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Interior Spruce Seedling Performance



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Post-planting Ecophysiology of Interior Spruce

by

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Introduction

In 1983 the Ministry of Forests Research Branch initiated a major new research project in the interior. Experimental project 966 focusses upon the post-planting ecophysiology of interior spruce, both white spruce (Picea glauca [Moech] Voss), and its naturally occurring hybrid with Engelmann spruce (Picea engelmannii Parry). The emphasis upon post-planting research reflects a concern for interior spruce field survival and growth performance, and is a natural extension of the successful nursery research programme. The ecophysiological framework recognizes the need to study nursery stock physiological attributes in the ecological context of the planting site.

In order to make best use of detailed and expensive ecophysiological investigations, the experiment is supported by companion silvicultural studies. These studies examine a range of silvicultural options on the same site, planted with the same nursery stock, in the same year. This organization of complimentary research studies permits faster, more direct, and more general extension of research results.

Research Site

A site was selected in the Prince George Forest Region (P.G.F.R.) (Figure 1). North-east facing slopes of the Bowron River Valley (SBS - ESSF, 800-1100 m a.s.l.) were chosen because of current logging activity and concern over regeneration success. Harvest operations on these relatively high yielding sites have often resulted, 3 years after logging, in extensive areas of herb, shrub and fern communities averaging 1.5 m in height. Slopes of 15-20%, high soil moisture and large volume residual debris constrain mechanical site preparation. Fall burning windows are short and inconsistent, and chemical vegetation control is largely untried in the area. Major biological constraints to early spruce survival and growth include low soil temperatures, excessive soil moisture, limited light availability, and snow and vegetation press.

Ecology staff of the P.G.F.R. provisionally classified the ecophysiology site as a SBS_f/01.2 (mesic shrub-devil's club-fern) association, with subhygric and permesotrophic moisture and nutrient regimes. The area was logged in the winter of 1982. In August of 1983 the site was patch scarified with a Bräcke cultivator pulled by a D7E prime mover equipped with a modified V-blade.

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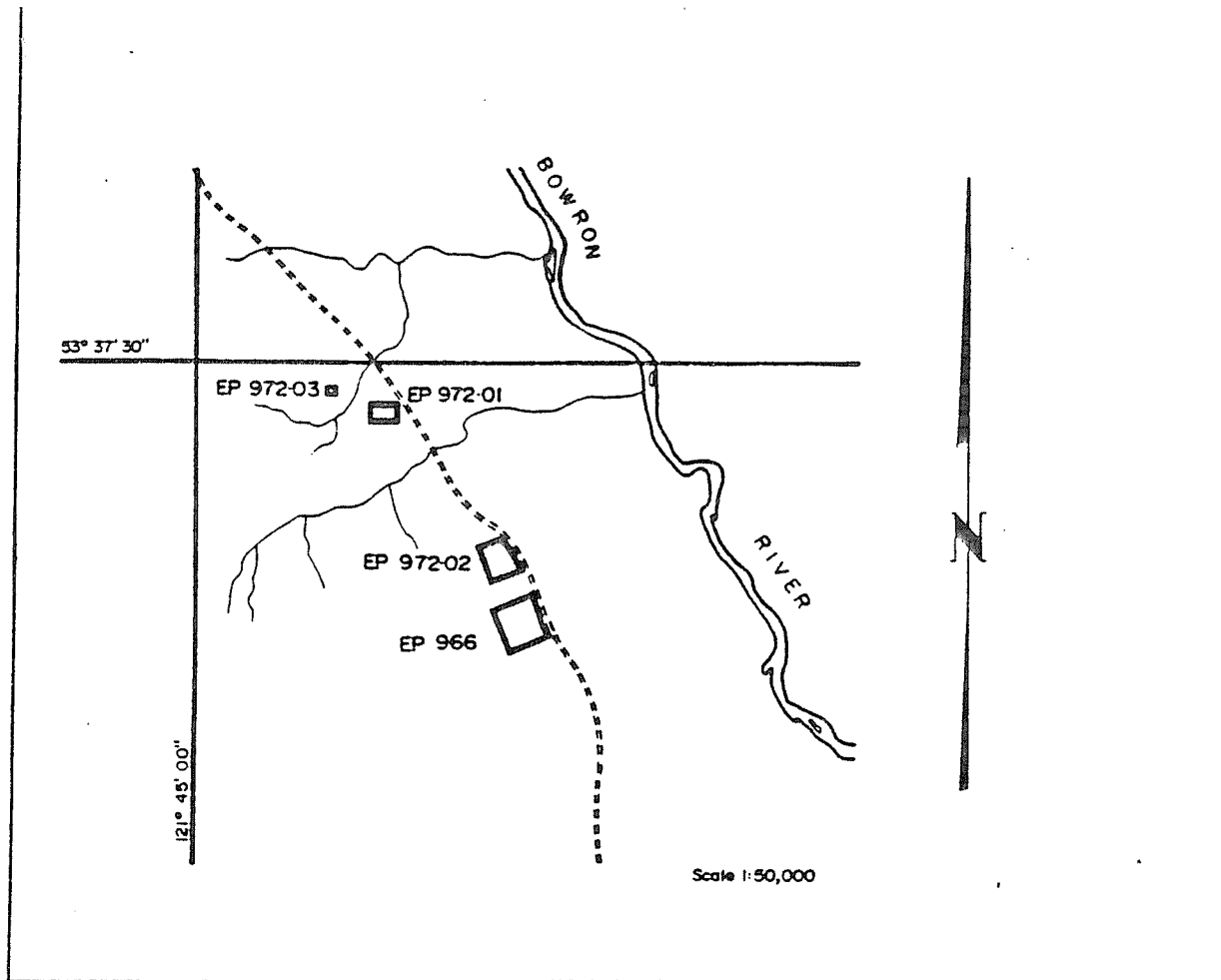


FIGURE 1 Bowron River Valley silviculture experiments.

Five microsite treatments were carried out: control, inverted organic mat, and 3 levels of mineral mounding. Figure 2 shows the 3 microsite treatments selected for intensive study and reported on here. The organic mats were 30 x 40 cm in plan area. These were manually capped with mineral soil packed loosely to depths of 6 cm (7 200 cm³), 12 cm (14 400 cm³) and 24 cm (28 800 cm³). This simulates the Bräcke cultivator, equipped with Robur Maskin A-B's Bräcke-Hoglagarre mounding attachment, which is designed to deliver 20 000 cm³ of mineral soil over an inverted organic mat (McMinn 1982).

Each treatment row (15 microsites) was replicated 18 times in a completely randomized block design. The microsites were planted on May 30 - June 1, 1984 with S.L. 4097, interior spruce 2+1 bareroot stock. Measurements reported were taken from the 4 main study areas in the project, and include data from the August 1983 to November 1984 period. Companion silvicultural research projects in the valley consider mechanical site preparation, prescribed fire, chemical vegetation control, stock size, and planting date. These are co-operative trails with R.G. McMinn (C.F.S.) and L.J. Herring (Research Officer, P.G.F.R.).

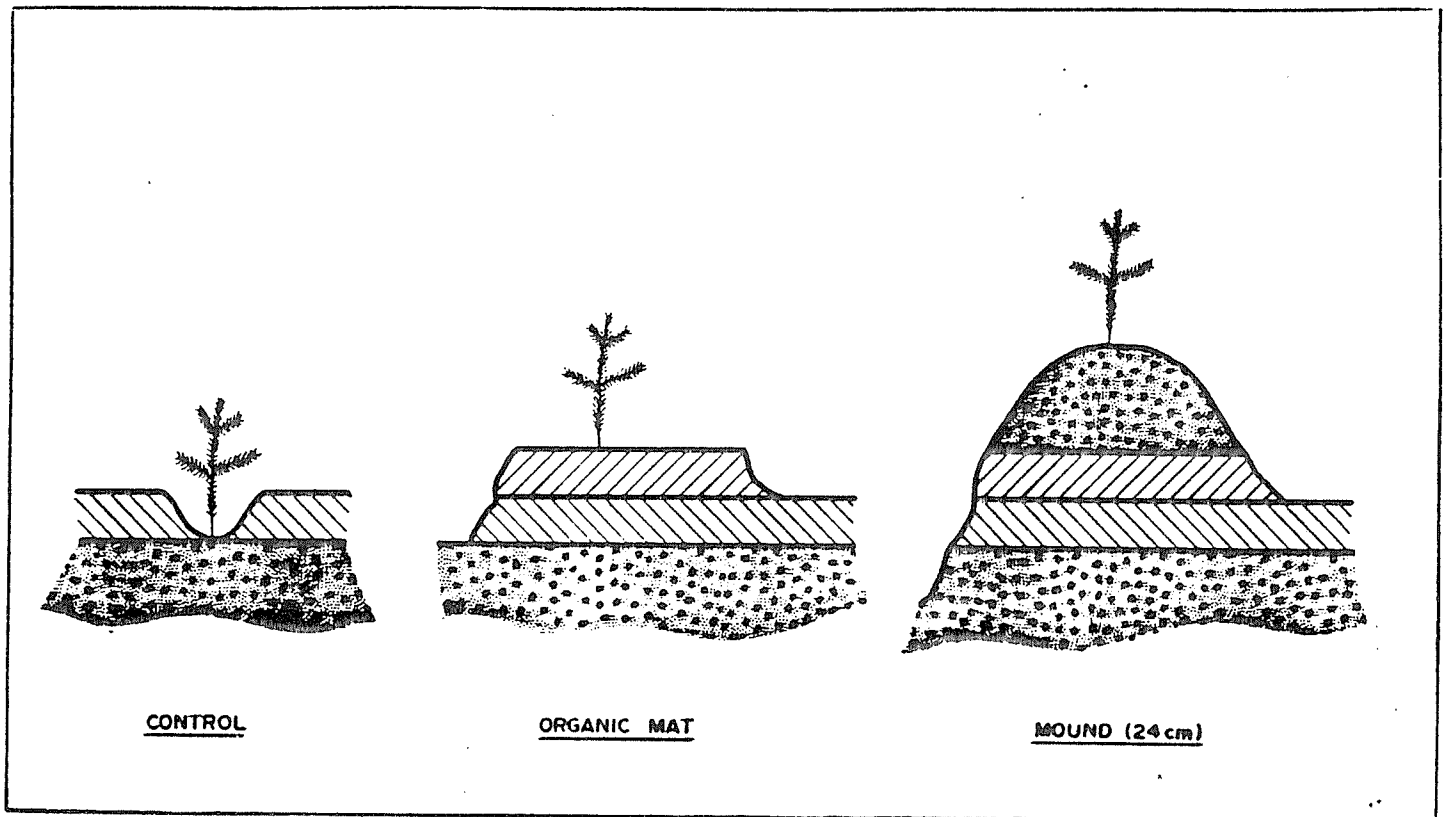


FIGURE 2 Schematic representation of the three intensively studied site preparation treatments.

Plant Physiology Studies

Post-planting physiological studies are directed toward identifying biological stresses which may limit seedling survival, growth and yield. In recent years technological advances have made field studies of detailed physiological processes possible.

Studies in this experiment include assessment of the following:

- i) carbohydrate levels before and after cold-storage and first season outplanting,
- ii) distribution of micro and macro nutrients within the plant,
- iii) chlorophyll pigments,
- iv) plant root growth,
- v) plant water potential, and
- vi) field rates of apparent plant photosynthesis.

At this time, results are available from investigations iv) through vi).

Root Growth

A main requirement for seedling survival after planting is the rapid renewal of intimate soil-root contact. The potential for root growth can be estimated by the amount of new roots grown during a specified period in a standard environment and is termed "Root Growth Capacity" (R.G.C.).

Figure 3 shows that planting stock in this experiment was lifted from the nursery when R.G.C. was high. The R.G.C. values fell initially after lifting but then recovered over time in cold storage (-2° C). Root growth capacity was high at time of outplanting (nearly 100 new roots greater than 1.0 cm per seedling). Highest field root growth was observed between 6 and 47 days after planting.

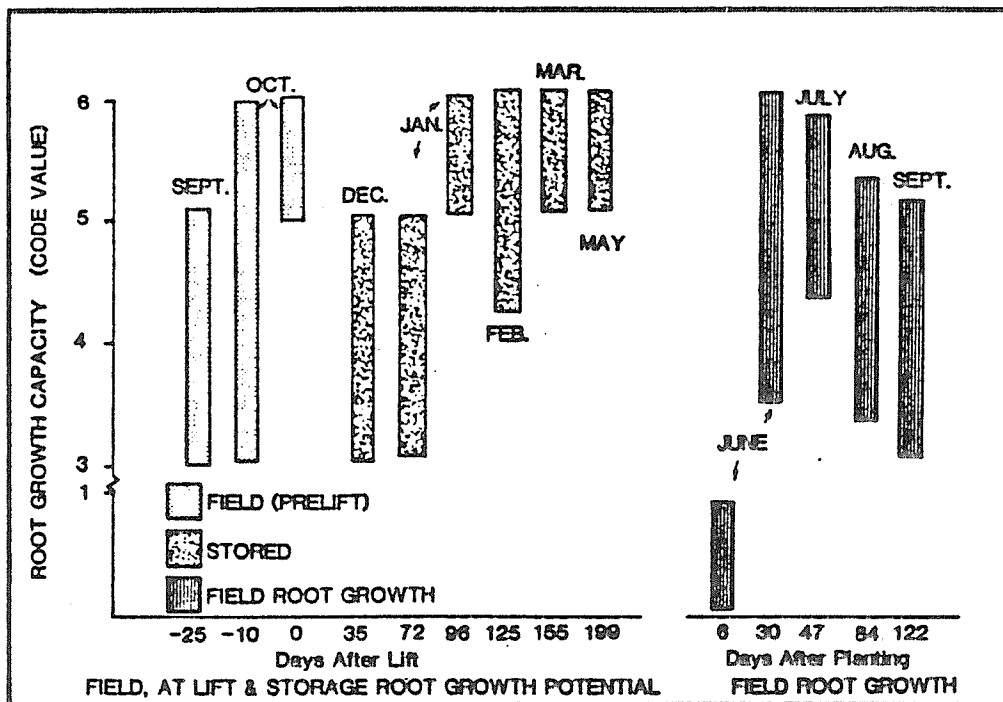


FIGURE 3 Interior spruce 2+1 root growth potential before, at, and after lift. Shown are ranges of root code values and field root growth.

Table 1 shows that type of site preparation greatly influenced amount of observed root growth. Bracketed values are actual numbers of new roots. Differences in field root growth were associated with large differences in growing degree days.

TABLE 1 Growing degree days at 10 cm in soil (5° C base). Number of new roots shown in brackets.

Days after planting	Control	Treatment Organic mat	Mound
6	1	10	21
27	62(15)	155(63)	205(95)
47	140	280	345
84	327	632	700
122	440	769	828

Water Potential

An essential factor in seedling water relations is maintenance of a sufficiently high water content (turgor) to permit normal functioning of the physiological and biochemical processes involved in growth. Turgor is regulated by relative rates of water absorption and water loss by the seedling over time. Water potential of seedlings, at any given time, can be measured by a Scholander-type pressure bomb.

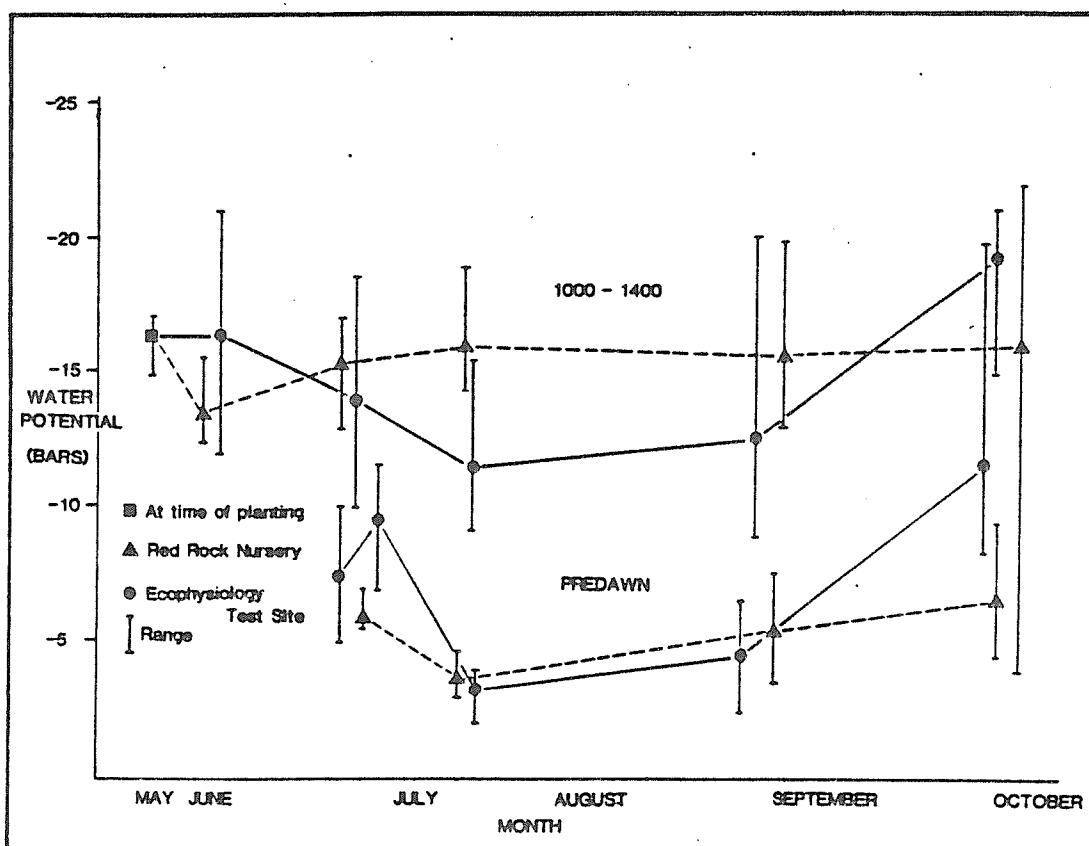


FIGURE 4 Pre-dawn and 1000 - 1400 hour seasonal water potentials.

Our experience with interior spruce, both in the field (Figures 4 and 5) and in the laboratory (Figure 6) suggests that spring and summer water potentials in healthy growing shoots should be greater than -10 bars and -15 bars, under pre-dawn and daytime conditions respectively. Daytime variation can easily be as much as ± 8 bars and depends on weather conditions (Figure 7). Fall water potentials become somewhat more negative and varied (Figure 4).

Seedling water potential is very responsive to air temperature and humidity (Figure 5). After sunrise, water potentials quickly decrease (become more negative) with increasing temperature and decreasing humidity until about -15 bars is reached. Water potential is then regulated at this value even though temperature and humidity continue to change. (Field photosynthesis data suggested that, if shoot water potential cannot be maintained at about -15 bars, stomatal closure will take place). Field data (Figure 8) and laboratory data (Figure 6) showed that, when both shoot and root water potentials are measured, seedlings in a non-stress condition always had root collar values at least 2 bars less negative than their shoot values. This separation of values appears to be maintained if 6 or more new roots are present (Figure 6). These data were confirmed by Day (1985)*

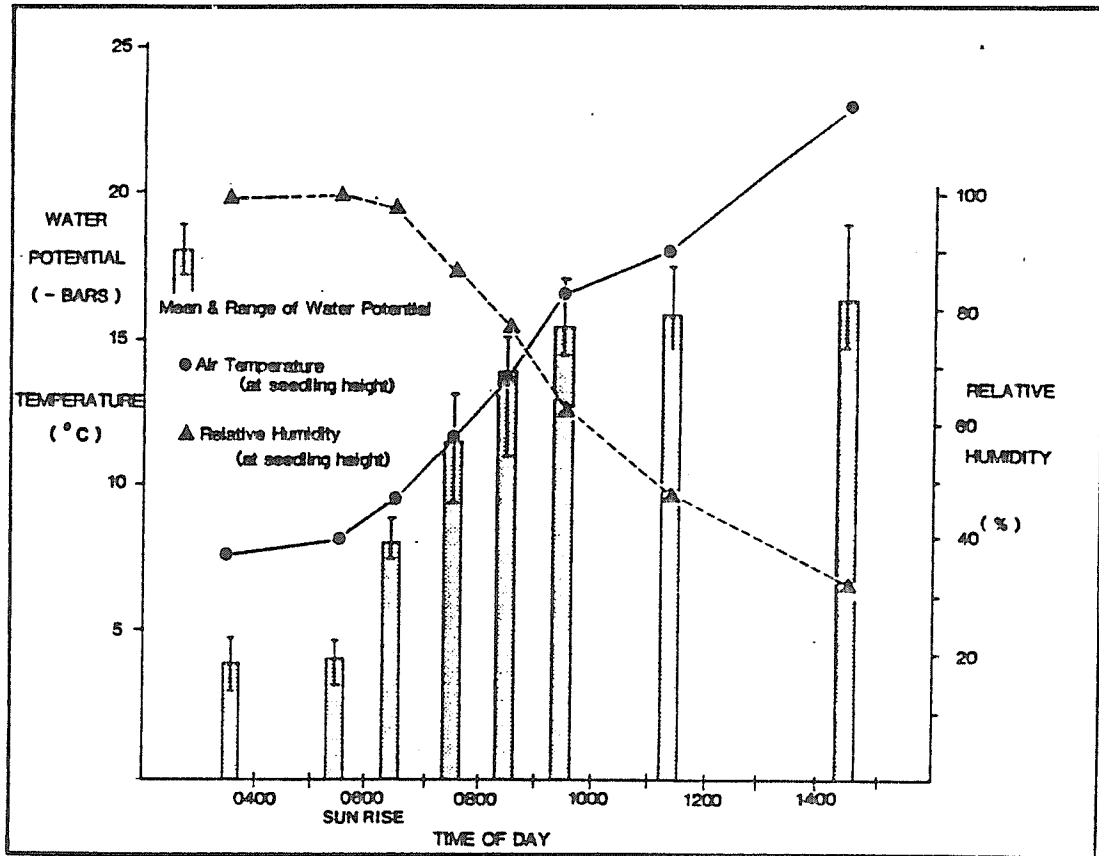


FIGURE 5 Seedling water potential, air temperature and relative humidity over time of day. July 14, 1984, Red Rock Nursery.

* Day, R.J. pers. comm. Feb. 1985.

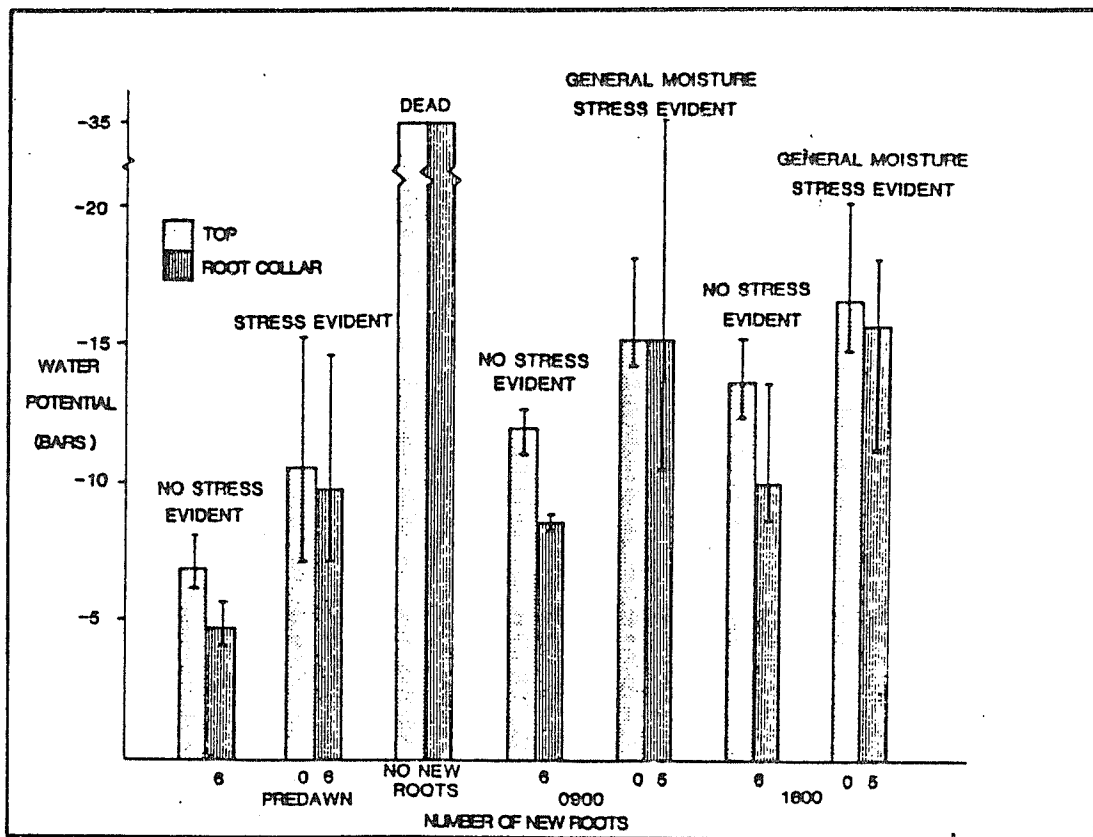


FIGURE 6 Interior spruce 2-0 bareroot water potentials of shoot and root.

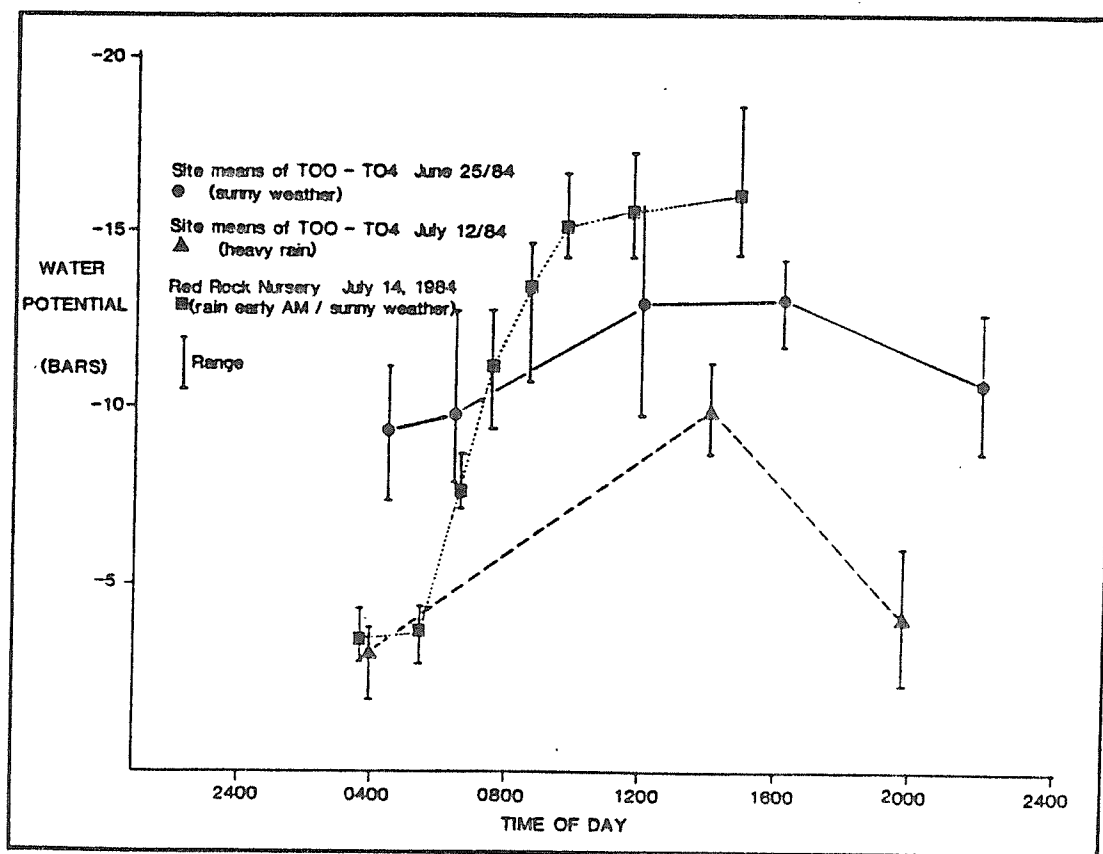


FIGURE 7 Daily water potentials of 2+1 interior spruce during the 1984 growing season.

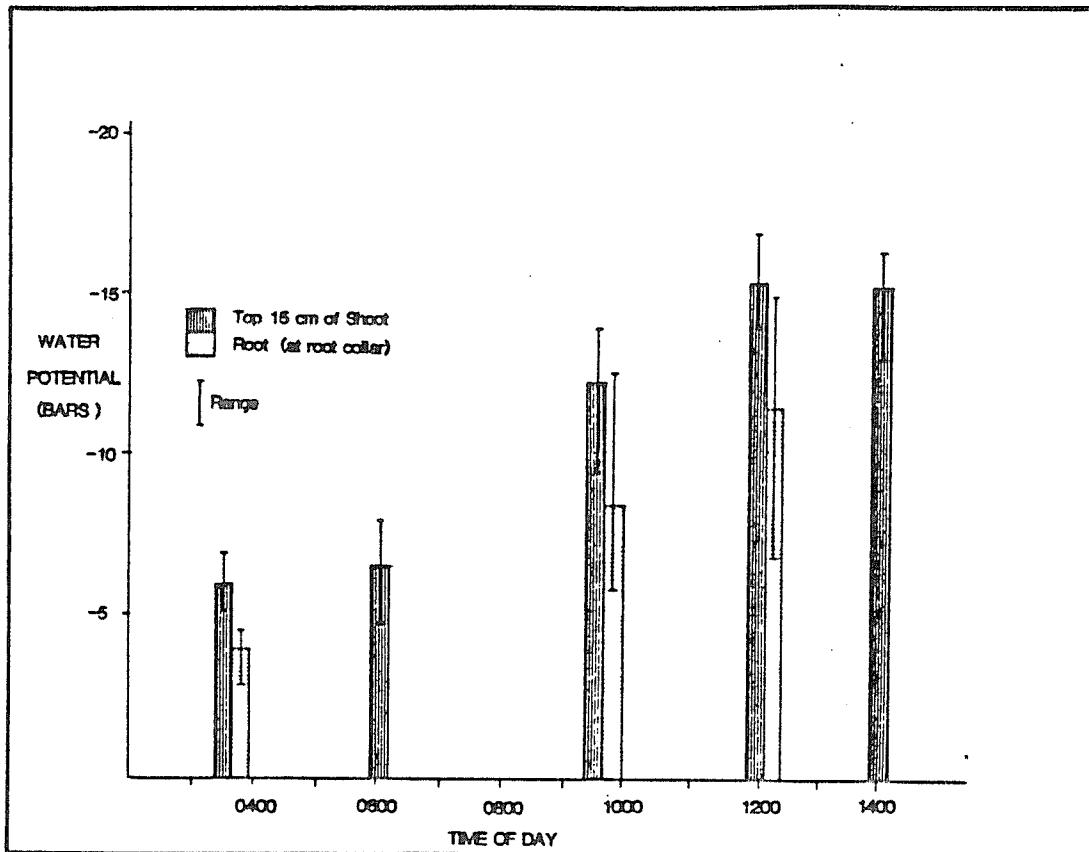


FIGURE 8 Water potentials of shoots and roots over time of day. June 22, 1984, Red Rock Nursery.

Photosynthesis

Photosynthesis is the process by which light energy is trapped and used to synthesize reduced carbon compounds from carbon dioxide and water. The process occurs only in illuminated green tissue. Major factors influencing photosynthesis are light, temperature, carbon dioxide, water, and mineral nutrition. According to Leith (1975) the total energy stored in plants each year by photosynthesis is about 100 times greater than that in all the coal mined in the world during a year. This amounts to about 10.0×10^{10} tonnes of dry matter.

Figure 9 shows field data collected one afternoon at Red Rock Nursery. Apparent photosynthesis is shown plotted against light intensity. Under these field conditions spruce appeared to saturate at about $600 \mu\text{Em}^{-2}\text{s}^{-1}$. This light saturation level has been confirmed on the test site, in our laboratory, and by Clark (1961). Preliminary results on the test site indicated that the light compensation point (point below which no net carbon uptake occurs) was approximately $100 \mu\text{Em}^{-2}\text{s}^{-1}$. Data obtained in laboratory studies further confirmed this (Binder and Lister 1984).

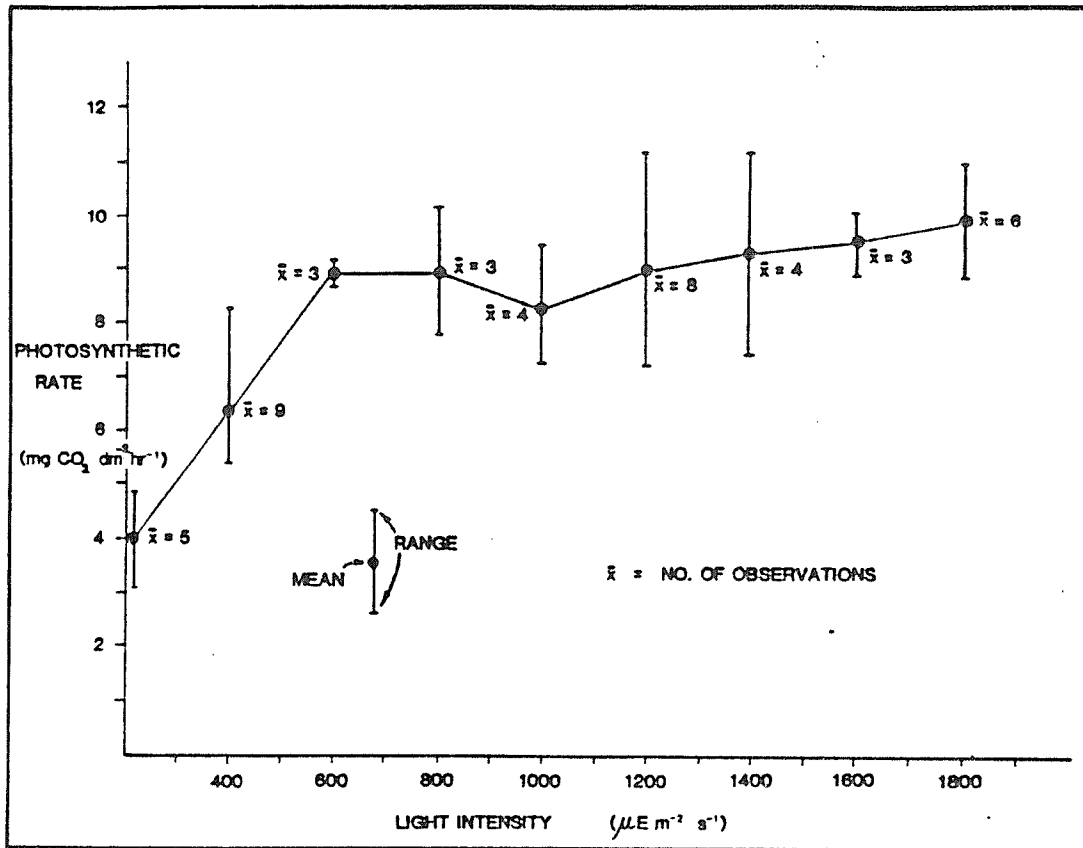


FIGURE 9 Photosynthetic rate over light intensity. August 26, 1984, Red Rock Nursery.

Site Ecology Studies

The major goal of the ecological studies in the ecophysiology programme is to determine the thermal and moisture regimes of the seedlings in the various treatments. This information is used in two ways: firstly, to provide information to be related to data on seedling survival, growth and physiology; and, secondly, to calibrate computer models that can be used to predict the influence of site factors and treatment on the seedling's environment.

Measurements are being made to quantify local weather conditions and treatment specific soil and atmospheric microclimatic conditions. These measurements include air temperature and humidity, wind speed, rainfall and radiation (photosynthetically active, solar and net) above the treatments; and soil temperature, soil heat flux, soil moisture and seedling temperature at each treatment. Electronic data loggers monitor the sensors and store this information on cassette tapes. These tapes are regularly removed and read into a microcomputer and the data are edited and analysed. Certain measurements are made manually.

Monitoring began in the fall of 1983 after mound construction. Daily soil temperatures were measured through winter 1983/84. Full scale monitoring (weekly, daily and/or hourly data) began at the time of planting (late May 1984) through to mid October 1984. Soil, snow and air temperature are being measured through winter 1984/85.

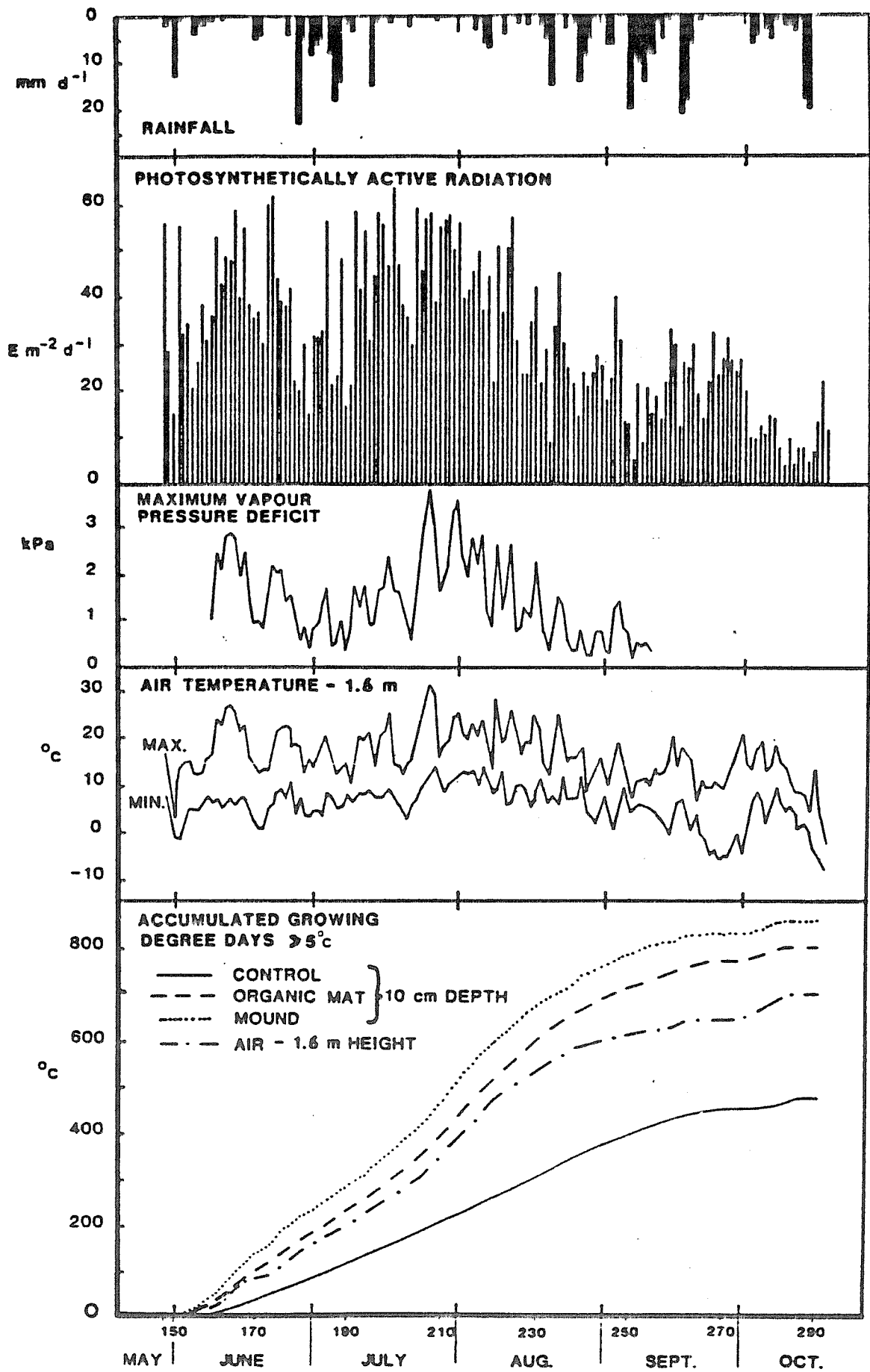


FIGURE 10 Daily weather conditions, May to October, 1984.

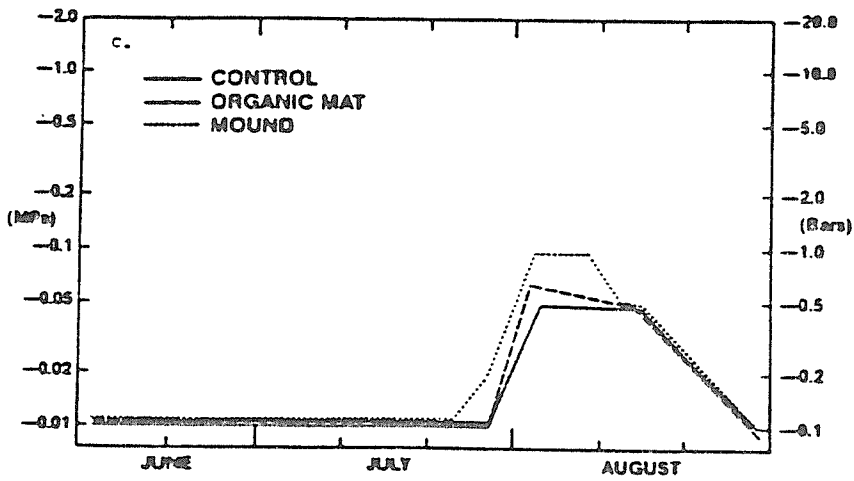
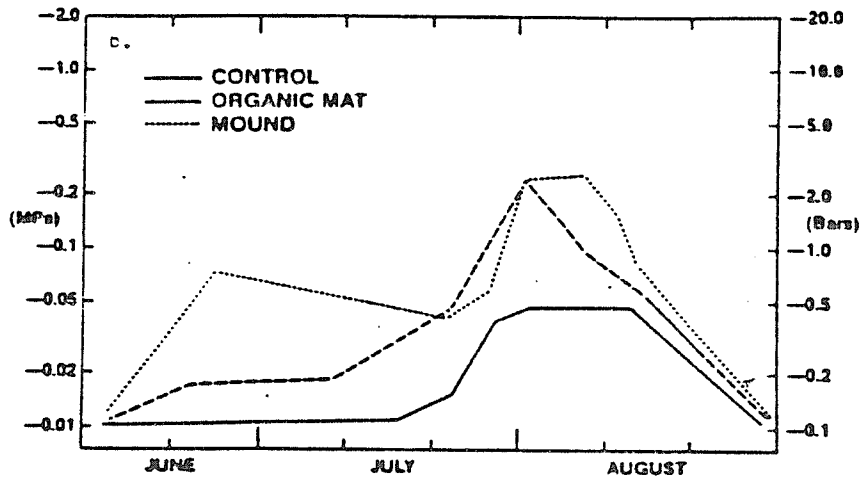
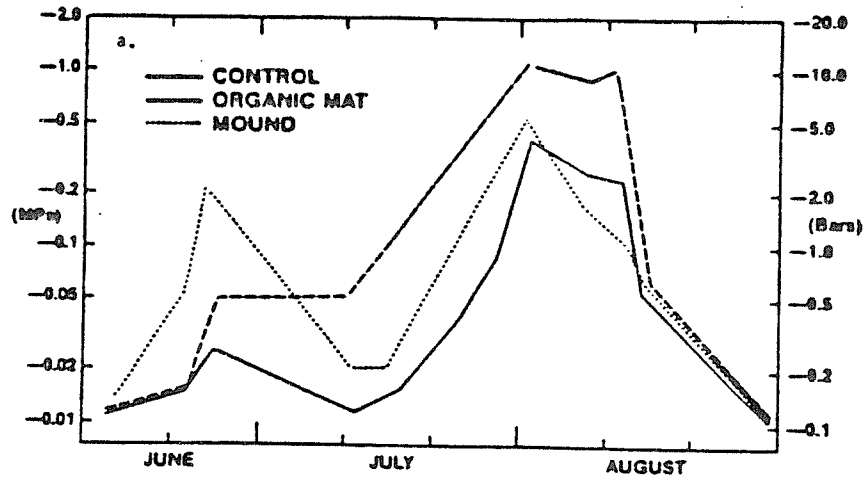


FIGURE 11 Soil water potential, June to August 1984 for the control, organic mat and mound treatments; (a) at 8 cm, (b) 20 cm and (c) 30 cm.

An initial analysis of the data is presented here. Figure 10 illustrates the variation in weather conditions from planting to mid October. Two relatively dry periods occurred during the summer, one in early June and the second from mid June to early August. These dry periods had high air temperature (20 to 30° C maximum), vapour pressure deficit and radiation conditions. The near-surface soil in all three treatments dried during these periods (Figure 11a). In general, the mounds and organic mat treatments dried out more than the control, partially resulting from a higher evaporative demand on their unshaded surfaces. The control was significantly wetter at 20 cm than the other two treatments (Figure 11b), while all three treatments were similar at 30 cm (Figure 11c).

Large differences in soil temperature were measured between treatments. Figure 10 shows the accumulated growing degree days (5° C base) at 10 cm below the surface of each treatment. The mound warmed the quickest, followed by the organic mat and then the control. The former was probably the result of the organic mat acting as an insulating layer. The latter resulted from the shading of the surface of the control by the brush and the higher heat capacity of the wetter soil. Typical diurnal soil temperatures are shown in Figure 12 for the mound and the control (the organic mat is similar to the mound). The 0.5 cm and 10 cm temperatures averaged, respectively, 10 and 7° C greater in the mound than in the control. On sunny days daytime surface temperatures on the mound and organic mat varied from 25 to 60° C depending on soil wetness and shading. Surface temperatures of the controls varied from 10 to 20° C. Winter soil temperatures fell to near zero. Snow temperatures around the seedling were about -3° C.

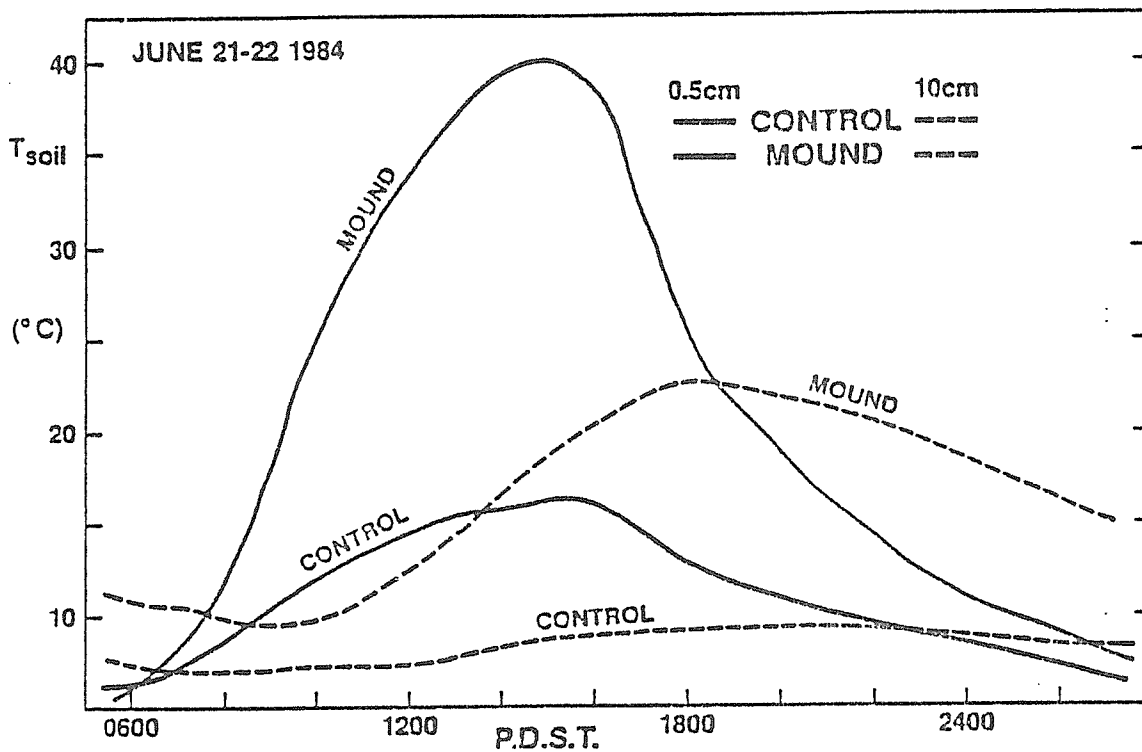


FIGURE 12 Daily 0.5 cm and 10 cm soil temperature in the mound and control. June 21-22, 1984.

Silvicultural Studies

One of the objectives of this section is to provide long-term silvicultural evaluation of site preparation treatments. Seedling survival, total height, groundline diameter and biomass measurements are the basis for this evaluation.

In order to determine the seasonal trend of some basic physiological processes on site, repeated measurements were made of mainstem shoot extension and root collar diameter increment. Apical extension was measured at roughly 14 day intervals from May 31st through September 10th on a sample of 25 trees per treatment. Measurements were made from a groundline permanent reference point to the top of the shoot. Secondary thickening, or stem diameter increments, were calculated as the difference between two serial measurements on reference points affixed at 180° on the main stem at the root collar. The use of permanent reference points and vernier calipers gave a measurement precision of ± 0.05 mm.

The seasonal trends of height and diameter increment are shown in Figure 13. Height growth was evident 15 days after planting. It peaked in mid-July and was largely finished by mid-late August. Stem diameter increment patterns showed a mid-season decline associated with both the corresponding height increment peak (Figure 13a) and mid-summer drying trends (Figure 10). No significant site preparation effects were apparent in trends of height or diameter increment.

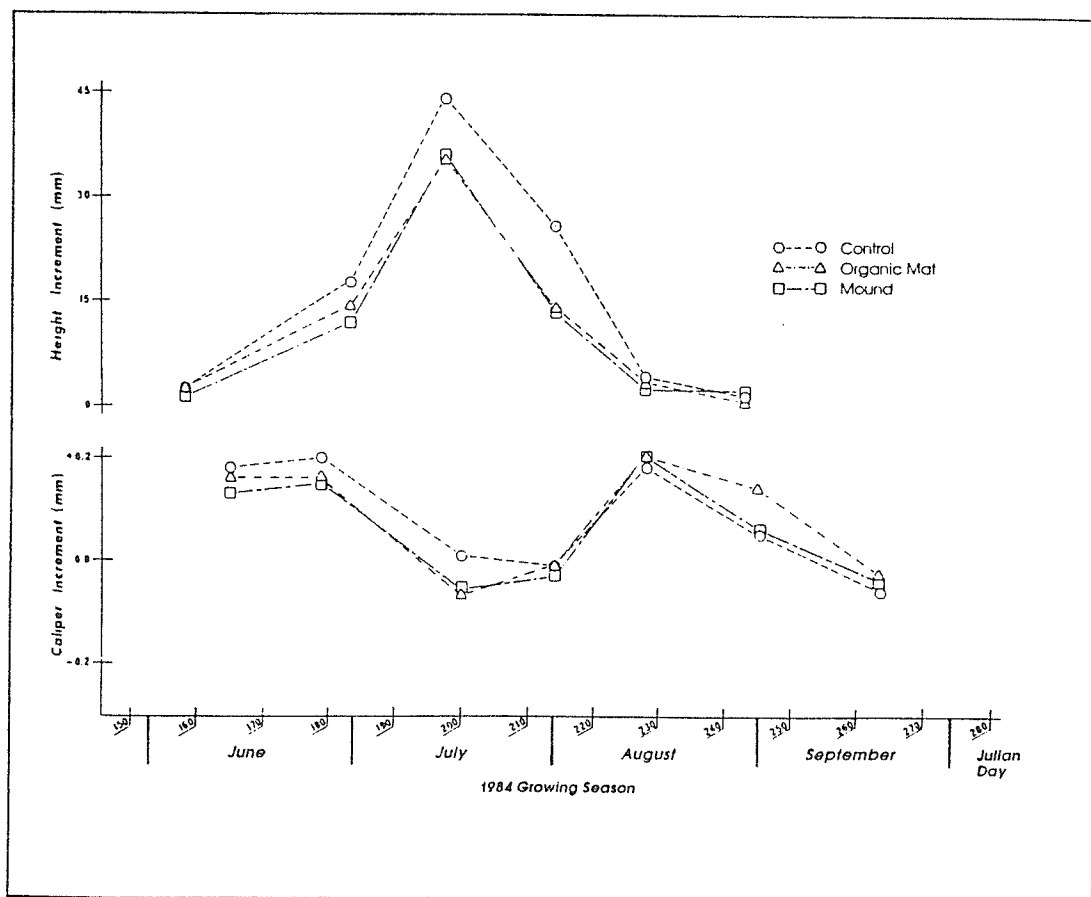


FIGURE 13 Seasonal trends in total height and ground-line stem diameter increments.

Photosynthetically active radiation (P.A.R., 400-700 nm wavelength, in $\mu\text{Em}^{-2}\text{s}^{-1}$) was measured over the season at a background level (1.5 m), and at the tip of planted seedlings in the mound and control treatments (approximately 36 cm above ground level). Li-cor 190SB quantum sensors sampled every minute and calculated 1/2 hour estimates of mean P.A.R. Figure 14 shows a typical clear day pattern. The mounding treatment light regimes were similar to background light levels. Only at low sun angles was there any appreciable light interception by competing vegetation. The control treatment, by comparison, showed a much reduced total radiation over the entire day.

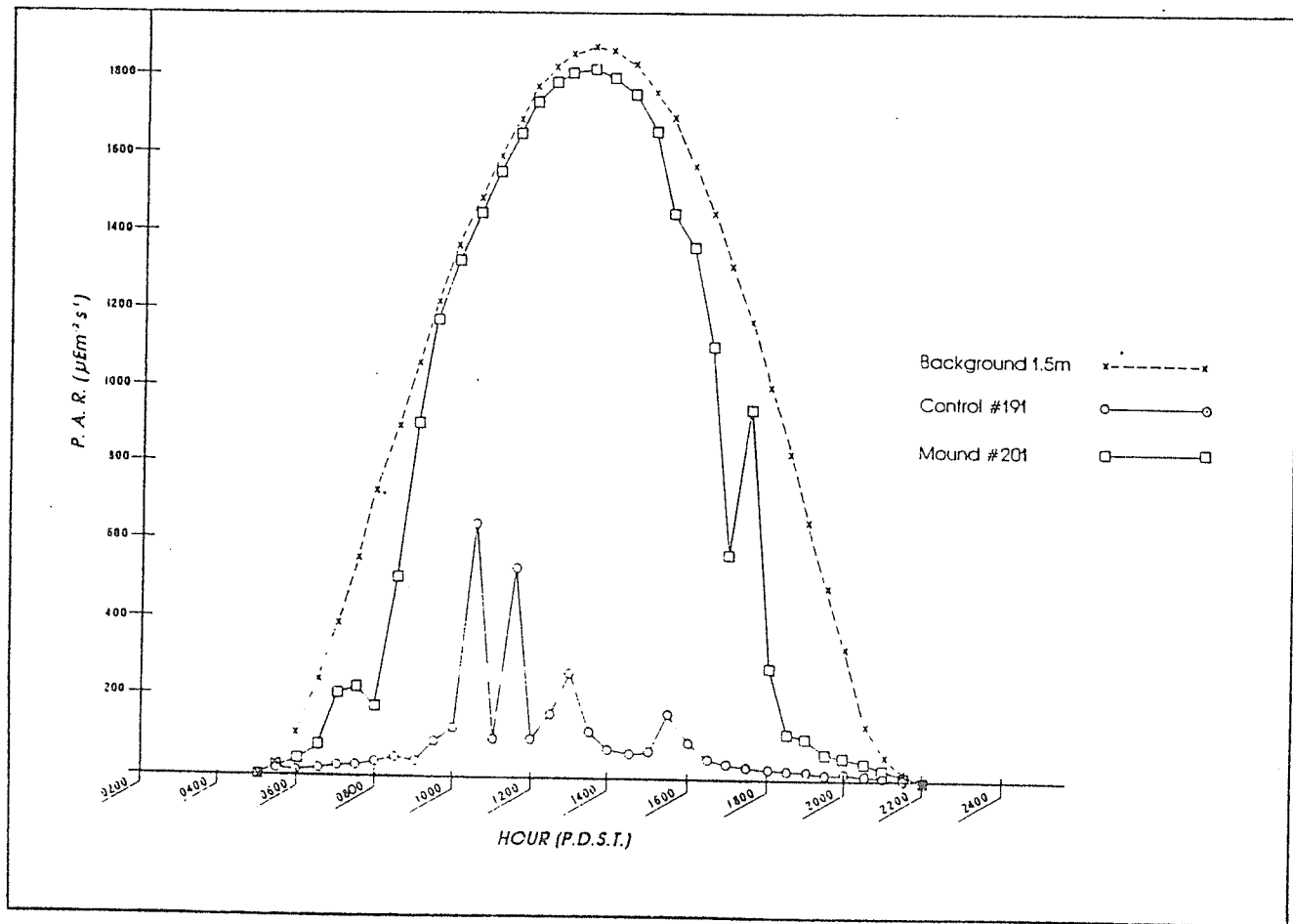


FIGURE 14 Daily pattern of photosynthetically active radiation (P.A.R.). Clear day, June 1984).

Summed over all sampled micro-sites throughout the season, the control treatment consistently received about 14% of daily background P.A.R., while mounds received over 70% (Figure 15). The relative increase and eventual coincidence of treatment lines in October - November was associated with reductions of competitive vegetation by fall frosts.

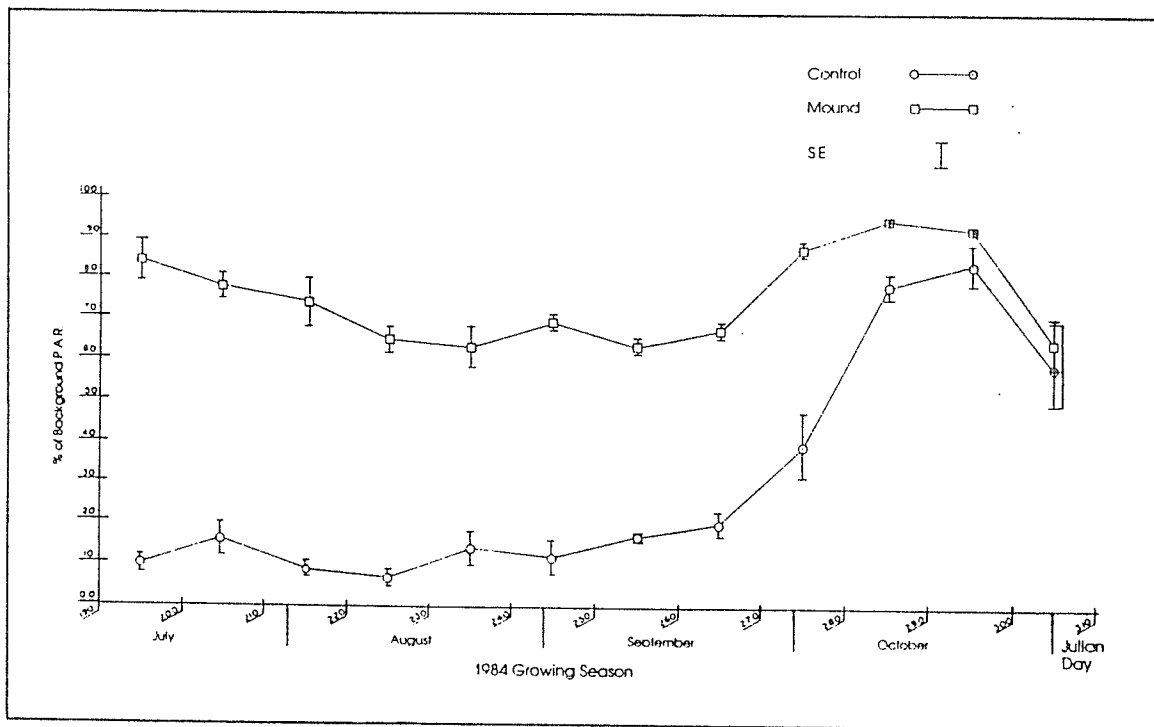


FIGURE 15 Seasonal differences in received radiation of mounding treatment and control.

Soil Fertility and Plant Nutrition Study

The primary aim of this segment of the programme is to evaluate, in relation to site conditions and treatment effects, the nutritional status of the planted spruce seedlings. The study consists of the following components:

1) Foliar analysis

Analysis of foliar nutrient concentrations in current year foliage has become the most accepted method of interpreting nutritional deficiencies in forest trees. In order to provide an index of the nutrient status of the seedlings prior to planting, foliar analysis of macronutrients (N, P, K, Ca, Mg, S) and of micronutrients (B, Cu, Fe, Mn, Zn) was carried out on a sample of seedlings (30) taken from cold storage in May 1984. At the end of the first growing season (October, 1984), samples of current foliage from 25 seedlings, planted in each of the three site preparation treatments, were analysed for micro macronutrients. Some preliminary results from this work are given below. Future foliar analyses will be carried out annually, in conjunction with biomass sampling.

ii) Mycorrhizal status of seedlings

The objective of this study is to determine the degree of ectomycorrhizal development and the species and abundance of specific fungal symbionts present on the roots of white spruce seedlings at the following times: before cold storage (October, 1983), after cold storage (May, 1984) and one growing season after outplanting (October, 1984). This work is being done under contract to the University of Calgary. A final report is anticipated by the end of March, 1985.

iii) Soil characteristics

In order to assess the impact of the site preparation treatments on soil fertility and subsequent plant nutrition, various chemical and physical soil parameters were measured on the three intensively monitored treatments (control, inverted organic mat and mound). At the time of planting, eighteen samples per treatment were taken (where applicable) from the following strata: mineral mound, inverted organic material, in situ organics, 0-15.0 cm mineral soil and 15.1-30.0 cm mineral soil. Analyses include the following: particle size, bulk density, pH, cation exchange capacity, exchangeable bases, available P, total C, total N and mineralizable N. Analytical results will be available by March 1985. Further soil analyses will be carried out where warranted by foliar analysis results. In addition to the above soil parameters, soil water retention and hydraulic conductivity characteristics of the site are under study.

Table 2 summarizes foliar nutrient concentration data for samples taken from cold storage (pre-planting) and from the three site treatments (after one growing season). Using these data, along with the critical levels and the deficiency diagnosis system employed by Ballard (1984), interpretations of seedling nutritional status were made.

TABLE 2 Nutrient concentrations in current foliage.

Nutrient	Pre-plant		Control		Mound		Organic mat	
	mean	S.E.	mean	S.E.	mean	S.E.	mean	S.E.
N %	2.03 ±	.045	1.25 ±	0.11	1.24 ±	.076	1.04 ±	.051
P %	0.24 ±	.003	0.23 ±	.018	0.23 ±	.018	0.19 ±	.006
K %	0.71 ±	.023	0.77 ±	.056	0.68 ±	.071	0.64 ±	.023
Ca %	0.79 ±	.028	0.12 ±	.013	0.22 ±	.019	0.15 ±	.011
Mg %	0.12 ±	.005	0.08 ±	.005	0.09 ±	.005	0.08 ±	.003
S %	0.22 ±	.009	0.12 ±	.009	0.10 ±	.004	0.09 ±	.003
B ppm	17.5 ±	1.06	9.7 ±	0.79	8.3 ±	0.51	8.9 ±	0.45
Fe ppm	26.6 ±	25.6	42.6 ±	4.41	36.7 ±	2.12	32.0 ±	1.77
Mn ppm	93.1 ±	72.8	34.0 ±	33.8	57.5 ±	56.0	35.7 ±	27.2
Zn ppm	30.4 ±	1.39	17.7 ±	1.75	23.9 ±	2.51	21.4 ±	1.54
Cu ppm	3.5 ±	0.12	2.0 ±	0.23	2.0 ±	0.12	1.9 ±	0.10

Prior to planting, most nutrients were in ample supply. The only exception was magnesium, the concentration of which was barely sufficient. After one growing season, there was an apparent "falldown" in foliar concentrations of a number of nutrients. From the October 1984 data, nitrogen, calcium and magnesium could be diagnosed as deficient, and boron as marginally deficient. Figure 16 illustrates these reductions in nutrient concentrations.

The N/S ratio indicated that sulphur nutrition was marginal. Copper and iron concentrations were also reduced to possibly deficient levels. Both these elements require further scrutiny. The critical level for total Fe is not well established. Ballard (1981) has suggested that "active iron" may be a better index of Fe nutrition.

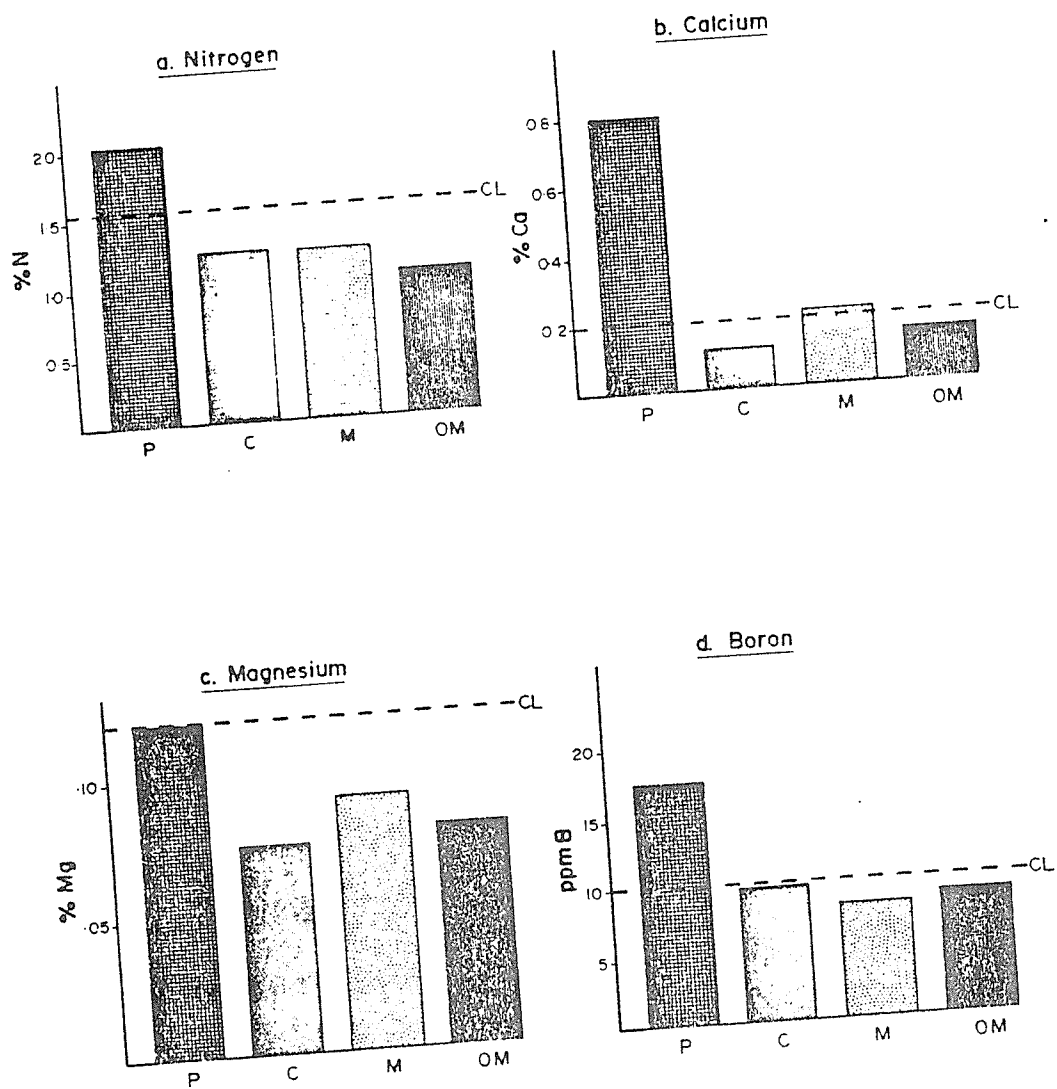


FIGURE 16 Changes in nutrient concentrations after one growing season. P - preplanting (May 1984), C, M and OM - postplanting (Oct. 1984) control, mound and organic mat treatments respectively. CL - critical level below which growth may be limited.

While the above data assisted in profiling the nutrient status of seedlings in the first growing season, results are preliminary. Further nutrient monitoring is planned as the seedlings acclimatize and exploit their planting environment.

Discussion

The different site preparation treatments created a range of planting site micro-environments. Radiation and soil temperature characteristics differed between treatments, and these differences were associated with observed field root growth (Table 1). Mound micro-sites reached a 10°C mean soil temperature on June 4th (5 days after planting). The control treatment, however, did not reach this temperature until July 24th (58 days after planting). By June 20th, the mound micro-sites had 6 times as many roots as control micro-sites. Over the first growing seasons mounding also tripled the number of days with a mean soil temperature greater than 10°C .

The long-term benefits associated with this thermal increase have yet to be assessed. However, this study supports McMinn's (1982) contention that soil warming is of primary importance to seedling establishment in sub-boreal ecosystems.

Incident radiation, aside from increasing soil temperature, is important silviculturally when there is severe competition for light. Physiological thresholds, such as light saturation and light compensation points, aid in assessing the biological significance of different treatment light regimes. The average control micro-site was exposed to light levels above compensation point for only 3 hours, or 24%, of the mean daily light period. By comparison, mounds were above light compensation for 11 hours, or 86%, of the same daily period. Assuming incident light in the $100\text{-}600\ \mu\text{Em}^{-2}\text{s}^{-1}$ intensity range is the most important for photosynthesis, calculations showed that mounds received over 4 times the total daily light energy of controls. The implication of this on relative rates of dry matter production is considerable.

No end of growing season biomass data are available yet. However, mid-season results (August 1, 1984) showed that, 62 days after planting, above-ground biomass values for the mound and organic mat treatments exceeded control treatment values by 40% and 10% respectively.

The mound micro-sites received considerable radiation in excess of light saturation ($600\ \mu\text{Em}^{-2}\text{s}^{-1}$) (Figure 14). A common question posed in the north-central interior is, "Are spruce in open or clear-cut conditions likely to suffer chlorophyll destruction, or solarization damage?" By September of the first growing season exposed seedlings, of all treatments, appeared yellower and were lower in total chlorophyll levels than seedlings beneath a canopy of competing vegetation. However, "yellow" seedlings may also have been associated with different first season growth rates, and different levels of mineral nutrition. Further experimentation is underway to isolate and assess factors implicated in solarization.

Observations to date provide no direct evidence of deleterious effects resulting from increasing exposure of spruce seedlings. Point measurements of soil surface temperatures as high as 60° C were observed without apparent subsequent damage. Although at depths of 8 and 20 cm mound and organic mat micro-sites were dryer than control (Figure 11), this did not appear to be a major limitation to growth.

Summary

Early results from this experiment were encouraging; both with respect to the interpretive usefulness of the studies undertaken, and the apparent early success of inverted mineral mounds. After more than 6 months in cold storage (-2° C), interior spruce 2+1 transplant stock performed well in the field. Root activity was apparent 6 days after planting and was well correlated with soil temperature.

The nursery seedlings were nutritionally well-balanced. The significance of first year nutrient fall downs will be assessed in subsequent years.

Strikingly different climatic and edaphic micro-site characteristics resulted from the different site preparation techniques. A provisional assessment of the implications of these results on early plant performance have been made and follow-up study is in progress. Constraints to successful regeneration included low soil temperature and light competition. Inverted mineral mounds alleviated these conditions and should ultimately improve seedling survival and growth.

Continued studies will assess the duration of site preparation effects and build upon our understanding of the relationship between micro-site environment and seedling physiology.

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