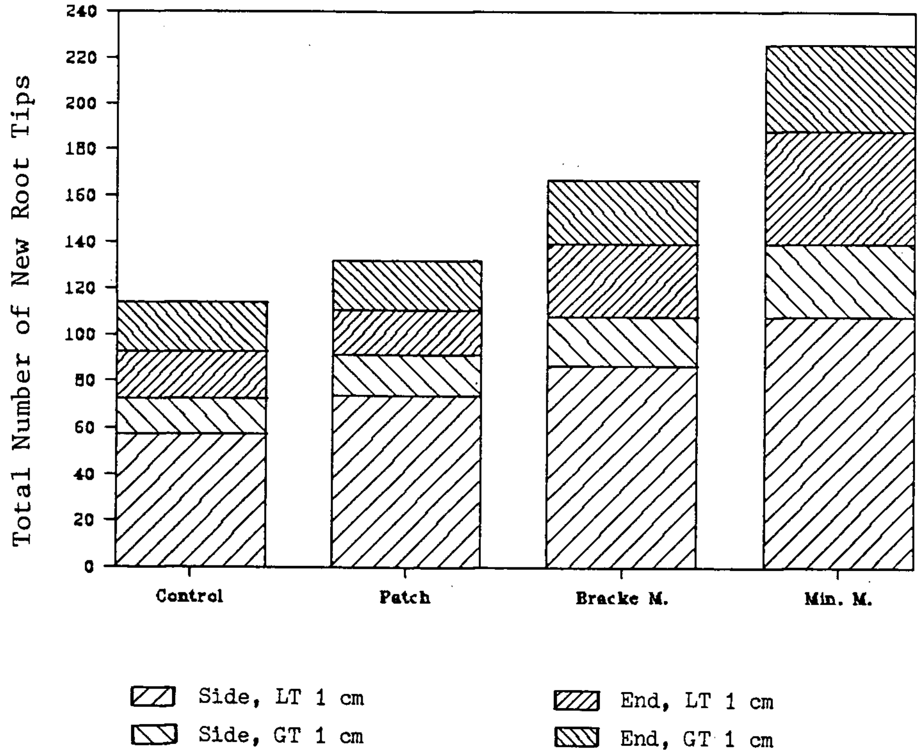

Figure 15. Total root egress 70 days after planting, Mackenzie spruce site.

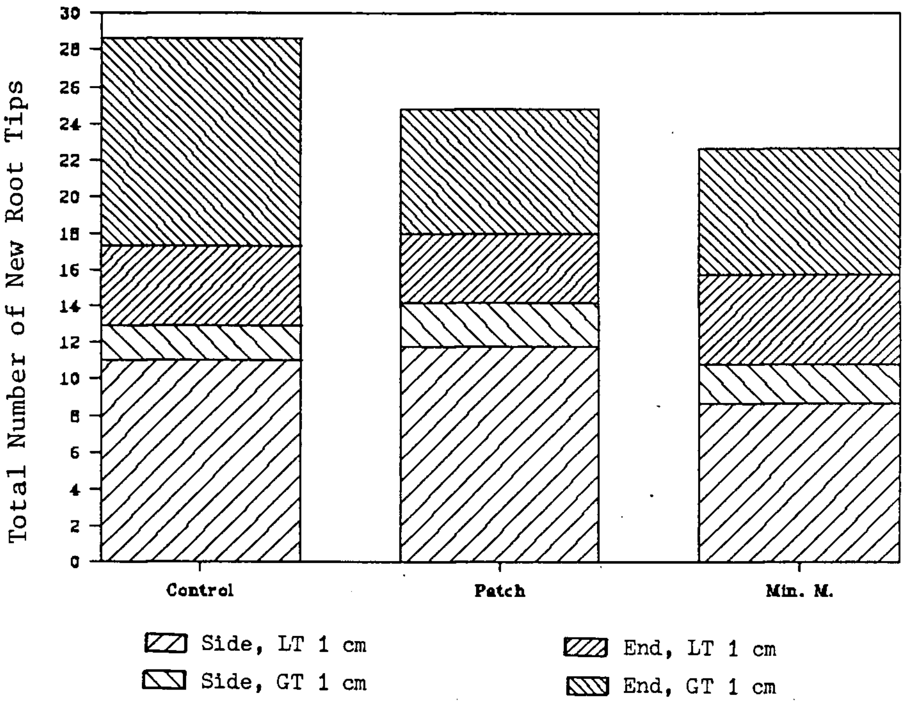

Figure 16. Total root egress 70 days after planting, Kluskus Road pine site.

and breaking plow treatment seedlings, which were similar and significantly greater than the patch and control treatment seedlings. On the Mackenzie site the Ministry Mounder treatment seedlings again had greater numbers of new roots in all categories than did all other treatment seedlings. The Bräcke Mounder seedlings generally had greater numbers of new roots than did the patch seedlings, which generally had greater numbers of new roots than did the control seedlings, however, these differences are not all significant. By this time the number of new roots greater than 1 cm in length was generally divided equally between the ends and sides of the root plugs. Seedlings on both mounded treatments at Iron Creek still had greater numbers of new roots greater than 1 cm in length growing from the ends of the plugs than from the sides.

Pine seedlings on the Kluskus Road site generally had similar numbers of new roots in all categories. Seedlings in the control treatment had significantly more roots greater than 1 cm on the end of the plug than mound or patch seedlings. At this time it was observed that many roots greater than 1 cm which had grown from the root plug earlier in the season had suberized and were not tallied.

The 95 day assessment of root egress is summarized in Table 9. On the Iron Creek site all three mounding treatment seedlings had significantly higher root area indices than did patch or control seedlings. The seedlings planted in mounds created by the Sinkkilä Mounder had a significantly higher root area index than did the seedlings planted in mounds created by the Ministry Mounder. Seedlings planted in mounds created by the Bräcke Mounder had a mean root area index intermediate of the two and not significantly different from either. On the Stewart Lake site seedlings planted in the Ministry Mounder, breaking plow and Bräcke Mounder treatments had signifi

Table 9. Mean root area indices, 95 days after planting. Means followed by the same letter do not differ significantly as determined by a Duncan's mean separation test (p 0.05).

Site	Mean	Treatment
Iron Creek spruce	87.948 a	sink. m.
	85.614 ab	bracke m.
	79.432 b	min. m.
	62.034 c	control
	55.758 c	patch
Stewart Lake spruce	80.296 a	min. m.
	76.940 a	br. plow
	75.260 a	bracke m.
	68.742 b	sink. m.
	62.294 c	D-180
	57.712 c	control
	57.378 c	patch
Mackenzie spruce	93.166 a	min. m.
	90.166 ab	patch
	87.014 bc	D-180
	86.812 bc	bracke m.
	82.036 c	control
	74.380 d	sink. m.
Kluskus Road pine	51.086 a	min. m.
	49.776 a	D-180
	49.424 a	V-plow
	49.094 a	patch
	39.990 b	control

cantly higher root area indices than did seedlings planted on all other treatments. Seedlings planted on the Sinkkilä Mounder treatment had a significantly higher mean root area index than the Donaren 180, control, and patch treatment seedlings. On the Mackenzie site the difference in mean root area index between the various treatments was less well defined than on the two other sites. The Ministry Mounder and patch seedlings had the highest mean root area indices, however, the patch seedlings' mean root area index was not significantly higher than the Donaren 180 and Bräcke Mounder seedlings' mean root area indices, which were not significantly higher than the control seedlings' mean root area index. The seedlings planted in the Sinkkilä Mounder treatment had a significantly lower mean root area index than in all other treatments.

The pine seedlings on the Kluskus Road site had similar mean root area indices, for all treatments except the control, which had a mean root area index significantly lower than the other treatments.

The 95 day assessment of root system dry weights is summarized in Table 10. On the Iron Creek site, seedlings on all three mounding treatments had greater root system dry weights than did seedlings on control and patch treatments. On the Stewart Lake site seedlings on the Ministry Mounder, Sinkkilä Mounder and breaking plow treatments had significantly higher root system dry weights than did seedlings on the control, Donaren 180, and patch treatments. Seedlings planted on the Bräcke Mounder treatment had intermediate root system dry weights. On the Mackenzie site differences between the various treatments were less significant. Seedlings planted in the Donaren 180, Bräcke Mounder and patch treatments had significantly greater root system dry weights than did seedlings planted on the Sinkkilä Mounder treatments which had the lowest root system dry weights. Seedlings planted

Table 10. Summary of seedling dry weight data, 95 days after planting. Means followed by the same letter do not differ significantly as determined by a Duncan's mean separation test (P 0.05).

	Iron Creek		Stewart Lake		Mackenzie		Kluskus Road	
Data Catagory	Mean	Treatment	Mean	Treatment	Mean	Treatment	Mean	Treatment
Shoot Weight	4.630 a	min. m.	6.699 a	min. m.	3.372 a	bracke m.	1.743 a	D-180
	4.139 ab	sink. m.	5.982 ab	bracke m.	3.167 a	min. m.	1.716 a	min. m.
	4.096 ab	bracke m.	5.935 ab	D-180	3.111 a	D-180	1.680 a	patch
	3.341 b	patch	5.735 ab	br. plow	3.027 a	patch	1.606 a	V-plow
	3.249 b	control	5.515 abc	sink. m.	2.353 b	sink. m.	1.376 a	control
			5.011 bc	control	2.301 b	control		
			4.347 c	patch				
Root Weight	1.186 a	min. m.	1.856 a	min. m.	1.401 a	D-180	0.657 a	patch
	1.177 a	bracke m.	1.660 a	sink. m.	1.366 a	bracke m.	0.624 ab	D-180
	1.093 a	sink. m.	1.577 a	br. plow	1.325 a	patch	0.555 ab	V-plow
	0.792 b	control	1.485 ab	bracke m.	1.302 ab	min. m.	0.512 b	min. m.
	0.628 b	patch	1.078 bc	control	1.180 ab	control	0.504 b	control
			0.970 c	D-180	0.917 b	sink. m.		
			0.793 c	patch				
Total Weight	5.816 a	min. m.	8.369 a	min. m.	4.738 a	bracke m.	2.367 a	D-180
	5.273 a	bracke m.	7.467 ab	bracke m.	4.512 a	D-180	2.337 a	patch
	5.232 a	sink. m.	6.997 ab	br. plow	4.469 a	min. m.	2.228 ab	min. m.
	4.041 b	control	6.668 b	sink. m.	4.352 a	patch	2.161 ab	V-plow
	3.969 b	patch	6.541 b	D-180	3.481 b	control	1.880 b	control
			6.089 b	control	3.270 b	sink. m.		
			4.599 c	patch				
Shoot:Root Ratio	5.120 a	patch	6.084 a	D-180	2.771 a	sink. m.	3.432 a	min. m.
	4.933 a	control	5.667 ab	patch	2.583 a	min. m.	3.055 a	V-plow
	4.128 a	min. m.	4.946 bc	control	2.557 a	bracke m.	2.924 a	D-180
	3.978 a	sink. m.	4.257 cd	bracke m.	2.416 a	patch	2.917 a	control
	3.725 a	bracke m.	3.909 d	br. plow	2.285 a	D-180	2.578 a	patch
			3.697 d	min. m.	2.255 a	control		
			3.689 d	sink. m.				

on the Ministry Mounder and control treatments had intermediate root system dry weights not significantly different, however, from any of the other treatments.

On the Kluskus Road site, pine seedlings on the patch treatment had significantly greater root system dry weights than did seedlings planted on the mound and control treatments. Seedlings planted on the Donaren 180 trench and V-plow treatments had intermediate dry weights, not significantly different from the other treatments.

3.3.2 Shoot Growth

The 95 day assessment of seedling shoot dry weights is summarized in Table 10. The 95 day assessment of seedling shoot growth is summarized in Table 11. On the Iron Creek site, spruce seedlings planted on the three mounding treatments had significantly longer 1987 leaders than did patch or control treatment seedlings. As well, seedlings planted on Ministry and Bräcke Mounder treatments had significantly larger root collar diameters than control treatment seedlings. All three mounding treatments produced seedlings with significantly greater total seedling dry weights than control or patch treatment seedlings. A comparison of shoot:root ratios produced no significant differences among any of the treatments.

On the Stewart Lake site only seedlings planted on the Donaren 180 and patch treatments had significantly longer 1987 leaders than did control or Ministry Mounder treatment seedlings. Breaking plow, Sinkkilä Mounder and Bräcke Mounder treatment seedlings had intermediate leader growth, not significantly different from any of the treatments. Seedlings planted on the Ministry Mounder treatment had significantly larger root collar diameters than did seedlings on the Donaren 180, control or patch treatments.

Table 11. Summary of seedling shoot growth data, 95 days after planting. Means followed by the same letter do not differ significantly as determined by a Duncan's mean separation test (P 0.05).

	White spruce						Lodgepole pine	
	Iron Creek		Stewart Lake		Mackenzie		Kluskus Road	
Data Catagory	Mean	Treatment	Mean	Treatment	Mean	Treatment	Mean	Treatment
Height (cm)	33.47 a	min. m.	35.64 a	D-180	27.90 a	patch	24.09 a	V-plow
	32.75 ab	sink. m.	35.04 ab	sink. m.	27.57 a	min. m.	23.89 a	patch
	32.00 ab	bracke m.	34.47 ab	bracke m.	26.08 b	D-180	23.20 a	D-180
	31.22 bc	patch	34.44 ab	br. plow	25.87 b	sink. m.	22.70 ab	min. m.
	25.91 c	control	34.31 ab	patch	25.34 b	bracke m.	21.45 b	control
			33.41 b	min. m.	25.23 b	control		
			32.98 b	control				
1987 Leader growth (cm)	14.66 a	min. m.	14.20 a	D-180	11.89 a	patch	n/a	
	14.60 a	sink. m.	14.00 a	patch	11.35 ab	min. m.		
	14.05 a	bracke m.	13.58 ab	br. plow	10.35 bc	D-180		
	12.38 b	patch	12.84 ab	sink. m.	9.96 c	sink. m.		
	11.75 b	control	12.63 ab	bracke m.	9.75 c	control		
			12.09 b	control	9.58 c	bracke m.		
			12.04 b	min. m.				
Root Collar diameter (mm)	3.344 a	min. m.	4.132 a	min. m.	3.420 a	patch	2.622 a	V-plow
	3.224 a	bracke m.	4.070 ab	bracke m.	3.196 b	min. m.	2.600 a	patch
	3.112 ab	patch	4.008 ab	br. plow	3.074 b	D-180	2.588 a	D-180
	3.046 ab	sink. m.	3.820 ab	sink. m.	2.832 c	control	2.168 b	control
	2.912 b	control	3.728 bc	D-180	2.630 cd	bracke m.	2.120 b	min. m.
			3.452 c	control	2.474 d	sink. m.		
			3.430 c	patch				

Seedlings planted on the Bräcke Mounder, breaking plow and Sinkkilä Mounder treatments had intermediate diameters not significantly different from the other treatments. Seedlings planted on the Ministry Mounder treatment had a significantly higher total dry weight than did seedlings planted on the Sinkkilä Mounder, Donaren 180, control and patch treatments. Seedlings planted on the patch treatment had total dry weights significantly lower than all the other treatments.

On the Mackenzie site, seedlings planted on the patch and Ministry Mounder treatments had significantly greater 1987 leader growth than did seedlings on the Sinkkilä Mounder, control and Bräcke Mounder treatments. Seedlings planted on the patch treatment also had significantly greater root collar diameters than all other treatments. Seedlings planted on Ministry Mounder and Donaren 180 treatments had significantly greater root collar diameters than control, Bräcke Mounder and Sinkkilä Mounder treatment seedlings. Only control and Sinkkilä Mounder treatment seedlings, however, had significantly lower total dry weights than any of the other treatment seedlings. A comparison of shoot:root ratios produced no significant differences among any of the treatments.

On the Kluskus Road site pine seedlings on the V-blade, patch and Donaren 180 treatments were significantly taller than on the control treatment. Seedlings on the Ministry Mounder treatment were intermediate and not significantly different from the other treatments. Seedlings on the V-blade, patch, and Donaren 180 treatments had significantly larger root collar diameters than seedlings on the Ministry mound and control treatments. A comparison of shoot weights and shoot:root ratios produced no significant differences among any of the treatments.

3.3.3 Foliar Analysis

The 95 day assessment of foliar analysis is summarized in Table 12. Foliar N concentration ranged from 0.982 to 1.440 % for spruce seedlings at Iron Creek, 1.240 to 1.464 % for spruce seedlings at Stewart Lake, and 1.130 to 1.648 % for spruce seedlings at Mackenzie. Foliar P concentration ranged from 0.164 to 0.266 % for spruce seedlings at Iron Creek, 0.144 to 0.190 % for spruce seedlings at Stewart Lake, and 0.198 to 0.262 % for spruce seedlings at Mackenzie. Iron Creek seedlings showed the most significant differences between treatments. Seedlings planted in the Ministry Mounder treatment had significantly lower N and P concentrations than seedlings planted in the patch treatment. Seedlings planted in the other treatments had intermediate values. No significant treatment differences were found at Stewart Lake. Only slight differences in N concentration values were found at Mackenzie.

Foliar N concentration ranged from 1.140 to 1.466 % and P concentration ranged from 0.124 to 0.180 % for pine seedlings at Kluskus Road.

Needle weight data is also presented in Table 12. Generally, treatment rankings were opposite those of the nutrient concentrations listed above.

3.3.4 Survival and Frost Damage

Survival and frost damage were tallied in late August as part of the FRDA 1.10 Project. Results are summarized in Table 13. Survival was high on all three spruce sites ranging from 89 to 100 %. Frost damage was highest on patch, control and Bräcke mound treatments at Iron Creek, and, control, Bräcke mound, Sinkkilä mound, and patch treatments at Stewart Lake. Frost damage was high on all treatments at Mackenzie with 40 to 63 % of all seedlings being affected.

Table 12. Foliar analysis of 1987 leader, growth, 95 days after planting. Means followed by the same letter do not differ significantly as determined by a Duncan's mean separation test (P 0.05).

	White spruce						Lodgepole pine	
	Iron Creek		Stewart Lake		Mackenzie		Kluskus Road	
Data Catagory	Mean	Treatment	Mean	Treatment	Mean	Treatment	Mean	Treatment
N conc. (%)	1.440 a	patch	1.464 a	patch	1.648 a	control	1.466 a	control
	1.252 ab	control	1.390 a	sink. m.	1.468 ab	sink. m.	1.438 a	min. m.
	1.168 bc	sink. m.	1.376 a	bracke m.	1.452 ab	min. m.	1.332 a	patch
	1.070 bc	bracke m.	1.364 a	D-180	1.346 ab	bracke m.	1.146 a	V-plow
	0.982 c	min. m.	1.358 a	br. plow	1.292 ab	patch	1.140 a	D-180
			1.352 a	control	1.130 b	D-180		
			1.240 a	min. m.				
P conc. (%)	0.266 a	patch	0.190 a	D-180	0.262 a	control	0.180 a	control
	0.204 ab	control	0.170 a	sink. m.	0.240 a	patch	0.158 ab	min. m.
	0.192 ab	bracke m.	0.166 a	control	0.238 a	sink. m.	0.142 ab	patch
	0.174 ab	sink. m.	0.166 a	bracke m.	0.224 a	min. m.	0.128 b	V-plow
	0.164 b	min. m.	0.162 a	patch	0.208 a	bracke m.	0.124 b	D-180
			0.144 a	br. plow	0.198 a	D-180		
			0.144 a	min. m.				
Weight of 100 needles (g)	0.195 a	bracke m.	0.174 a	D-180	0.153 a	min. m.	0.492 a	patch
	0.192 a	sink. m.	0.160 a	bracke m.	0.126 ab	sink. m.	0.484 a	D-180
	0.186 a	min. m.	0.158 a	min. m.	0.125 ab	bracke m.	0.466 a	V-plow
	0.163 a	control	0.154 a	br. plow	0.124 ab	patch	0.374 a	control
	0.157 a	patch	0.145 a	patch	0.124 ab	D-180	0.367 a	min. m.
			0.143 a	sink. m.	0.096 b	control		
			0.140 a	control				

Table 13. Summary of survival and frost damage at the end of the first growing season (from McMinn and Bedford 1988).

Site	Treatment	% Survival	% Frost Damage
Iron Creek spruce	br. plow	99	1
	patch	98	24
	control	98	16
	bracke m.	97	11
	min. m.	97	9
	sink. m.	96	5
Stewart Lake spruce	patch	99	11
	D-180	98	7
	br. plow	98	5
	min. m.	97	3
	control	96	22
	bracke m.	92	18
	sink. m.	92	15
Mackenzie spruce	patch	100	40
	control	99	50
	D-180	98	63
	min. m.	96	52
	sink. m.	94	49
	bracke m.	89	54
Kluskus Road pine	min. m.	61	0
	control	73	3
	D-180	83	0-1
	patch	86	0-1
	V-plow	87	0-1

Survival was generally low for the pine seedlings at Kluskus Road and ranged from 61 to 87 %. Frost damage was low for the pine seedlings ranging from 0 to 3 %.

3.4 Vegetation Ingrowth and Competition

A summary of the assessment of vegetation ingrowth and competition as measured by MOF in the second and third weeks of August, 1987, is presented in Table 14. Generally, the mounding and plowing treatments had significantly lower percent cover of vegetation greater than 20 cm height than did patch and control treatments. No treatment difference was observed at the Kluskus Road Site. Competition and ingrowth was greatest at the Stewart Lake site followed by Iron Creek, Mackenzie, and Kluskus Road, in descending order.

Table 14. Summary of the assessment of vegetation ingrowth and competition. Values sharing a common letter are not significantly different, p = 0.01 (from MacKinnon and McMinn 1988)

Location	Treatment	Total % cover vegetation > 20 cm	Total % cover vegetation < 20 cm	Competition Index[1]
Stewart Lake	herbicide	5.275 a	13.250 a	21.130 a
	Ministry mounder	9.886 a,b	6.795 a	46.213 a
	breaking plow	16.180 b,c	10.320 a	59.293 a
	Bracke mounder	19.731 c	8.115 a	85.834 a
	Bracke patch & fertilizer	42.840 d	9.220 a	264.401 b
	Donaren	47.620 d	8.760 a	268.150 b
	control	47.760 d	14.040 a	335.546 b
	Bracke patch	48.380 d	8.320 a	274.807 b
Kluskus	Ministry mounder	4.720 a	4.780 a	27.916 a
	V-blade	5.280 a	8.780 a	16.501 a
	Sinkkila	7.900 a	10.640 a,b	34.044 a
	control	10.490 a	17.408 b	43.305 a
Mackenzie	herbicide	4.960 a	24.840 b	38.356 a
	Bracke mounder	9.109 a,b	13.087 a	26.762 a
	Ministry mounder	13.157 a,b,c	11.530 a	85.883 a
	V-blade	13.800 a,b,c	24.040 b	84.534 a
	Bracke patch	18.700 b,c	22.940 b	118.317 a
	control	20.640 c	45.420 c	112.496 a
Iron Creek	herbicide	4.660 a	11.540 a,b	14.910 a
	Ministry mounder	8.180 a	6.820 a	50.394 a
	Bracke mounder	11.560 a	11.100 a,b	49.170 a
	breaking plow	14.575 a	8.350 a,b	55.739 a
	Bracke patch	26.080 b	13.660 a,b	171.342 b
	control	32.340 b	14.660 b	215.358 b

[1] Competition Index = $\frac{\text{\% cover of vegetation greater than 20 cm x average height of vegetation}}{\text{distance of nearest vegetation to the seedling}}$

4 Discussion

4.1 Microclimate

Unfortunately the climatic monitoring program (FRDA 1.25) began after the crucial period of spring root growth, and one can only extrapolate back as to what root zone temperatures might have been at this crucial time of root development. However, the variation in soil thermal regimes over the different site preparation treatments monitored in this study closely matches the findings of other similar studies (Macadam 1988, Herring and Letchford 1987, Orlander 1986, Spittlehouse 1988). The period monitored in this study seems to match phases 3 and 4 (Figure 17) described by Macadam (1988), suggesting that root zone temperatures in all treatments were at a maximum before the monitoring program began, and that at this time the same treatment differences observed were even greater. Based on the assumption that these studies are comparable, we can state that the mounding and plowing treatments probably reached higher root zone soil temperatures earlier than patch, trench and control treatments. We still cannot test the hypothesis that little root growth would occur until root zone temperatures warmed to levels above 10 degrees C, as seedling sampling did not begin till 45 days after planting and we cannot accurately predict when these threshold temperatures were reached. Also, new roots which had suberized by this time were not included in the tally.

Soil temperatures are especially critical at the time of spring planting as studies have shown seedlings to be most susceptible to moisture stress immediately after planting (Grossnickle 1988, Grossnickle and Blake 1985, 1987). Rapid, early, new root growth improves water uptake by establishing intimate soil/root contact, and by exploiting more soil volume. New

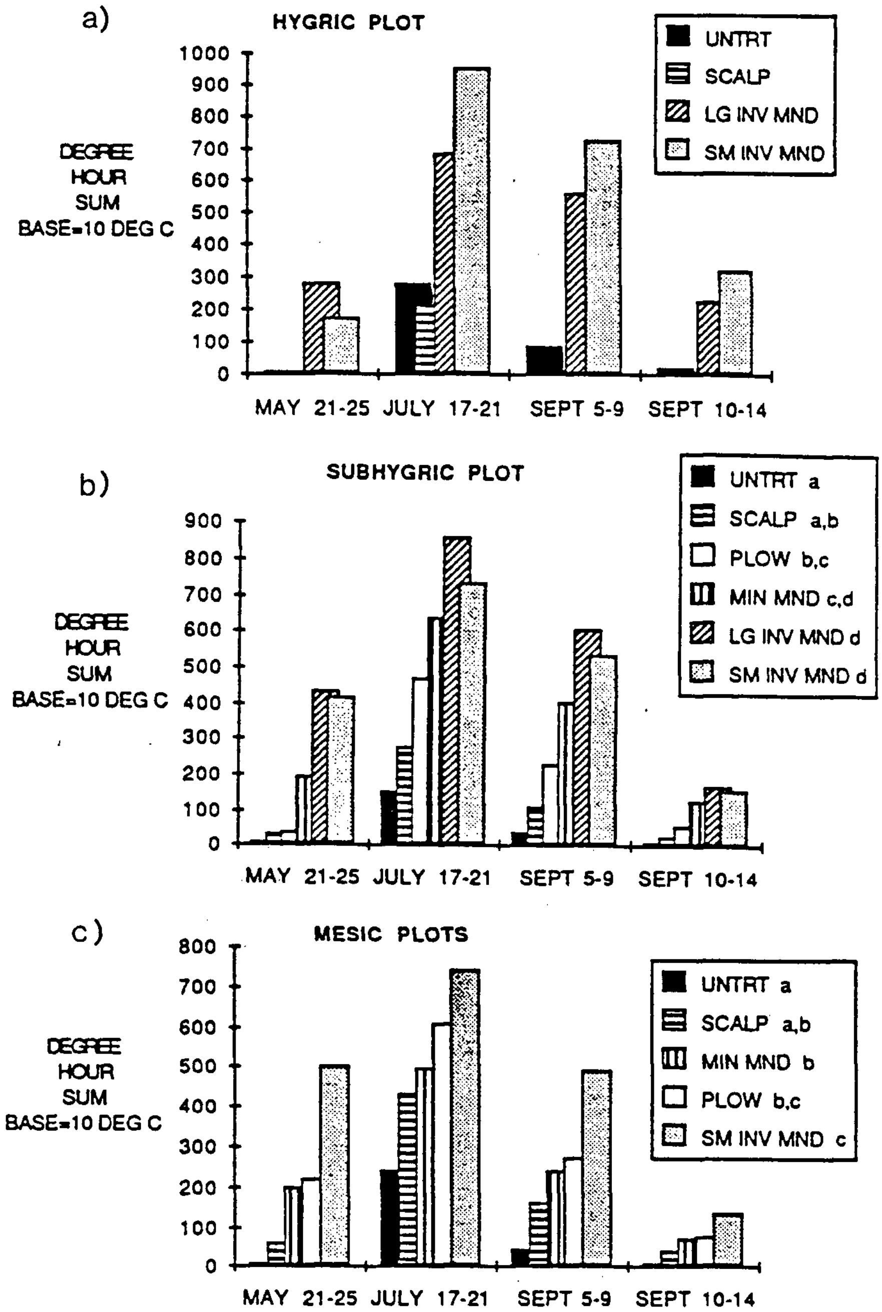

Figure 17. Total degree hours greater than 10 degrees C recorded at a depth of 10 cm in (a) hygric, (b) subhygric, and (c) mesic plots, by Macadam (1988). Treatments followed by a common letter are not significantly different during the July period (p less than 0.05) as determined using Tukey's HSD mean separation test.

unsuberized roots can also absorb more water than older, lignified ones (Hunt 1987, Grossnickle and Blake 1985, 1987). The optimal root zone temperature for white spruce is approximately 20 degrees C, with 5 to 10 degrees C seen as a minimum temperature for root growth (Dobbs and McMinn 1977, Binder et al 1987).

The temperature regimes of each site preparation treatment can be rationalized by examining the characteristics of the planting microsite created and its subsequent affect on soil thermal properties. The presence of a surface organic layer distinguishes the control treatment from all others. The insulating effect of the organic matter and vegetation directly prevents the incoming solar radiation from reaching the mineral soil below. It also helps conserve moisture, and prevent heat loss at night thus creating the cooler, stable thermal patterns observed in the control treatment and humus/mineral soil interface zone below the mineral soil mounds.

The exposure of mineral soil by patch, V-plow, and trenching treatments allows incoming solar radiation to warm the soil profile. However, the amount and depth of temperature increase is limited by the moisture content of the soil. This was especially evident on the Stewart Lake and Iron Creek sites which had high and fluctuating water tables. The additional draining and elevating effect of the plowing and all mounding treatments contributed to higher summer root zone temperatures in these treatments.

The improved drainage and increased surface area of the soil, however, cause the increased temperature fluctuation in response to weather changes and increased night-time radiation, thereby more rapidly lowering soil temperature. These treatments also react more rapidly as the radiation input declines in the fall. The benefits, however, of earlier warming of the root zone in the spring more than compensate for this sensitivity to climatic conditions.

4.2 Root Egress

The 45 day assessment of root egress supports the hypothesis that the numbers of new roots greater than 1 cm in length would be greatest on treatments with the warmest root zone temperatures. The mound and plowing treatments had both warmer root zone temperatures and greater numbers of new root tips greater than 1 cm in length than patch or control microsites. Andersen et al. (1986) suggested that root elongation was suppressed more by low soil temperature than tip initiation. A decline in total number of new root tips, but greater numbers of roots greater than 0.5 cm in length, with increasing temperature may reflect increased utilization of carbohydrates for elongation at the expense of new tip development. The results from the Mackenzie site (Figure 12) in which the patch seedlings had a greater total number of root tips than did the Bräcke Mounder seedlings, but fewer new roots greater than 1 cm in length, support this idea.

The 70 day assessment also supports this hypothesis with the mounding and plowing treatment seedlings having greater numbers of new roots greater than 1 cm in length than patch or control treatment seedlings. The 95 day assessment confirms this as well, however, variability in success of the various treatments over the three sites can in part be explained by other factors, primarily soil moisture. The Iron Creek and Stewart Lake sites both had high fluctuating water tables and experienced large precipitation events in July and August. This had the greatest negative impact on seedlings planted in the patch, trench and control treatments. Some seedlings planted in the shallower mounds formed by the Bräcke Mounder were also negatively affected. This is reflected in Figures 13 and 14. Seedlings in the control treatments faired better than seedlings in the patch treatment for two reasons: 1) transpiration of competing vegetation may have lowered the water table in the control treatment; and, 2) patch seedlings, while planted on the shoulder of the patch, were still planted in a lower position relative to control seedlings (Figure 6).

The destructive effect of flooding on new root tips of white spruce has been demonstrated by Levan and Riha (1986) and Grossnickle (1987). Conifers studied by Lieffers and Rothwell (1986) showed limited penetration of the water table by seedling roots, no change in internal pore space, and blackened, necrotic roots near the water table. These match similar, visual observations made at time of sampling in this study. Ballard (1982) states that "root respiration, strongly affected by soil aeration and temperature, releases the energy needed for active uptake of nutrients across the root cell membranes", and is a requirement for root growth.

The surge in numbers of roots greater than 1 cm in the Bräcke mound treatment past the Ministry mound treatment, on the Iron Creek site (Figure 13) at the 70 day assessment may reflect an improvement in moisture conditions in this microsite. Macadam (1988) found shallow inverted mounds to be the most susceptible to drying, and the high levels of input by precipitation at this time may have improved conditions considerably. Temperature monitoring at this time (Appendix C) shows that the two microsites had similar temperatures, with the Ministry Mounder being slightly warmer.

The Mackenzie site, while prone to spring flooding, was somewhat drier over the course of the growing season and thus the results in the patch, control, and trench treatments were better than at Iron Creek or Stewart Lake. The poor results obtained in the Sinkkilä Mounder treatment reflect the high organic matter component and level of porosity in these mounds, compared to those formed by the Ministry Mounder and to a lesser extent, the Bräcke Mounder, and are a direct result of high soil moisture potentials. Mound formation by the Sinkkilä on this site was hampered by mechanical malfunction and the percentage of acceptable mounds reduced (Hedin 1987).

The results of this site give a more representative comparison of temperature effects, without the added complication of periodic flooding. However, soil moisture is still a very important factor on this site. Microclimate monitoring showed the Bräcke mounds to have slightly higher temperatures than the Ministry mounds on this site, however, this is not reflected in better root growth (Figure 15). Increased root growth in mounds with greater depths of capping may reflect improved moisture holding capacity (Macadam 1988) and supports the findings of McMinn (1985b). Increased moisture in the deep mounds may have resulted in the damping of temperature increase and fluctuation by increasing the heat capacity of the soil in the capping. Thus, while root zone soil temperature is an important factor in seedling root growth, it is not the only factor involved and soil moisture may play an equal if not greater role in limiting root egress.

Emphasis on root egress data should be placed on the 45 and 70 day tallies of new root tips, as root area indices measured the total root system of which new root growth was only a small fraction, and values are therefore greatly influenced by initial plug root development.

Root egress data supports the hypothesis that root initiation would primarily occur from the end of the root plug. This is the result of container culture and design, with most of the root buds being located at the bottom of the plug. By the 70 day assessment spruce seedlings had comparable or greater numbers of new tips growing from the sides of the plugs as from the ends. Pine seedlings still showed greater numbers growing from the end of the plug than from the sides. This may be the result of differences in species rooting patterns or the generally poor performance of the pine seedlings.

4.3 Seedling growth response

Seedling growth response data support the hypothesis that there would be little difference in first year morphological response to the different treatments. Seedling height and leader growth may reflect conditions previously present in the nursery rather than conditions present in the field. Grossnickle (1987) found shoot development of white spruce seedlings was not influenced by flooding or soil temperature treatments in a controlled laboratory study.

Root collar diameter is more representative of current season growth conditions (D. P. Lavender, pers. com.). Mounding treatment seedlings generally had higher total dry weights and root collar diameters than other treatment seedlings.

Seedling foliar nitrogen and phosphorus concentration data tend to support the hypothesis that there would be little treatment differences. However, trends found within the data would have benefited from increased sampling. A comparison of nutrient concentrations with weight of 100 needles or total seedling dry weight data suggests a dilution by growth of similar nutrient contents obtained in the nursery prior to outplanting. Thus, nutrient concentrations measured at the end of the first growing season do not reflect the nutrient potentials of the various site preparation treatment microsites (McMinn, pers. com.). Ballard (1984), while trying to identify the important white spruce nutritional problems in plantations in the central interior, used foliar analysis of 2 to 8 year old seedlings to overcome this problem. Concentrations plotted against the weight of 100 needles or total seedling dry weight result in a negative linear trend which supports this theory.

Foliar P concentration values generally followed the same ranking as N concentration values for the different treatments. No induced deficiency due to increased N availability was observed.

4.4 Subsequent 1988 observations

Observations made during the fall 1988 end-of-second growing season sampling period support trends established during the first growing season. Seedlings planted in the mounding treatments have shown a boom or bust type of performance. Those seedlings which have survived were by far the largest in terms of height and diameter. Root egress appeared to be concentrated in the inverted organic layer below the mineral soil capping. This is not surprising as this layer offers excellent aeration, texture, and nutrition. Successful mounds appear to be ones with enough mineral soil capping to: compress the inverted organic layer, provide continued control of competing vegetation, retain moisture and not dry out completely, and, provide adequate elevation and drainage. This supports the findings of McMinn (1985b) who found that seedlings grew best and had the greatest mass of fine roots at the end of the second growing season in mounds with the deepest mineral soil cappings. Macadam (1988) found that in the hygric plots, large and small inverted mounds responded similarly, dropping to very low moisture levels only briefly in early September. In the subhygric plots, both sizes of inverted mounds had dropped to a level of approximately -1 bar by mid-July, but while the small mounds continued to drop to a very low level from that point, the large mounds responded more readily to moisture inputs in the form of precipitation. The small inverted mounds in the mesic plots were drier earlier in the season than any other treatment. This rapid early drying of smaller mounds could have led to increased moisture stress on the newly planted seedlings.

Seedling mortality in the deep mineral mounds appears to be the result of planting depth, especially with the 211 plug pine seedlings on the Kluskus Road site. On deep mounds planting depth was a compromise between getting a portion of the root plug below the inverted organic layer and seedling burial such that insufficient leaf area remained above the soil surface. Mortality occurred where one or both of these constraints was not met. Development and testing of seedlings with a longer root plug is ongoing (McMinn, pers. com.).

Seedling mortality on the Sinkkilä mounds, especially on the Mackenzie site, appears to be from excessive drying and subsequent seedling moisture stress. These mounds were among the loosest in composition of all mound types. This is the result of the different mechanics of mound formation employed by the different implements. The ripper tines of the Sinkkilä Mounder appear to be less effective at scooping up a mineral soil capping than the shovels and buckets of the Bräcke and Ministry Mounders, respectively. The tines also tend to collect and roll slash under the mounds during formation (L. Bedford, pers. com.) which leads to poor ground contact. Hedin (1987) found the Sinkkilä Mounder to have the least success in forming mineral soil capping at the Mackenzie site, and the most at Stewart Lake. This correlates well with second growing season observations with Stewart Lake seedlings doing quite well. A second season of settling seems to have improved the mound characteristics and may be required before planting on this treatment.

Seedlings in the patch and trench treatments appeared to have little new root growth. Many of the seedlings appeared chlorotic, especially on the wetter plots. In some cases the lower portion of the root plug had rotted. Seedlings on drier plots were doing better, however, increased competition is providing excessive shading. Patch seedlings have suffered from snow pressed vegetation, especially at Iron Creek. All indications appear to suggest that patch size is too small to provide adequate control of competing vegetation. This is reflected in assessment of ingrowth presented in Table 14. While mound size is not that much greater, seedling elevation above competing vegetation and winter press damage appears to be significant.

Overall, the 1988 observations support the hypothesis that root egress is a good, early indicator of site preparation treatment suitability and success. Treatments with good first year root egress generally had good second year seedling performance. The importance of rapid, early root growth to long term seedling performance and survival has been stressed by many authors (Binder et al. 1987, Carlson 1986, Hunt 1987).

4.5 Weaknesses of the study

Generally the study suffered from combining the objectives of a 3 year operational assessment of seedling performance with a 1 year detailed study of root egress. The logistics and compromises resulting from this miss-match led to the following:

1) the author had to rely on other agencies to collect correlating data, especially the environmental monitoring data; contract delays resulted in no data collected for the critical period just after planting;

2) the experimental layout followed that of the FRDA 1.10 study which resulted in an increased estimate of the experimental error; a completely

randomized design supplemented with matched seedling microsite data (i.e. moisture regime, aspect, planting height, competition) may have provided more usable data;

3) use of operational microsites required large numbers of samples to accurately estimate average seedling response;

4) the large sample size reduced the amount of detailed measurements logistically possible to collect;

5) first year growth response and foliar analysis may be premature and not reflect subtle treatment differences which may appear after 2 or more growing seasons; and,

6) varying degrees of burial of seedlings' root collar may have affected results by altering root:shoot ratios between the different treatments; testing buried versus non- buried seedlings on mounded microsites was not an objective of the operational study.

5 Conclusions

Results of this study show the difference in root egress and performance of white spruce and lodgepole pine seedlings to various site preparation treatments, on four sites representative of the backlog problem in the northern interior of British Columbia. Greater numbers of roots greater than 1 cm in length were found on spruce seedlings planted in mounded and plowed treatments than in control or patch treatments. This supported the hypothesis that numbers of new roots greater than 1 cm in length would be greatest on treatments with the warmest root zone temperatures. Mounded and plowed treatment microsites had thermal regimes characterized by higher root zone temperatures than patch or control treatments. However, seedlings on patch and control treatments on the Iron Creek and Stewart Lake sites suffered from high and fluctuating water tables.

Second year observations supported the hypothesis that root egress is a good early indicator of site preparation suitability and success.

6 Practical Applications

The results of this study have yielded the following practical applications:

1) On spruce sites similar to those studied, mounding or plowing treatments should be prescribed. Patch or trench treatments which result in a depressed planting position should be avoided, especially where high or fluctuating water tables are present.

2) Measurement of root egress can be used as a good early indicator of site preparation treatment suitability and success.

3) Future studies on root egress over various site preparation treatments should be limited in size to allow detailed measurement of new roots and sampling at 1 week intervals throughout the growing season. Microsite monitoring must begin at or before time of planting and continue throughout the growing season. Seedling data must be accompanied by specific microsite description data, including moisture regime, planting height and competition.

4) Design of machines capable of consistently producing inverted mineral soil over humus mounds, with greater than 10 cm mineral soil capping, should be encouraged.

5) Mounds with a loose consistency may yield better seedling performance if allowed a full season to settle before planting. Further studies are needed to address this point.

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Appendix A

Soil texture and humus form/depth (MOF internal report submitted to Lorne Bedford, under contract, by Coleen Hackinen 1987)

A.1 Iron Creek

A.1.1 Humus form

Humus forms were all found to be moders, with the exception of Plot A4 in the northern corner of the site which was classified as a mor.

A.1.2 Humus depth

Humus depths ranged from 10 to 52 cm across the 20 plots examined. As shown in Figure A.1, very deep organics (range 26 to 37 cm) were found on the northern edge of the site (A Blocks) and were generally associated with a high water table (above or near the organic/mineral soil interface at time of sampling). A small pocket of deep organic material was present in the centre of the site (Plot D7) where the humus depth reached 52 cm. Relatively thick organics were found on the western portion of the site (B Block) as well as the southwesterly corner (Plot E10), where humus depths ranged from 16 to 25 cm. There was a tendency for the organic layer depths to decrease southward through B Block. Humus depths in the remainder of the site (C and D Blocks, Plots E1 to E9) were relatively uniform and ranged from 10 to 18 cm depth.

A.1.3 Soil texture

Profile description and sample retrieval was complicated by a high water table at time of sampling. When the mineral soil was below the water table, it was necessary to reach below the water surface and retrieve mineral soil as a 'grab sample'. In order to allow hand texturing, the saturated sample required several days of air-drying.

Textures in the B horizons were dominantly clay loams with some silty clay loams identified in the southwestern corner of the site (Plots E9, E8, B11).

Most profiles displayed reasonably well developed Ah horizons. Textures in the A horizons were found to be silty clay loams on the southern portion of the site (Blocks D and E), and clay loams on the northern portion (Blocks A, B, and C), with the exception of Plot B11 where a loam A horizon was present.

Mound textures were dominantly clay loams, with some silty clay loams and loams. The mound tended to reflect the dominant horizon texture as influenced by the degree of mixing of mineral and organic (or Ah) material.

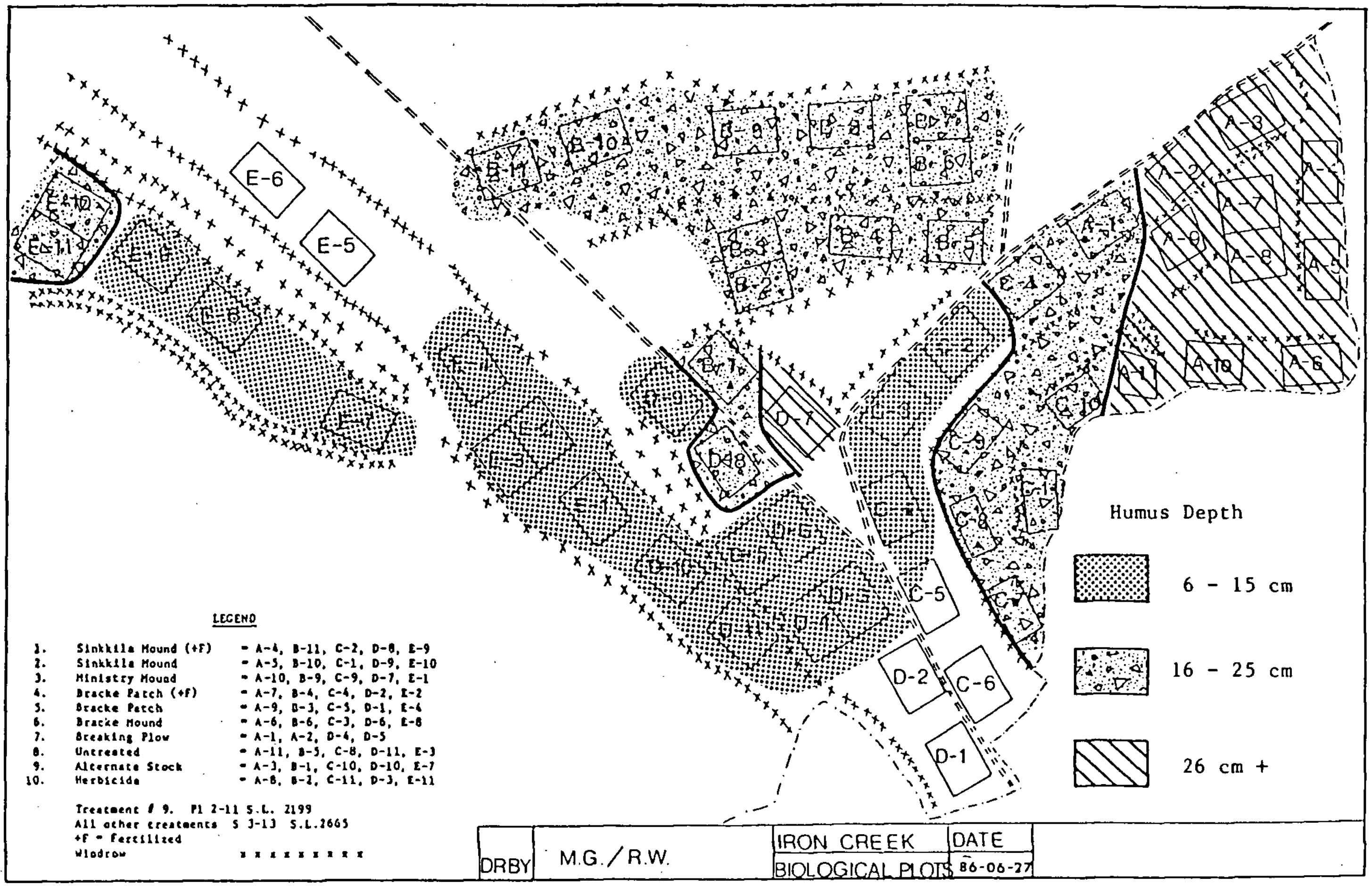


Figure A.1 Humus depth classes, Iron Creek site.

A.2 Stewart Lake

A.2.1 Humus form

Humus forms were all found to be moders (mormoders and leptomoders).

A.2.2 Humus depth

Humus depths ranged from 9 to 24 cm. Although some variability was probably a result of machine site preparation effects, humus depth appeared to be closely related to topography. Wetter sites (receiving areas) tended to display thicker organic horizons (western and southern portions of site), as shown in Figure A.2.1.

A.2.3 Soil texture

B horizons were dominated by silty clay loams and clay loams, with some pockets of silty loams. Silty clay loams were found along the northeast and northwest edges of the site and clay loams were dominant in the wetter areas (southern and western portions).

Some soils contained substantial amounts of what were considered to be very fine coarse fragments (greater than 2 mm). Since soil texture refers to the less than 2 mm mineral fraction, these fragments were ignored during hand- texturing. In the absence of refined measurement techniques (ie. sieve) it is very difficult to determine the correct texture classification of these soils.

A horizons were generally quite thin (less than 5 cm) or absent. A horizon texture was variable and appeared to depend to a large extent on the form and degree of development (ie. Ae horizons - silty loam or silty clay loam; Ah horizons - loam, silty loam, clay loam, or silty clay loam).

Mound texture appeared to depend mainly on the depth of the scalp, which determined the proportion of organic and mineral soil (Ah, B and/or C horizons) present in the mound, and the degree of mixing of these materials. Silty clay loam and silty loam textures were found in mounds composed of B and C horizon material. Mounds dominated by B horizon soil generally reflected the texture of the B horizon (clay loam, silty loam, silty clay loam). Where A and B horizon soil were dominant in the mound, silty loam and silty clay loam textures prevailed. Some mounds, especially those with silty loam textures, showed evidence of wind erosion (loss of fines) where a capping of coarse fragments was present on the mound surface. On mounds with higher clay content, evidence of erosion was less obvious. It appeared that the clays were acting as a "glue" to form larger, less erodible peds.

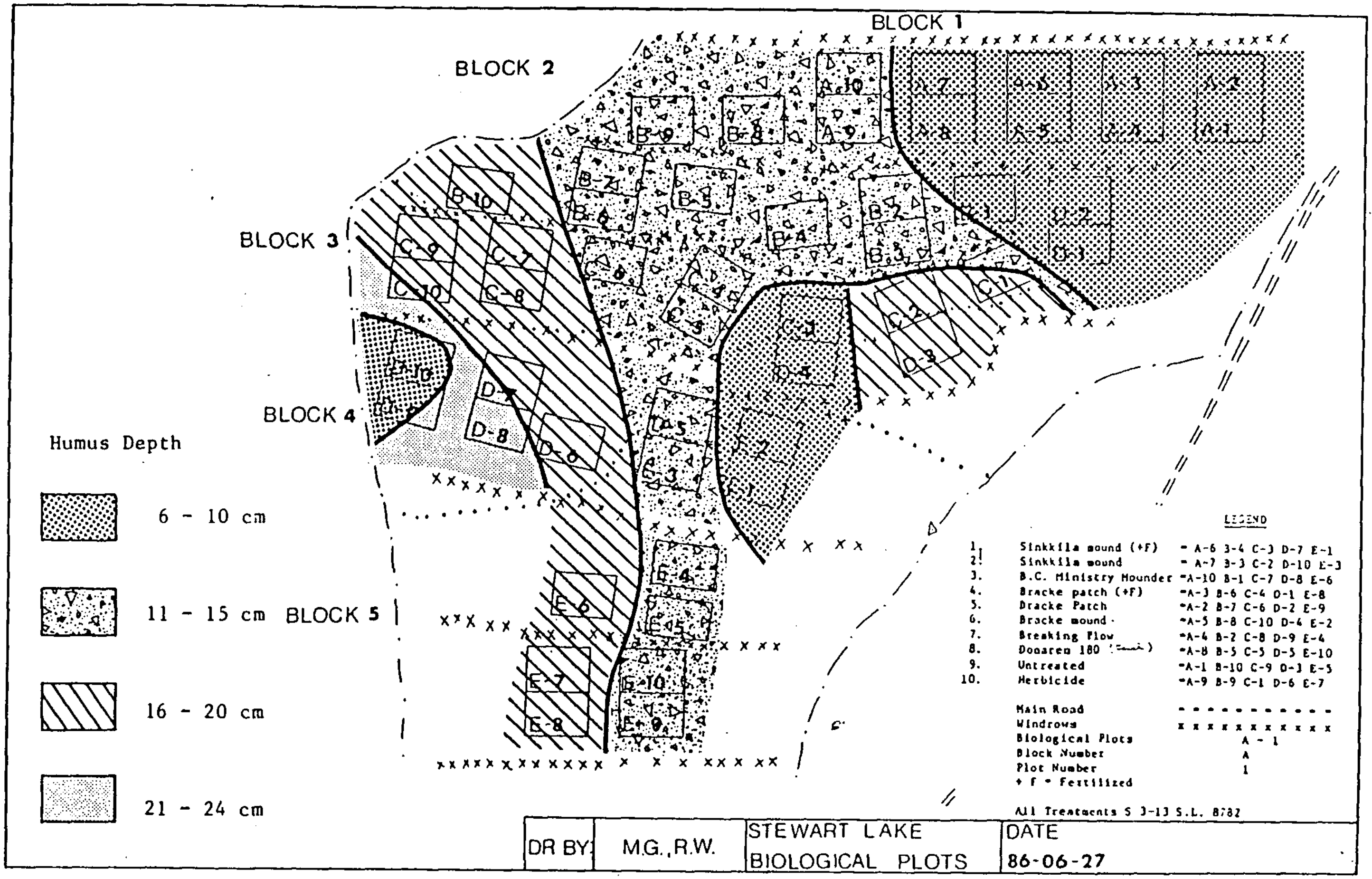


Figure A.2.1 Humus depth classes, Stewart Lake Site.

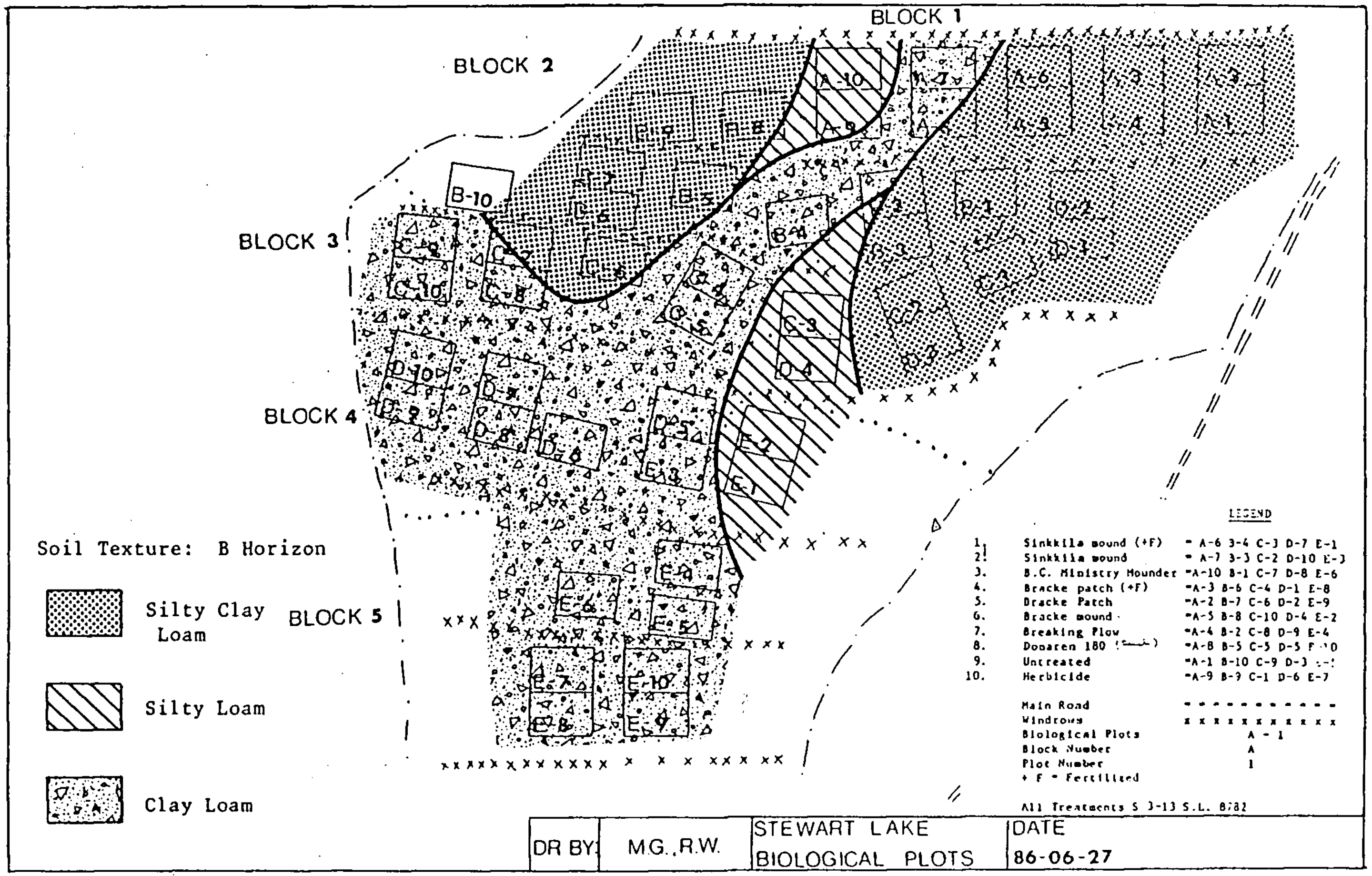


Figure A.2.2 Soil texture of the B horizon, Stewart Lake site.

A.3 Mackenzie

A.3.1 Humus form

Humus forms at the Mackenzie site included saprimulls, moders and mors. Saprimulls (profiles with thick Oh and thin or absent Ah(g) horizons) were found in wet pockets at the western extremity and northeast corner of the site. Mors and moders were found in alternating bands along the east-west axis as shown in Figure A.3.1. Humus form appeared to correspond to topography in that saprimulls were generally found in depressions, moders on slope toes and mors on lower slopes.

A.3.2 Humus depth

Humus depth was highly variable, ranging from 2 cm to more than 38 cm. Some variability may be attributed to previous site disturbances resulting from logging, since some areas contained considerably more slash than others. Very thick deposits of organic material (greater than 26 cm) were found in the northeast corner of the site. The thinnest organic layers (less than 11 cm) occupied an area to the southeast, as well as along a band extending from the third to ninth transects, as shown in Figure A.3.2.

A.3.3 Soil texture

B horizon textures were dominantly silt loams, with some pockets of finer textured soils (silty clay loams, clay loams, and silty clays), as shown in Figure A.3.3.

A horizons were generally very thin or absent. Textures of the A horizons were extremely variable, and included: silty clay loams, silty loams, silts, clay loams, sandy clay loams, loams and silts.

Mounds which contained inorganic soil were sampled for hand texture analysis, however, many mounds consisted dominantly of organic material. Only 12 mound texture determinations were possible from the 25 plots sampled. Of these, five were found to be silty loams, three silty clay loams, two silty clays, one silt and one sandy clay loam. Mound textures appeared to reflect the texture of the dominant horizon in the mound as influenced by the degree of mixing with organic materials.

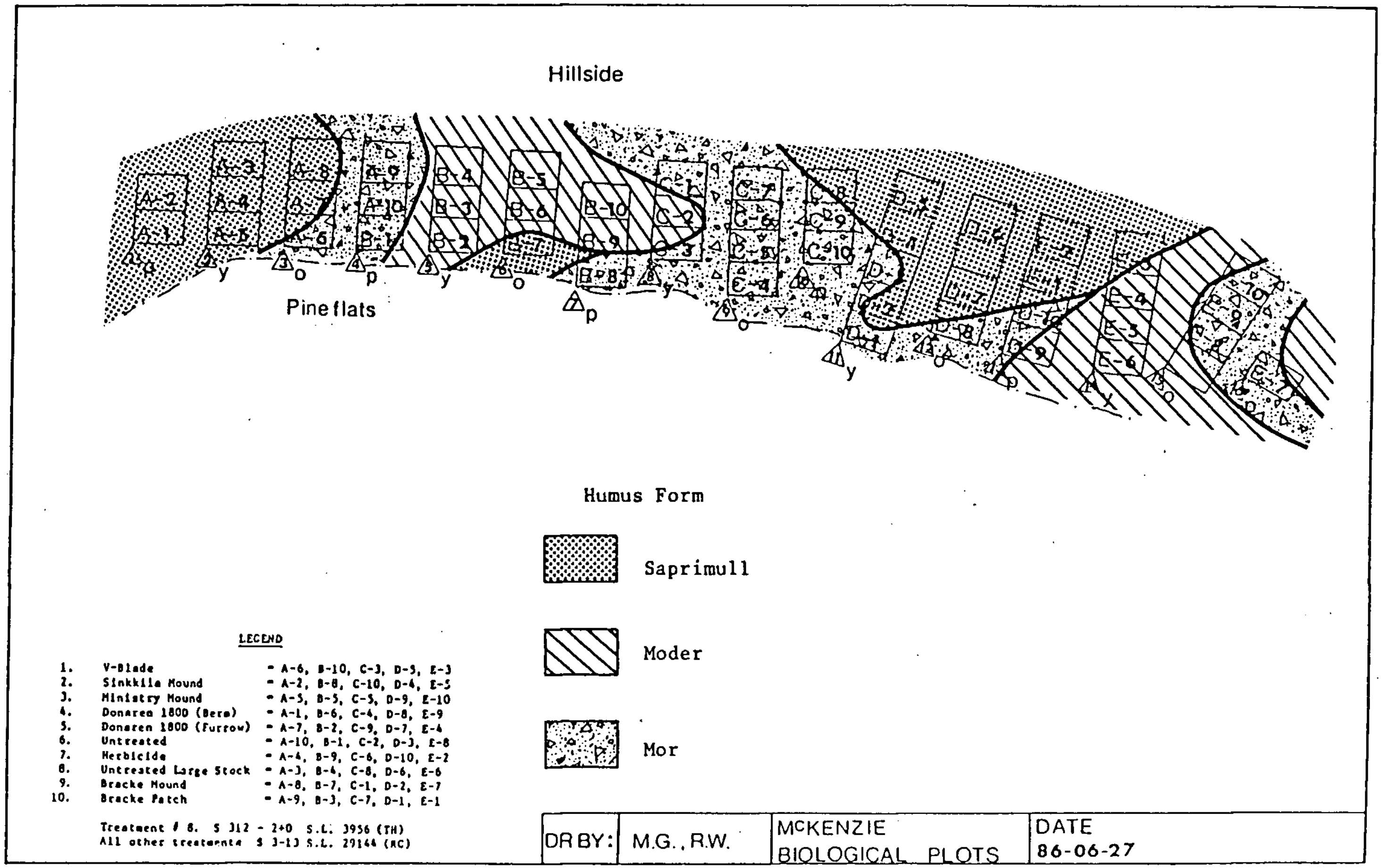


Figure A.3.1 Humus form, McKenzie site.

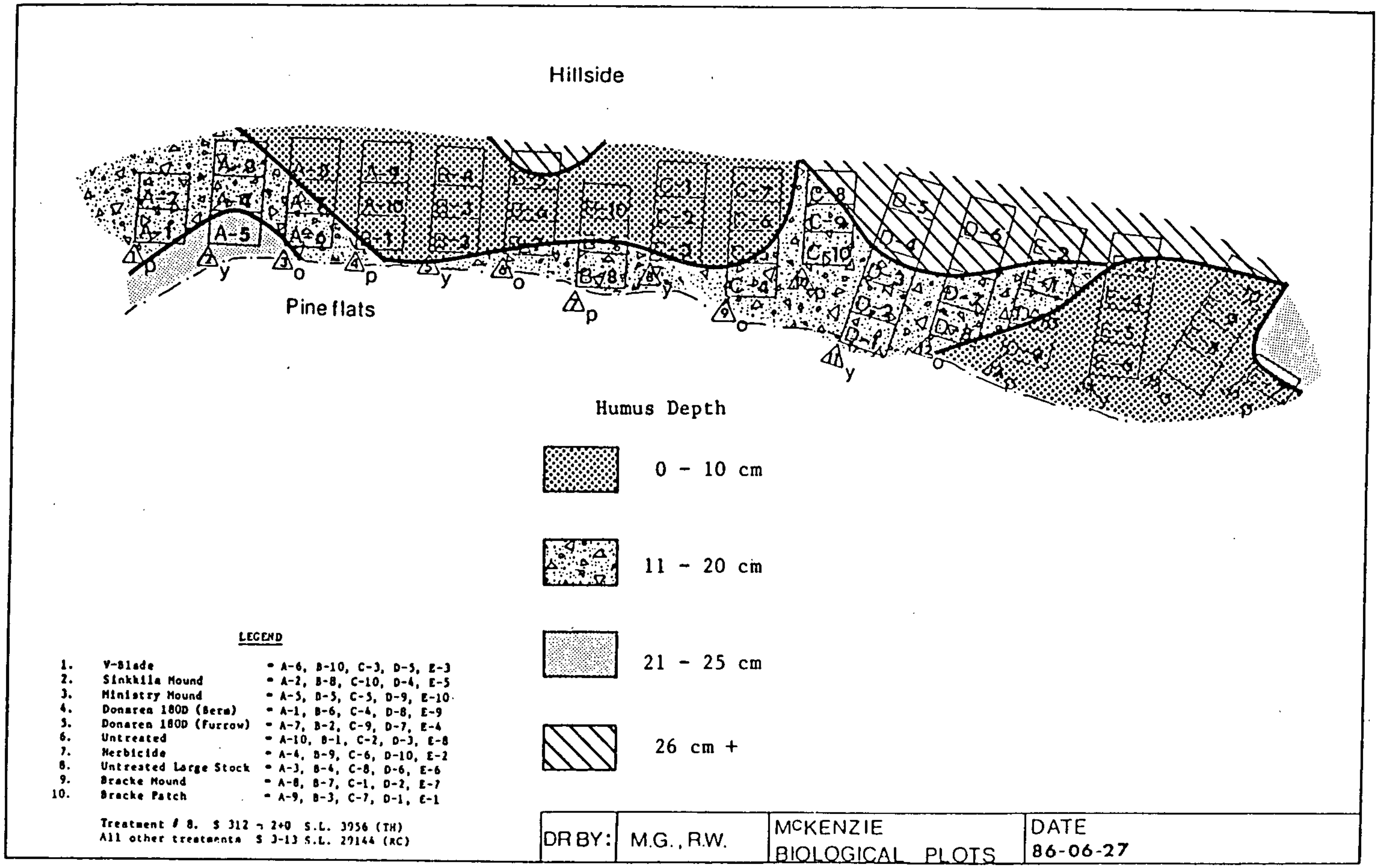


Figure A.3.2 Humus depth, McKenzie site.

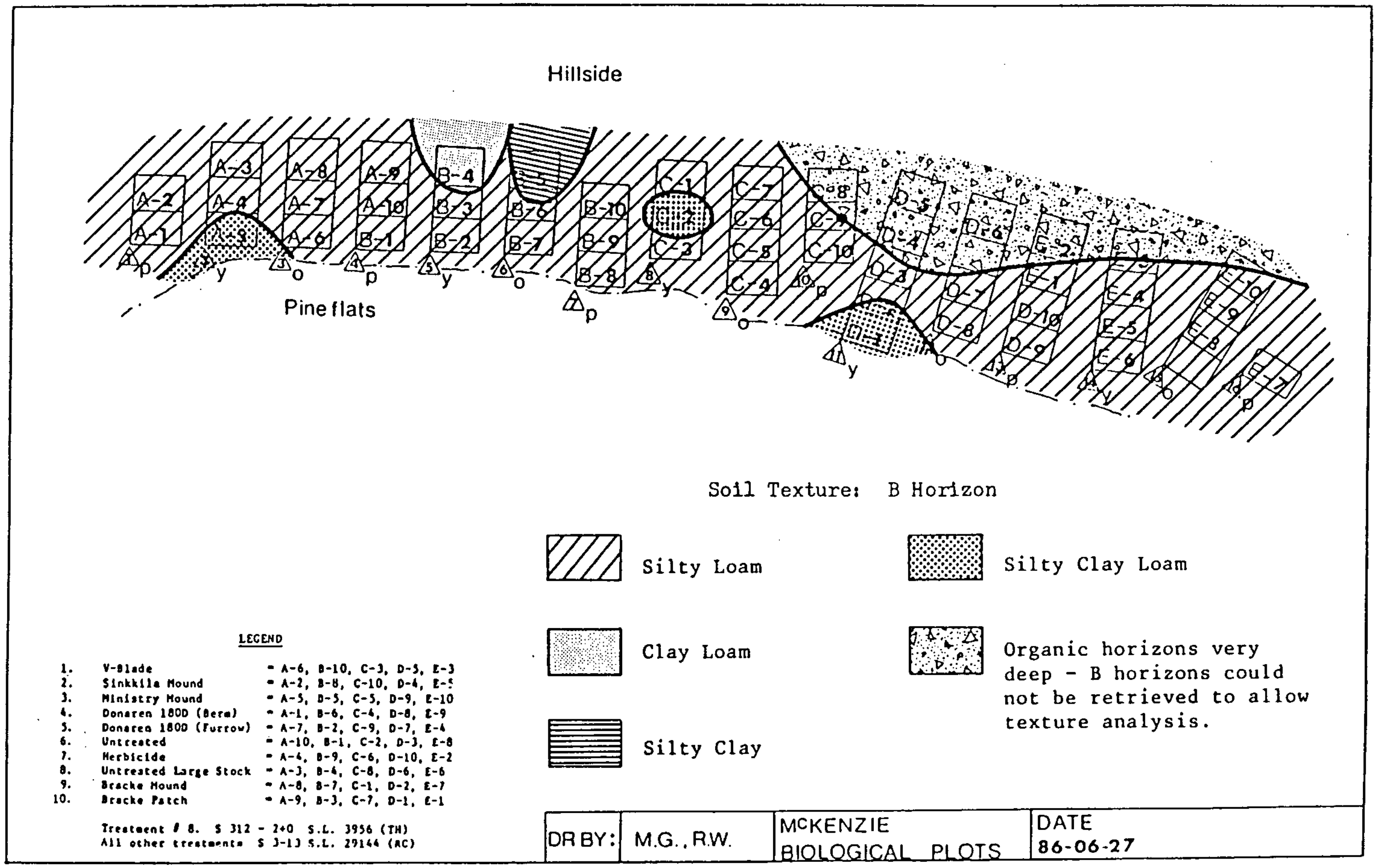


Figure A.3.3 Soil texture of the B horizon, McKenzie site.

A.4 Kluskus Road

A.4.1 Humus form

The humus forms present on this site were found to be moders (dominantly mormoders) and mors. As shown in Figure A.4.1, moders occupied a band along the northern boundary of the site. Moving south from this band the humus forms gradually changed to mors. The transition from moder to mor humus form roughly coincided with topographical characteristics in that the moders occupied a position of slightly higher elevation. Mors were found on the slope and bench located south of the moders.

A.4.2 Humus depth

The depth of organic horizons (L, F, H and O) ranged from 3 to 17 cm. The thickness of the humus horizons was lowest in the northeast corner of the site, as shown in Figure A.4.2. The deepest organic profiles were located in the centre of the site along the southern boundary. Pockets of moderately deep organics (11 - 15 cm) were found to the east and west and were associated with a relatively high water table.

A.4.3 Soil texture

The texture of the B horizons were dominantly silt loams, however, pockets of sandier soils (sandy clay, sandy clay loam, and sandy loam) were found to the northwest and northeast, as shown in Figure A.4.3.

A horizons in the soil profiles examined were either absent or very thin (less than 2 cm).

Soil textures in the mounds produced by the Ministry Mounder were highly variable, both within and across plots, and included silty clay loams, loams, sandy loams, and silty loams. The mound textures were not necessarily representative of the texture of the underlying B horizon. This may have been caused by two factors. Firstly, the degree of incorporation of organic matter into the mineral soil was variable (both within and across plots). Organic matter would tend to bias the hand texturing result toward higher silt content. Secondly, some mounds were very dry and showed evidence of wind erosion in that the fines had been removed, leaving a cap of coarse fragments on the surface of the mound. Some attempt to overcome the effects of this additional variable was made by sampling slightly below the coarse material on the mound surface but above the underlying organic layer.

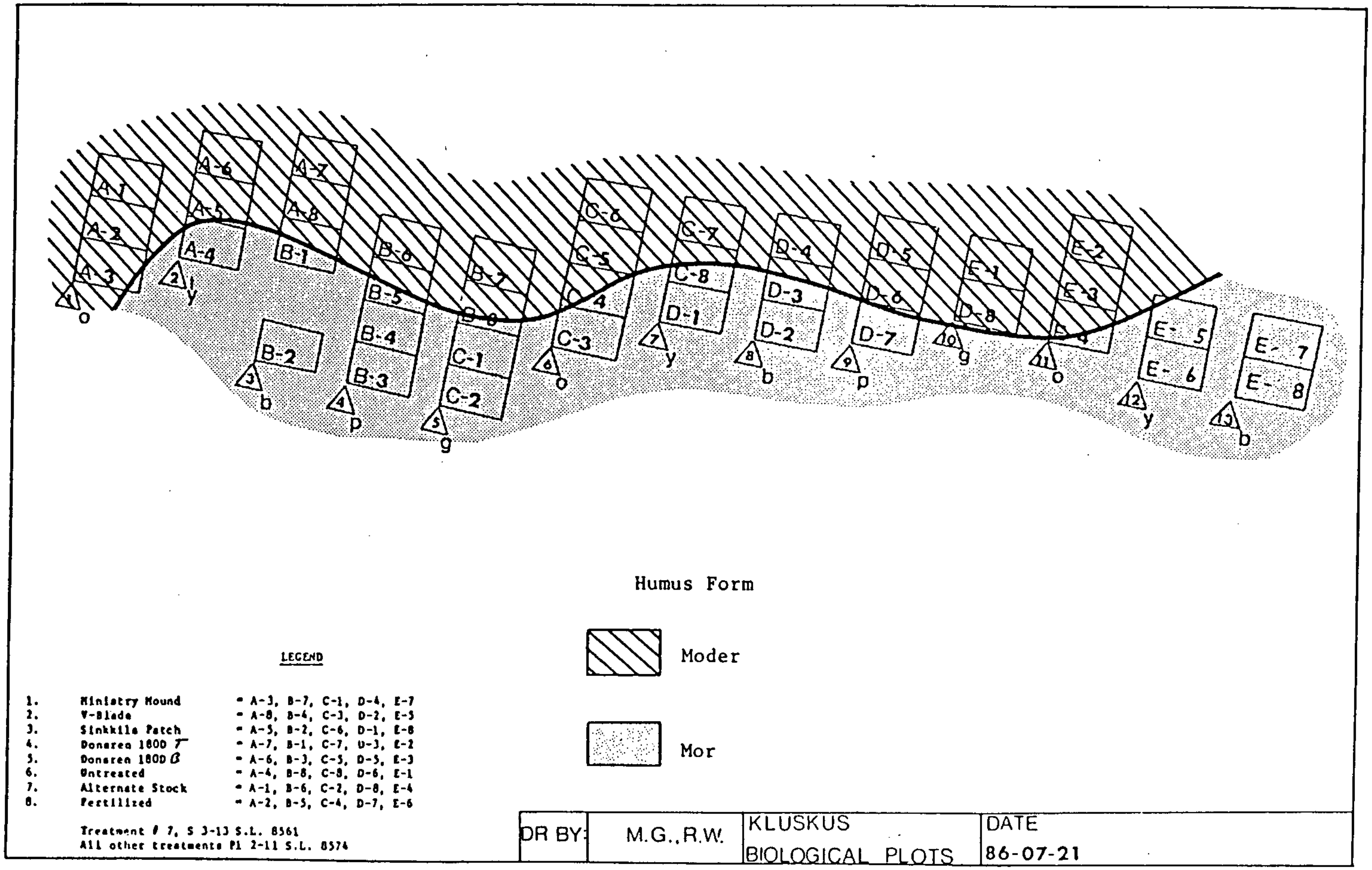


Figure A.4.1 Humus form, Kluskus Road site.

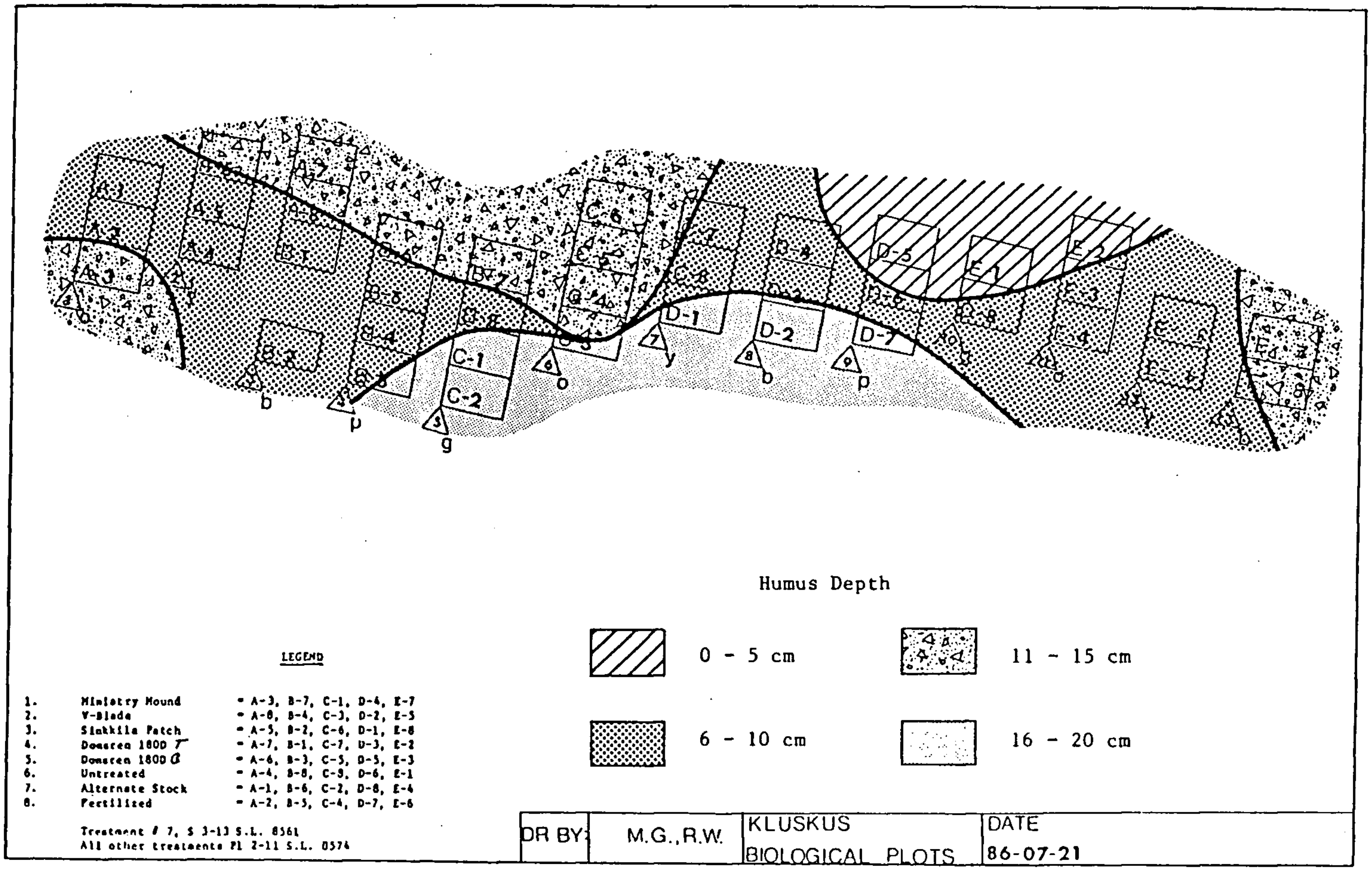


Figure A.4.2 Humus depth classes, Kluskus Road site.

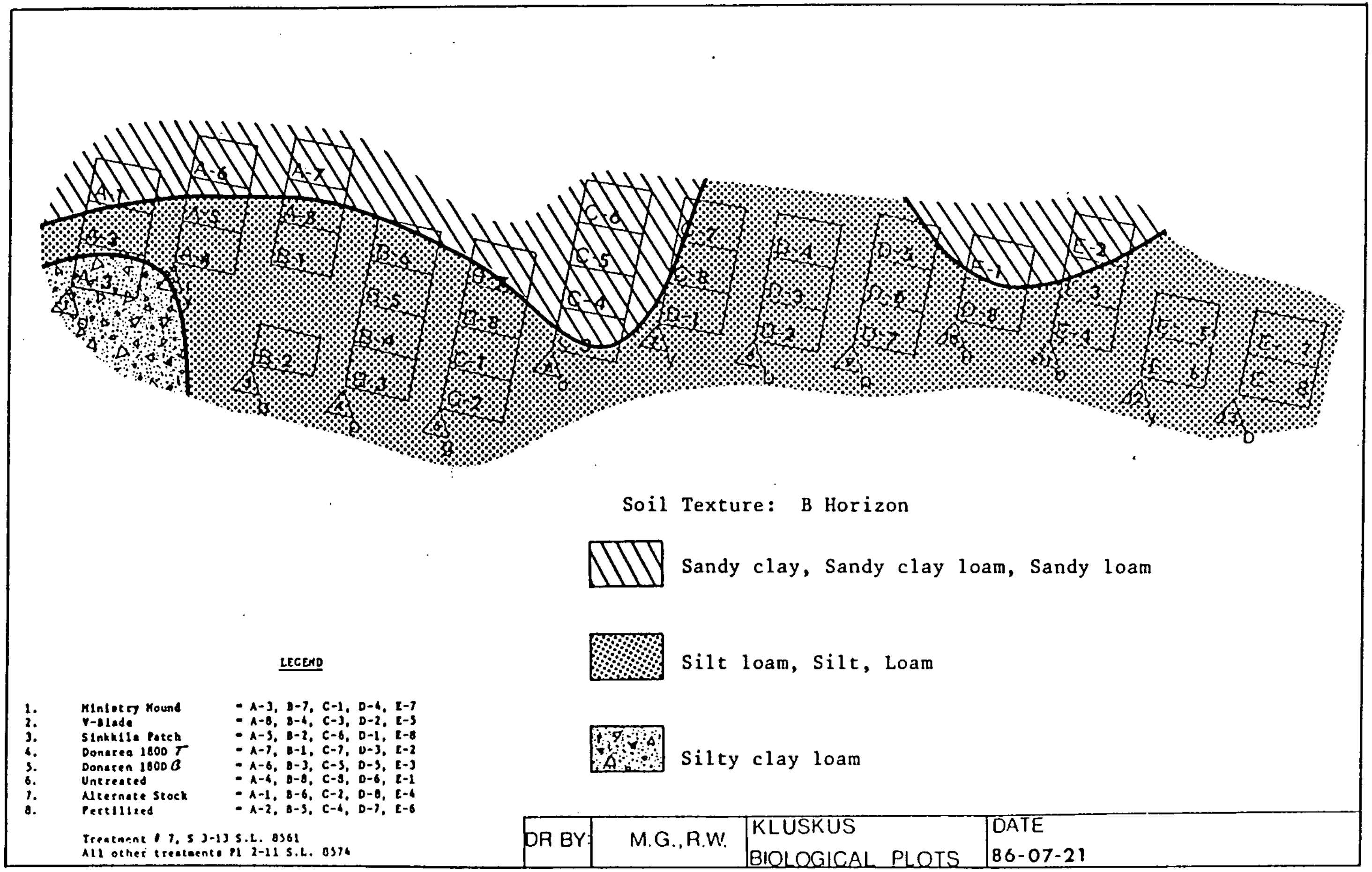


Figure A.4.3 Soil texture of the B horizon, Kluskus Road site.

Appendix B

Field assessment of inverted humus mounds (Hedin 1987)

The distribution of mound classes for each implement is presented in Tables B.1 - B.3. Table B.4 compares mounding success by machine and by site. Average mound dimensions of acceptable mounds for each implement is presented in Tables B.5 - B.7. Table B.8 presents ground contact assessments within acceptable mound classes for each implement.

Table B.1. Distribution of mound classes - Ministry Mounder (from Hedin 1987).

Mound class	Fort St. John		Dawson Creek		Mackenzie		Vanderhoof	
	Avg no. per transect	% of total	Avg no. per transect	% of total	Avg no. per transect	% of total	Avg no. per transect	% of total
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer	5.0	25.0	12.7	63.3	9.3	46.5	3.1	15.5
14-19 cm mineral soil in cap over inverted organic layer	4.2	21.0	3.9	19.4	3.7	18.5	4.3	21.5
10-13 cm mineral soil in cap over inverted organic layer	3.2	16.0	1.3	6.6	2.7	13.5	5.5	27.5
6-9 cm mineral soil in cap over inverted organic layer	1.6	8.0	0.8	4.1	1.1	5.5	3.6	18.0
3-5 cm mineral soil in cap over inverted organic layer	0.4	2.0	0.2	1.0	0.6	3.0	1.8	9.0
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	1.4	7.0	0.1	0.5	1.2	6.0	0	0
Acceptable	15.8	79.0	19.0	94.9	18.6	93.0	18.3	91.5
Less than or equal to 2 cm mineral soil in cap over inverted organic layer	0	0	0	0	0.1	0.5	0	0
Mineral cap over mineral soil	0	0	0	0	0.1	0.5	0	0
Inverted organic mound	0.5	2.5	0	0	0.5	2.5	0.3	1.5
Organic mound, not inverted	1.1	5.5	0.1	0.5	0.2	1.0	0.6	3.0
Mineral over undisturbed organic	0.7	3.5	0.6	3.1	0.1	0.5	0	0
Organic over mineral, not inverted	0	0	0	0	0.1	0.5	0	0
Vertical mound, not overturned	0.7	3.5	0.2	1.0	0	0	0	0
No mound	1.2	6.0	0.1	0.5	0.3	1.5	0.8	4.0
Unacceptable	4.2	21.0	1.0	5.1	1.4	7.0	1.7	8.5
Total	20.0	100.0	20.0	100.0	20.0	100.0	20.0	100.0

Averages and percentages are calculated from original data and therefore there may be discrepancies because of rounding.

Table B.2. Distribution of mound classes - Sinkkila (from Hedin 1987).

Mound class	Fort St. John Avg no. per transect	Fort St. John % of total	Dawson Creek Avg no. per transect	Dawson Creek % of total	Mackenzie* Avg no. per transect	Mackenzie* % of total
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer	0.1	0.5	0.6	3.0	0.1	0.4
14-19 cm mineral soil in cap over inverted organic layer	0.6	3.0	3.7	18.5	0.1	0.5
10-13 cm mineral soil in cap over inverted organic layer	3.6	18.0	6.2	31.0	0.6	2.9
6-9 cm mineral soil in cap over inverted organic layer	5.2	26.0	3.4	17.0	1.5	7.5
3-5 cm mineral soil in cap over inverted organic layer	4.8	24.0	1.8	9.0	2.2	11.0
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	2.1	10.5	0.2	1.0	4.4	22.0
Acceptable	16.4	82.0	15.9	79.5	8.9	44.3
Less than or equal to 2 cm mineral soil in cap over inverted organic layer	0.1	0.5	0.5	2.5	0.2	1.0
Less than 5 cm well-decomposed inverted organic layer over undisturbed organic	0	0	0	0	0.1	0.4
Inverted organic mound	1.3	6.5	0.3	1.5	1.1	5.9
Organic mound, not inverted	0.7	3.5	1.6	8.0	5.3	26.5
Organic over mineral, not inverted	0	0	0.1	0.5	0	0
Vertical mound, not overturned	0.3	1.5	0.3	1.5	1.4	6.9
no mound	1.2	6.0	1.3	6.5	3.0	15.0
Unacceptable	3.6	18.0	4.1	20.5	11.1	55.7
Total	20.0	100.0	20.0	100.0	20.0	100.0

Averages and percentages are calculated from original data and therefore there may be discrepancies because of rounding.

* Poor performance on this site was due in part to failure of the hydraulic braking on the ripper.

Table B.3. Distribution of mound classes - Bracke Mounder (from Hedin 1987).

Mound class	Fort St. John		Dawson Creek		Mackenzie	
	Avg no. per transect	% of total	Avg no. per transect	% of total	Avg no. per transect	% of total
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer	0.1	0.5	0.1	0.5	0	0
14-19 cm mineral soil in cap over inverted organic layer	0.2	0.9	2.3	11.5	0.7	3.6
10-13 cm mineral soil in cap over inverted organic layer	1.0	5.0	5.8	29.0	2.9	14.6
6-9 cm mineral soil in cap over inverted organic layer	5.1	25.5	5.9	29.5	3.8	19.1
3-5 cm mineral soil in cap over inverted organic layer	6.2	30.9	1.8	9.0	4.9	24.5
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	1.7	8.6	0	0	1.7	8.6
Acceptable	14.3	71.4	15.9	79.5	14.0	70.4
Less than or equal to 2 cm mineral soil in cap over inverted organic layer	0.2	0.9	0.4	2.0	0.3	1.4
Less than 5 cm well-decomposed inverted organic layer over undisturbed organic	0	0	0.1	0.5	0	0
Inverted organic mound	2.3	11.8	0.1	0.5	2.1	10.5
Organic mound, not inverted	1.5	7.7	0.6	3.0	1.2	5.9
Mineral over undisturbed organic	0.3	1.4	1.7	8.5	0.2	0.9
Vertical mound, not overturned	0	0	0.1	0.5	0.1	0.4
No mound	1.4	6.8	1.1	5.5	2.1	10.5
Unacceptable	5.7	28.6	4.1	20.5	6.0	29.6
Total	20.0	100.0	20.0	100.0	20.0	100.0

Averages and percentages are calculated from original data and therefore there may be discrepencies because of rounding.

Table B.4. Comparison of moundeing success (from Hedin 1987).

Overall success acceptable and unacceptable mound classes	Success in achieving deep mineral capping - ≥ 10 cm
BY MACHINE	
INCREASING SUCCESS→	INCREASING SUCCESS→
1. Sinkkilä Mackenzie Dawson Creek Fort St. John	1. Sinkkilä Mackenzie Fort St. John Dawson Creek
2. MINISTRY mounder Fort St. John Vanderhoof Mackenzie Dawson Creek	2. MINISTRY mounder Fort St. John Vanderhoof Mackenzie Dawson Creek
3. Bräcke mounder Fort St. John Mackenzie Dawson Creek	3. Bräcke mounder Fort St. John Mackenzie Dawson Creek
BY SITE	
INCREASING SUCCESS→	INCREASING SUCCESS→
1. FORT ST. JOHN Bräcke mounder Ministry mounder Sinkkilä	1. FORT ST. JOHN Bräcke mounder Sinkkilä Ministry mounder
2. DAWSON CREEK Sinkkilä Bräcke mounder Ministry mounder	2. DAWSON CREEK Bräcke mounder Sinkkilä Ministry mounder
3. MACKENZIE Sinkkila Bräcke mounder Ministry mounder	3. MACKENZIE Sinkkilä Bräcke mounder Ministry mounder

Machines or locations underlined with the same line are not statistically different to 95% confidence.

Table B.5. Average dimensions of acceptable mounds - Ministry Mounder[a] (from Hedin 1987).

Mound class	Fort St. John		Dawson Creek		Mackenzie		Vanderhoof	
	Height cm	Area cm^2	Height cm	Area cm^2	Height cm	Area cm^2	Height cm	Area cm^2
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer	44	1552	38	4017	37	2614	30	1829
14-19 cm mineral soil in cap over inverted organic layer	37	1564	35	3863	33	2389	25	2076
10-13 cm mineral soil in cap over inverted organic layer	33	1209	34	3692	36	2063	25	2113
6-9 cm mineral soil in cap over inverted organic layer	29	744	21	2033	31	1018	27	2594
3-5 cm mineral soil in cap over inverted organic layer					31	2150	28	1567
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	22	950			35	2833		
Overall	36	1328	36	3882	35	2397	27	2094

[a] Dimensions shown only when sample size was greater than 5.

Table B.6. Average mound dimensions of acceptable mounds - Sinkkila[a] (from Hedin 1987).

Mound class	Fort St. John		Dawson Creek		Mackenzie	
	Height cm	Area cm²	Height cm	Area cm²	Height cm	Area cm²
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer			41	2067		
14-19 cm mineral soil in cap over inverted organic layer	35	3050	31	2549		
10-13 cm mineral soil in cap over inverted organic layer	32	1856	36	2295	31	2215
6-9 cm mineral soil in cap over inverted organic layer	31	1650	34	2048	29	1619
3-5 cm mineral soil in cap over inverted organic layer	30	1496	30	1428	28	1263
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	28	1114			34	2178
Overall	31	1626	34	2199	32	1872

[a] Dimensions shown only when sample size was greater than 5.

Table B.7. Average mound dimensions of acceptable mounds - Bracke Mounder[a] (from Hedin 1987).

Mound class	Fort St. John		Dawson Creek		Mackenzie	
	Height cm	Area cm²	Height cm	Area cm²	Height cm	Area cm²
Greater than or equal to 20 cm mineral soil in cap over inverted organic layer						
14-19 cm mineral soil in cap over inverted organic layer			26	1474	24	1500
10-13 cm mineral soil in cap over inverted organic layer	24	936	23	1912	24	1241
6-9 cm mineral soil in cap over inverted organic layer	21	889	20	1660	22	1339
3-5 cm mineral soil in cap over inverted organic layer	19	913	18	1824	21	1137
Greater than or equal to 5 cm well-decomposed inverted organic layer over undisturbed organic	16	758			24	1328
Overall	20	890	22	1745	23	1257

[a] Dimensions shown only when sample size was greater than 5.

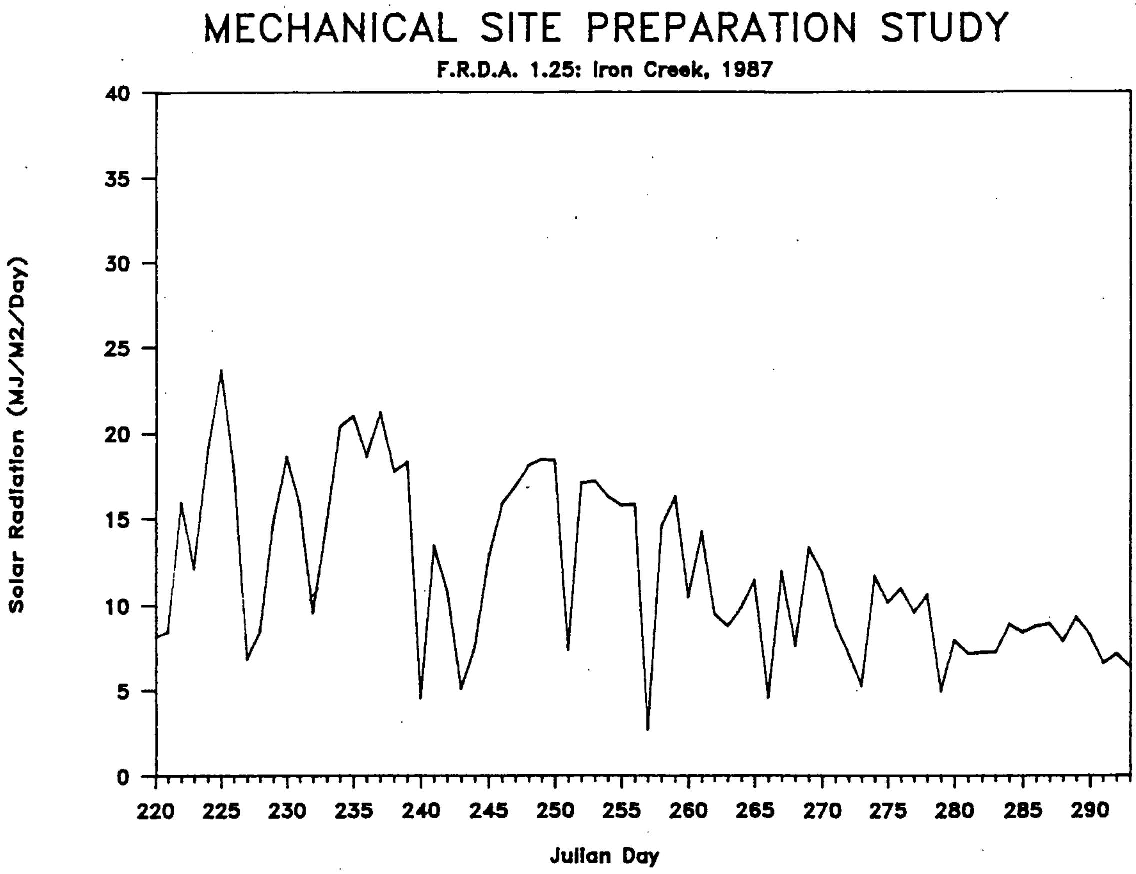
Table B.8. Ground contact within acceptable mound classes (from Hedin 1987).

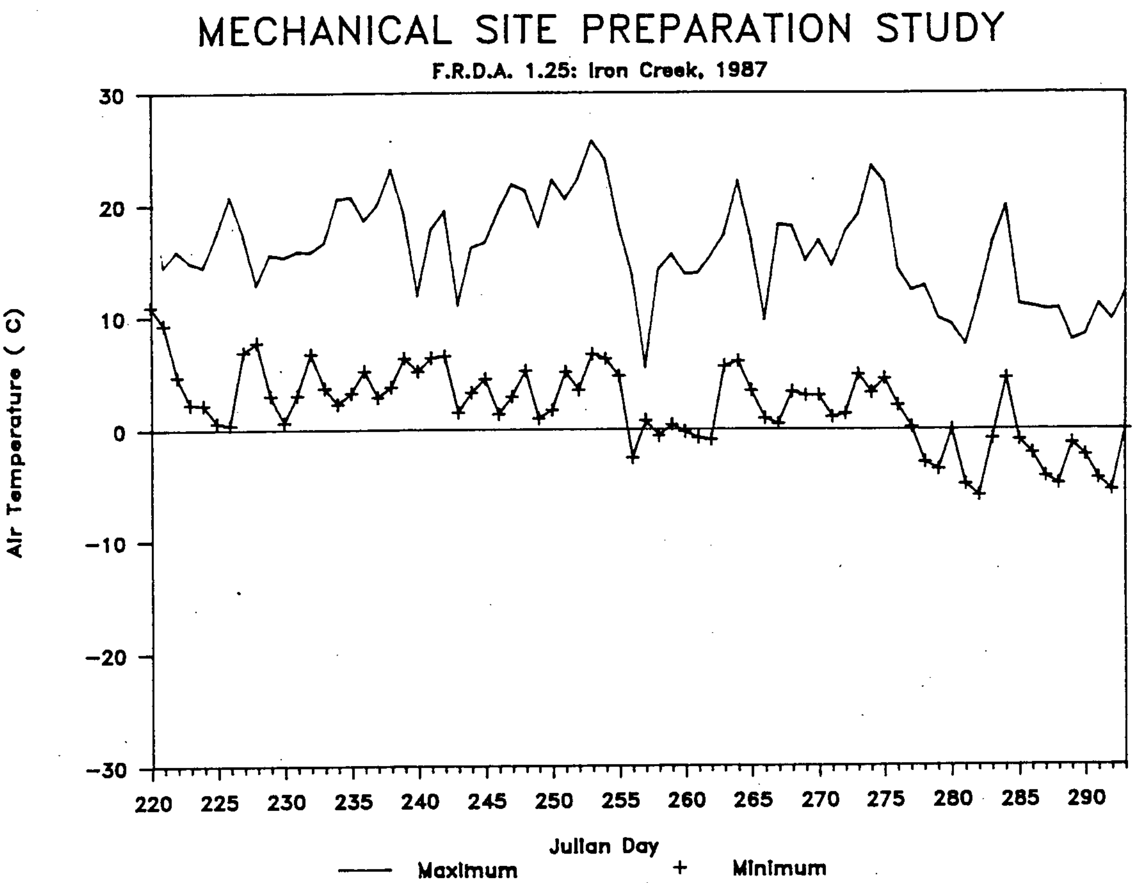
	Fort St. John (no.)	Dawson Creek (no.)	Mackenzie (no.)	Vanderhoof (no.)
Sinkkilä				
Good ground contact	164	152	163	N/A
Poor ground contact	0	6	13	
Total	164	158	176	
Ministry mounder				
Good ground contact	158	180	183	181
Poor ground contact	0	6	3	2
Total	158	186	186	183
Bräcke mounder				
Good ground contact	156	154	150	N/A
Poor ground contact	1	4	5	
Total	157	158	155	

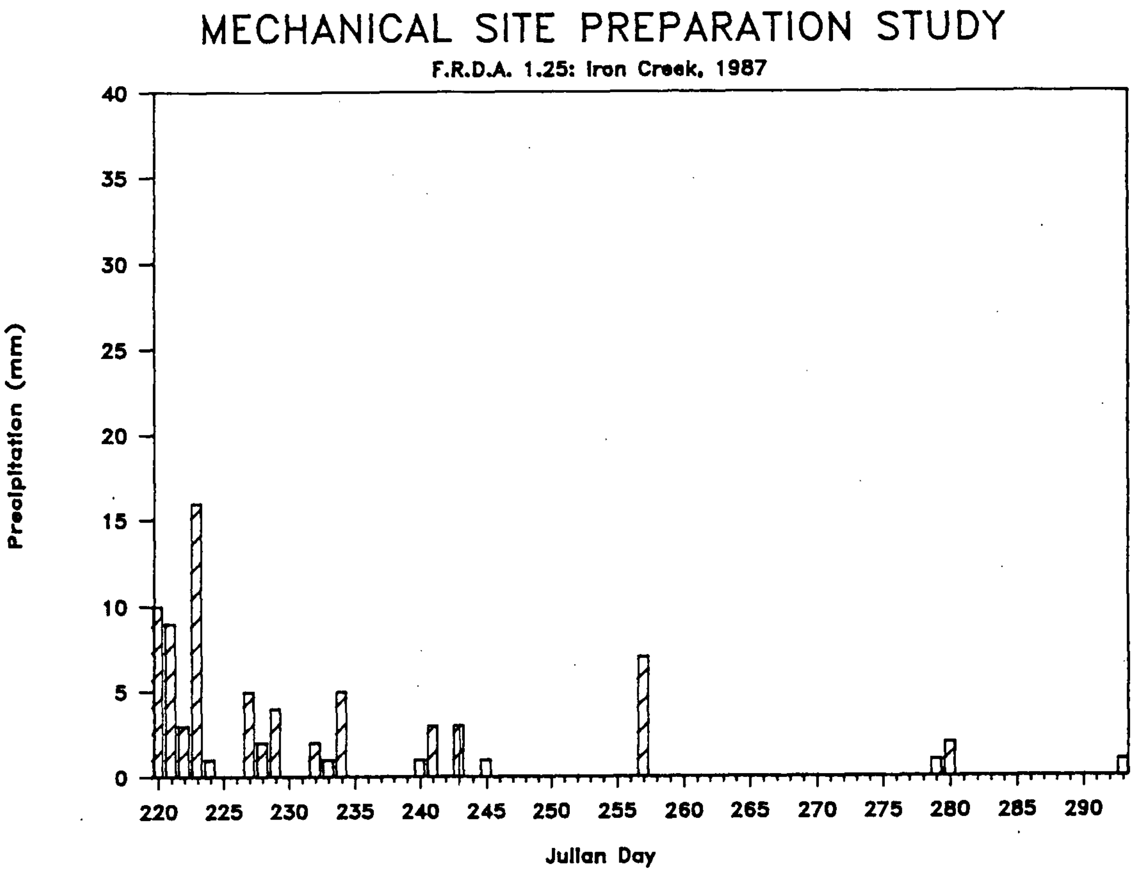
Appendix C

Results of the environmental monitoring project (FRDA 1.25)

Graphs prepared by S. Jenvey under contract to MOF.


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Solar Radiation (MJ/M2/Day)
0
5
10
15
20
25
30
35
40
220 225 230 235 240 245 250 255 260 265 270 275 280 285 290
Julian Day


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Air Temperature (C)
30
20
10
0
-10
-20
-30
220 225 230 235 240 245 250 255 260 265 270 275 280 285 290
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Precipitation (mm)
40
35
30
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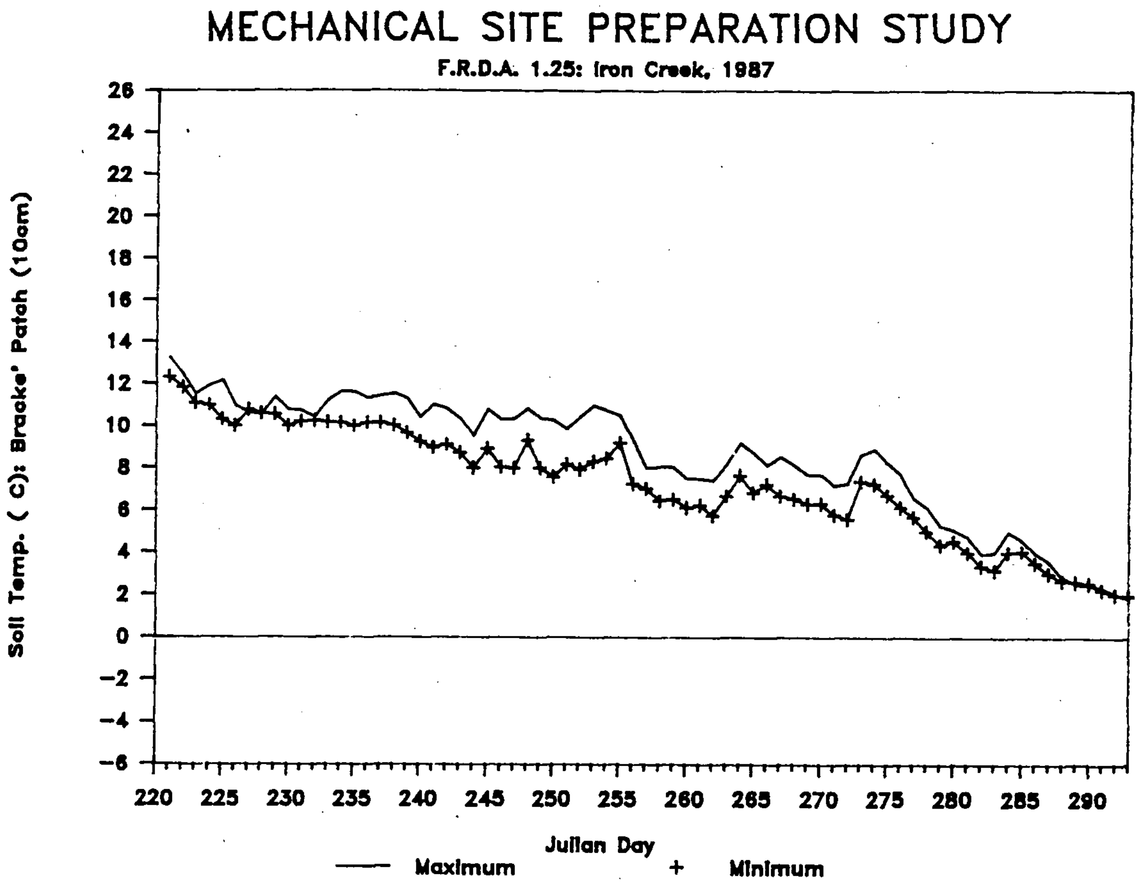
220 225 230 235 240 245 250 255 260 265 270 275 280 285 290
Julian Day


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Soil Temp. (C): Bracke' Patch (10cm)
26
24
22
20
18
16
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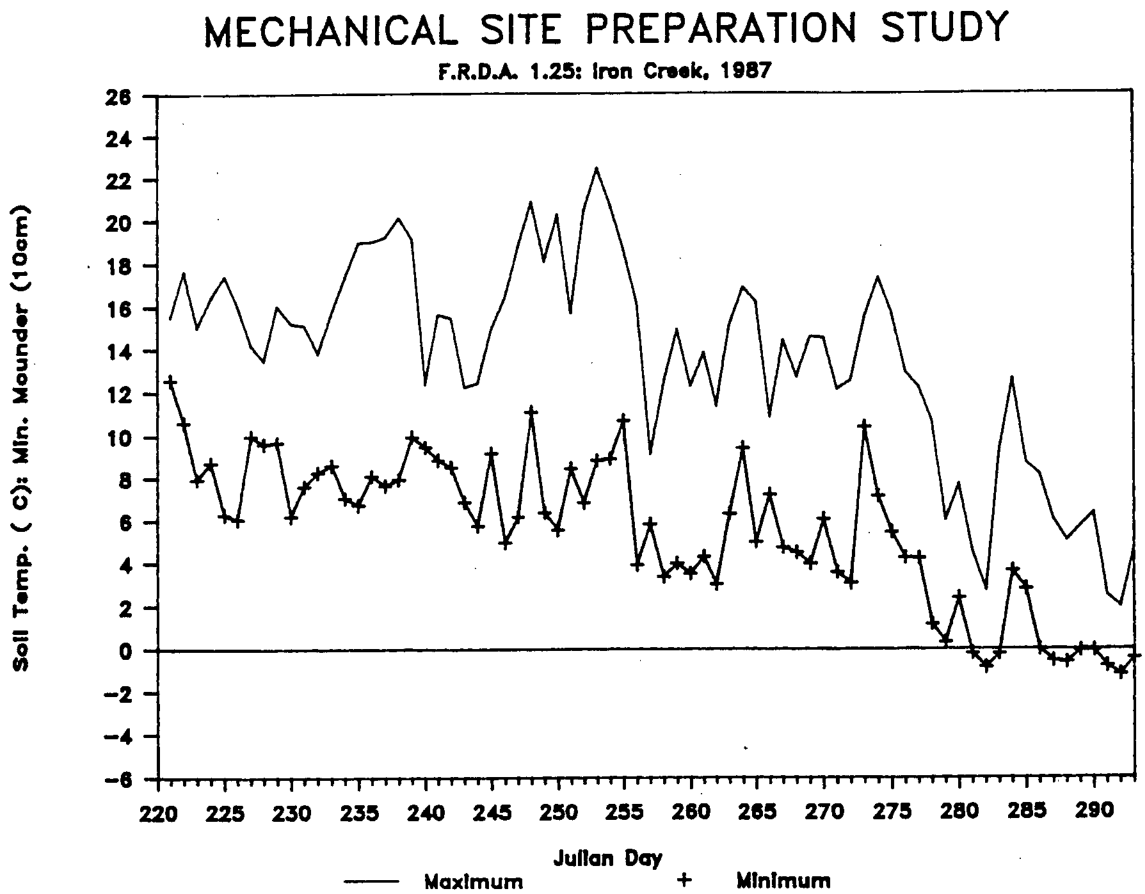
-2
-4
-6
220 225 230 235 240 245 250 255 260 265 270 275 280 285 290
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Soil Temp. (C): Min. Mounder (10cm)
26
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275
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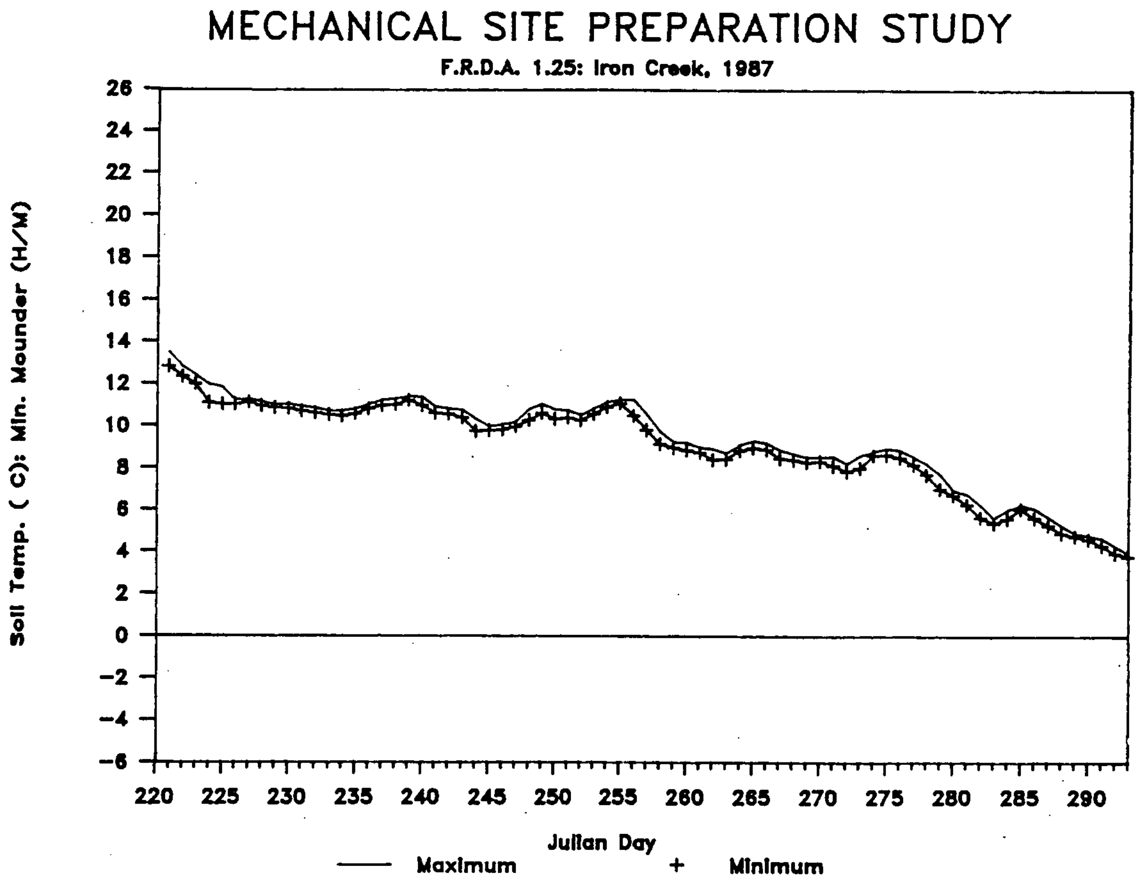
285
290
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Soil Temp. (C): Min. Mounder (H/M)
26
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275
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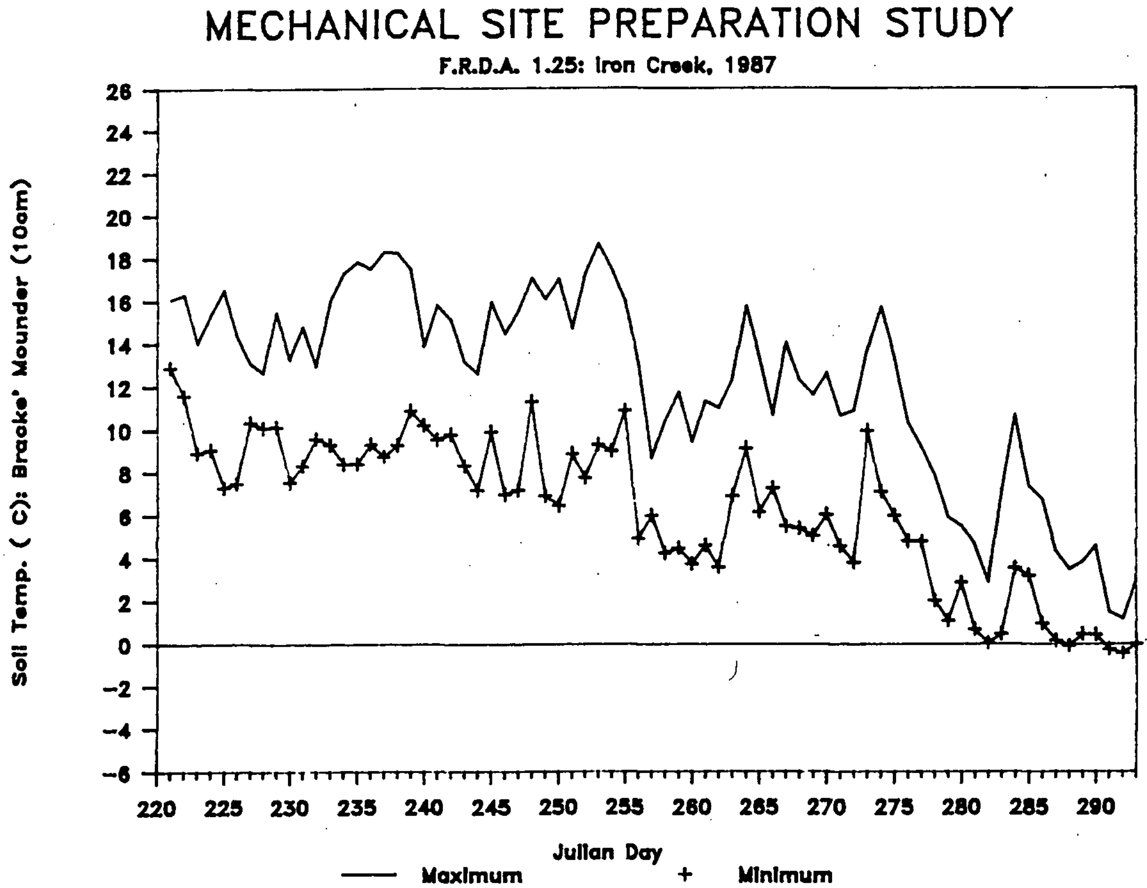
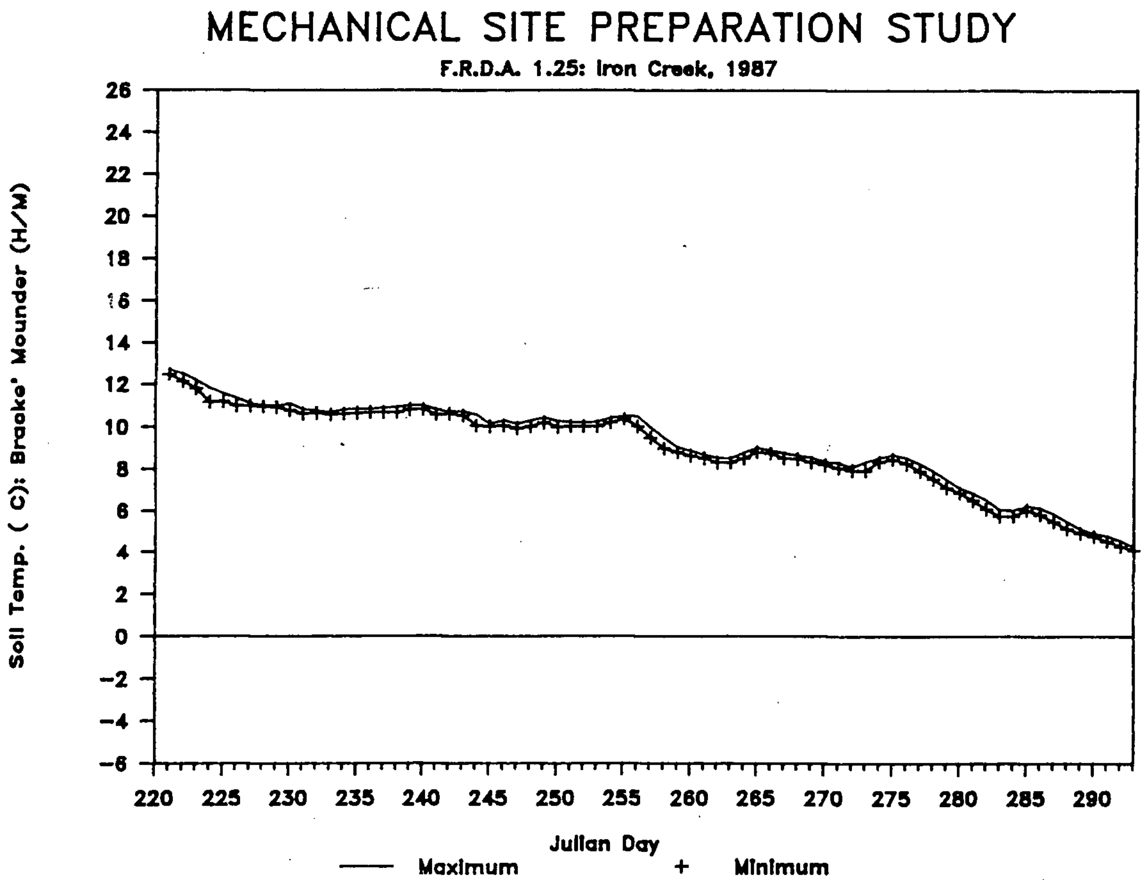
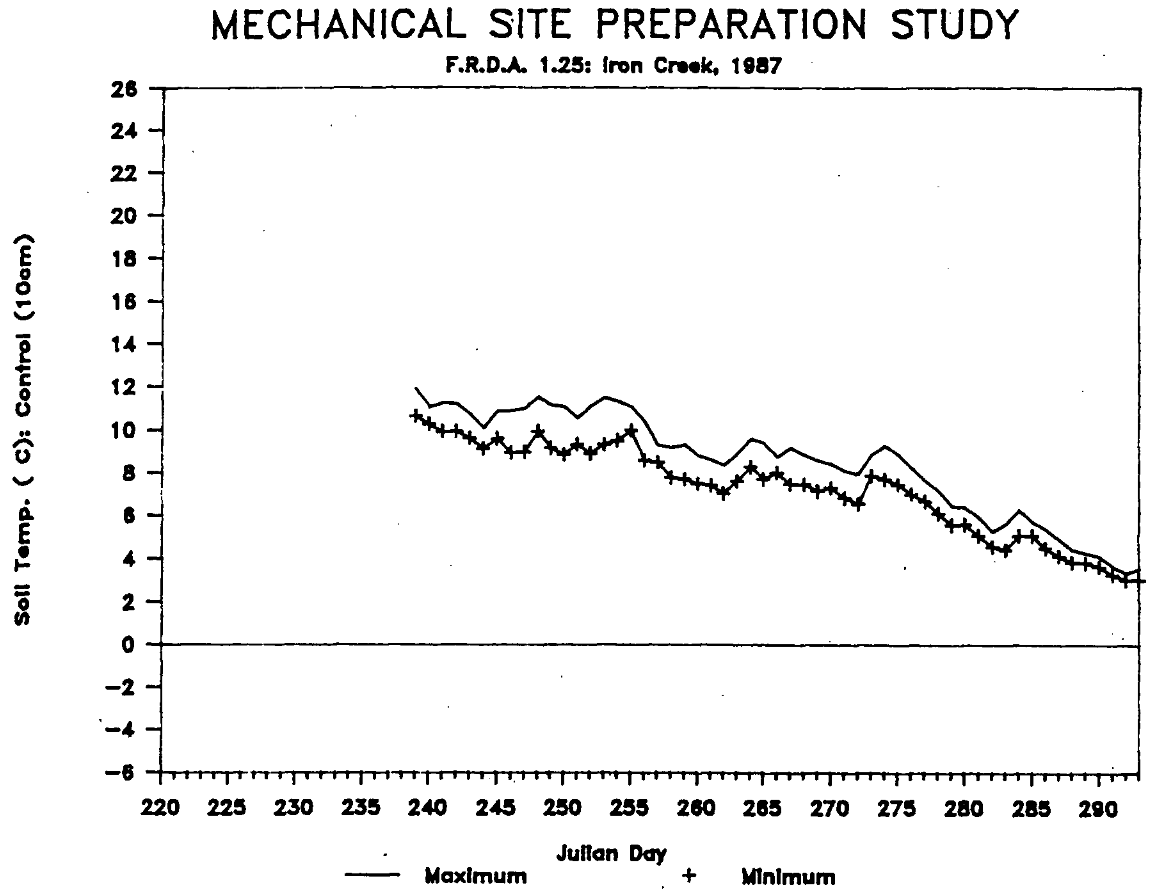
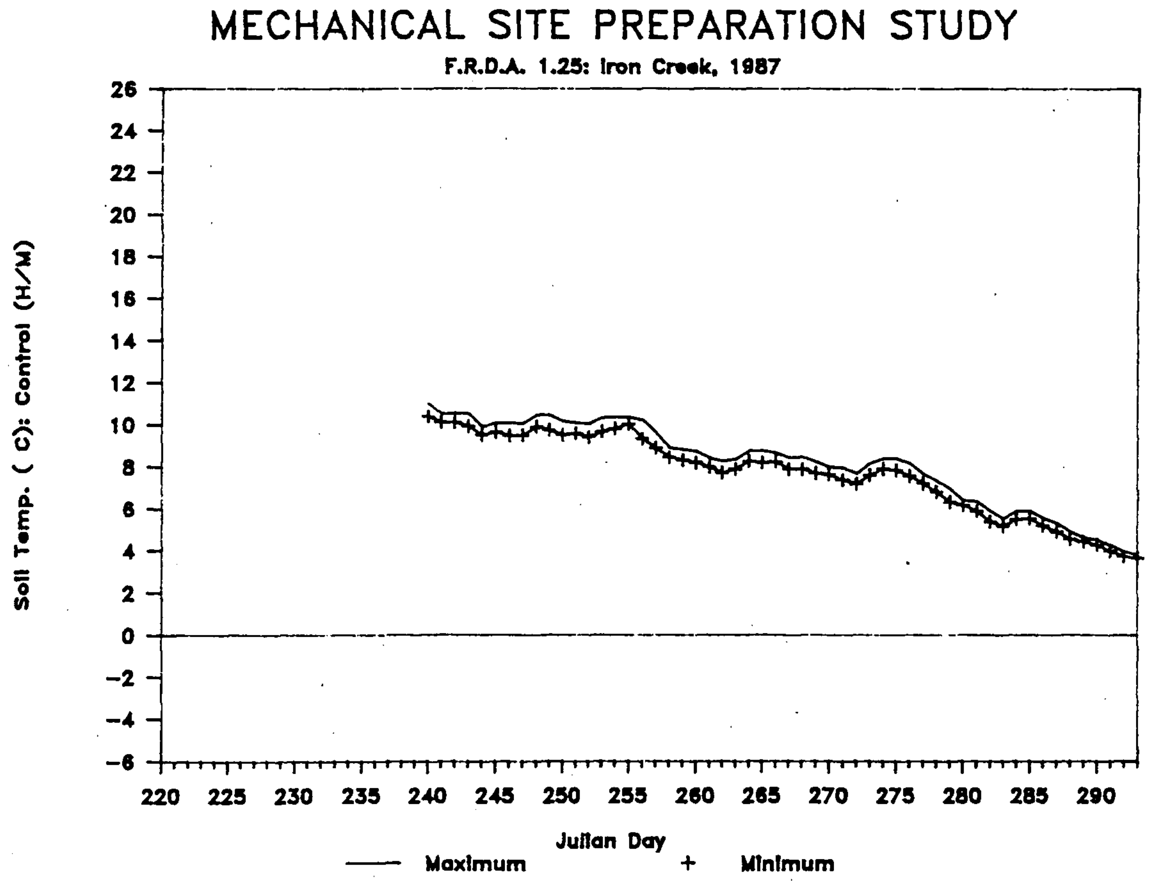
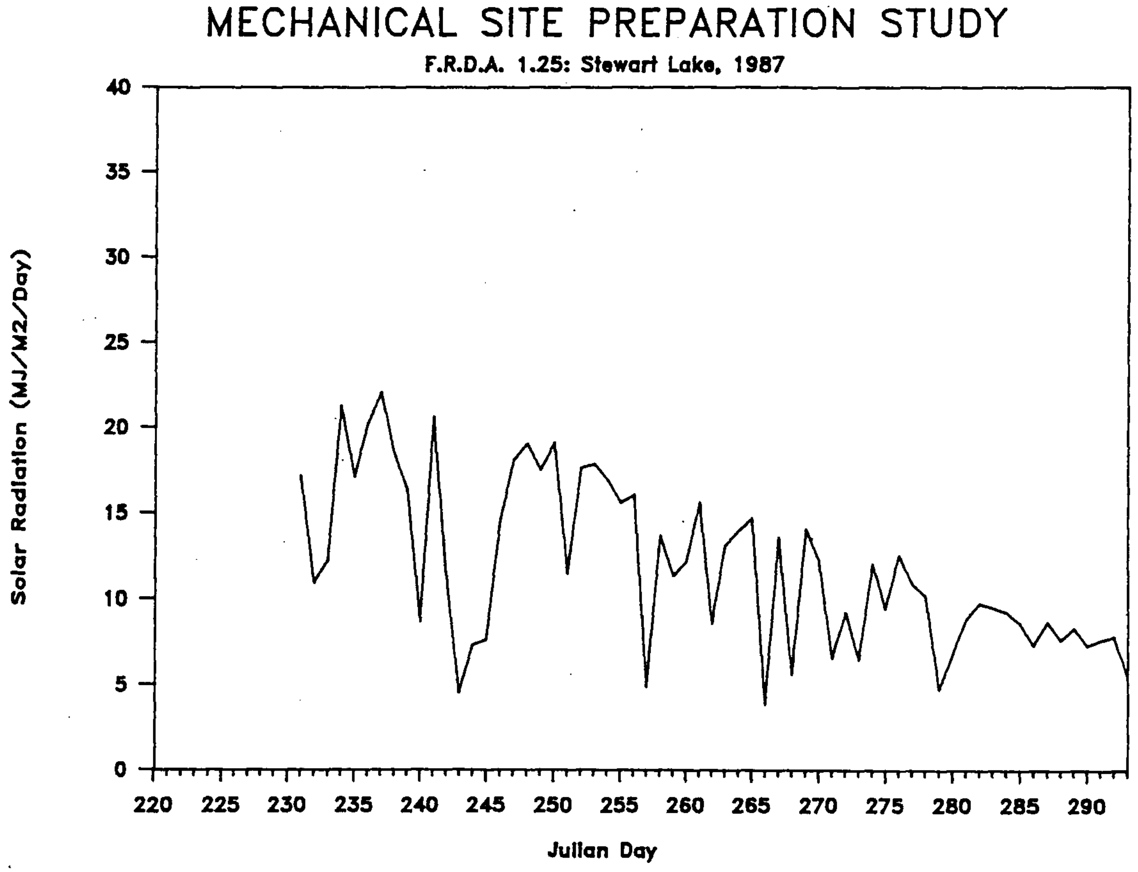
285
290
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Soil Temp. (C): Bracke' Mounder (10cm)
Julian Day
Maximum
Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Soil Temp. (C): Bracke' Mounder (H/M)
Julian Day
Maximum
Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Soil Temp. (C): Control (10cm)
Julian Day
Maximum
Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Iron Creek, 1987
Soil Temp. (C): Control (H/M)
Julian Day
Maximum
Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Stewart Lake, 1987
Solar Radiation (MJ/M2/Day)
40
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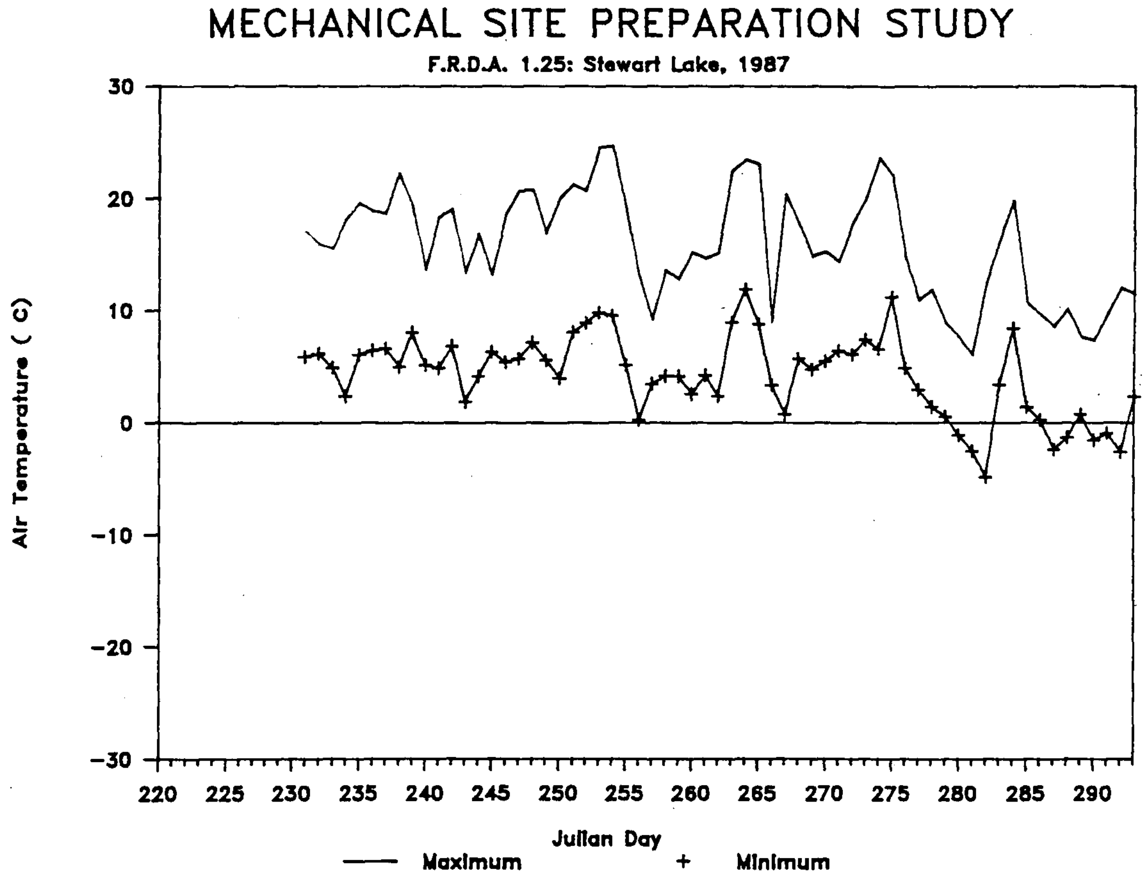
Julian Day


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Stewart Lake, 1987
Air Temperature (C)
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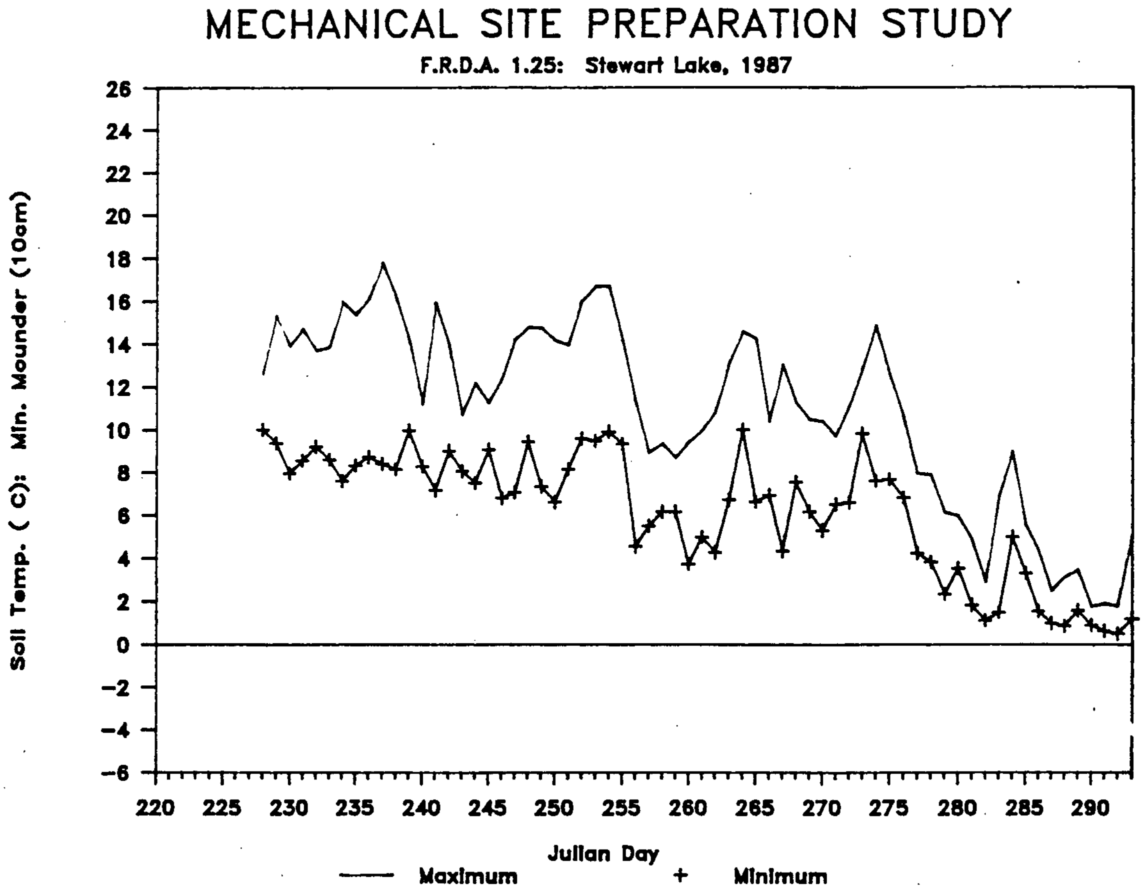
290
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Stewart Lake, 1987
Soil Temp. (C): Min. Mounder (10am)
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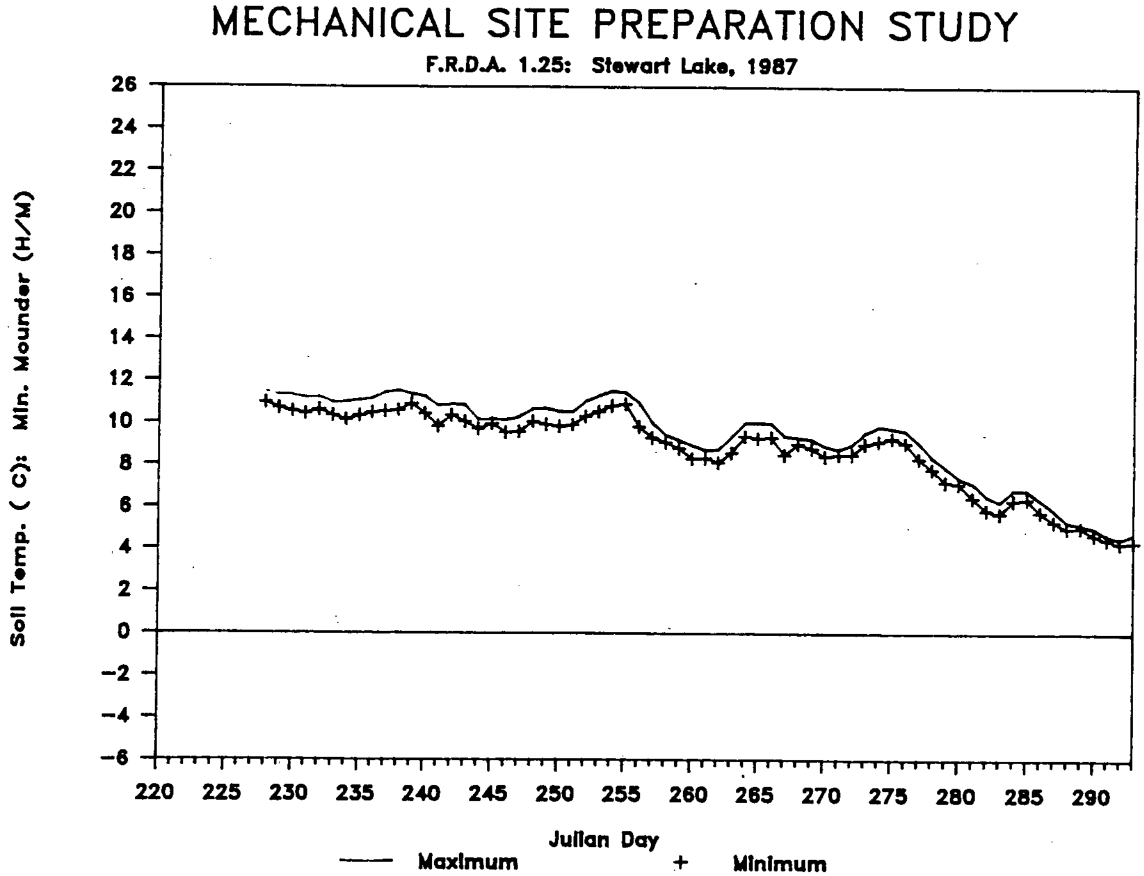
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Stewart Lake, 1987
Soil Temp. (C): Min. Mounder (H/M)
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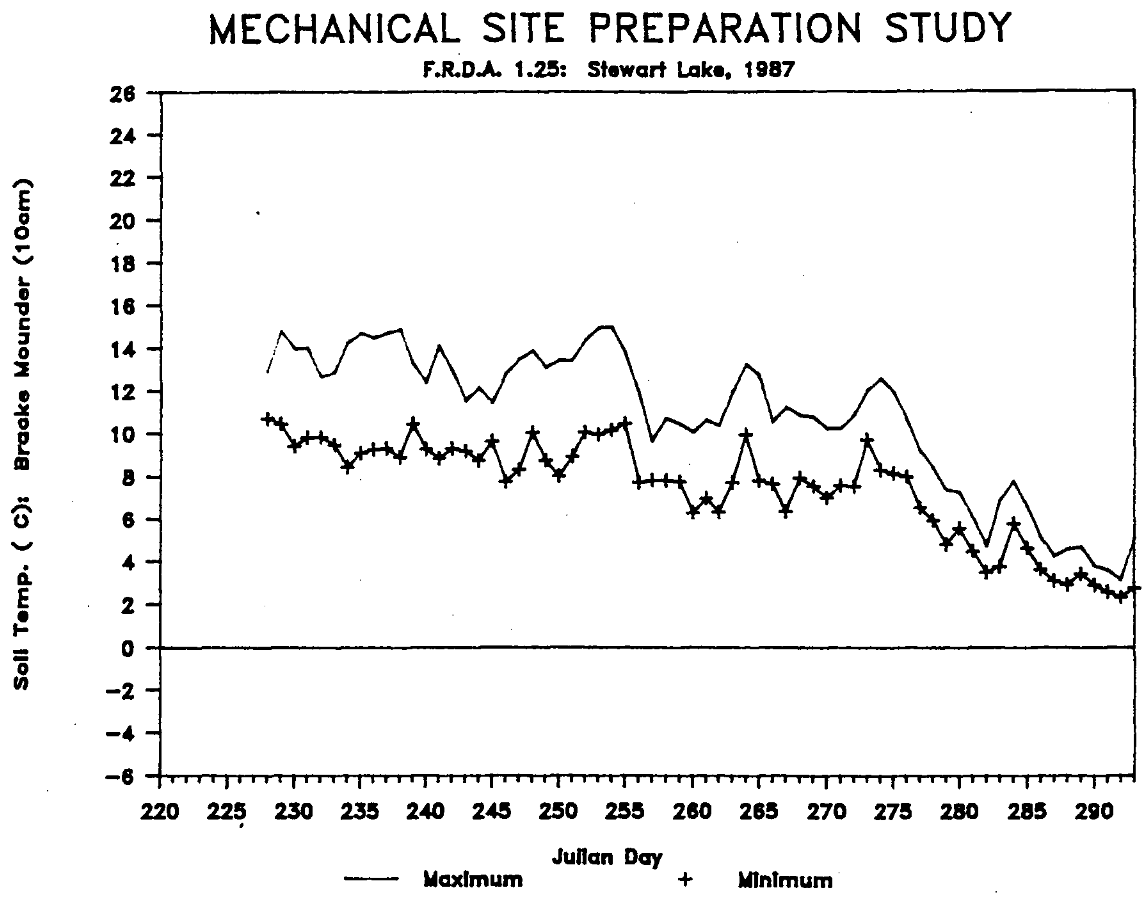
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Stewart Lake, 1987
Soil Temp. (C): Bracke Mounder (10cm)
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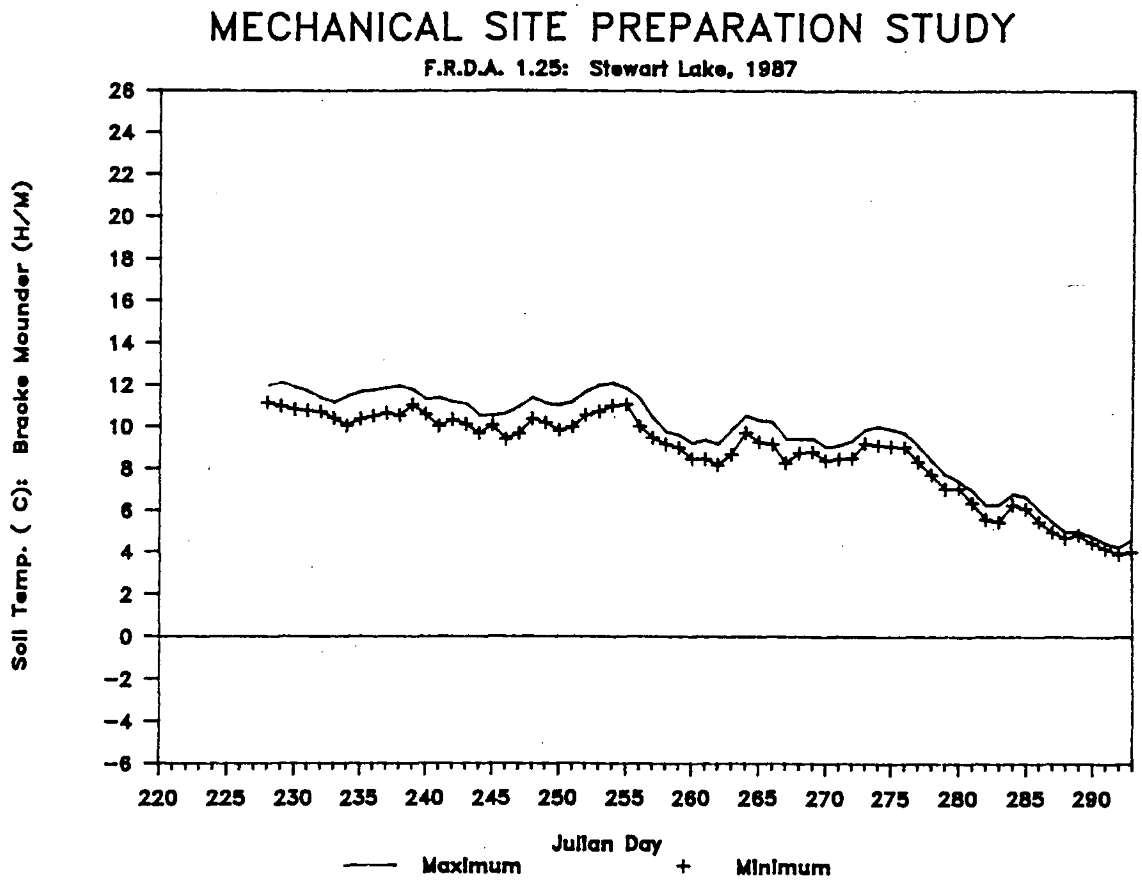
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Stewart Lake, 1987
Soil Temp. (C): Bracke Mounder (H/M)
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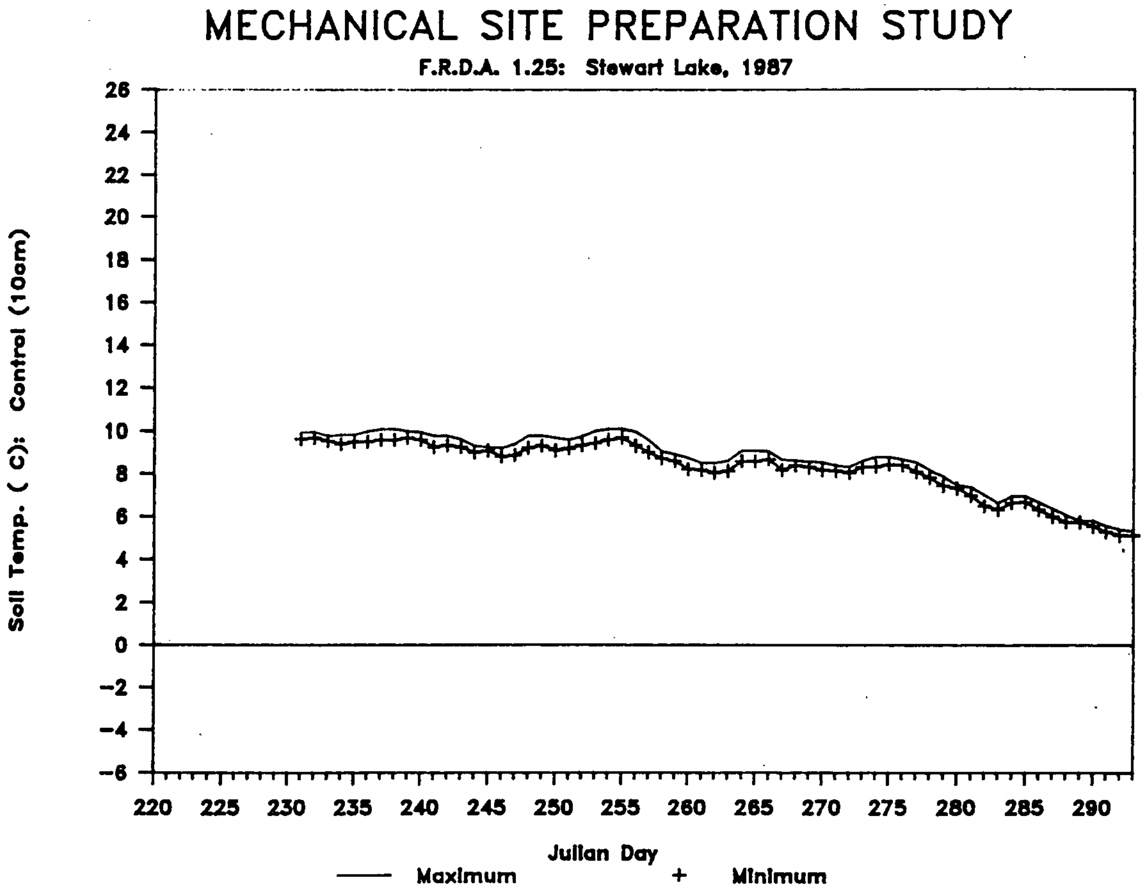
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Stewart Lake, 1987
Soil Temp. (C): Control (10cm)
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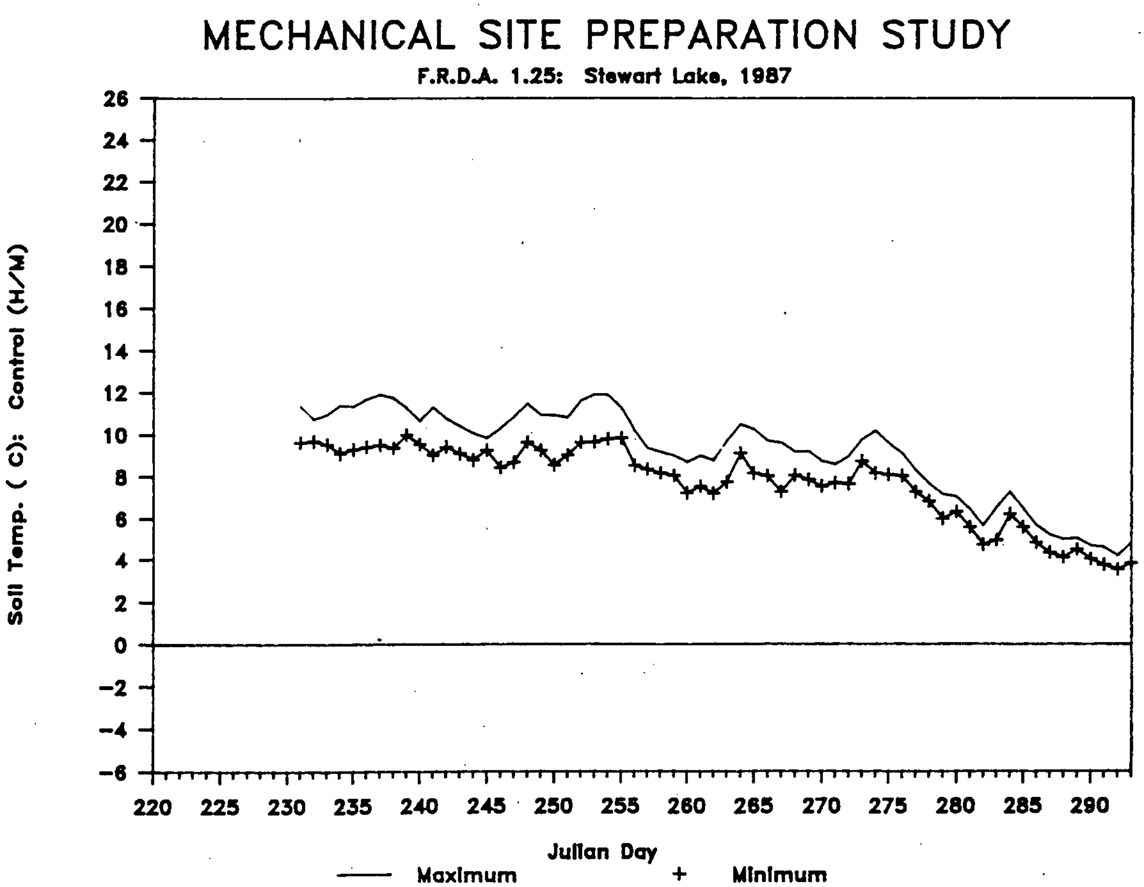
275
280
285
290
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Stewart Lake, 1987
Soil Temp. (C): Control (H/M)
26
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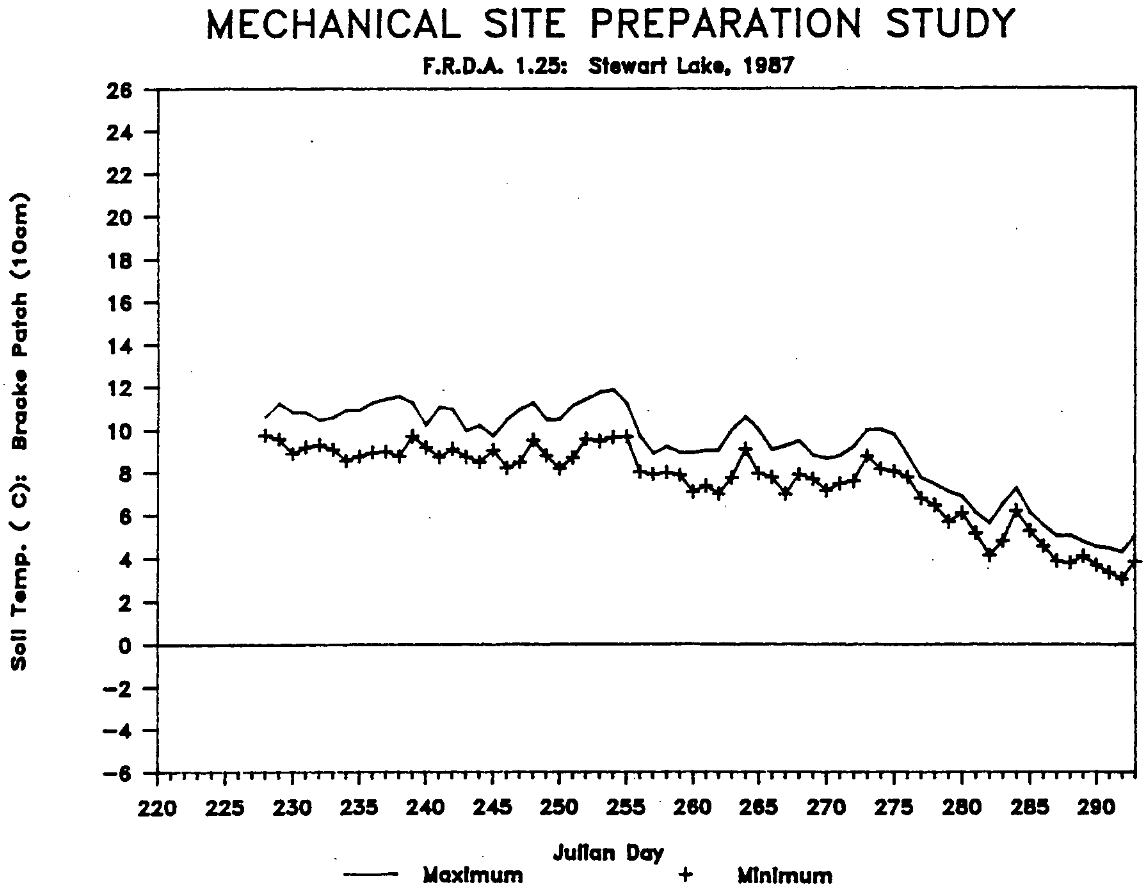
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Stewart Lake, 1987
Soil Temp. (C): Bracke Patch (10cm)
26
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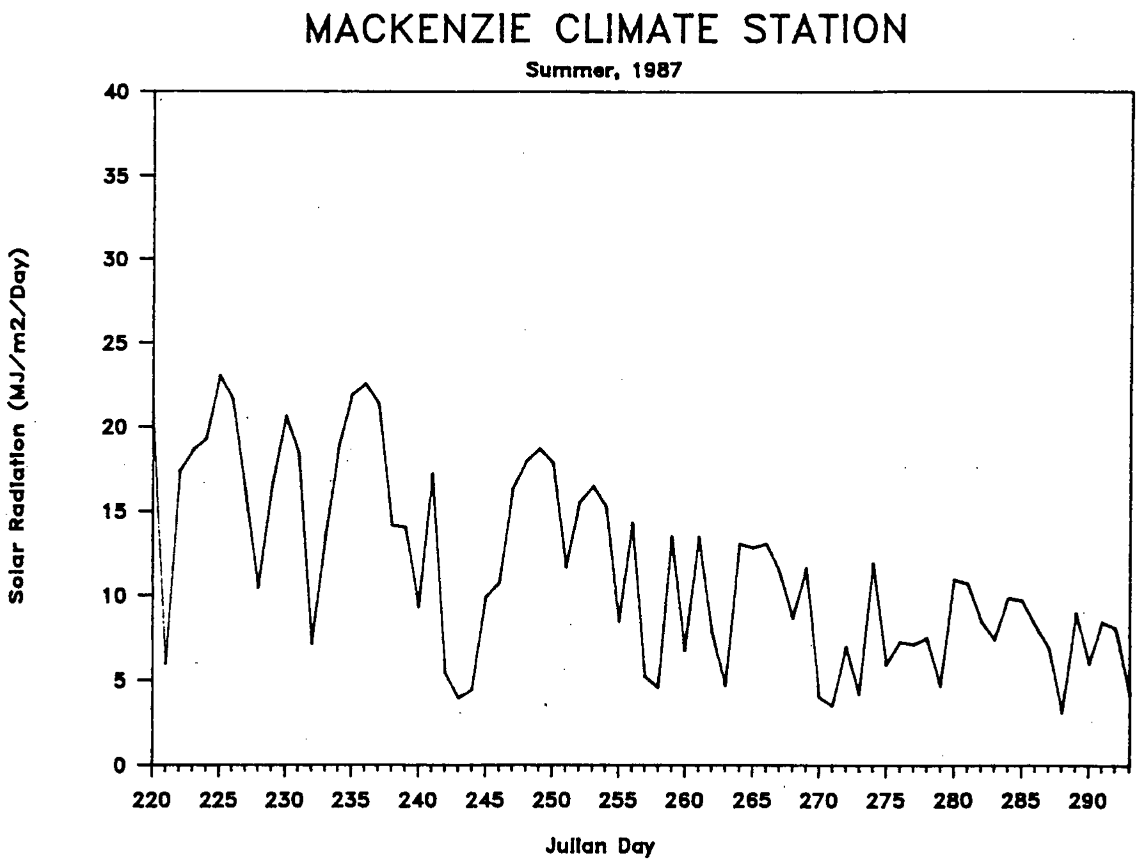
220 225 230 235 240 245 250 255 260 265 270 275 280 285 290
Julian Day
Maximum
+ Minimum


MACKENZIE CLIMATE STATION
Summer, 1987
Solar Radiation (MJ/m2/Day)
40
35
30
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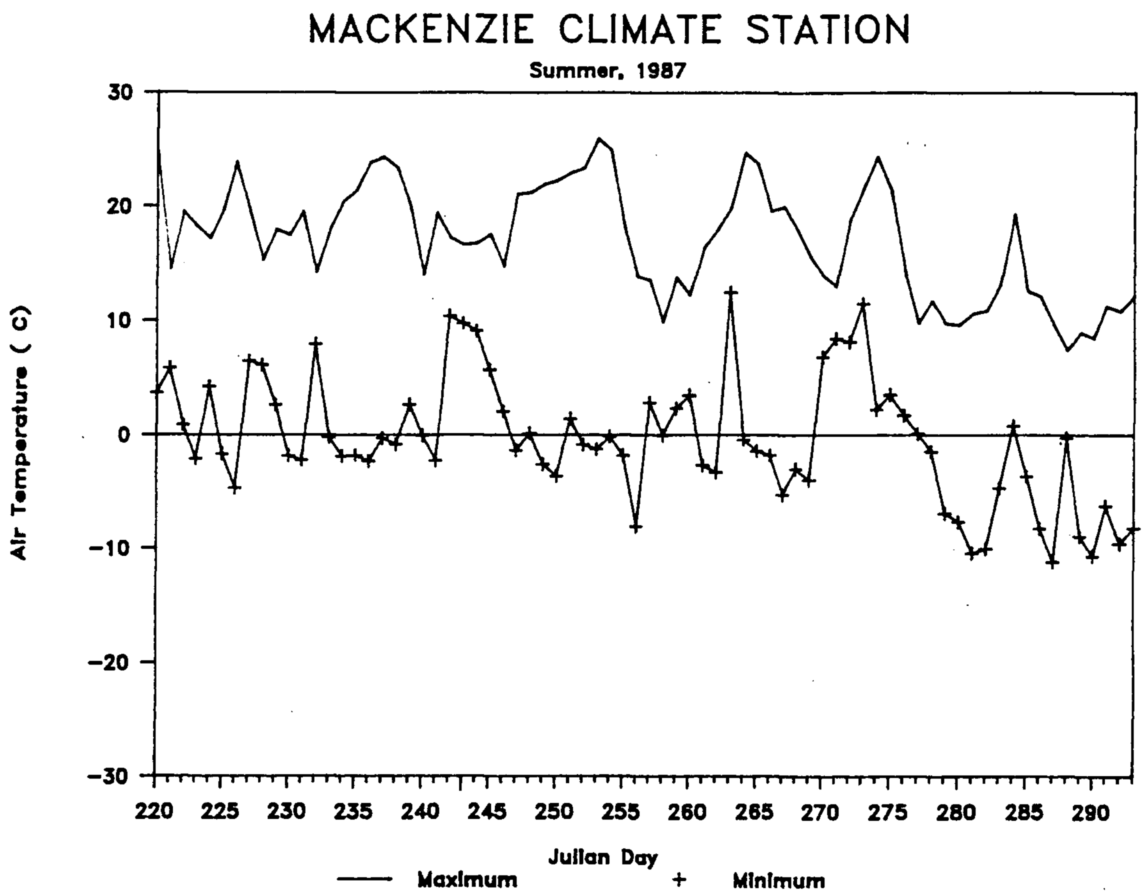
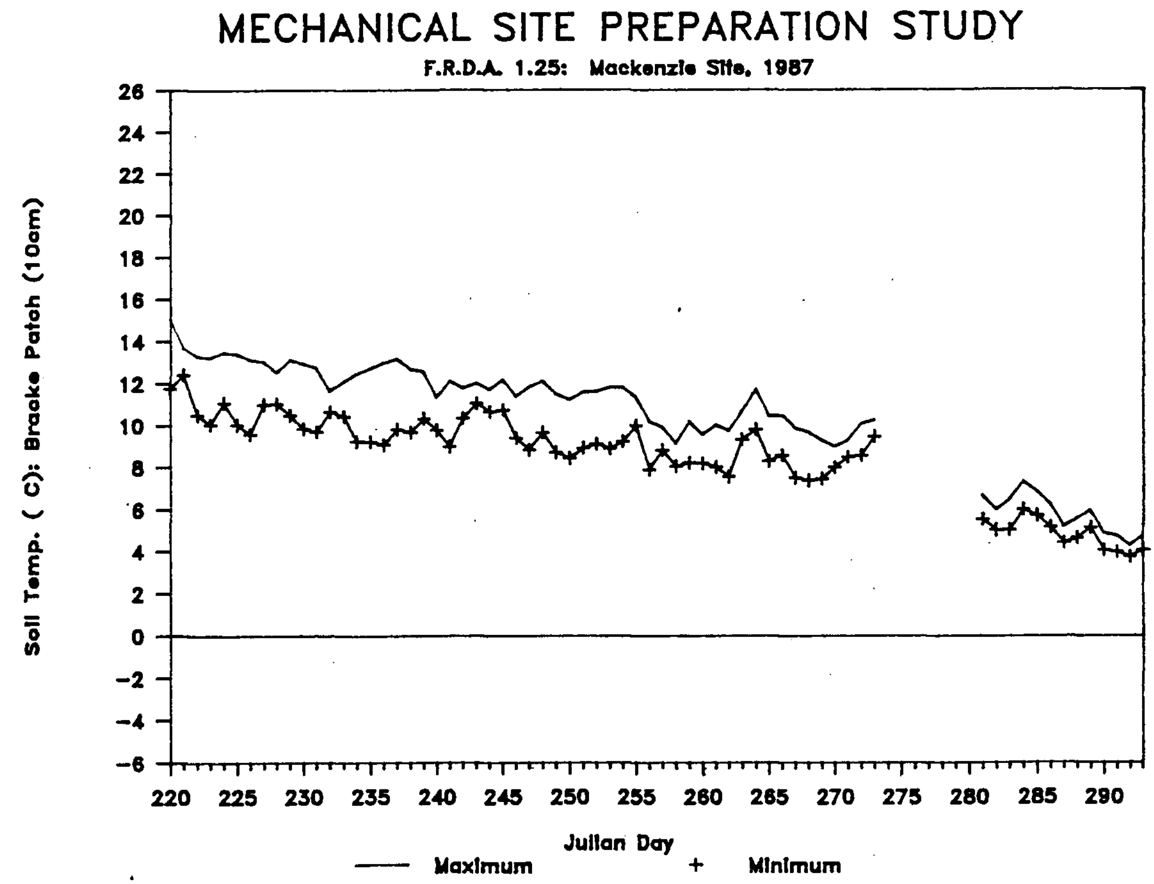
220 225 230 235 240 245 250 255 260 265 270 275 280 285 290
Julian Day


MACKENZIE CLIMATE STATION
Summer, 1987
Air Temperature (C)
30
20
10
0
-10
-20
-30
220 225 230 235 240 245 250 255 260 265 270 275 280 285 290
Julian Day
Maximum
+ Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Mackenzie Site, 1987
Soil Temp. (C): Bracke Patch (10cm)
26
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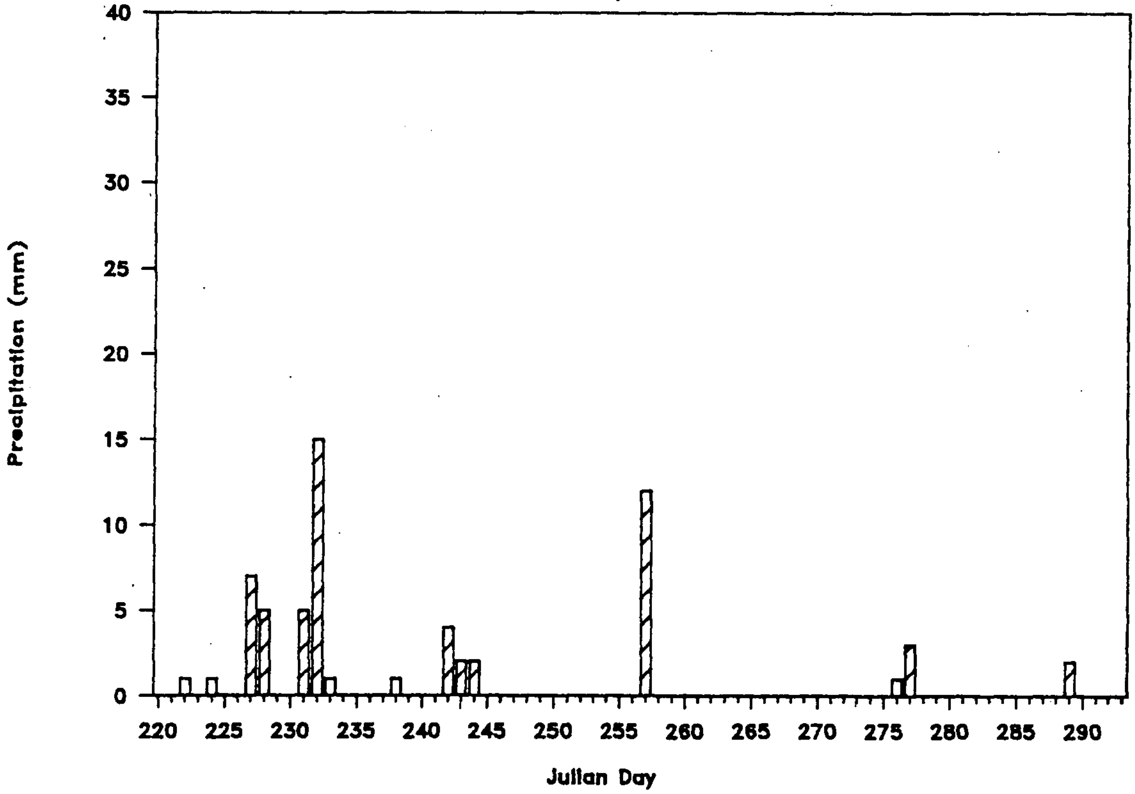
-4
-6
220 225 230 235 240 245 250 255 260 265 270 275 280 285 290
Julian Day
Maximum
+ Minimum

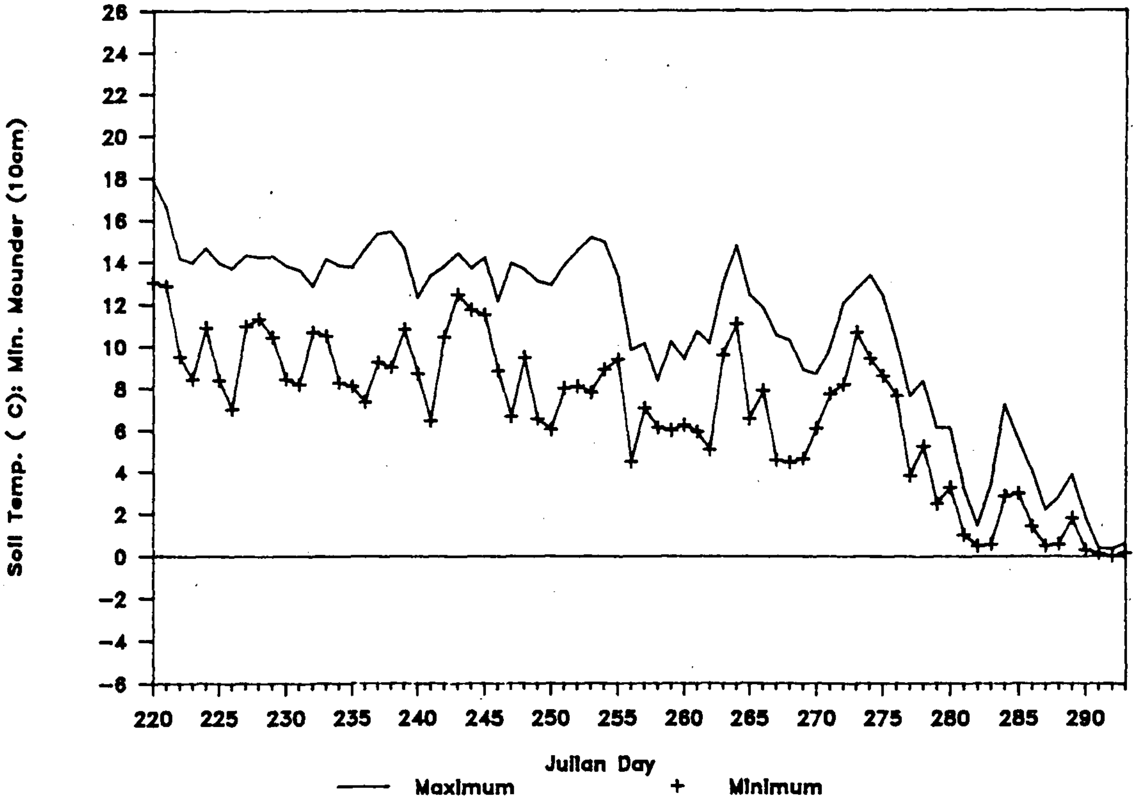
MACKENZIE CLIMATE STATION

Summer, 1987



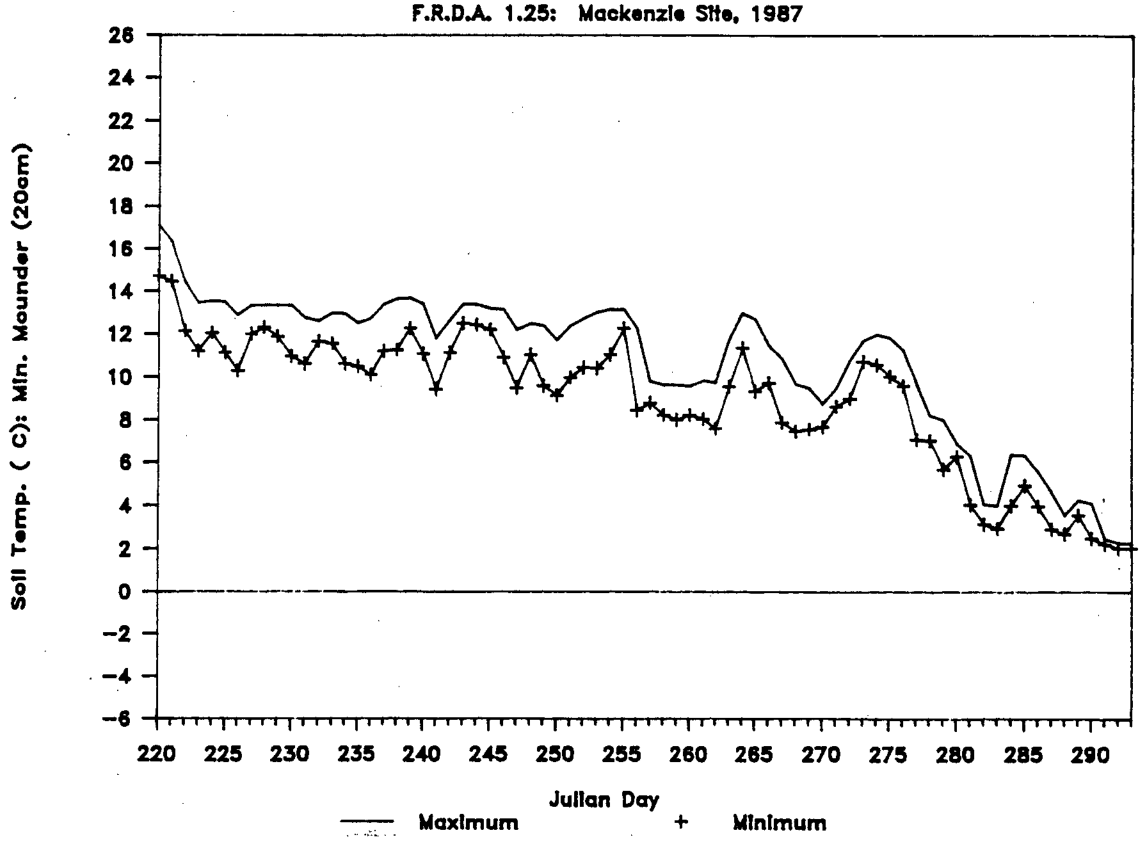
MECHANICAL SITE PREPARATION STUDY

F.R.D.A. 1.25: Mackenzie Site, 1987



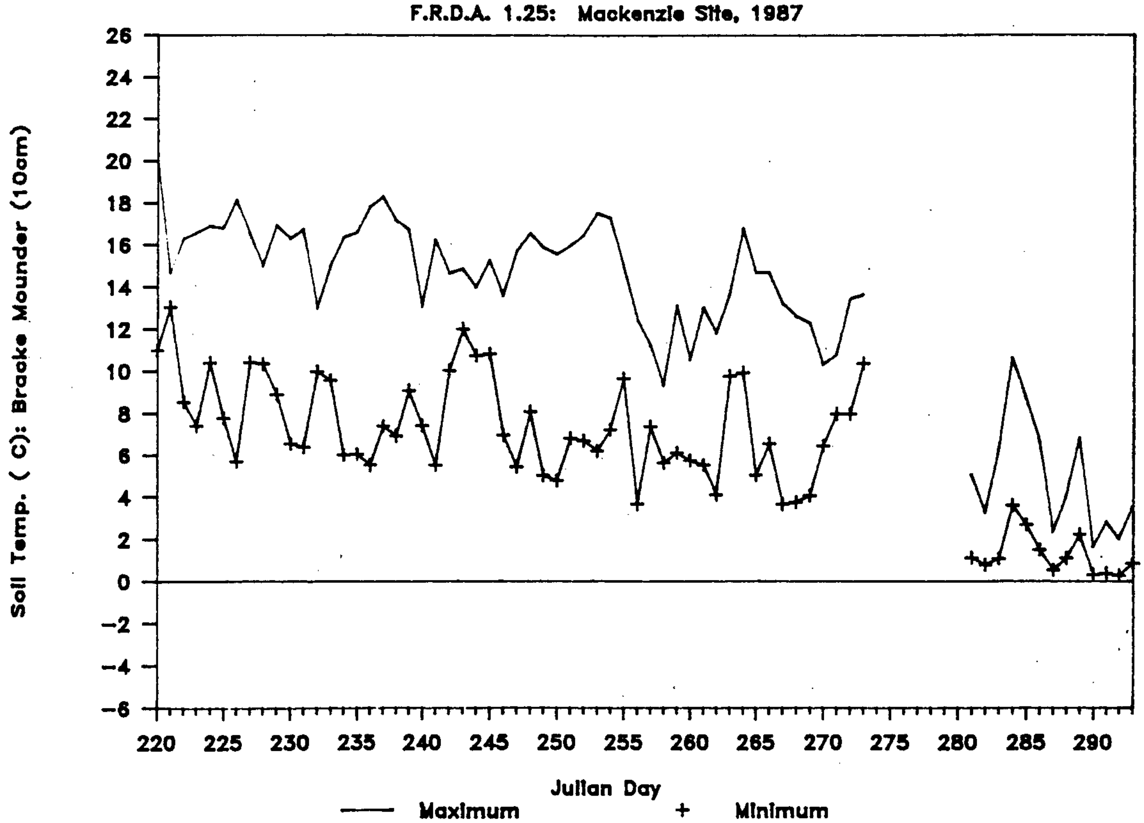
MECHANICAL SITE PREPARATION STUDY

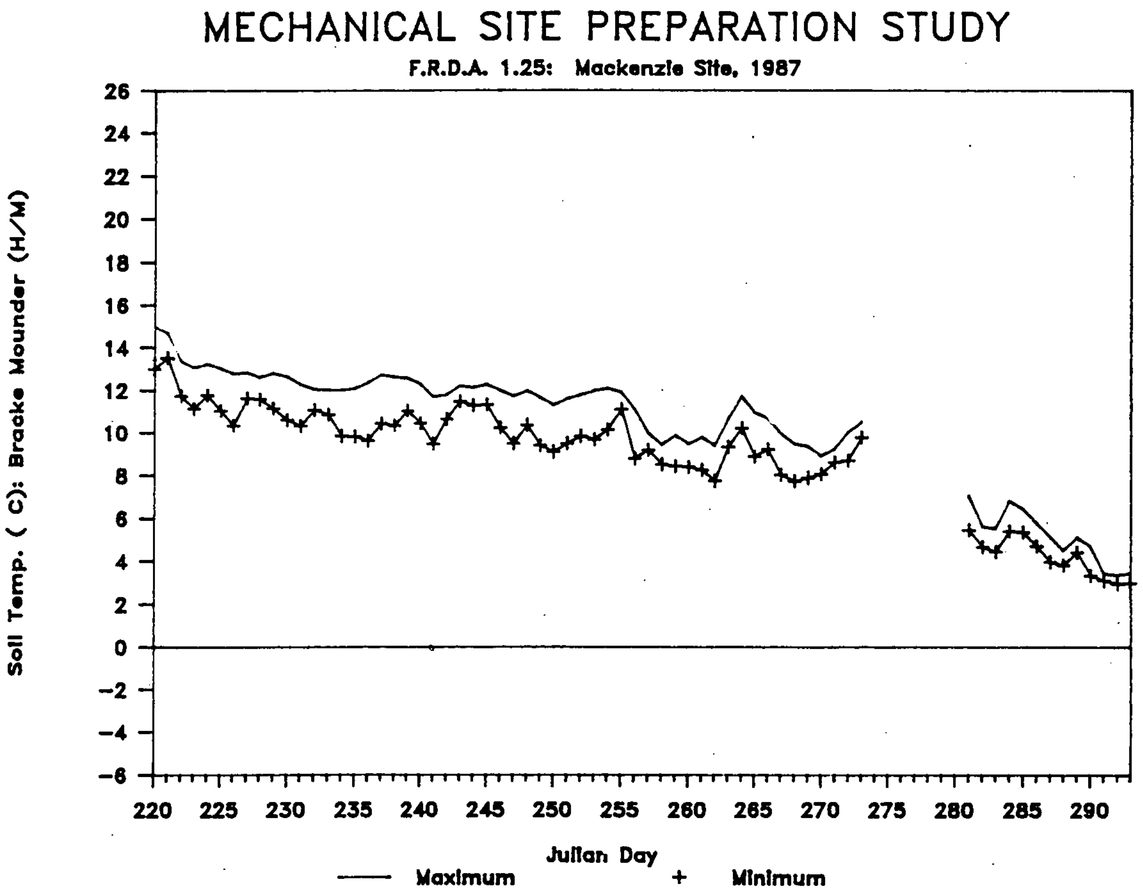
F.R.D.A. 1.25: Mackenzie Site, 1987



MECHANICAL SITE PREPARATION STUDY

F.R.D.A. 1.25: Mackenzie Site, 1987




MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Mackenzie Site, 1987
Soil Temp. (C): Bracke Mounder (H/M)
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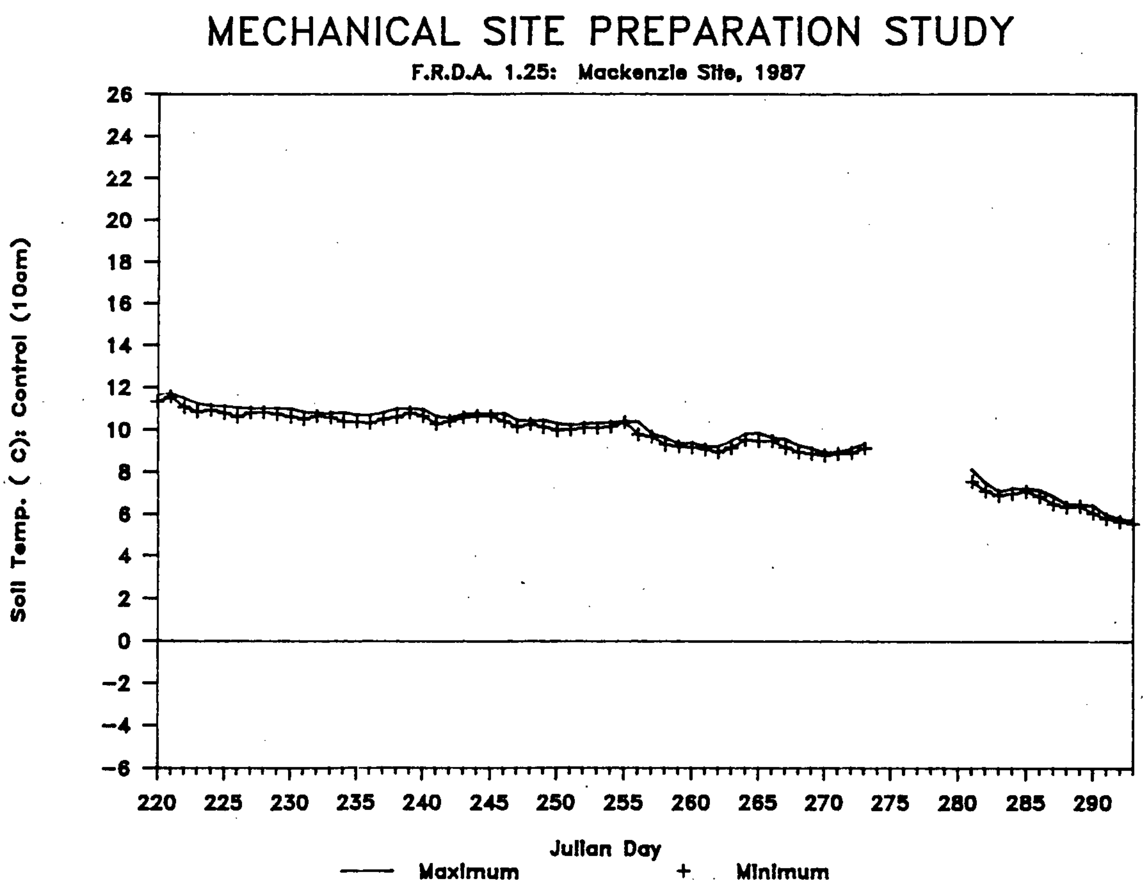
Julian Day
Maximum
Minimum


MECHANICAL SITE PREPARATION STUDY
F.R.D.A. 1.25: Mackenzie Site, 1987
Soil Temp. (C): Control (10cm)
26
24
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20
18
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220
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270
275
280
285
290
Julian Day
Maximum
Minimum

MECHANICAL SITE PREPARATION STUDY