GROWTH OF INTERIOR SPRUCE SEEDLINGS ON FOREST FLOOR MATERIALS

by

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ABSTRACT

On a site with a high water table and thick forest floor near Smithers, B.C., two year-old Interior spruce (Picea glauca (Moench) Voss X Picea engelmanni Parry) container seedlings were outplanted onto mineral soil, H-layer material, F-layer material, and rotten wood. Large and small screef sizes were utilized. Temperature and volumetric water contents of the various substrates were monitored over the 1989 growing season, and fertilization with NH_4NO_3 was carried out at the beginning of the 1990 growing season. Destructive sampling of the seedling population took place in August 1989 and August 1990 in order to determine height, root collar diameter, root mass, shoot mass, total seedling mass, and shoot to root ratio. Foliar N concentrations were also determined in late August 1990.

Differences in height and diameter for the seven screef size/substrate treatments were not significant, but the organic substrates produced seedlings of greater root, shoot, and total seedling mass than did mineral soil. Greater seedling mass was correlated most strongly with higher substrate temperature, and to a lesser extent with lower soil moisture content, as well as with higher foliar N concentration. There were no significant differences in survival between the treatments. Seedlings growing in the organic substrates had higher foliar N levels, and fertilization improved growth for all parameters.

It is concluded that on sites such as this, better growth results can be achieved by planting Interior spruce seedlings high above the water table in F-layer material, where conditions are warmer and drier, than by making deep screefs down to more traditionally acceptable planting substrates such as mineral soil or even the well decomposed H-layer material.

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1.0 INTRODUCTION

White spruce (Picea glauca (Moench) Voss) is a major timber species of north-central British Columbia, and it commonly crosses with Engelmann spruce (Picea engelmanni Parry) to form a hybrid known as Interior spruce. Although some of the literature refers to Interior spruce, the majority of work has been done on pure white spruce. Since the two are closely related, and it is not usually known to what degree hybridization takes place, this study assumes that research concerning the pure species also applies to the hybrid.

It is generally recommended that white spruce seedlings be planted in mineral soil, as organic materials of the forest floor have been thought to be an unsuitable substrate. For most sites where the water table is not close to the soil surface this policy is correct, because forest floor materials can dry out during hot summer weather, as reported by Potts (1985). Also, since low soil temperature is often a limiting factor to seedling growth in north-central B.C., thermal properties such as conductivity, heat capacity, and diffusivity make mineral soil more likely to warm up at depth than organic materials. This however, assumes that both materials are equally exposed to solar radiation. On some sites, particularly in the Interior Cedar-Hemlock zone near Hazelton, the forest floor can be thick and the water table high, so that the mineral soil is insulated from solar radiation, remaining cold and waterlogged for most of the growing season. Broadcast burning is a common form of site preparation in the Hazelton area, but it may be ineffectual at reducing the thickness of the forest floor in wetter, lower slope areas.

Other site preparation methods such as mounding are aimed at alleviating this problem through creation of microsites that are warmer and drier. However, this procedure is costly and the equipment is not always readily available, particularly if problem areas are limited to small portions of larger clearcut blocks.

This study investigates the possibility that on sites with a thick forest floor and high water table that have not been mechanically site prepared, forest floor material may be an appropriate planting substrate for Interior spruce seedlings.

The objectives of the study were as follows:

1....To compare growth and survival of Interior spruce seedlings planted in F-layer material, H-layer material, mineral soil, and rotten wood.

2....To determine whether soil temperature had an effect on growth and survival of the seedlings.

3....To determine whether soil moisture content had an effect on growth and survival of the seedlings.

4....To determine whether nitrogen was a limiting factor to seedling growth on this site.

2.0 LITERATURE REVIEW

2.1 GROWTH CHECK IN WHITE SPRUCE

Interior spruce is a valuable crop tree in B.C., and is the species most abundantly planted. In 1987, Interior spruce, together with white spruce and Engelmann spruce, comprised 48% of the seedlings grown in British Columbia (Silv. Br. MOF, 1987). In spite of the abundance with which we are planting these species and the hybrid, there are problems with growth and survival rates on particular site types. It is not unusual for white spruce seedlings to undergo a period of growth check after outplanting. Growth check is described by Mullin (1963) as a condition where shoots of seedlings do not extend more than 1 inch (2.5 cm) per year, whereas in the nursery, shoot extension of 6 inches (15 cm) per year is common. Foliage is generally chlorotic, and needles are abnormally short.

Overall survival rates for white spruce and Interior spruce in B.C. in 1990 were 69% and 83% respectively (Silv.Br. MOF, 1990, unpubl.), but there are some problem areas where survival is low enough to have warranted problem analyses. One of these was done for the Sub-Boreal Spruce (SBS) and Boreal White and Black Spruce (BWBS) zones in the Prince George Forest Region of B.C. (Butt 1986). In this study the main causes of plantation failure were perceived to be brush competition, cold soils, and inappropriate moisture conditions. Another problem analysis was done for the Interior Cedar-Hemlock (ICH) zone in the Prince Rupert Forest Region (Beaudry and McCullough 1989), where the main factors associated with regeneration failure were perceived to be poor treatment timing, brush competition, and poor site prescriptions as a result of lack of experience and data. Shallow soils, deep humus, excessive moisture, snow press, and low impact site preparation which stimulated competing vegetation were also regarded as important factors. Of the above list of factors, it is mainly soil temperature, soil moisture, and forest floor depth, as well as nitrogen availability that are relevant to this project, and which will be discussed below.

A number of researchers have looked at the physiological response to low rooting temperature and excessive moisture. These have mostly been controlled environment studies, but as well there have been some ecophysiological studies that have attempted to assess the combination of factors found in the field.

2.2 SOIL TEMPERATURE EFFECTS

The optimum temperature for root growth of white spruce is 19^{o}C, (Heninger and White 1974), but according to Binder *et al.* (1987), the average midsummer soil temperature on some sites in north-central B.C. was 10^{o}C at 10cm depth. In addition to soil temperatures being well below the optimum for root growth of white spruce, Dobbs and McMinn (1977) found that shoot growth is hindered as well by low soil temperature. They found such noticeable differences in shoot growth at various soil temperatures that they suggest a threshold soil temperature exists around 10^{o}C, below which shoot growth progresses more slowly.

In part, cold soils are a direct result of climate, in that the winters are long and cold, and the growing season is short, so that the number of degree-days accumulated by a site over the growing season is relatively small. The climate, in combination with the type of coniferous vegetation in northern ecosystems typically leads to the development of a mor humus form (Kimmins 1987), which is thick and slow to decompose. Klinka *et al.* (1981)

define a mor humus as having distinct F and H horizons greater than 1 cm, and being predominantly mycogenous. Fungi decompose organic material relatively slowly, and there is a tendency, which becomes more marked with increasing altitude and latitude, for northern ecosystems to accumulate organic matter through the rotation (Salonius 1983).

The thermal properties of organic material are such that a thick forest floor acts as an insulating layer, preventing the lower mineral horizons from warming up significantly, even when air temperatures rise in mid-summer. This is especially true in cases where there is a high water table. Thermal conductivity (λ), which is a measure of how well a material moves heat, is lower for organic material than for mineral soil, partly because of the physical properties of the material, and partly because of the larger amount of air spaces in the organic material. Stathers and Spittlehouse (1990) state that the thermal conductivity of dry mineral soil is five times that of dry organic material. Since water is a better conducter than air, and because water improves thermal contact between soil particles, moist soils have higher thermal conductivity than dry soils (Lutz and Chandler 1946). Volumetric heat capacity (C) is also important. It is a measure of the amount of heat required to raise the temperature of a given volume of soil by $1^{o}C$. Dry mineral soil has a volumetric heat capacity that is 3.3 times that of dry organic material (Stathers and Spittlehouse 1990), and the heat capacity of both materials is raised as water content increases. Thermal diffusivity (λ/C) is a measure of how much and how rapidly a material will be warmed at depth in response to surface temperature change. Organic material has a lower thermal diffusivity than mineral soil, with the result that underlying horizons remain cold the year round. Low thermal admittance ($\lambda C)^{0.5}$ accounts for the large surface temperature fluctuations sometimes associated with forest floor materials, especially in the Southern interior of British Columbia. It was previously thought that root collar damage occurred as a result of extremely high temperatures at the surface of the organic layer, but it has since been shown by Black *et al.* (1991) that the damage is a result of summer frost. Since a relatively small amount of heat is stored by the surface of the forest floor, that material cools rapidly at night and does not warm the air above it sufficiently to prevent frost damage to the seedlings.

2.3 WATER RELATIONS

A number of explanations for the condition of growth check in white spruce are found in the literature. One theory is that growth check is a result of internal moisture stress leading to stomatal closure and reduced rates of photosynthesis, and hence reduced growth rates. Binder *et al.* (1987) think it possible that slow growth in white spruce is a result of just such a well developed drought resistance mechanism. This idea is supported by work by Buxton *et al.* (1985) who found that for lodgepole pine and white spruce, survival was inversely proportional to shoot growth when the seedlings were subjected to severe drought stress. White spruce had higher survival, but less growth than pine under these circumstances. Under moderate water stress, however, it was found that white spruce experienced stomatal closure gradually with increasing water stress, whereas lodgepole pine did not close its stomàta until water stress was much greater. This suggests that pine is able to endure normal diurnal temperature and humidity fluctuations without stomatal closure, whereas white spruce seedlings will respond to gradually increasing internal moisture stress by gradual stomatal closure.

There are several reasons why moisture stress may occur for white spruce seedlings, besides the most obvious which is lack of available soil moisture. The literature suggests that soil temperature and ability for water uptake are linked in white spruce seedlings, and Goldstein *et al.* (1985) even suggest that the position of treeline in northern ecosystems is determined by soil temperatures that limit water uptake rather than by summer air temperatures. Although viscosity of water increases as temperature drops, it accounts for only part of the resistance to water uptake at low soil temperatures. This is particularly the case in seedlings removed from cold storage and grown at low soil temperatures, and it is suggested that cold storage may somehow decrease the permeability of root cell membranes (Grossnickle and Blake 1985). This effect on resistance to water uptake was found to be reversible with time, but resulted in a period of water stress for newly planted seedlings.

Delucia (1986) however, feels that cold soils affect photosynthetic rate in more ways than by creating water stress in the seedling. He worked with Engelmann spruce and found that leaf intracellular CO_2 levels were not well correlated with either photosynthesis or stomatal behavior, and suggested that low soil temperatures somehow decrease the strength of the carbohydrate sink in the roots. This would allow accumulation of carbohydrates in the shoot and hence decrease photosynthesis through feedback inhibition.

Another cause of poor water uptake in white spruce is flooding or waterlogged soil conditions. Lees (1964) found that total immersion of white spruce seedlings for 14 days resulted in 100% mortality, whereas shorter periods of flooding caused less seedling death. Two-year-old seedlings were more tolerant of flooding than one-year-old seedlings. Grossnickle (1986) found that flooding caused reduction in white spruce root growth, a condition that persisted even after flooding subsided. In this experiment, seedling water stress was exacerbated by cold storage. Chronically waterlogged soils tend to be deficient in oxygen, and Zinkan *et al.* (1974) showed that lowering the oxygen content in the soil solution to 27% of normal resulted in reduced vitality and growth in white spruce, as well as foliar nitrogen deficiency. Another problem, particularly in chronically waterlogged soils, is that chemically reduced forms of elements such as iron and manganese can exist in concentrations high enough to be toxic to roots. This was found to be the case for iron on a Sitka spruce plantation in Britain (Sanderson and Armstrong 1980). Krajina *et al.* (1982) discuss the silvics of white spruce, and report that this species thrives on sites that are flooded frequently. This seems to be in contradiction with the research discussed above, but it may have to do with an inappropriate comparison between nursery seedlings and wild seedlings, since nursery seedlings, particularly if cold-stored, may have less ability to withstand flooding. Also, short periods of flooding would not result in anaerobic conditions, particularly at cold temperatures.

Poor root-soil contact as a result of plug shape and planting technique can also cause water stress. As well, bulk density of soil may restrict expansion of the root system. Minore *et al.* (1969) found Sitka spruce roots to have less ability to penetrate soils of high bulk density than did roots of other species, such as lodgepole pine.

Another cause of water stress in white spruce seedlings which leads to stomatal closure is low air humidity. White spruce responds to decreasing air humidity by gradual stomatal closure, whereas lodgepole pine appears to have a threshold point that allows it to withstand lower humidity levels before stomata close. The implications are that lodgepole pine may be better suited to enduring diurnal fluctuations in air humidity than white spruce (Grossnickle and Blake 1986; 1987).

2.4 EFFECTS OF NITROGEN AVAILABILITY

The element that is most commonly limiting to tree growth in northern coniferous forests is nitrogen (Armson 1977). It is essential to production of amino acids and proteins, and one of the main symptoms of a deficiency is chlorosis, indicating an inhibition of chlorophyll production (Kimmins 1987).

Although nitrogen is abundant in forest systems, it may be of limited availability as ammonium (NH_4^+) or nitrate (NO_3^-), which are the forms usable by plants. In northern forest soils ammonium is more abundant than nitrate because of the low pH, and because nitrate is readily leached. The relative rates of immobilization and mineralization contribute to availability of nitrogen (Knowles 1969). In cold soils the rate of decomposition proceeds slowly, which is one reason why availability of nitrogen is limited. Van Cleve *et al.* (1990) showed that concentrations of ammonium-N were greatly increased when soil was heated to 8-10^{o}C above ambient temperature. Nitrogen concentrations in the needles of black spruce (Picea mariana (Mill.) B.S.P.) were also increased significantly by this treatment.

3.0 EXPERIMENTAL METHODS

3.01 SITE DESCRIPTION

A cutblock was chosen approximately 25 km W. of Smithers, B.C., in the Trout Creek valley, near the headwaters of the Kitseguecla River, at an elevation of 700 meters. This site is in the Interior Cedar-Hemlock moist cold subzone (ICHmc1), and before logging supported a stand composed mainly of western hemlock and some large white spruce, with a few scattered subalpine fir. The research area was situated on a bench, on the lower portion of a 15-20% slope, of NW aspect. The humus-form was a hemihumimor according to criteria in Klinka *et al.* (1981), with an average H-layer thickness of 14.7 cm and an average F-layer thickness of 10.6 cm. The mineral soil was a Gleyed Humo-Ferric Podzol (Canadian Soil Survey Committee 1978) with a texture of loam to clay-loam. The site is classified as hygric according to Walmsley *et al.* (1980), with a water table ranging from 3-4 cm above the surface of the mineral horizon to 10-15 cm below the surface of the mineral horizon, depending on weather and position in the microtopography of the research area. The site prescription produced by Pacific Inland Resources recommended planting Interior spruce.

The experimental area was approximately 0.3 hectares in size and was chosen because of its thick forest floor with well differentiated horizons, as well as because it appeared to be fairly homogenous in the characteristics of the forest floor and height of the water table.

3.02 STOCK TYPE

Interior spruce container stock (Sx 313 Psb) was planted between June 12 and June 17, 1989. It had been grown and cold-stored in a local Smithers nursery.

3.03 EXPERIMENTAL DESIGN

This experiment uses a randomized complete block design with a split plot allocation of the watering treatment. There were three blocks, each split into two sub-blocks (refer to Figure 3.03.A), for which seedlings in one sub-block were watered weekly and not watered in the other sub-block. The watering treatment took place during the summer of 1989, and was subsequently shown to have had no significant effect. Therefore the same split-plot layout was used in the summer of 1990 to administer a nitrogen fertilization treatment. There were seven treatments, each with 27 replicates in each of the 6 sub-blocks, for a total of 1134 seedlings. The replicates of all seven treatments were randomly allocated within each sub-block as far as stumps and microtopography allowed. This is illustrated by Figure 3.03.B, although it depicts only 6 replicates of each treatment rather than the actual 27.

Figure 3.03.A - Layout of research area

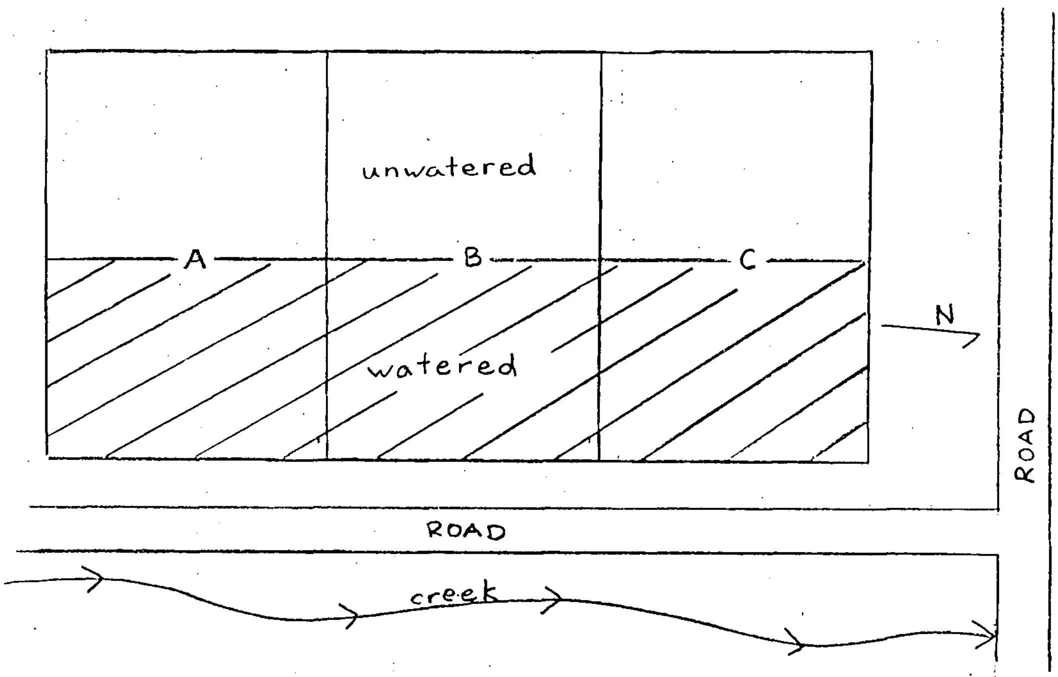
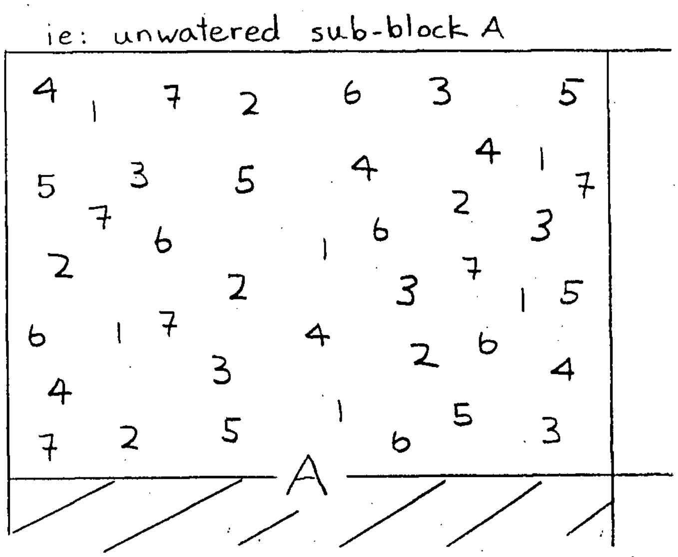


Figure 3.03.B - Example of distribution of treatments within each sub-block



* this diagram shows only 6 replicates, whereas the actual sub-block contained 27 replicates of each treatment

The seven treatments involved different combinations of the following 4 types of planting substrate and 2 screef sizes.

Planting substrate

1....mineral soil: humo-ferric podzol; loam to clay-loam; ph 5.3

2....H-layer: (humus material) - a terrestrial master horizon dominated by fine substances in which the original structures are macroscopically indiscernible (Klinka *et al.* 1981); pH 4.2

3....F-layer: (formultningsskiktet, fermented[1] , decayed materials) - a master organic horizon characterized by more-or-less disintegrated plant residues in which partial (rather than entire), macroscopically discernible vegetative structures are dominant (Klinka *et al.* 1981); pH 4.5

4....rotten wood: generally bright orange; decomposed at least to the point of being fibrous; pH3.7

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[1]Klinka *et al.* (1981) note that the term 'fermented' originally referred to the presence of anaerobic processes, but has come to mean the decomposition of carbohydrates with the evolution of gas or the formation of acid or both and is used extensively in literature pertaining to this horizon.

Screef size

A screef is a patch of ground where undesirable material is cleared away to expose appropriate planting substrate. Two screef sizes were utilized. Refer to Figure 3.03.C.

1....Small screef: regular planting size screef down to the substrate of concern but not exposing it.

2....Large screef: 50cm x 50cm of the substrate of concern is exposed

Treatments

The seven treatments as shown in Figure 3.03.C were:

1....Mineral soil; large screef

2....Mineral soil; small screef

3....H-layer; large screef

4....H-layer; small screef

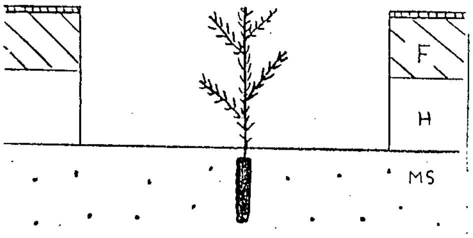
5....F-layer; large screef

6....F-layer; small screef

7....Rotten wood; small screef*

* no large screef treatment was employed for rotten wood because it did not occur in large enough patches to accomodate 50cm X 50cm.

TREATMENT 1



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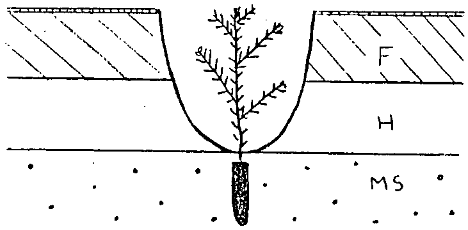

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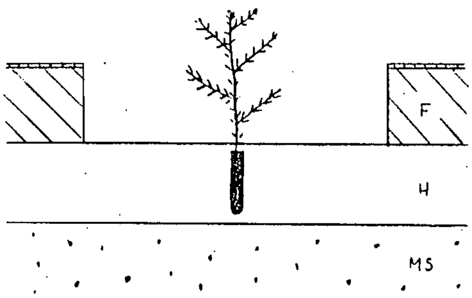

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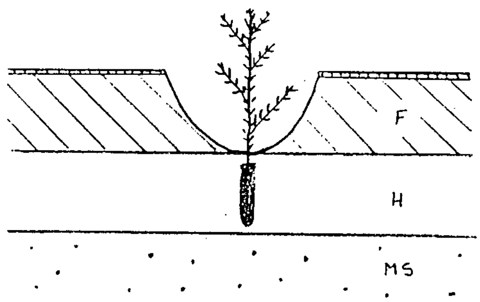

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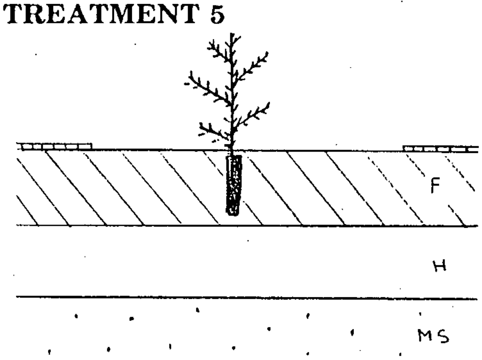

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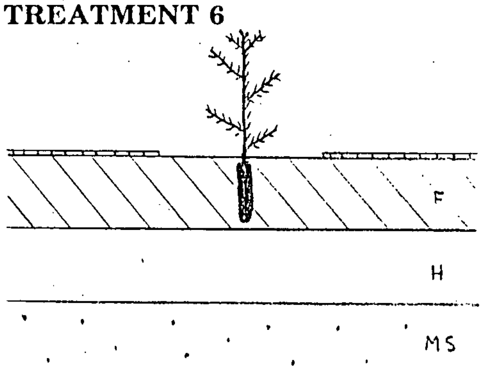

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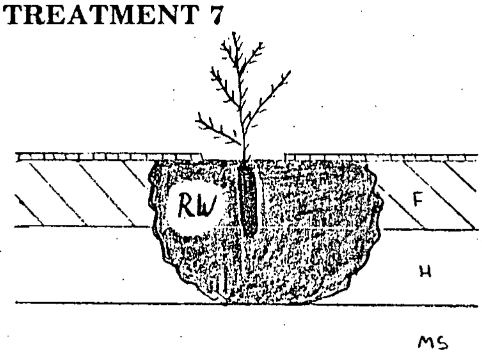


FIGURE 3.03.C

3.04 STATISTICAL ANALYSIS

Analysis of variance was carried out using UBC:GENLIN (Greig and Bjerring 1980). This package was also used to test for homogeneity of variance. SAS - Proc univariate (SAS Institute Inc. 1982) was used to check that the data points come from a normal distribution. Both GENLIN and SAS were used on the UBC/MTS system.

Results of the homogeneity of variance tests and the transformations used to satisfy this assumption for analysis of variance are reported in Appendix B. Results of the normality test are reported in Appendix C.

Duncan's Multiple Range test was used on GENLIN to separate means that were significantly different.

A randomized complete block design was used for this project, and a single model was used for analysis of variance of all data except soil temperature data. A split-plot was used for allocating the watering treatment in 1989, and the fertilization treatment in 1990. In the following model:

$$\mathbf{X_{jilq} = \mu + B_j + TR_i + E1_{ji} + W_l + W{*}TR_{li} + E2_{(i)jl} + SE_{(ijl)q}}$$

μ is the overall mean, B_j is the effect of the j^{th} block, TR_i is the effect of the i^{th} treatment, $E1_{ji}$ is the interaction between the j^{th} block and the i^{th} treatment, W_l is the effect of the l^{th} watering or fertilization treatment, $W{*}Tr_{li}$ is the interaction of the l^{th} watering or fertilization treatment with the i^{th} treatment, $E2_{(i)jl}$ is the interaction of the j^{th} block with the l^{th} watering or fertilization treatment within the i^{th} treatment, and $SE_{(ijl)q}$ is the sampling error, the effect of the q^{th} replicate within each experimental unit.

Analysis of soil temperature data collected for each of the seven screef size/planting substrate treatments was carried out using the following model:

$$X_{iq} = \mu + TR_i + E1_{iq}$$

where μ is the overall mean, TR_i is the effect of the i^{th} treatment, and E1 is the residual error.

3.05 SOIL TEMPERATURE MONITORING

A seven-channel CR-21 data logger with thermistors (101-probes) and a cassette recorder was used to record soil temperatures. An area with average forest floor characteristics was selected in one of the blocks, and one thermistor was installed beside a representative seedling in each of the seven treatments. The thermistors were placed at a depth of 7 cm, which is approximately where the midpoint of the root plug would be. Average temperature was recorded once an hour, and daily maximum and minimum were recorded once every 24 hours. Temperature monitoring was continuous in the same spot for the period of June 17 to August 26, 1989, with the exception of July 15 and August 11-12.

3.06 WATERING

Seedlings in the 'watered' treatment were each given one liter of water once a week. Water was either pumped or carried from a nearby creek, and was poured on so that at least a 25 cm diameter area was wetted. Watering was carried out weekly during the summer of 1989, from June 21 to August 16.

3.07 SOIL MOISTURE CONTENT DETERMINATION

Soil moisture content was monitored weekly, at two depths: 2-3 cm and 9-10 cm, which were later averaged. These depths were representative of the position occupied by the upper and lower third of the seedling root plug. Soil samples were collected for each treatment from three locations within each sub-block, and bulked. These locations had been prepared in the same manner as if seedlings were to be planted there. The samples were then weighed, dried in ovens for 30 hours at 100°C, and weighed again. Volumetric moisture content was calculated by the following formula:

$$\mathbf{MC_{vol} = (M_w/M_s)(\rho_b/\rho_w)}$$

where:

M_w = mass of water (kg)

M_s = mass of solids (kg)

ρ_b = bulk density of soil (kg dry soil/m^3 soil)

ρ_w = density of water (1000 kg/m^3)

Moisture content was sampled before the watering treatments began in order to establish a baseline, and then weekly for seven more weeks.

3.08 DETERMINATION OF MOISTURE RETENTION CURVES FOR FOREST FLOOR MATERIALS

A 'hanging column' apparatus (Hillel 1980) (Figure 3.08.A) was used to determine the water contents of H-layer, F-layer, and rotten wood, over a range of matric potentials ranging from 0 to -20 kPa. Matric potential was calculated using:

$$\psi_m = -\rho_w g h$$

where:

ψ_m = matric potential (kPa)

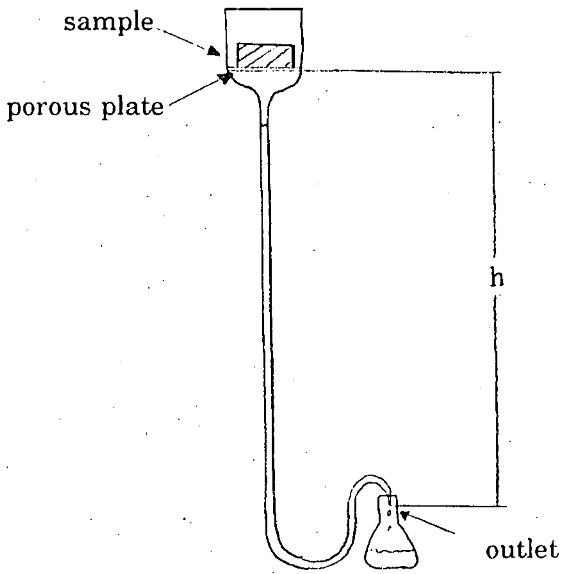
ρw = density of water (1000 kg/m^3)

g = acceleration of gravity (9.81 m/s^2)

h = height of hanging column (m)

Undisturbed core samples were obtained using tuna fish cans opened at both ends. Samples were refrigerated until use.

Figure 3.08.A - **Hanging column apparatus**



Samples were placed on the porous plates in the funnels as shown above, below which the system was filled with water. The samples were then flooded and allowed to stand for 12 hours. The outlet was adjusted to a height of 0, which was at the interface of the sample and the porous plate, and the samples were allowed to drain to a point of equilibrium. The top of the funnel was covered with plastic with only one small hole, to minimize evaporation. The outlet was then moved down successively from 0 to 0.05, 0.10, 0.20, 0.35, 0.60, 0.85, 1.10, 1.60, and 1.98 m, over a period of several days. At each point the system was allowed to reach equilibrium, and the mass of water drained off was measured. After the last measurement was taken, the soil samples were removed, weighed, dried at 105^{o}C for 48 hours, and weighed again, and volumetric water contents at each matric potential were determined.

3.09 BULK DENSITY DETERMINATION

Bulk density was determined by the undisturbed core method (Blake and Hartge 1986) for the organic materials and the excavation method (Blake and Hartge 1986) for mineral soil, where coarse fragments would have prevented insertion of the cylinder into the soil. Bulk density was determined by the formula:

$$\rho_b = M_s / V_t$$

where:

ρ_b = bulk density (kg/m^3)

M_s = mass of solids (kg)

V_t = volume of soil (m^3)

3.10 DETERMINATION OF FOREST FLOOR DEPTH

The depth of the forest floor horizons were measured on the southern face of each of the large screef holes that had been created for Treatment 1, in each of the sub-blocks, for a total of 162 measurments.

3.11 SEEDLING GROWTH MEASUREMENT

At the end of the first growing season (third week of August 1989), 9 randomly selected seedlings were harvested from each of the seven treatments in each of the 6 sub-blocks. If any of the seedlings chosen were dead or had large amounts of dead foliage, they were rejected and another was chosen that was of better vigour. This was to ensure that material measured and weighed was live.

The roots were excavated carefully to get all pieces greater than 0.5 cm in length, and the root mass was contained in a plastic bag tied around the root collar. Seedlings were refrigerated until they were measured. Height was measured from the root collar to the tip of the terminal bud. Diameter was measured just above the root collar in two places and an average was calculated. The root was separated from the shoot at the root collar, and each was dried at 70^{o}C for 3 days. Samples were then weighed. At the end of the second growing season (third week of August 1990) the procedure was repeated.

3.12 FERTILIZATION

In mid-May of 1990, half the seedlings in the same split-plot layout that had been irrigated the previous year were fertilized with ammonium nitrate (NH_4NO_3) fertilizer at a concentration of 200 kg/ha (70 kg/ha N). Each seedling was given 5 g of ammonium nitrate in 500 ml of water, which was sprinkled over a 50cm x 50cm area. In some cases, as with the small screef treatments down to mineral soil it was not possible to spread the solution out evenly, as it pooled in the bottom of the hole.

3.13 FOLIAR NITROGEN ANALYSIS

Digestion for foliar nitrogen analysis was done using the Parkinson and Allen method (Parkinson and Allen 1975). Analysis for ammonium-N was carried out using a Technicon TRAACS 800 Auto-analyser. Blanks were included with each batch, and the mg/l N obtained for the blanks was subtracted from the mg/l N obtained for each sample.

Reference samples were also included with each batch to determine that the analysis was within acceptable limits of accuracy. Four batches were run, so that the blanks and reference samples were repeated four times, but no replication of samples was possible due to the limited quantities of foliage available for sampling.

3.14 WEATHER MONITORING

It was not within the range of this project to have a weather station on site, so weather information was obtained from the Smithers airport, which is approximately 15 km from the site, and slightly lower in elevation at 520 meters.

4.0 RESULTS

4.1 SEEDLING GROWTH

Total seedling growth was measured in August 1989 and August 1990 for the parameters of diameter, height, root mass, and shoot mass. Total seedling mass is the sum of root mass and shoot mass, and shoot to root ratio is shoot mass divided by root mass. A representative sample of 25 seedlings was also measured for these parameters at the time of planting, and from these initial measurements the increases in seedling size/mass from June 1989 to August 1989, and from June 1989 to August 1990 were calculated. These mean values for the initial seedling measurements are presented in Table 4.1.0.1.

In the following report of results, 'treatment' is used to refer to the seven combinations of screef size and planting material described in Section 3.03. 'Watering treatment' refers to the unwatered and watered subplots, and 'fertilization treatment' refers to the unfertilized and fertilized subplots.

When error bars are shown on bar graphs, they represent the standard error of the mean.

When transformations were necessary to meet the assumptions of analysis of variance, the transformed data were used in the analysis, and those results are recorded in the tables of significance. However, the real means and standard deviations are recorded in the growth result tables, not the transformed values. The 1990 diameter data was not successfully transformed to meet the analysis of variance assumption of equal variances. Refer to Appendix B.

Table 4.1.0.1 - Initial seedling measurements

Growth parameter	Size/mass
Diameter	0.29 cm
Height	23.0 cm
Root mass	0.684 g
Shoot mass	1.596 g
Total mass	2.280 g
Shoot:root	2.33

Significant growth results for treatments, watering, fertilization, and blocking are shown in Tables 4.1.0.2 to 4.1.0.5.

Table 4.1.0.2 - Significant differences between treatments (α=0.05)

Growth parameter	Total Aug 89	Total Aug 90
Diameter	ns	ns +
Probability	**0.12939**	**0.14071**
Height	ns	ns
Probability	**0.06709**	**0.10042***
Root weight	3,6>1,4,2 5,7>4,2 1>2	6,3>4,1,2 7,5>1,2 4,1>2
Probability	**0.00071**	**0.00017***
Shoot weight	3>7,1,6,5,4,2 7>2	6,4,3>1,2 5>2
Probability	**0.00546**	**0.01640***
Total weight	3>7,6,1,5,4,2 7,6>4,2 1,5>2	6,4,3>1,2 5>2
Probability	**0.00107**	**0.00906***
Shoot: root	2>3,7,5,6 4>5,6 1>6	2>4,1,5,3,6,7 4>1,5,3,6,7 1>7
Probability	**0.00810***	**0.00002***

* transformed data used

\+ not successfully transformed, so analysis of variance was carried out on data having unequal variances.

Table 4.1.0.3 - Significant differences between watering treatments ($\alpha=0.05$)

Growth parameter	Total Aug 89
Diameter	ns
Probability	**0.19277**
Height	ns
Probability	**0.50290**
Root weight	ns
Probability	**0.21430**
Shoot weight	ns
Probability	**0.60193**
Total Weight	ns
Probability	**0.40667**
Shoot:root	ns
Probability	**0.29665***

* transformed data used

Table 4.1.0.4 - Significant differences between fertilization treatments ($\alpha=0.05$)

Growth parameter	Total Aug 90
Diameter	ns
Probability	**0.56534**
Height	F>NF
Probability	**0.00375***
Root weight	F>NF
Probability	**0.00312***
Shoot weight	F>NF
Probability	**0.00027***
Total weight	F>NF
Probability	**0.00028***
Shoot:root	ns
Probability	**0.66276***

* transformed data used

Table 4.1.0.5 - Significant differences between blocks ($\alpha = 0.05$)

Growth parameter	Total Aug 89	Total Aug 90
Diameter	A>B,C	B,A>C
Probability	**0.00290**	**0.04320**
Height	ns	A>B,C
Probability	**0.08513**	**0.00000***
Root wt.	A>C	A>C
Probability	**0.00602**	**0.03049***
Shoot wt.	ns	A>B>C
Probability	**0.93057**	**0.00000***
Total wt.	ns	A>B,C
Probability	**0.39108**	**0.00000***
Shoot:root	C>A	ns
Probability	**0.01252***	**0.12210***

* transformed data used

DIAMETER

Seedling diameters for the seven screef size/substrate treatments are presented in Table 4.1.1.1 and Figures 4.1.1.A and 4.1.1.B. Seedling diameters for the watering and fertilization treatments are presented in Tables 4.1.1.2 and 4.1.1.3 respectively.

Table 4.1.1.1 - Seedling diameter by treatment (cm)

Treatment	Total Aug 89	Increase Jun 89-Aug 89	Total Aug 90	Increase Jun 89-Aug 90
1-lg.screef	**0.44***	**0.15**	**0.69**	**0.40**
min.soil	0.06+		0.21	
2-sm.screef	**0.43**	**0.14**	**0.63**	**0.34**
min.soil	0.07		0.22	
3-lg.screef	**0.46**	**0.17**	**0.83**	**0.54**
H-layer	0.07		0.19	
4-sm.screef	**0.41**	**0.12**	**0.79**	**0.50**
H-layer	0.08		0.21	
5-lg.screef	**0.44**	**0.15**	**0.80**	**0.51**
F-layer	0.07		0.18	
6-sm.screef	**0.45**	**0.16**	**0.99**	**0.70**
F-layer	0.07		1.15	
7-sm.screef	**0.45**	**0.16**	**0.76**	**0.47**
rotten wood	0.06		0.22	

* mean
\+ standard deviation

Figure 4.1.1.A - **Seedling diameter by treatment**

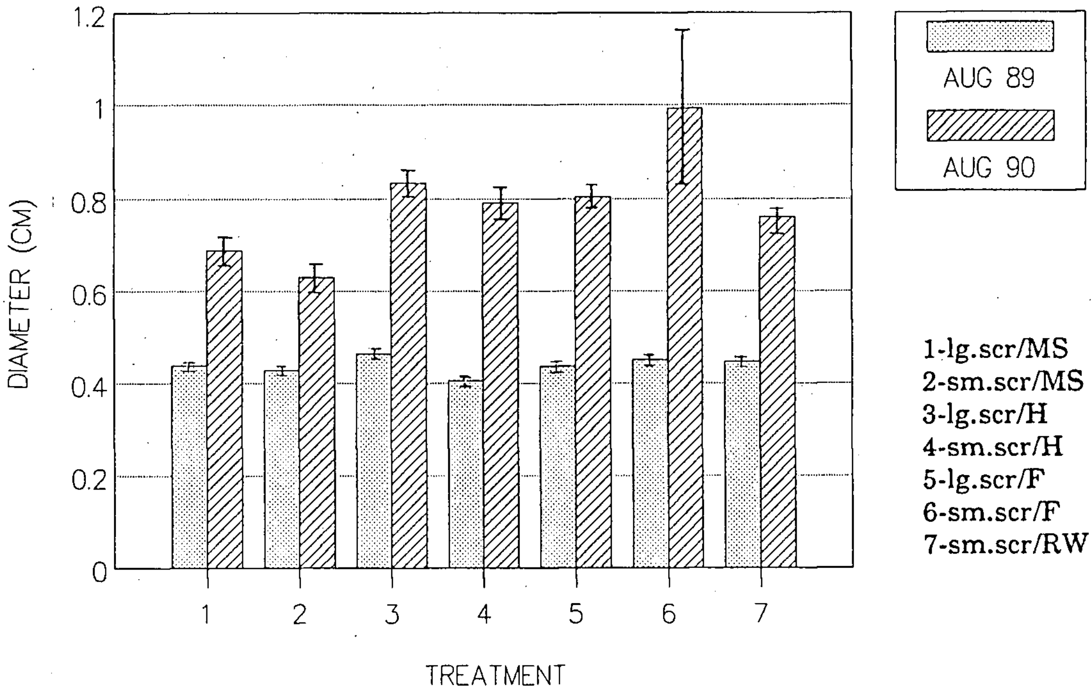


Figure 4.1.1.B - **Increase in seedling diameter by treatment**

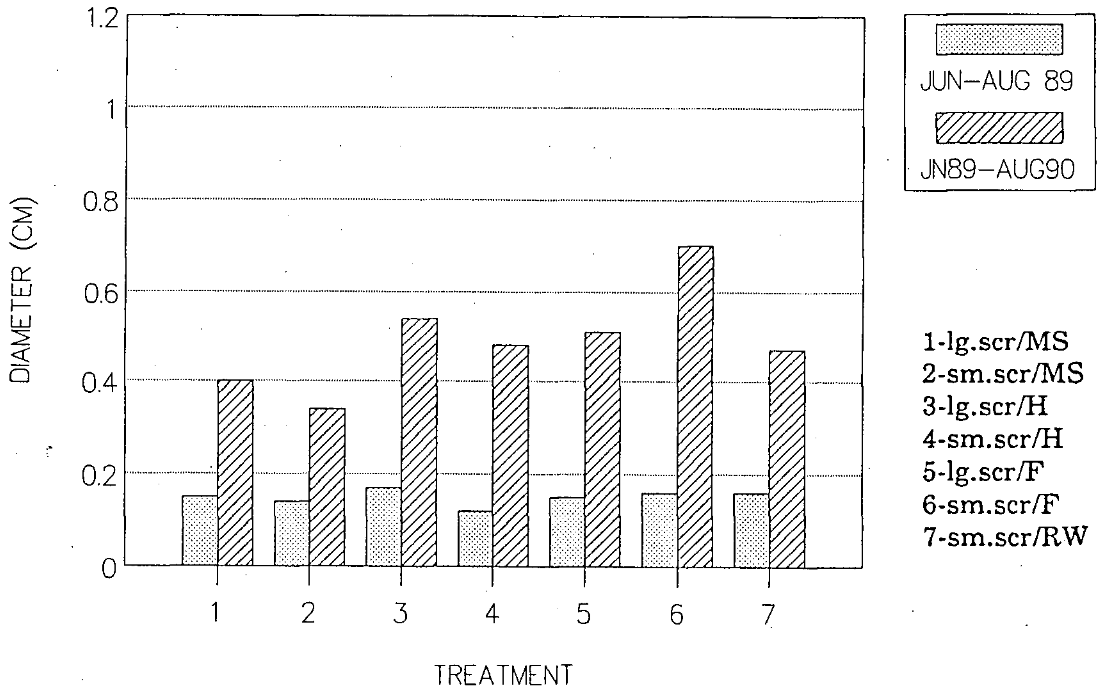


Table 4.1.1.2 - Seedling diameters by watering treatment (cm)

Watering treatment	Total Aug 89	Increase Jun 89-Aug 89
Unwatered	**0.43***	**0.14**
	0.78+	
Watered	**0.45**	**0.16**
	0.63	

* mean
\+ standard deviation

Table 4.1.1.3 - Seedling diameters by fertilization treatment (cm)

Fertilization treatment	Total Aug 90	Increase Jun 89-Aug90
Unfertilized	**0.76***	**0.47**
	0.67+	
Fertilized	**0.81**	**0.52**
	0.23	

* mean
\+ standard deviation

SIGNIFICANT DIFFERENCES IN DIAMETER

Significant differences are presented in Tables 4.1.0.2 to 4.1.0.5, and are summarized for diameter below. Refer to Figure 3.03.C for a description of the screef size/substrate treatments.

Total diameter August 1989

Diameters of seedlings in the seven treatments were not significantly different in August 1989. Neither did seedlings in the watered treatment have significantly different diameters than seedlings in the unwatered treatment. Diameters did vary significantly between blocks, with Block A seedlings having larger mean diameter than seedlings in Blocks B and C. There was also a significant interaction between block and treatment, as well as between blocks and watering, within treatment (E2).

Total diameter August 1990

Again, there were no significant differences in diameter of seedlings from the seven treatments in August 1990, and neither were there significant differences between fertilized seedlings and unfertilized seedlings. Seedlings in blocks B and A were significantly greater in diameter than seedlings in block C.

HEIGHT

Seedling heights for the seven screef size/substrate treatments are presented in Table 4.1.2.1 and Figures 4.1.2.A and 4.1.2.B. Seedling heights for watering and fertilization treatments are presented in Tables 4.1.2.2 and 4.1.2.3 respectively.

Table 4.1.2.1 **Seedling height by treatment (cm)**

Treatment	Total Aug 89	Increase Jun89-Aug 89	Total Aug 90	Increase Jun 89-Aug 90
1-lg.screef	**28.6***	**5.6**	**34.3**	**11.3**
min.soil	3.6+		6.6	
2-sm.screef	**31.3**	**8.3**	**37.3**	**14.3**
min.soil	4.2		8.5	
3-lg.screef	**29.6**	**6.6**	**37.9**	**14.9**
H-layer	3.5		7.6	
4-sm.screef	**30.3**	**7.3**	**38.8**	**15.8**
H-layer	3.6		7.8	
5-lg.screef	**28.0**	**5.0**	**34.1**	**11.1**
F-layer	3.2		5.7	
6-sm.screef	**29.0**	**6.0**	**36.3**	**13.3**
F-layer	4.8		7.6	
7-sm.screef	**28.7**	**5.7**	**33.4**	**10.4**
rotten wood	3.7		6.7	

* mean
\+ standard deviation

Figure 4.1.2.A - Seedling height by treatment

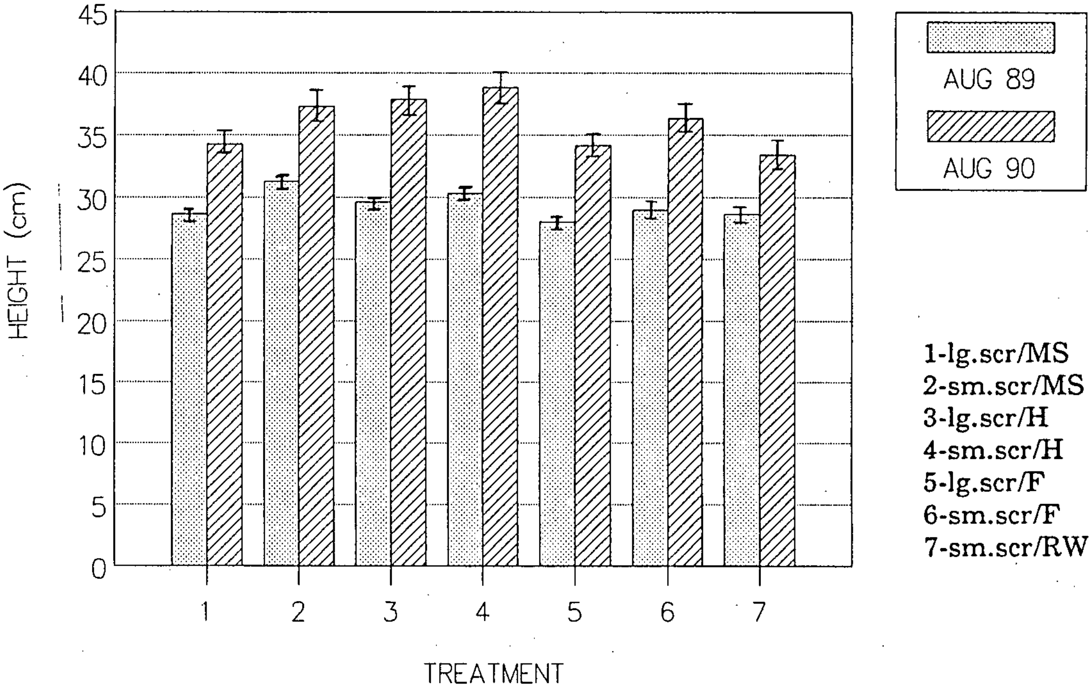


Figure 4.1.2.B - Increase in seedling height by treatment

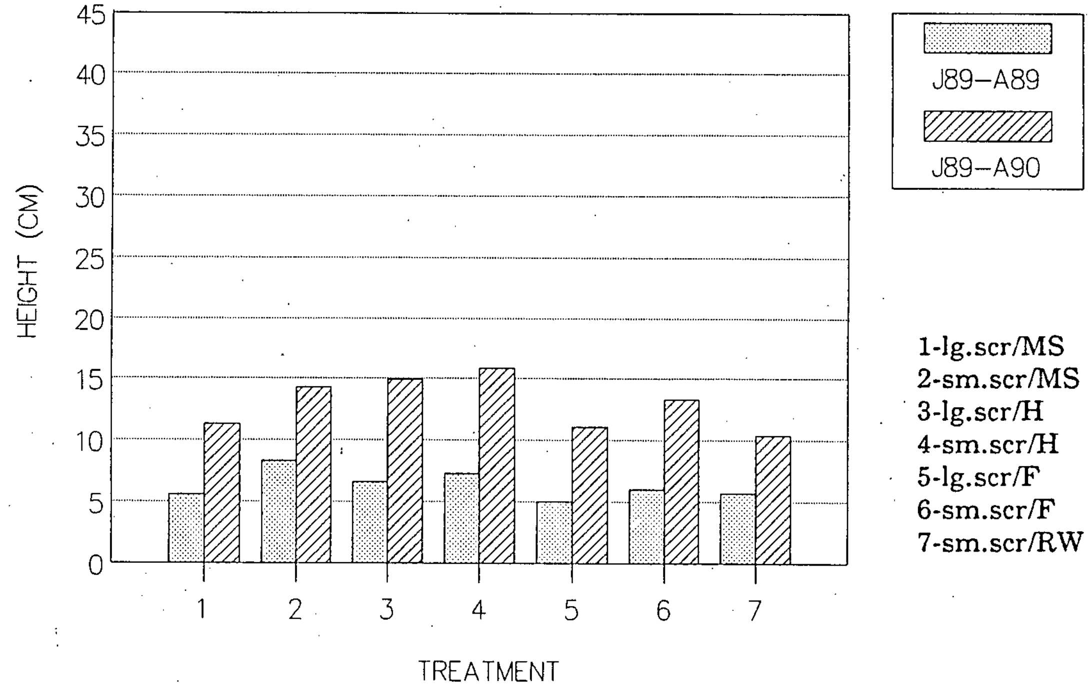


Table 4.1.2.2 - Seedling heights by watering treatments (cm)

Watering treatment	Total Aug 89	Increase Jun 89-Aug 89
Unwatered	**29.5*** 4.2+	**6.5**
Watered	**29.2** 3.7	**6.2**

* mean
\+ standard deviation

Table 4.1.2.3 - Seedling heights by fertlization treatment (cm)

Fertilization treatment	Total Aug 90	Increase Jun 89-Aug 90
Unfertilized	**34.4*** 6.2+	**11.4**
Fertilized	**37.4** 8.1	**14.4**

* mean
\+ standard deviation

SIGNIFICANT DIFERENCES IN HEIGHT

Significant differences are presented in Tables 4.1.0.2 to 4.1.0.5, and are summarized below for height. Refer to Figure 3.03.C for a description of the screef size/substrate treatments.

Total height August 1989

Seedlings from the seven treatments were not significantly different from one another. Watering did not have a significant effect on height of the seedlings, and there were no significant differences between blocks.

Total height August 1990

In August 1990, there were no significant differences in height between the seven treatments. Fertilized seedlings were taller than unfertilized seedlings, and seedlings from block A were significantly taller than seedlings in blocks B and C.

ROOT MASS

Seedling root mass for the seven treatments is presented in Table 4.1.3.1 and Figures 4.1.3.A and 4.1.3.B. Root mass by watering and fertilization treatment is presented in Tables 4.1.3.2 and 4.1.3.3 respectively.

Table 4.1.3.1 - **Seedling root mass by treatment (g)**

Treatment	Total Aug 89	Increase Jun 89-Aug 89	Total Aug 90	Increase Jun 89-Aug 90
1-lg.screef	**0.930***	**0.246**	**2.324**	**1.640**
min.soil	0.334+		1.751	
2-sm.screef	**0.756**	**0.072**	**1.409**	**0.725**
min.soil	0.231		1.480	
3-lg.screef	**1.147**	**0.463**	**3.297**	**2.613**
H-layer	0.337		1.664	
4-sm.screef	**0.841**	**0.157**	**3.008**	**2.324**
H-layer	0.301		2.593	
5-lg.screef	**1.041**	**0.357**	**3.210**	**2.526**
F-layer	0.331		2.145	
6-sm.screef	**1.110**	**0.426**	**3.538**	**2.854**
F-layer	0.357		1.923	
7-sm.screef	**1.037**	**0.353**	**3.313**	**2.629**
rotten wood	0.281		2.296	

* mean
\+ standard deviation

Figure 4.1.3.A - Seedling root mass by treatment

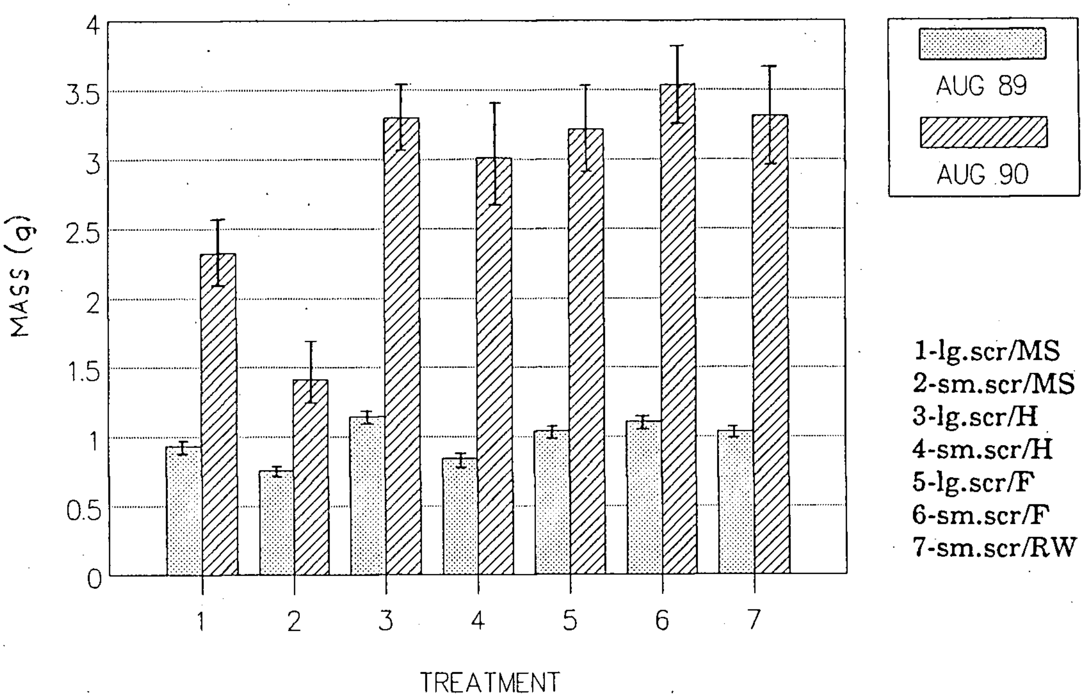


Figure 4.1.3.B - Increase in root mass by treatment

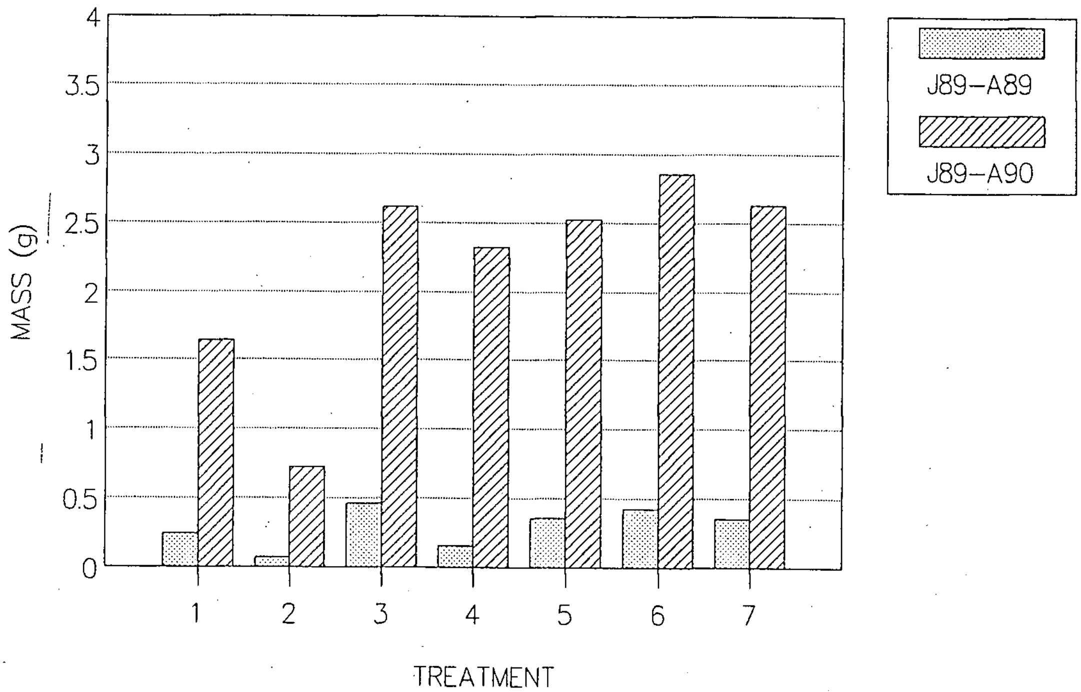


Table 4.1.3.2 - Seedling root mass by watering treatment (g)

Watering Treatment	Total Aug 89	Increase Jun 89-Aug89
Unwatered	**0.948*** 0.328+	**0.264**
Watered	**1.013** 0.345	**0.329**

* mean
\+ standard deviation

Table 4.1.3.3 - Seedling root mass by fertilization treatment (g)

Fertilization Treatment	Total Aug 90	Increase Jun 89-Aug 90
Unfertilized	**2.362*** 1.716+	**1.678**
Fertilized	**3.296** 2.287	**2.612**

* mean
\+ standard deviation

SIGNIFICANT DIFFERENCES IN ROOT MASS

Significant differences are presented in Tables 4.1.0.2 to 4.1.0.5, and are summarized below for root mass. Refer to Figure 3.03.C for a description of the screef size/substrate treatments.

Total root mass August 1989

In August 1989, seedlings from treatments 3, 6, 5 and 7 had significantly greater root mass than seedlings from treatment 4 and 2. Treatment 1 seedlings also had greater root mass than treatment 2 seedlings, and seedlings from treatments 3 and 6 had greater root mass than treatment 1 seedlings. Watering had no significant effect on root mass. Block A seedlings had significantly greater root mass than block C seedlings. There was significant interaction between blocks and watering, within treatment (E2).

Total root mass August 1990

Root mass of seedlings from treatments 6, 3, 7, 5, 4 and 1 were significantly greater than root mass of seedlings from treatment 2. Seedlings from treatment 6, 3, 7, and 5 had significantly greater root mass than seedlings from treatment 1. Treatment 6 and 3 seedlings had significantly greater root mass than seedlings from treatment 4. Fertilized seedlings had greater root mass than unfertilized seedlings, and seedlings from block A had significantly greater root mass than seedlings from block C.

SHOOT MASS

Seedling shoot mass for the seven screef size/substrate treatments is presented in Table 4.1.4.1 and Figures 4.1.4.A and 4.1.4.B. Seedling shoot mass by watering and fertilization treatment is presented in Tables 4.1.4.2 and 4.1.4.3 respectively.

Table 4.1.4.1 - Seedling shoot mass by treatment (g)

Treatment	Total Aug 89	Increase Jun 89-Aug 89	Total Aug 90	Increase Jun 89-Aug 90
1-lg.screef	**3.391***	**1.795**	**8.090**	**6.494**
min.soil	0.679+		5.437	
2-sm.screef	**3.082**	**1.486**	**7.317**	**5.721**
min.soil	0.792		6.195	
3-lg.screef	**3.783**	**2.187**	**11.474**	**9.878**
H-layer	0.703		5.747	
4-sm.screef	**3.123**	**1.527**	**12.004**	**10.408**
H-layer	0.790		6.436	
5-lg.screef	**3.244**	**1.648**	**10.071**	**8.475**
F-layer	0.681		4.880	
6-sm.screef	**3.331**	**1.749**	**11.862**	**10.266**
F-layer	0.766		6.259	
7-sm.screef	**3.445**	**1.849**	**9.608**	**8.012**
rotten wood	0.712		6.878	

* mean
+ standard deviation

Figure 4.1.4.A - Seedling shoot mass by treatment

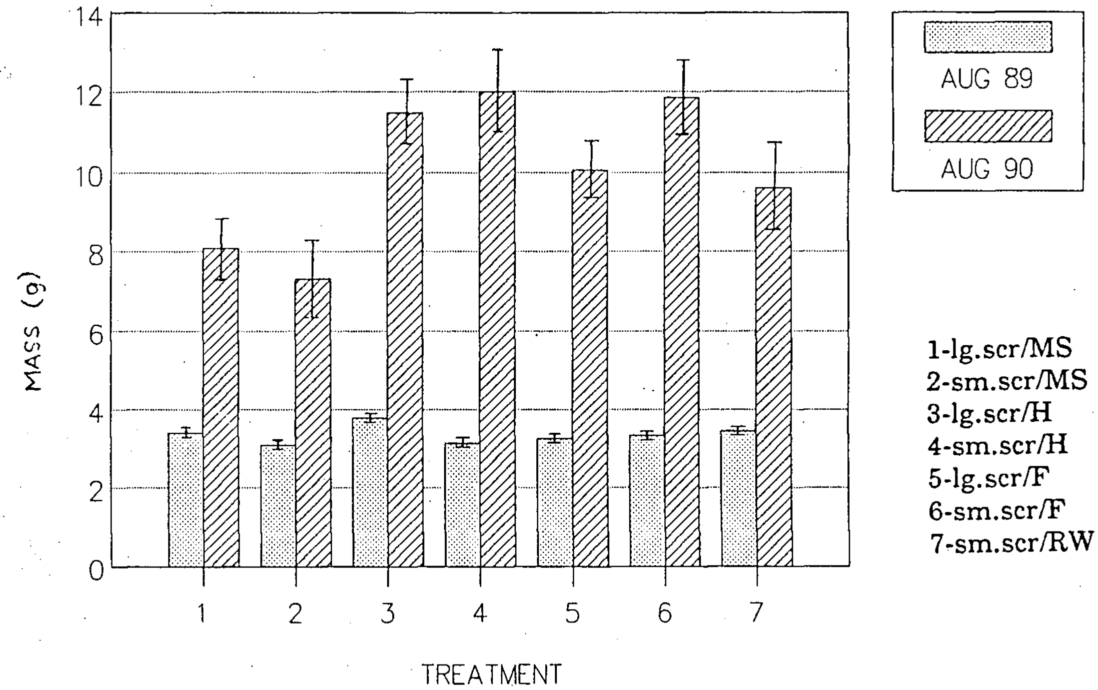


Figure 4.1.4.B - Increase in shoot mass by treatment

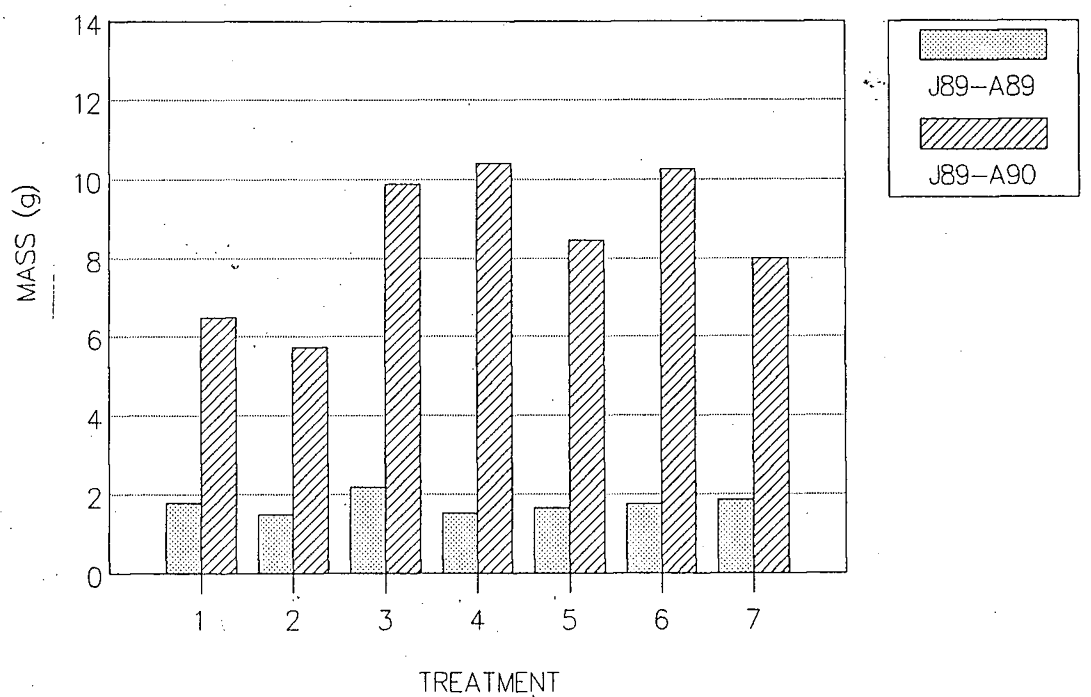


Table 4.1.4.2 - Seedling shoot mass by watering treatment (g)

Watering Treatment	Total Aug 89	Increase Jun 89-Aug 89
Unwatered	**3.316*** 0.767+	**1.720**
Watered	**3.369** 0.753	**1.773**

* mean
\+ standard deviation

Table 4.1.4.3 - Seedling shoot mass by fertilization treatment (g)

Fertilization Treatment	Total Aug 90	Increase Jun 89-Aug 90
Unfertilized	**8.313*** 4.827+	**6.717**
Fertilized	**11.502** 6.784	**9.906**

* mean
\+ standard deviation

SIGNIFICANT DIFFERENCES IN SHOOT MASS

Significant differences are presented in Tables 4.1.0.2 to 4.1.0.5, and are summarized for shoot mass below. Refer to Figure 3.03.C for a description of the screef size/substrate treatments.

Total shoot mass August 1989

Shoot mass of seedlings from treatment 3 was significantly greater than shoot mass from any other treatment, and shoot mass of seedlings from treatment 7 was greater than that of seedlings in treatment 2. There were no significant differences between watered and unwatered seedlings, or between blocks. There was significant interaction between blocks and watering, within treatment (E2).

Total shoot mass August 1990

In August 1990, seedlings from treatments 6, 4, and 3 had significantly heavier shoots than seedlings in treatments 1 and 2, and treatment 5 seedlings had significantly greater shoot mass than seedlings in treatment 2. Fertilized seedlings had greater shoot mass than unfertilized seedlings. Block A seedlings had significantly heavier shoots than block B seedlings, which in turn had significantly heavier shoots than block C seedlings.

TOTAL MASS

Total seedling mass for the seven treatments is presented in Table 4.1.5.1 and Figures 4.1.5.A and 4.1.5.B. Total seedling mass by watering and fertilization treatment is presented in Tables 4.1.5.2 and 4.1.5.3 respectively.

Table 4.1.5.1 - Total seedling mass by treatment (g)

Treatment	Total Aug 89	Increase Jun 89-Aug89	Total Aug 90	Increase Jun 89-Aug 90
1-lg.screef	**4.321***	**2.041**	**10.414**	**8.134**
min.soil	0.886+		7.066	
2-sm.screef	**3.838**	**1.558**	**8.726**	**6.446**
min.soil	0.956		7.594	
3-lg.screef	**4.931**	**2.651**	**14.771**	**12.491**
H-layer	0.924		7.170	
4-sm.screef	**3.964**	**1.684**	**15.012**	**12.732**
H-layer	0.942		8.522	
5-lg.screef	**4.285**	**2.005**	**13.281**	**11.001**
F-layer	0.859		6.815	
6-sm.screef	**4.440**	**2.160**	**15.399**	**13.119**
F-layer	0.958		7.970	
7-sm.screef	**4.482**	**2.202**	**12.921**	**10.641**
rotten wood	0.770		8.949	

* mean
\+ standard deviation

Figure 4.1.5.A - Total seedling mass by treatment

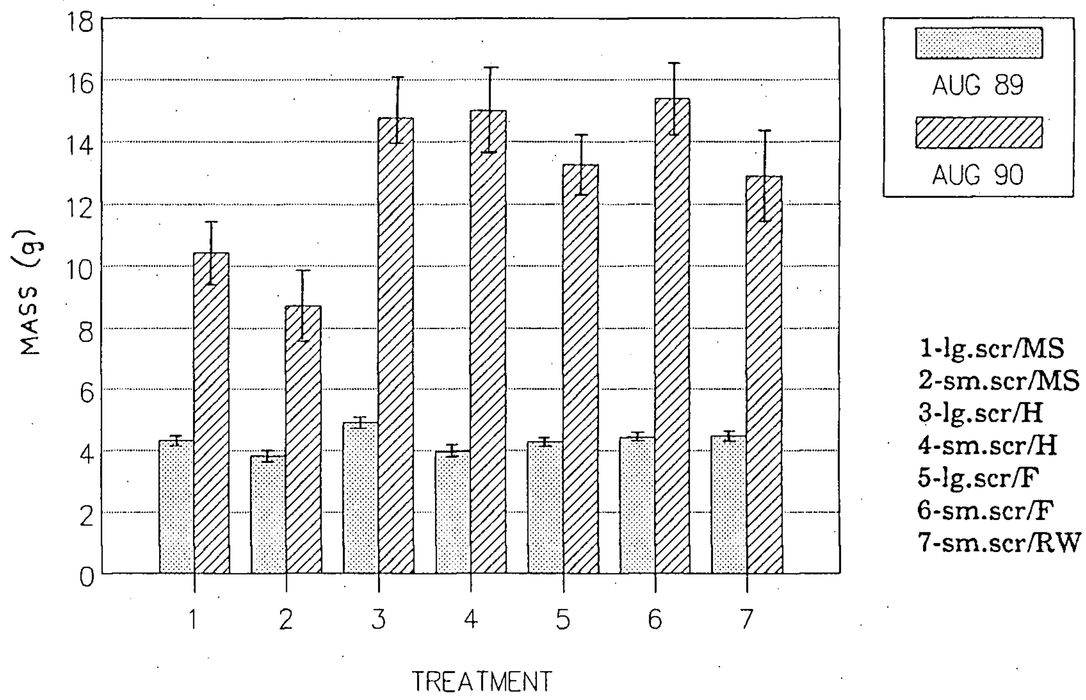


Figure 4.1.5.B - Increase in total seedling mass by treatment

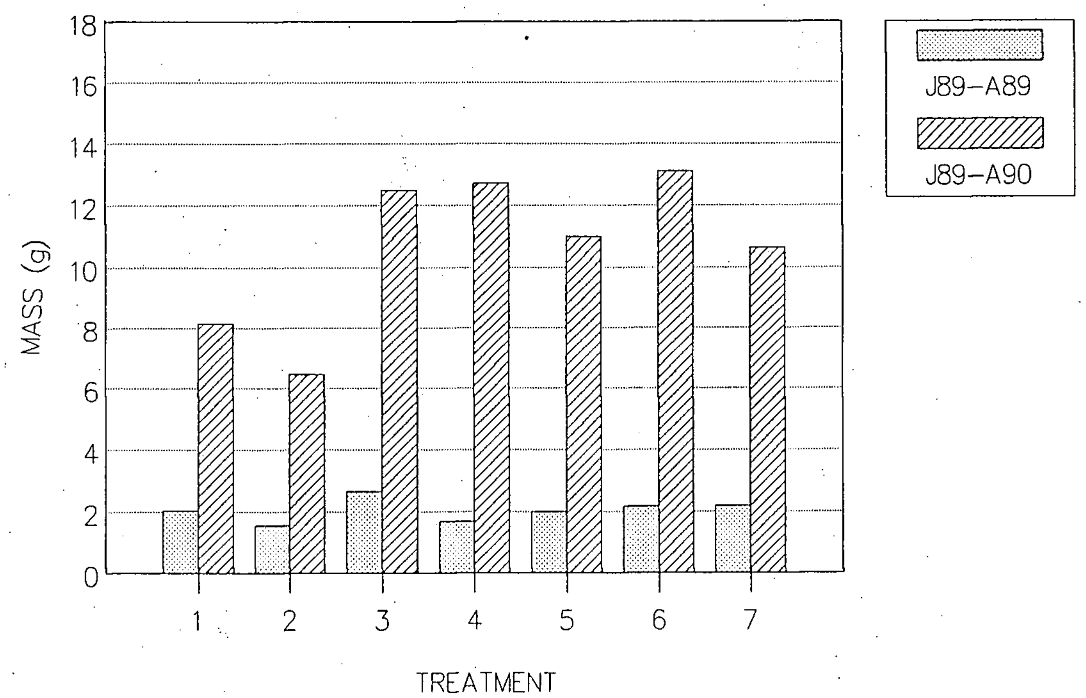


Table 4.1.5.2 - Total seedling mass by watering treatment (g)

Watering treatment	Total Aug 89	Increase Jun 89-Aug 89
Unwatered	**4.264*** 0.941+	**1.984**
Watered	**4.382** 0.966	**2.102**

* mean
\+ standard deviation

Table 4.1.5.3 - Total seedling mass by fertilization treatment (g)

Fertilization treatment	Total Aug 90	Increase Jun 89-Aug 90
Unfertilized	**10.675*** 6.369+	**8.395**
Fertilized	**14.798** 8.735	**12.518**

* mean
\+ standard deviation

SIGNIFICANT DIFFERENCES IN TOTAL SEEDLING MASS

Significant differences are presented in Tables 4.1.0.2 to 4.1.0.5, and are summarized below for total seedling mass. Refer to Figure 3.03.C for a description of screef size/substrate treatments.

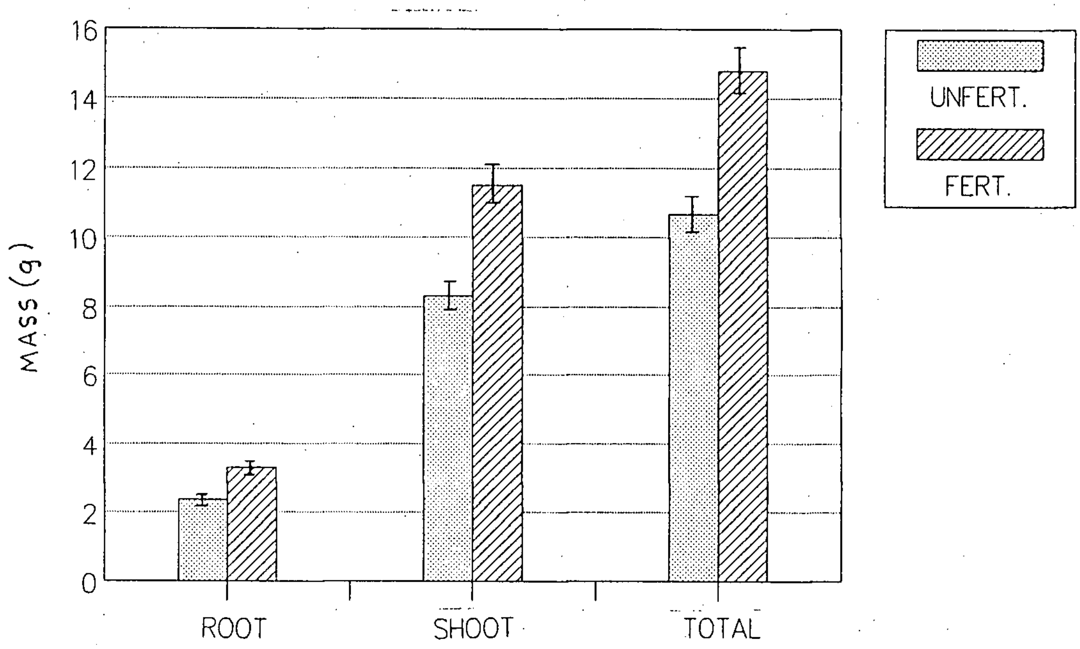
Total mass August 1989

In August 1989 mass of entire seedlings from treatment 3 was greater than that of seedlings from any other treatment. Seedlings from treatments 7 and 6 were heavier than seedlings from treatments 4 and 2, and seedlings from treatments 1 and 5 were significantly heavier than seedlings from treatment 2. Watering produced no significant differences in seedlings mass, and there were no differences between blocks. There was significant interaction between blocks and watering, within treatment (E2).

Total mass August 1990

Total mass of seedlings was significantly greater in treatments 6, 4, and 3 than in treatments 1 and 2. Treatment 5 seedlings were also heavier than treatment 2 seedlings. Fertilized seedlings were significantly heavier than unfertilized seedlings. Block A seedlings were heavier than block B and C seedlings.

Figure 4.1.5.C - Root mass, shoot mass, total mass by fertilization treatment



SHOOT MASS TO ROOT MASS RATIO

Shoot mass to root mass ratios for the seven treatments are presented in Table 4.1.6.1 and Figures 4.1.6.A and 4.1.6.B. Ratios for watering and fertilization treatments are presented in Tables 4.1.6.2 and 4.1.6.3 respectively.

Table 4.1.6.1 - Shoot mass to root mass ratio by treatment

Treatment	Total Aug 89	Increase Jun 89-Aug 89	Total Aug 90	Increase Jun 89-Aug 90
1-lg.screef	**4.02***	**1.69**	**4.04**	**1.71**
min.soil	1.36+		1.66	
2-sm.screef	**4.36**	**2.03**	**7.01**	**4.68**
min.soil	1.60		3.50	
3-lg.screef	**3.61**	**1.28**	**3.66**	**1.33**
H-layer	1.36		1.25	
4-sm.screef	**4.14**	**1.81**	**5.13**	**2.80**
H-layer	1.74		2.57	
5-lg.screef	**3.41**	**1.08**	**3.75**	**1.42**
F-layer	1.29		1.72	
6-sm.screef	**3.28**	**0.95**	**3.71**	**1.38**
F-layer	1.25		1.62	
7-sm.screef	**3.59**	**1.26**	**3.51**	**1.18**
rotten wood	1.38		2.39	

* mean
\+ standard deviation

Figure 4.1.6.A - Shoot to root ratio by treatment

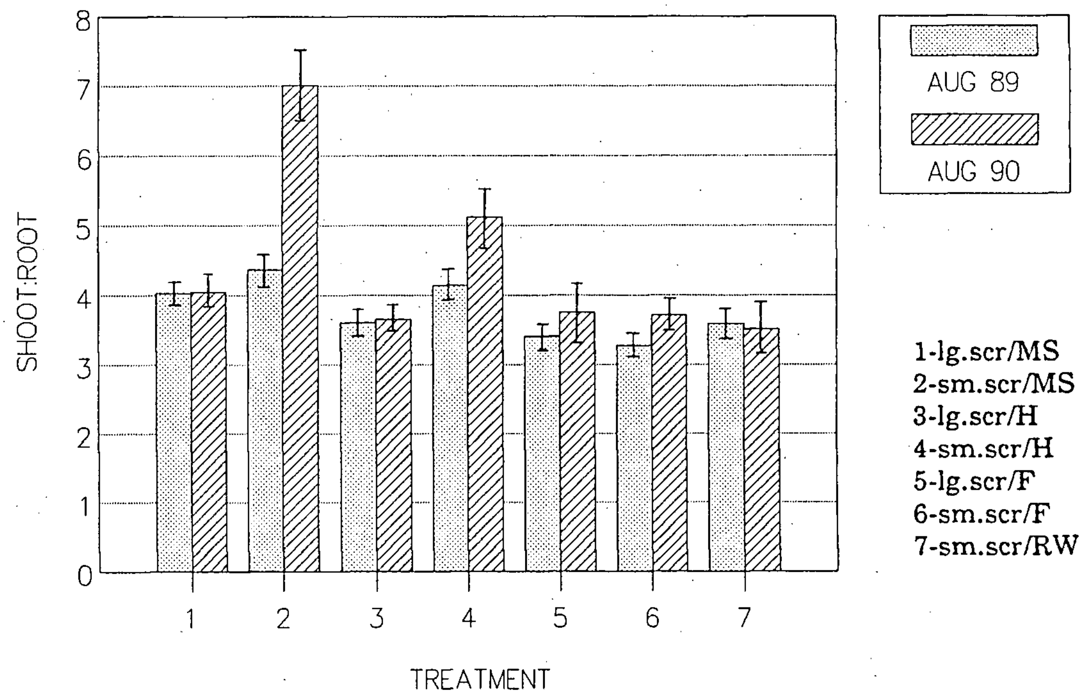


Figure 4.1.6.B - Increase in shoot to root ratio by treatment

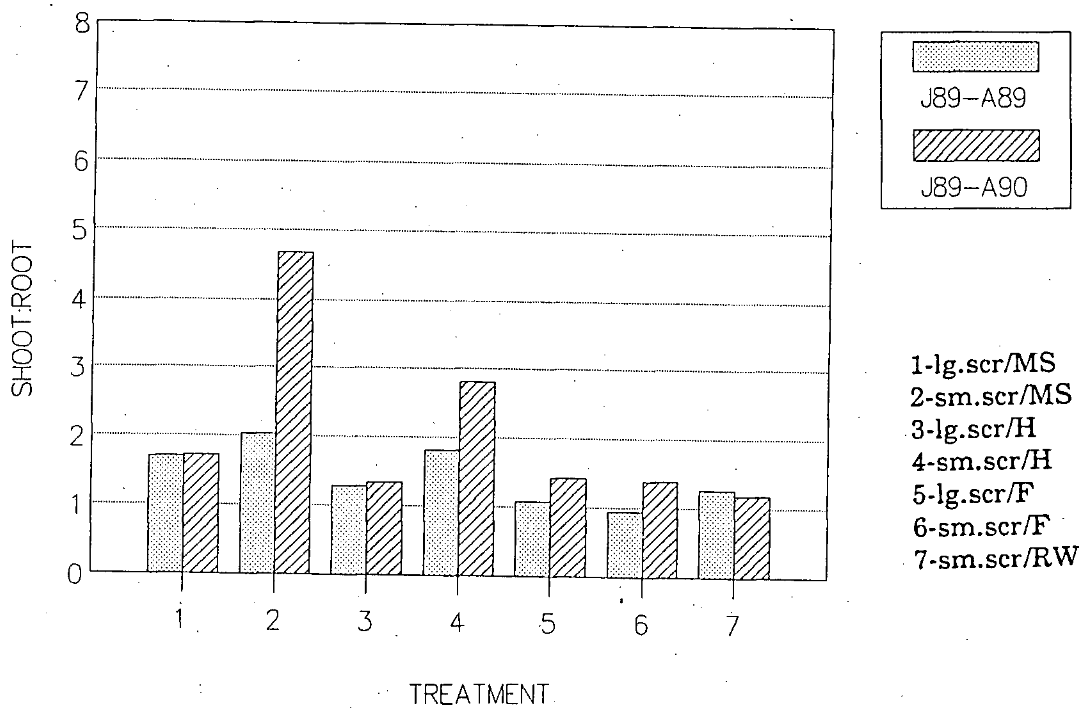


Table 4.1.6.2 - Shoot mass to root mass ratio by watering treatment

Watering treatment	Total Aug 89	Increase Jun 89-Aug 89
Unwatered	**3.91*** 1.65+	**1.58**
Watered	**3.64** 1.23	**1.31**

* mean
\+ standard deviation

Table 4.1.6.3 - Shoot mass to root mass ratio by fertilization treatment

Fertilization treatment	Total Aug 90	Increase Jun 89-Aug 90
Unfertilized	**4.48*** 2.50+	**2.15**
Fertilized	**4.30** 2.43	**1.97**

* mean
\+ standard deviation

SIGNIFICANT DIFFERENCES IN SHOOT MASS TO ROOT MASS RATIO

Significant differences are presented in Tables 4.1.0.2 to 4.1.0.5, and are summarized below for shoot mass to root mass ratio. Refer to Figure 3.03.C for a description of the screef size/substrate treatments.

Shoot mass to root mass ratio August 1989

Seedlings from treatments 2, 4, and 1 had higher shoot to root ratios than seedlings from treatment 6, and seedlings from treatment 4 also had a significantly higher ratio than seedlings from treatment 5. Treatment 2 seedlings had the highest shoot to root ratio, and it was significantly higher than the ratio for treatments 3, 7, 5 and 6. Watering had no significant effect on shoot to root ratio. Seedlings from block C had significantly higher shoot to root ratios than seedlings from block A. There was significant interaction between blocks and watering, within treatment (E2).

Shoot mass to root mass ratio August 1990

Treatment 2 seedlings had a significantly greater shoot to root ratio than seedlings from any other treatment. Treatment 4 seedlings had a higher shoot to root ratio than seedlings from treatments 1, 5, 3, 6, and 7. Seedlings from treatment 1 also had a significantly higher shoot to root ratio than seedlings from treatment 7. Fertilization resulted in no significant differences in shoot to root ratio, and there were no differences between blocks in August 1990.

4.3 SEEDLING SURVIVAL

Seedling survival was assessed on three dates, August 1989, May 1990, and August 1990. Significant differences in seedling survival are presented in Table 4.3.0.1. Seedling survival by screef size/substrate treatment are found in Table 4.3.0.2 and Figure 4.3.0.A. Seedling survival by watering and fertilization treatments is presented in Table 4.3.0.3. Seedling survival by block is found in Table 4.3.0.4 and Figure 4.3.0.C.

Table 4.3.0.1. - Significant differences in seedling survival (α=0.05)

Date	Treatments 1-7	Watering/ fertilization	Block
Aug 89	ns	ns	ns
Probability	**0.30011**	**0.58785**	**0.08235**
May 90	ns	ns	A>C,B
Probability	**0.05499**	**0.41099**	**0.00099**
Aug 90	ns	F>NF	A>C>B
Probability	**0.12633**	**0.00157**	**0.00008**

Table 4.3.0.2 - **Seedling survival by treatment (%)**

Treatment	Aug 89	May 90	Aug 90
1-lg.screef	**100.00***	**96.08**	**77.45**
min.soil	0.00+	4.80	8.67
2-sm.screef	**100.00**	**98.04**	**66.67**
min.soil	0.00	3.04	13.24
3-lg.screef	**99.38**	**96.08**	**72.55**
H-layer	1.51	4.80	14.25
4-sm.screef	**97.53**	**92.16**	**55.88**
H-layer	3.02	8.04	25.43
5-lg.screef	**95.68**	**85.29**	**69.61**
F-layer	4.32	13.79	14.61
6-sm.screef	**98.15**	**81.37**	**69.61**
F-layer	3.10	14.61	22.76
7-sm.screef	**98.15**	**82.35**	**61.77**
rotten wood	2.03	17.05	23.75

* mean
\+ standard deviation

Figure 4.3.0.A - Seedling survival by treatment

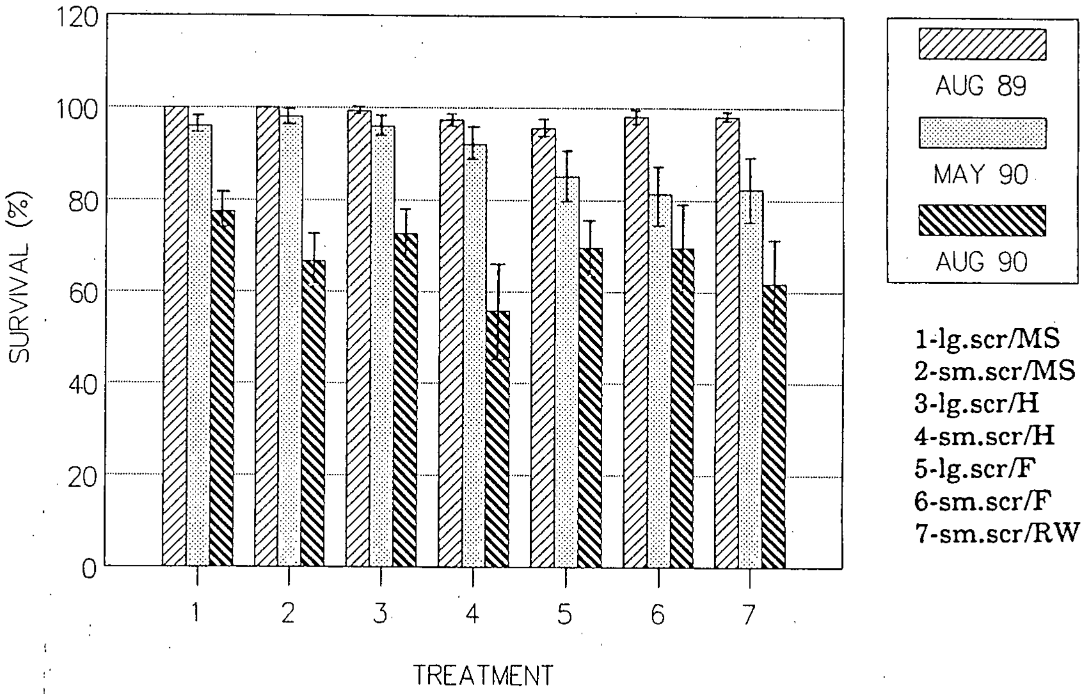


Table 4.3.0.3 - Seedling survival by watering/fertilization treatment (%)

Watering/ fertilization	Aug 89	May 90	Aug 90
Unwatered	**98.59***	-	-
	2.18+	-	-
Watered	**98.24**	-	-
	3.23	-	-
Unfertilized	-	**91.32**	**60.51**
	-	11.56	16.86
Fertilized	-	**89.08**	**74.79**
	-	12.52	17.26

* mean
\+ standard deviation

Figure 4.3.0.B - Seedling survival by fertilization treatment (Aug 1990)

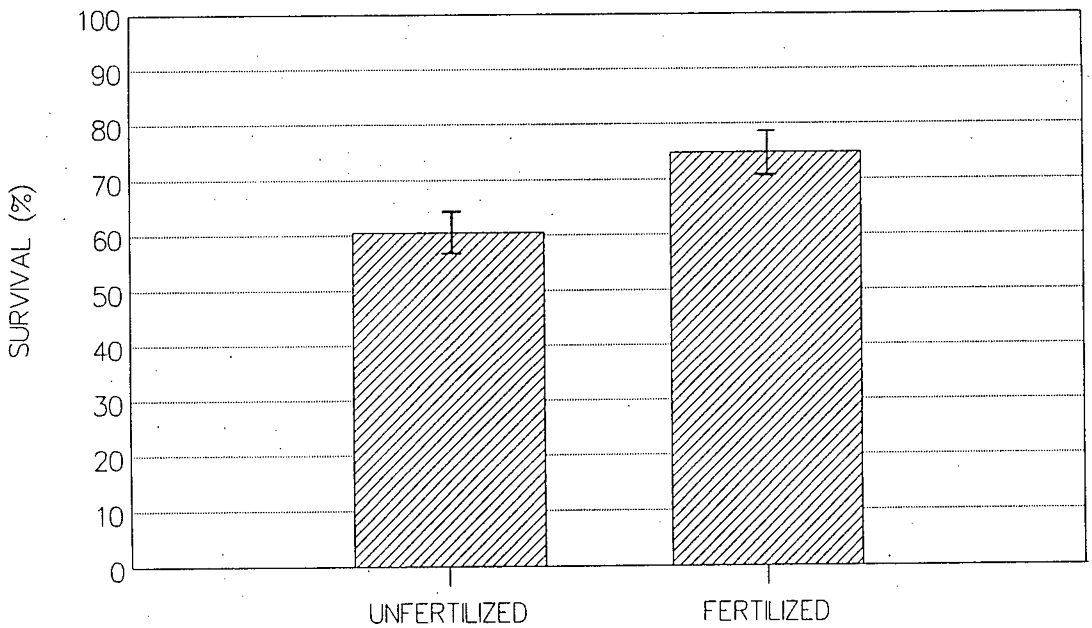
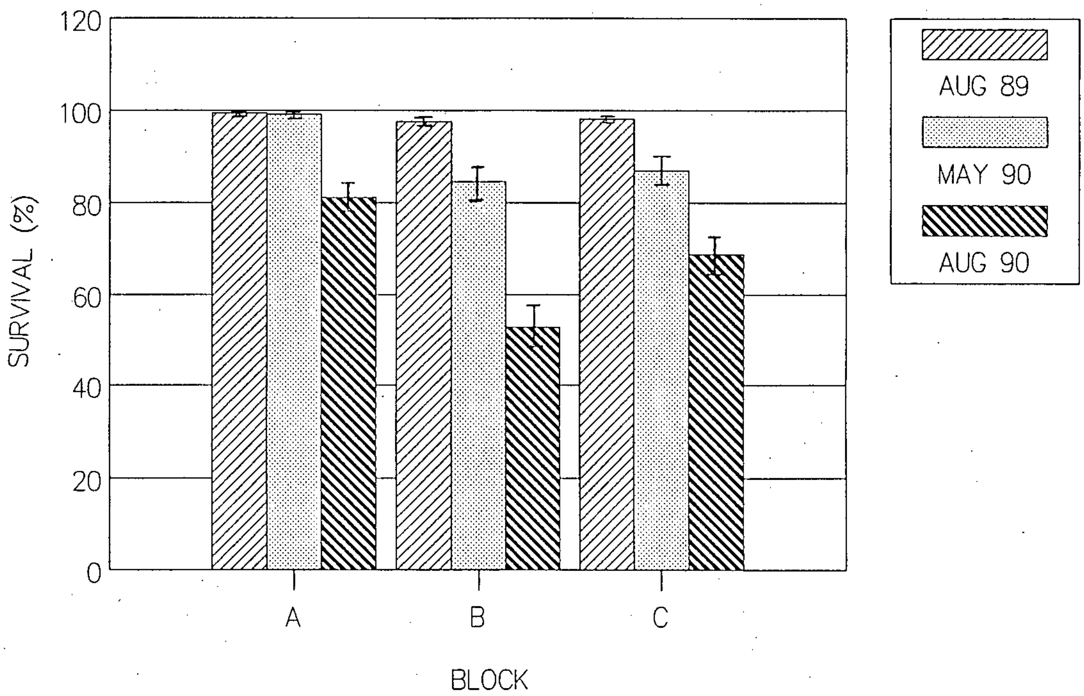


Table 4.3.0.4 - Seedling survival by block (%)

Block	Aug 89	May 90	Aug 90
A	**99.47***	**99.16**	**81.09**
	1.34+	2.13	11.11
B	**97.62**	**84.45**	**52.94**
	3.73	14.15	17.26
C	**98.15**	**86.98**	**68.91**
	2.41	10.62	14.49

* mean
+ standard deviation

Figure 4.3.0.C - Seedling survival by block



SIGNIFICANT DIFFERENCES IN SURVIVAL RESULTS

Significant differences for survival are presented in Table 4.3.0.1, and are summarized below. Refer to Figure 3.03.C for a description of the seven screef size/substrate treatments.

Seedling survival

There were no significant differences in seedling survival between the 7 treatments on any of the dates of assessment. Watering resulted in no significant differences in survival in August 1989. Fertilized seedlings did not have significantly different survival than unfertilized seedlings in May 1990, but in August 1990 fertilized seedlings had significantly higher survival than unfertilized seedlings. In August 1989 there were no significant differences in seedling survival between blocks. In May 1990 there was significantly higher survival in block A than in blocks C or B, and in August 1990 block A seedlings had higher survival than block C seedlings, which in turn had significantly higher survival than block B seedlings.

4.4 FOLIAR NITROGEN CONCENTRATION

Foliage was collected in the third week of August 1990, and foliar nitrogen analysis was done as described in Section 3.13. Significant differences in foliar nitrogen concentrations are presented in Table 4.4.0.1, and foliar N contents by treatment are in Table 4.4.0.2. The percentage of seedlings sampled having adequate nitrogen levels of 1.55 cg/g or greater (Ballard and Carter 1985), is presented by screef size/substrate treatment in Table 4.4.0.3, and by substrate in Table 4.4.0.4.

Table 4.4.0.1 - Significant differences in foliar N for treatments and fertilization treatments (α=0.05)

Treatment/ Fert. trmt	Significant differences
Treatment 1-7	6,5>2,1 7>1
Probability	**0.01816**
Fertilization treatment	F>NF
Probability	**0.01321**

Table 4.4.0.2 - Foliar nitrogen concentration by treatment (cg/g)

Treatment	Foliar N
1-lg.screef	**1.314***
min.soil	0.457+
2-sm.screef	**1.675**
min.soil	1.314
3-lg.screef	**1.906**
H-layer	0.575
4-sm.screef	**2.170**
H-layer	0.926
5-lg.screef	**2.543**
F-layer	1.128
6-sm.screef	**2.643**
F-layer	0.872
7-sm.screef	**2.258**
rotten wood	0.939

* mean
\+ standard deviation

Figure 4.4.0.A - Foliar nitrogen concentration by treatment

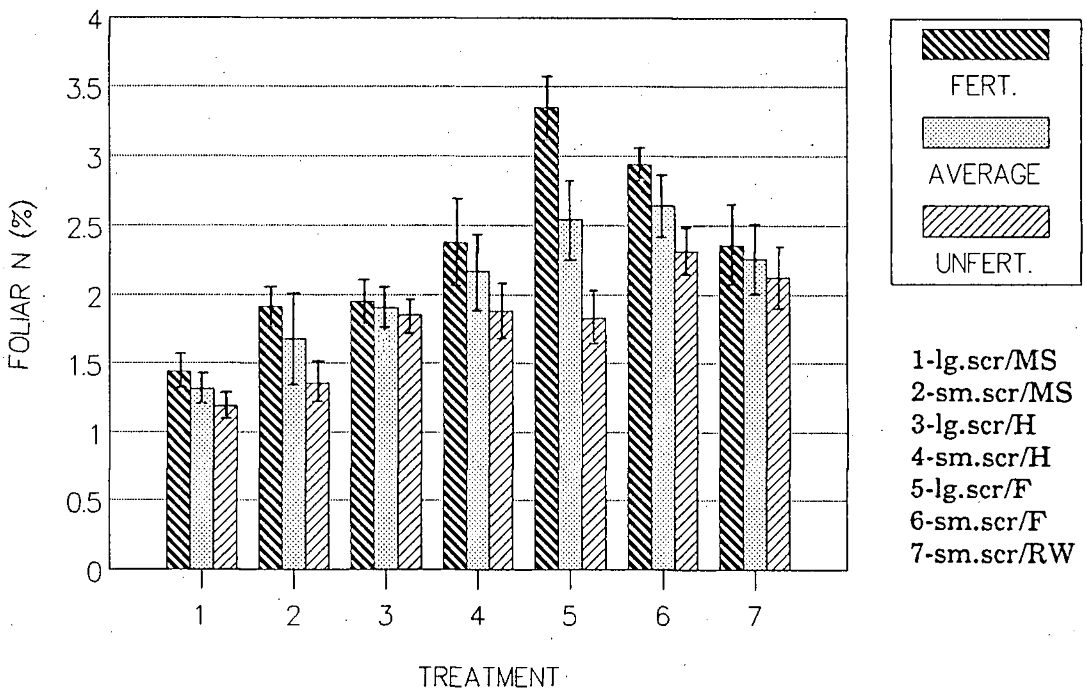


Table 4.4.0.3 - Percent of seedlings with adequate N levels by treatment*

Treatment	Total % Adequate	Unfertilized % Adequate	Fertilized % Adequate
1-lg.screef min.soil	22.2	11.0	33.0
2-sm.screef min.soil	50.0	33.0	62.0
3-lg.screef H-layer	64.7	62.0	67.0
4-sm.screef H-layer	75.0	60.0	86.0
5-lg.screef F-layer	70.5	55.0	87.0
6-sm.screef F-layer	94.1	87.0	100.0
7-sm.screef rotten wood	85.7	83.0	87.0

* based on seedlings sampled for foliar N

Table 4.4.0.4 - Percent seedlings with adequate N levels by substrate*

Treatment	% Adequate
Min. soil	34.3
H-layer	70.0
F-layer	82.3
Rotten wood	85.7

* based on seedlings sampled for foliar N

Figure 4.4.0.B - Percent seedlings with adequate N levels by treatment

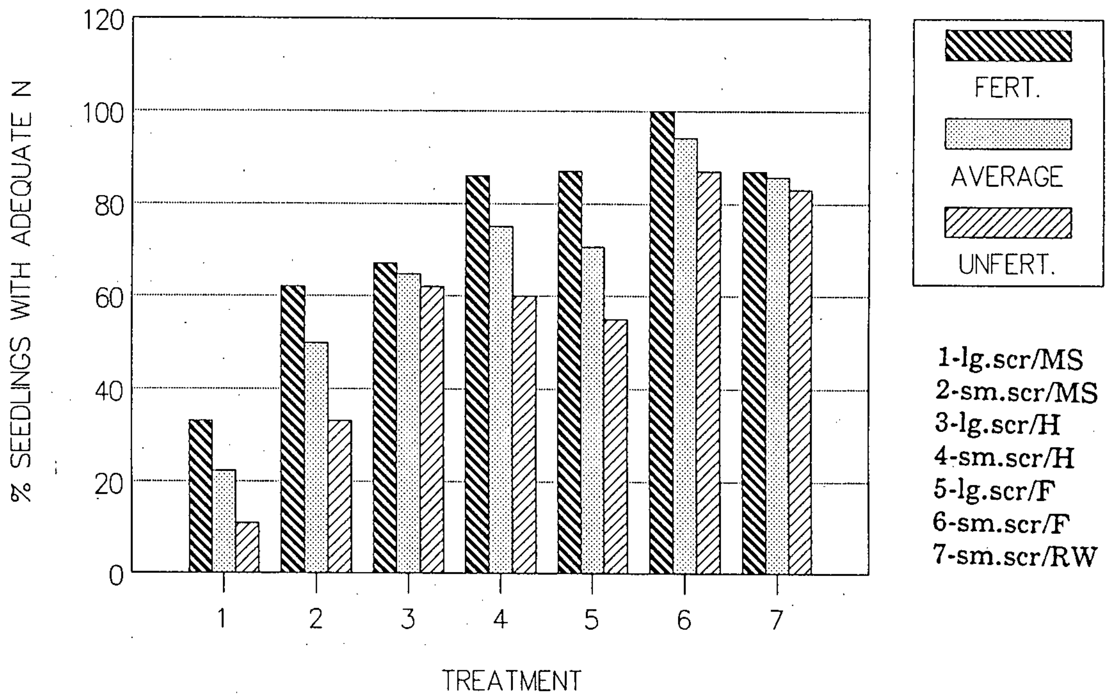
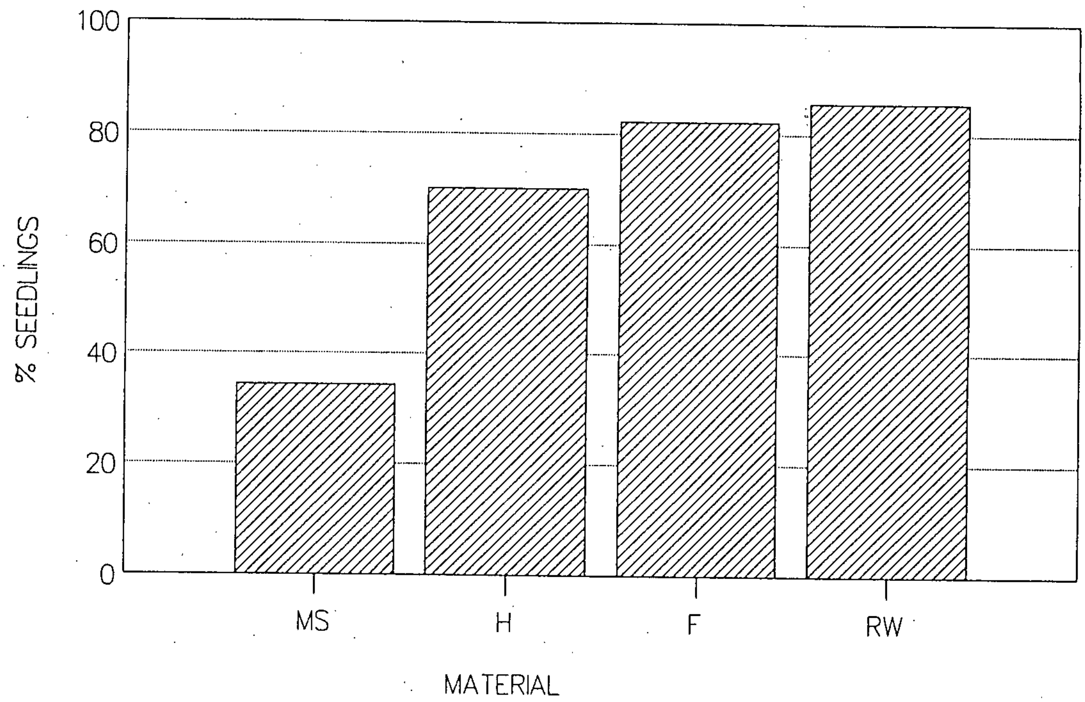


Figure 4.4.0.C - Percent seedlings having adequate N levels by substrate



SIGNIFICANT DIFFERENCES IN FOLIAR N CONCENTRATION

Significant differences are presented in Table 4.4.0.1, and are summarized below. Refer to Figure 3.03.C for a description of the screef size/substrate treatments.

Foliar nitrogen content

Foliar nitrogen content of seedlings in treatments 6 and 5 was significantly higher than that of seedlings in treatments 2 and 1. Foliar N content of seedlings in treatment 7 was significantly higher than of seedlings in treatment 1. Fertilized seedlings had significantly higher foliar nitrogen than unfertilized seedlings. There were no significant differences between blocks.

4.5 SOIL TEMPERATURE

Soil temperatures were recorded continuously for each screef size/substrate treatment during the period from June 18 to August 25, 1989. Because of the limitation of the number of channels on the data logger, soil temperatures were monitored in one location only, so there is no data for block to block differences, or for differences between watered versus unwatered subunits, or fertilized versus unfertilized subunits. Hourly average temperatures were recorded, as well as daily maximum and minimum temperatures. Significant differences in soil temperatures between treatments are presented in Table 4.5.0.1, and mean daily soil temperatures are found in Table 4.5.0.2 and Figures 4.5.0.A and 4.5.0.B. Daily maxima and minima over the growing season for each of the seven screef size/substrate treatments are presented in Figures 4.5.0.C (a-g).

Table 4.5.0.1 - Significant differences for soil temperatures by treatment (α=0.05)

Temperature measurement	Significance
Daily maximum	7>6,3,4,1,2 5,6,3>4,1,2 4,1>2
Probability	**0.00000***
Daily minimum	7,6,4,5>3,2,1 3>2,1 2>1
Probability	**0.00000***
Daily average	7,5,6>3,4,1,2 3,4>1,2
Probability	**0.00000***
Daily range	7>5,1,6,4,2 3,5>1,6,4,2 1,6>4,2 4>2
Probability	**0.00000***

* transformed data used

Table 4.5.0.2 - Daily Soil Temperatures (ºC)

Treatment	Maximum	Minimum	Average	Range
1-lg.screef min.soil	**13.278*** 1.469+	**9.974** 1.384	**11.292** 1.295	**3.304** 1.120
2-sm.screef min.soil	**11.179** 1.127	**10.546** 1.265	**10.811** 1.213	**0.633** 0.272
3-lg.screef H-layer	**15.671** 1.955	**11.339** 1.636	**13.239** 1.627	**4.332** 1.269
4-sm.screef H-layer	**13.794** 1.733	**12.336** 1.560	**13.002** 1.587	**1.458** 0.514
5-lg.screef F-layer	**16.106** 1.946	**12.273** 1.794	**14.034** 1.758	**3.832** 0.973
6-sm.screef F-layer	**15.702** 2.044	**12.441** 1.749	**13.898** 1.821	**3.261** 0.976
7-sm.screef rotten wood	**16.821** 2.321	**12.493** 1.812	**14.479** 1.934	**4.328** 1.115

* mean
\+ standard deviation

Figure 4.5.0.A - Daily maximum & minimum soil temperatures by treatment

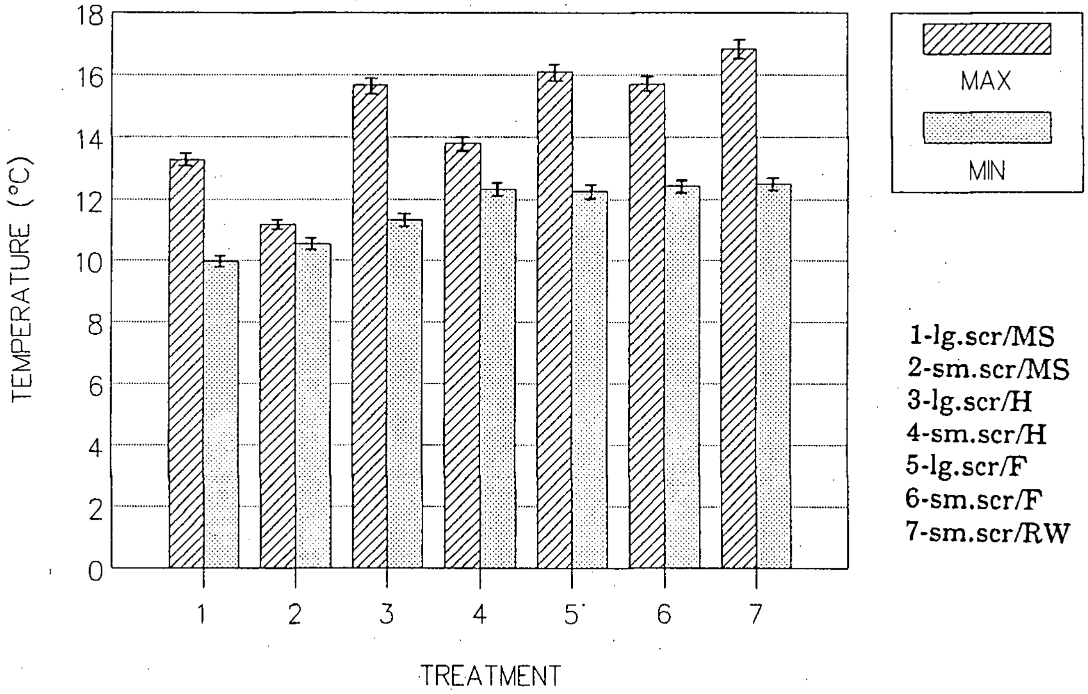


Figure 4.5.0.B - Daily average soil temperatures & daily range in soil temperature

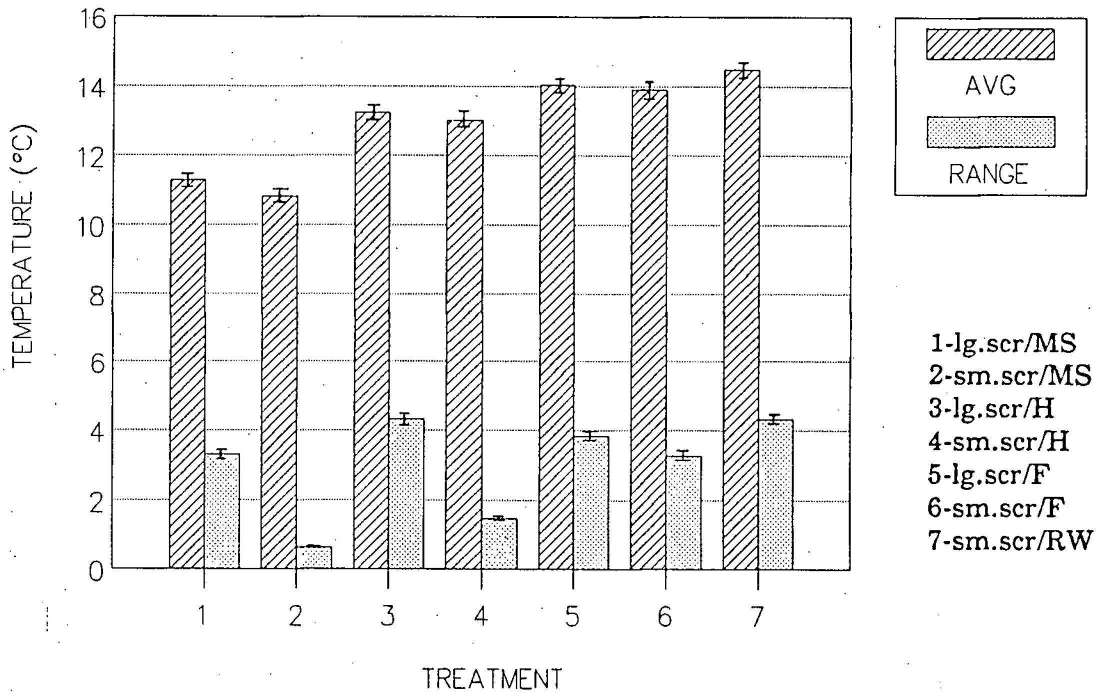
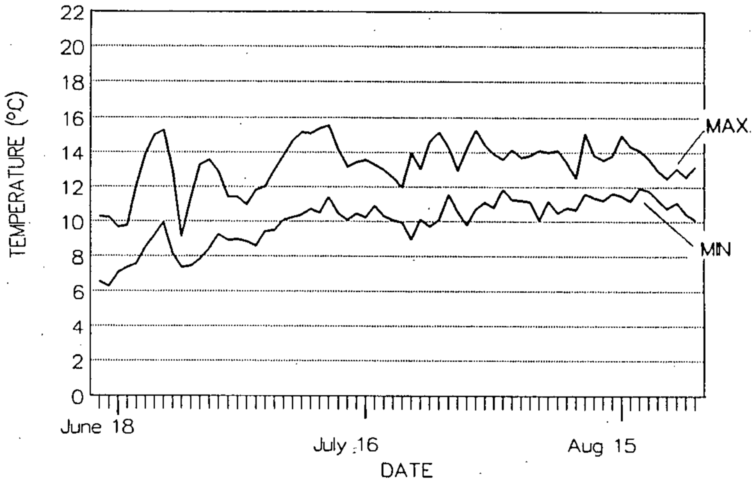
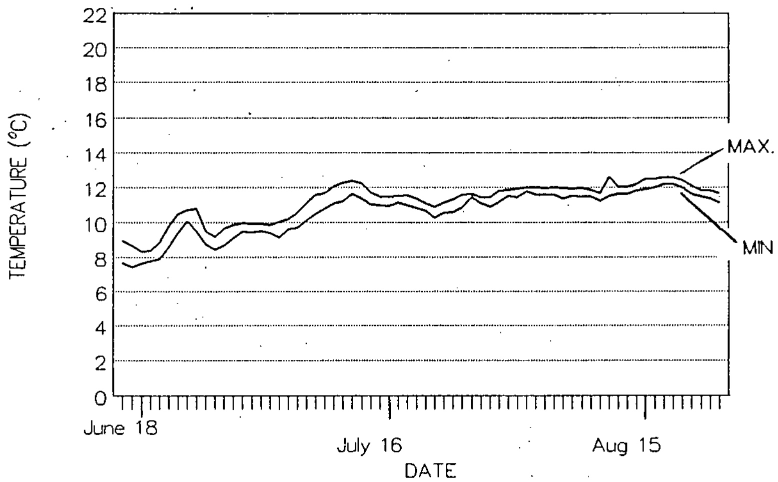


Figure 4.5.0.C(a-g) - **Daily maximum and minimum soil temperatures (June 18-Aug 22/89)**

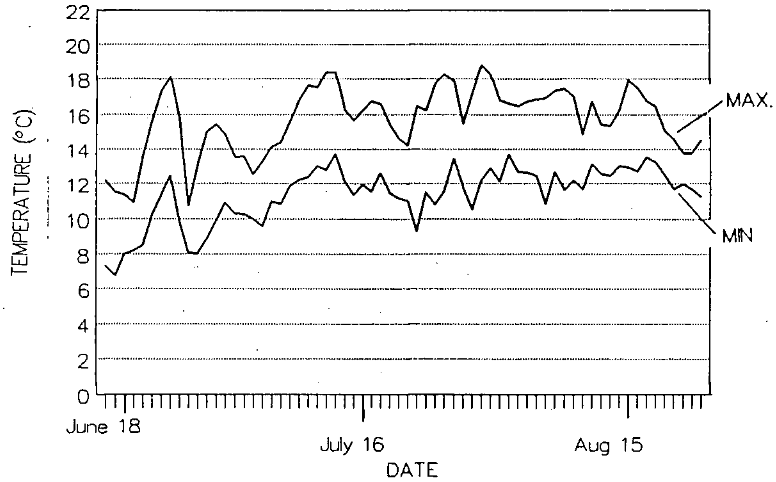
a - **Treatment 1 (large screef, mineral soil)**



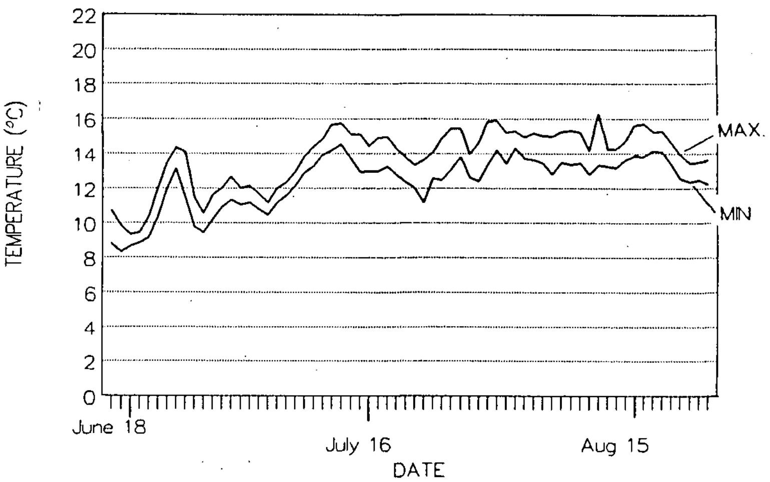
b - **Treatment 2 (small screef, mineral soil)**



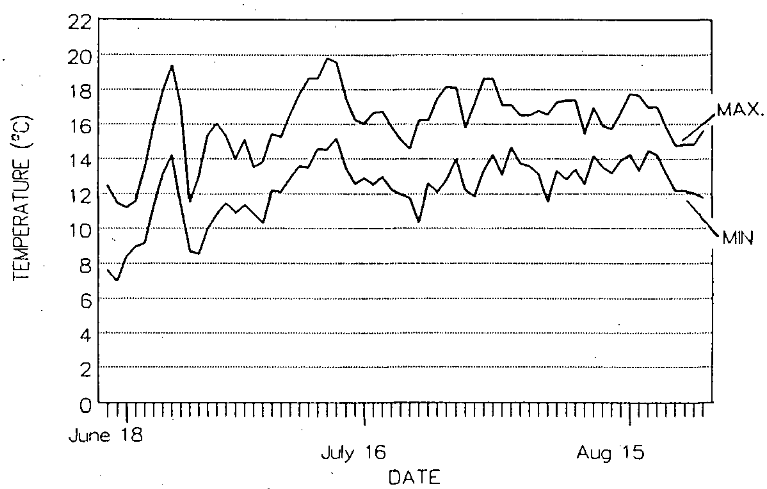
c - **Treatment 3 (large screef, H-layer)**



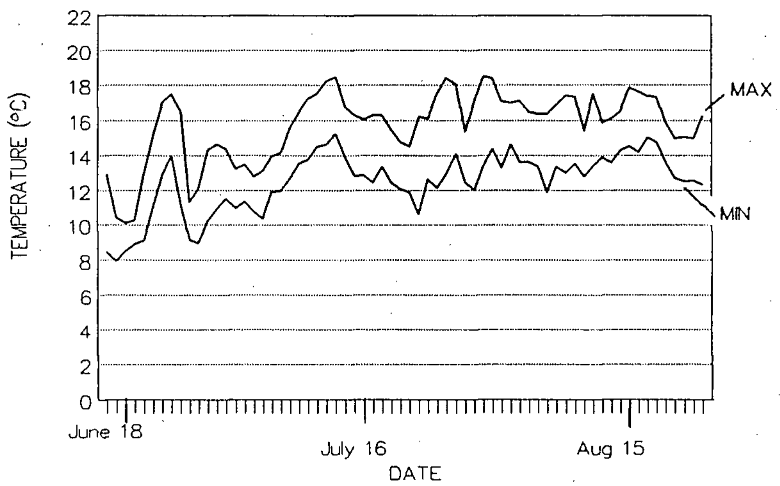
d - **Treatment 4 (small screef, H-layer)**



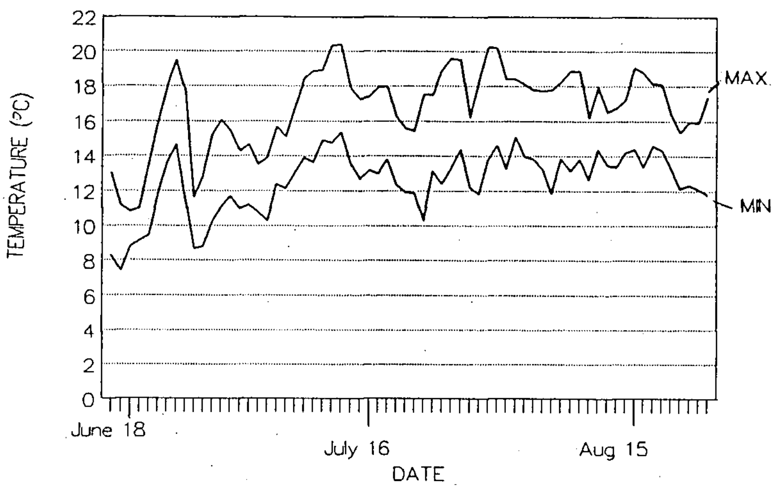
e - **Treatment 5 (large screef, F-layer)**



f - Treatment 6 (small screef, F-layer)



g - Treatment 7 (small screef, rotten wood)



SIGNIFICANT DIFFERENCES IN MEAN DAILY SOIL TEMPERATURE

Significant differences are presented in Table 4.5.0.1 and are summarized below.

Daily maximum

Substrate in treatments 7 and 5 had significantly higher daily maximum temperatures than soil materials in the other 5 treatments. The daily maximum temperatures for substrates in treatments 6 and 3 were significantly higher than the temperatures of substrates in treatments 4, 1, and 2. Soil material in treatments 4 and 1 was warmer than material in treatment 2.

Daily minimum

The daily minimum temperature for treatments 1, 2, and 3 was significantly lower than for treatments 5, 4, 6, and 7. Mineral soil treatments 1 and 2 had lower minimum temperatures than treatment 3 , and treatment 1 had a lower daily minimum temperature than treatment 2.

Daily average

Substrates in treatments 7, 5, and 6 was significantly warmer than substrates in treatments 3, 4, 1, and 2. Treatments 3 and 4 had higher average temperatures than in treatments 1 and 2.

Daily range

Rotten wood in treatment 7 had a significantly wider range in daily temperature than substrates in treatments 5, 1, 6, 4, and 2. Substrate of treatments 3 and 5 had a wider range in temperature than material in treatments 1, 6, 4, and 2. Substrate in treatments 1 and 6 had a wider range than substrate in treatments 4 and 2, and treatment 4 had a wider range than treatment 2.

4.6 SOIL MOISTURE CONTENT

Gravimetric moisture contents of the soil materials in the seven treatments were determined in the week prior to commencing the watering treatment in June 1989, in order to get a baseline measurement. Moisture contents were then determined weekly from June 21 to August 16, while the watering treatment was underway. Significant differences in water content are presented in Tables 4.6.0.1 to 4.6.0.3. Mean volumetric water contents for each of the seven screef size/substrate treatments are found in Table 4.6.0.4 and Figure 4.6.0.A. These data were not successfully transformed to meet the analysis of variance requirement for equal variances. Refer to Appendix B.

Table 4.6.0.1 - Significant differences in water contents between treatments (α=0.05)

Time Period	Significant differences
Before watering	1,2>4,3,7,6,5 4,3,7>6,5
Probability	**0.00000**
During watering	1,2>4,3,7,5,6 4,3,7>5,6
Probability	**0.00000**

Table 4.6.0.2 - Significant differences in water contents between watering treatment subplots (α=0.05)

Time period	Significant differences
Before watering	ns
Probability	**0.15094**
During	ns
Probability	**0.08812**

Table 4.6.0.3 - Significant differences in water contents between blocks (α=0.05)

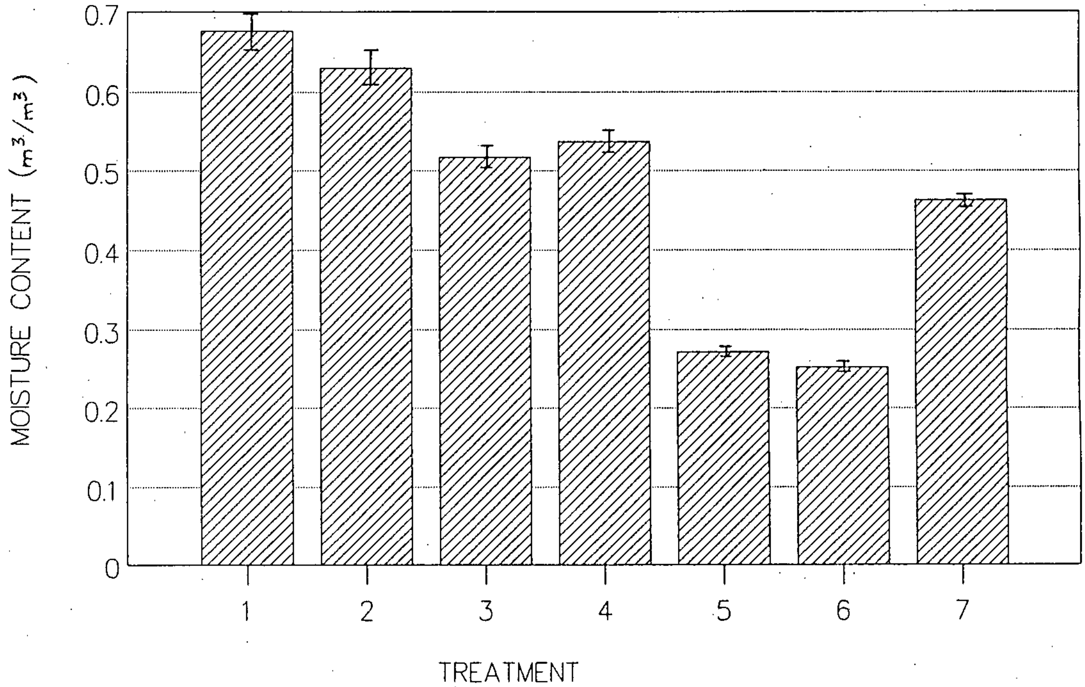
Time period	Significant differences
Before watering	ns
Probability	**0.14481**
During watering	C>A>B
Probability	**0.00001**

Table 4.6.0.4 - Mean volumetric water contents of material by treatment (m^3/m^3)

Treatment	Before watering	During watering
1-lg.screef	**0.678***	**0.676**
min.soil	0.256+	0.149
2-sm.screef	**0.600**	**0.630**
min.soil	0.092	0.135
3-lg.screef	**0.494**	**0.517**
H-layer	0.080	0.090
4-sm.screef	**0.520**	**0.536**
H-layer	0.076	0.088
5-lg.screef	**0.289**	**0.272**
F-layer	0.022	0.027
6-sm.screef	**0.295**	**0.251**
F-layer	0.072	0.026
7-sm.screef	**0.468**	**0.463**
rotten wood	0.057	0.049

* mean
\+ standard deviation

Figure 4.6.0.A - Volumetric water content by treatment



SIGNIFICANT DIFFERENCES IN VOLUMETRIC WATER CONTENT

Significant differences are presented in Tables 4.6.0.1 to 4.6.0.3, and are summarized below.

Volumetric water contents before watering

Water contents of mineral soil in treatments 1 and 2 were significantly higher than water contents of the soil materials in any of the other treatments. The water contents of substrates from treatments 4, 3 and 7 were significantly higher than water contents of substrates from treatments 5 and 6 . There were no significant differences in water content in the subunits that were to be watered or unwatered before the watering treatment began. There were no differences in water contents of the soil materials between blocks.

Volumetric water contents during watering treatments

The volumetric water contents of mineral soil from treatments 1 and 2 were significantly higher than the water contents of soil materials from any other treatment. The water contents of substrates in treatments 4, 3, and 7 were significantly higher than the water contents of substrates from treatments 5 and 6. There were no significant differences in volumetric water contents of soil materials in the unwatered and watered subunits during the period of watering. Blocks had significantly different water contents, with block C water content higher than block A, which was higher than block B water content.

4.7 SOIL CHARACTERISTICS

4.7.1 MOISTURE RETENTION

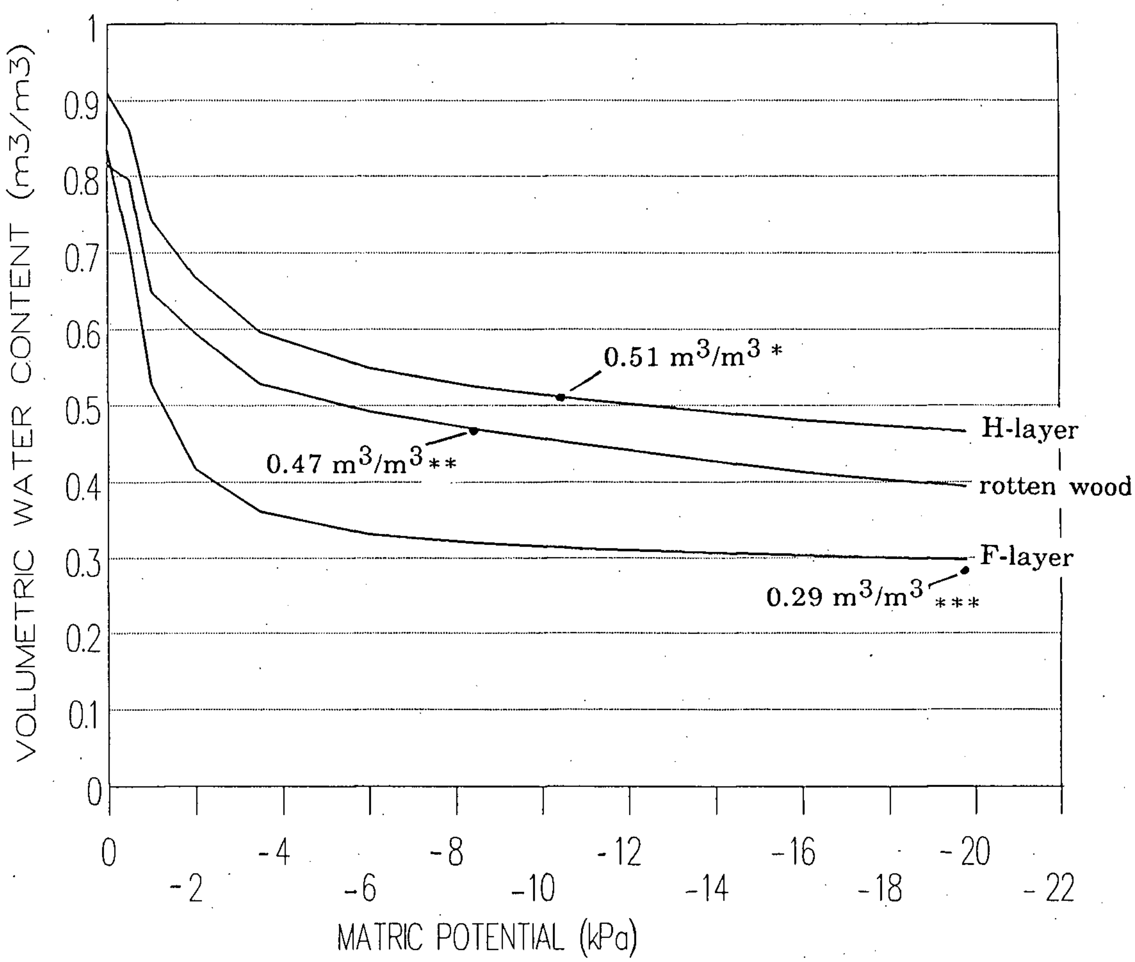
Water retention curves for the three substrates of the forest floor were obtained as described in Section 3.08. Volumetric water contents over the range of matric potentials obtained through use of the hanging column apparatus are presented in Table 4.7.1.1, and are plotted as water retention curves in Figure 4.7.1.A. Also plotted in Figure 4.7.1.A are the mean volumetric water contents of each of the substrates for the period of June 21-Aug 16, 1989.

Table 4.7.1.1 - Volumetric water contents of forest floor substrates (m^3/m^3)

Matric potential (kPa)	H layer	F layer	Rotten wood
-0.0	**0.909***	**0.835**	**0.815**
	0.101+	0.062	0.089
-0.5	**0.861**	**0.705**	**0.795**
	0.072	0.039	0.101
-1.0	**0.744**	**0.527**	**0.650**
	0.039	0.047	0.053
-2.0	**0.669**	**0.417**	**0.595**
	0.068	0.041	0.055
-3.5	**0.597**	**0.360**	**0.529**
	0.066	0.034	0.052
-6.0	**0.549**	**0.330**	**0.492**
	0.061	0.032	0.061
-8.5	**0.524**	**0.319**	**0.468**
	0.055	0.031	0.066
-11.0	**0.508**	**0.312**	**0.448**
	0.049	0.030	0.071
-16.0	**0.480**	**0.303**	**0.412**
	0.039	0.029	0.075
-19.8	**0.465**	**0.297**	**0.394**
	0.032	0.029	0.074

* mean
\+ standard deviation

Figure 4.7.1.A - Water retention curves for forest floor materials



* mean volumetric water content for H-layer
** mean volumetric water content for rotten wood
*** mean volumetric water content for F-layer

4.7.2 BULK DENSITY

Bulk density was determined using the method described in Section 3.09, and mean bulk densities for the four substrates are presented in Table 4.7.2.1.

Table 4.7.2.1 - Soil bulk density (kg/m^3)

Material	Bulk density
Mineral soil	**1521.73*** 89.84+
H-layer	**169.62** 10.83
F-layer	**123.44** 15.66
Rotten wood	**166.00** 14.70

* mean
\+ standard deviation

4.7.3 FOREST FLOOR DEPTH

Mean forest floor depths, and the mean depth for the F-layer and H-layer are given in Table 4.7.3

Table 4.7.3.1 - Forest floor depth (cm)

Horizon	Depth
H-layer	**14.72*** 4.52+
F-layer	**10.65** 6.16
Total	**27.79** 7.74

* mean
\+ standard deviation

4.8 WEATHER

Weather information was obtained from the Smithers airport, approximately 15 km from the research site, and is summarized below for the growing seasons of 1989 and 1990.

Table 4.8.0.1 - Weather information from Smithers airport

Date	Mean daily maximum (°C)	Mean daily minimum (°C)	Mean daily average (°C)	Total monthly ppt.(mm)
May 89	16.8	3.1	9.6	10.0
Jun 89	21.8	6.3	12.7	14.1
Jul 89	22.6	8.7	15.7	15.7
Aug 89	22.6	10.3	16.5	42.0
May 90	16.5	3.9	10.2	39.3
Jun 90	18.5	7.0	12.7	75.0
Jul 90	23.6	8.7	16.2	29.0
Aug 90	24.6	9.8	17.5	17.2

Figure 4.8.0.A - Temperature and precipitation 1989 (mid-May to mid-Aug)

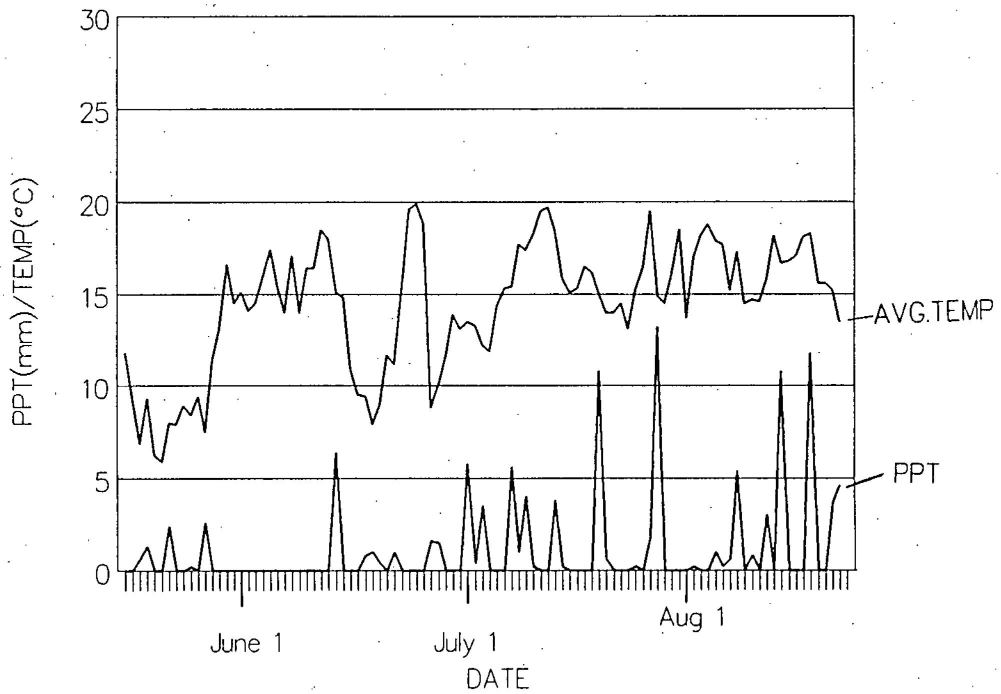
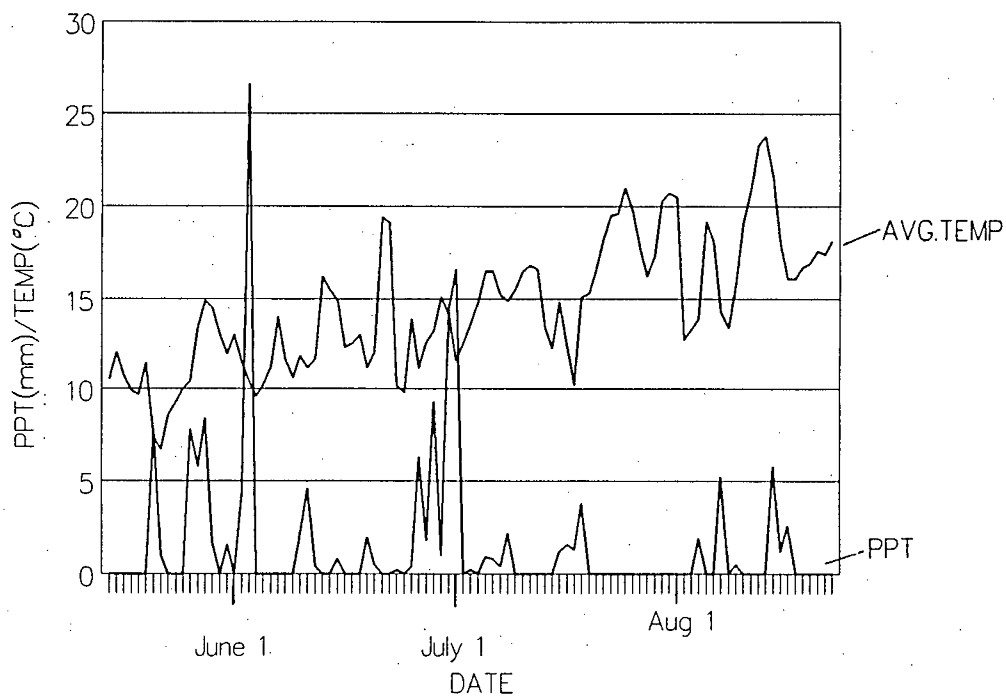


Figure 4.8.0.B - Temperature and precipitation 1990 (mid-May to mid-Aug)



5.0 DISCUSSION

The main objective of this study was to look at the ability of Interior spruce seedlings to grow and survive in four substrates: mineral soil, H-layer, F-layer, and rotten wood, on a hygric site with a thick forest floor in the ICHmc1. A further objective was to gather data concerning soil temperature and moisture conditions on this site, and determine whether these factors were related to growth and survival. As well, there was an attempt to determine whether nitrogen was a limiting factor to growth and survival on this site, and whether this varied for the four substrates.

This chapter will first discuss the results of the soil temperature study, then go on to the results of the soil moisture study, and the effects of the watering treatment. Then it will discuss the effects of fertilization with ammonium nitrate, and the outcome of the foliar nitrogen study. This information will be used to interpret and discuss the results of the seedling growth study, with regard to several growth parameters, as well as seedling survival.

5.1 SOIL TEMPERATURE RESULTS

Due to the constraint of having only one data logger with seven channels, soil temperatures were taken in one location only, selected because it appeared to be average in its forest floor characteristics for the research site as a whole. Statistically, it is not possible to say that this data is representative of the entire research site, but it is assumed that while the temperatures themselves may have varied slightly from place to place, the relative relationship between the temperatures of the materials in the seven treatments would be similar over time.

Soil temperature fluctuation reflected fluctuation in air temperature, as can be seen by comparing Figures 4.5.0.C(a-g) with Figure 4.8.0.A.

Trends in temperature for the materials in the seven treatments were very similar for daily maximum and daily average, but occurred over a larger temperature range for daily maximum, and so were more pronounced. Mean daily maximum temperature was also most clearly correlated with the various parameters of seedling growth, particularly root mass, which will be discussed in detail further on.

The highest mean daily maximum temperature occurred in rotten wood (treatment 7) at 16.8°C. This was followed by F-layer material (treatments 5 and 6), at 16.1°C and 15.7°C respectively, then by H-layer material (treatments 3 and 4), at 15.7°C and 13.8°C, and finally by mineral soil (treatments 1 and 2) at 13.3°C and 11.2°C. Rotten wood in treatment 7 reached a significantly higher mean daily maximum temperature than any of the materials in the other treatments, except treatment 5. It should also be noted that the large screef treatments for mineral soil, H-layer, and F-layer had higher mean daily maximum temperatures than the small screef treatments in the same materials. Trends in mean daily average temperature were similar, ranging from 14.5°C for rotten wood in treatment 7, to 10.8°C for mineral soil/small screef in treatment 2.

These results are as expected, and can be explained in terms of several factors. The four materials have different thermal properties, and these vary further with water content. Difference in volumetric heat capacity of the four materials is probably the most important factor. Mineral soil has a higher volumetric heat capacity than organic material, largely as a result of differences in bulk density, and the volumetric heat capacity of both materials increases as water content increases (Lutz and Chandler 1946). On this site, mineral soil had a higher volumetric water content than the organic materials, and this factor in combination with its much greater bulk density, accounts in large part for why mineral soil remained cooler than the forest floor materials throughout the growing season. Bulk densities of the materials varied from 1522 kg/m^3 for mineral soil to 169 kg/m^3 for H-layer, to 166 kg/m^3 for rotten wood, to 123 kg/m^3 for F-layer.

Again, because of differences in bulk density, H-layer material had a higher heat capacity than F-layer material. It also had higher water content than F-layer material, further increasing the heat capacity. However, while daily maximum temperature was greater for F-layer material than H-layer material, the difference between the two was not as great as between mineral soil and the H-layer. There is a greater difference in water content between the two organic materials than between the H-layer and mineral soil, but the difference in bulk density is very much less, which probably accounts for the lesser difference in maximum temperature. In addition, H-layer material was darker in colour, and moister, than F-layer material, and so could be expected to have a lower albedo than the F-layer surface, and therefore would have absorbed a higher proportion of solar radiation. This is possibly why treatment 3 achieved maximum daily temperatures close to those of F-layer materials, in spite of the differences in water content and bulk density.

Rotten wood had the highest daily maximum temperature, but it had a bulk density and water content similar to that of H-layer material. A possible reason for its higher temperature is its dominant position in the microtopography, which will be discussed further on.

A second factor to consider is thermal conductivity which governs the ability of a material to move heat. The greater amount of air spaces and pores in organic material, particularly the F-layer, make it a poorer conductor than mineral soil. Since water is a better heat conductor than air, increased water content improves thermal conductivity.

The large screef treatments however, show that thermal conductivity had much less impact on soil temperatures than did volumetric heat capacity. Enough surface area was exposed in these treatments that mineral soil, having a higher thermal conductivity and a higher water content than the other substrates, should have warmed more than the organic substrates, which was not the case at the 7-8 cm depth of the probes. It appears that volumetric heat capacity (C) was large enough in this situation to lower the thermal diffusivity (λ /C), so that sufficient heat did not move downwards to produce temperatures as high as those occuring in the organic substrates.

Microtopography was mentioned earlier as a possible reason why rotten wood achieved the highest maximum daily temperature, while probably having a higher volumetric heat capacity than F-layer material. In the spot where soil temperature was monitored, and again this is typical of the entire research site, rotten wood and F-layer material formed the uppermost horizon, with rotten wood often forming mounds on the F-layer surface. This was followed by H-layer material, and finally by mineral soil, which occupied the lowermost horizon. Materials in the highest position would have been exposed to solar radiation for more of the day than material in lower positions, as well as being less shaded by vegetation. In particular, mineral soil in small screef treatments was shaded nearly all the time.

Mean daily minimum soil temperature results are interesting with regard to screef size. The lowest mean daily minimum temperature was reached in treatment 1 (large screef/mineral soil) at 9.9^{o}C, followed by treatment 2 (small screef/mineral soil) at 10.5^{o}C, and then by material in treatment 3 (large screef/H-layer) at 11.3^{o}C. These three treatments were all significantly different from one another at α=0.05. The other four treatments (5, 4, 6, 7) were not significantly different from each other, ranging in minimum daily temperature from 12.3°C for treatment 5 to 12.5°C for treatment 7. The large screef treatments for mineral soil, H-layer, and F-layer all reached lower daily minimum temperatures than the small screef treatments of the same material. This is because removal of the organic material allowed greater surface area for the emission of long wave radiation during the night. In the discussion of daily maximum temperature, it was noted that the small screef treatments, particularly 2 and 4 (mineral soil and H-layer), did not warm up as much as large screef treatments because of insulation provided by the overlying forest floor material, and because so little surface area was exposed to incoming solar radiation. For the same reason, heat did not escape as readily during the night, and these treatments did not cool down as much as the same materials in large screef situations. In addition, the steep-sided screef holes of treatments 2 and 4 (refer to Figure 3.03.A) would have emitted long wave radiation back and forth during the night, limiting cooling.

Along with daily minimum soil temperatures, it is helpful to look at the daily range in temperature for each of the seven treatments, which was calculated as the difference between daily maximum and daily minimum. Since they neither warmed up nor cooled down as much, soil materials in small screef treatments had significantly smaller daily temperature ranges than did soil materials in large screef treatments. This is most noticeable for treatment 2 (small screef/mineral soil) and treatment 4 (small screef/H-layer), which had average daily temperature ranges of 0.6°C and 1.5°C respectively, as opposed to 4.3°C for treatment 7 (small screef/rotten wood).

5.2 SOIL MOISTURE RESULTS

Volumetric water content of the soil materials in the seven treatments, in each of the three blocks, was monitored weekly during the period of June 19 to August 15, 1989, as described in Chapter 3. The first measurement was taken before commencing the watering treatment, and it established that there were no initial significant differences ($\alpha=0.05$) in soil water content between the watered and unwatered subplots. However, the water content determination for the subsequent seven weeks of the watering treatment also revealed no significant difference in water content between the two subplots. In other words, the watering treatment did not create significant differences in water content between the watered and unwatered subplots.

The purpose of the watering treatment was to determine whether lack of moisture was a limiting factor to survival and growth of seedlings on this site, particularly for seedlings growing in the F-layer, which because of its structure and elevated position above the water table was most likely to dry out. The watering treatment was not effective in creating a significant change in soil water content which could be correlated with growth and survival data. No differences in any of the growth parameters, or in seedling survival, were found as a result of the watering treatment, so the question remains unsettled.

There were significant differences in volumetric water content for the four substrates. Mineral soil had the highest water content at 0.64 m^3/m^3, followed by the H-layer at 0.51 m^3/m^3, rotten wood at 0.47 m^3/m^3, and finally by the F-layer at 0.29 m^3/m^3. Except for rotten wood and the H-layer, the water contents of all soil materials were significantly different from one another. There were no significant differences in water content as a result of screef size. It should be noted that the volumetric water content of mineral soil is higher than expected considering the bulk density of that material, and it is possible that excess water from seepage got into the soil tins during sampling.

The differences in water content of the four substrates can be explained in terms of their structure, and position above the water table. Mineral soil occupied the lowest position, and the water table was very close to the upper limits of this horizon, so naturally the water content was very high. H-layer material and rotten wood were similar in bulk density and somewhat similar in texture, since both were quite decomposed, and lost their structure easily when rubbed between the fingers. Neither material had large pore spaces such as were observed in the F-layer, which may account for the similarity of the volumetric water contents, as well as similarity in their water retention curves (Figure 4.7.1.A). The F-layer material is only partially decomposed, retaining much of the structure of the litter materials. The result of this is a substantial volume of large pore spaces in the F-layer, which drain quickly as precipitation occurs. This structure, together with its higher position above the water table result in F-layer material having a lower overall moisture content. These water contents are particularly important with regard to their effect on soil thermal characteristics.

The initial determination of water content, before watering began, revealed no significant differences at $\alpha=0.05$ between blocks. Subsequent monitoring during the seven weeks of the watering treatment, however, showed that block C material had significantly higher water content than material in block A, which was in turn significantly higher than material in block B. It is possible that fluctuations in the height of the water table during this period varied between the blocks, so that differences were revealed at some times and not at others, depending on recent trends in precipitation. Differences in water content of the three blocks is possibly related to differences in seedling growth, which will be discussed further on.

Water retention curves were determined for the H-layer, F-layer, and rotten wood, but no water retention curve was attempted for mineral soil for two reasons. First, coarse fragment content of the mineral soil meant it was not possible to get undisturbed core samples, so that the hanging column method was not suitable, and a more complicated laboratory method would have been required. Second, the water content of the mineral soil on this site was so high all year around, that its ability to retain moisture seemed irrelevant. The three water retention curves and the average water contents for the three organic materials are shown in Figure 4.7.1.A. Although these curves only deal with high (not very negative) matric potentials to -20 kPa, it can be seen that average water contents of H-layer material and rotten wood fall onto their respective curves at close to -10 kPa. The average water content of F-layer material does not quite fall on the retention curve at -20 kPa, but it is close, and if the slope of the curve remained constant the point would fall onto the curve at around -25 kPa. To put this in perspective, conifer seedlings survive soil water potentials of -2 to -3 MPa (-2000 to -3000 kPa) (Ballard and Dosskey 1985), although growth may be inhibited at much less negative water potentials. Day and MacGillivray (1975) found that root growth was severely limited at soil moisture potentials of -1.5 bars (-150 kPa), and Spittlehouse and Stathers (1990) state that most plants stop growing at about -1 MPa (-1000 kPa). In this study, soil matric potentials were no lower than -30 kPa, so it can safely be said that on this particular site, lack of moisture was not a limiting factor to growth or survival, even in the F-horizon.

The hydraulic conductivity of soil is also an important factor in terms of seedling water relations. It was beyond the scope of this study to determine hydraulic conductivity of the four soil materials, but it is recognized that the ability of a soil to move water along gradients to roots is as important as the amount of water present at various matric potentials.

The steep drop-off of the water retention curve for the F-layer material at very low matric potential is also an indication that much of the water in the F-layer is drained off rapidly from large pore spaces, accounting for its lower water content than the other soil materials.

5.3 FERTILIZATION & FOLIAR NITROGEN ANALYSIS

In May 1990, ammonium nitrate fertilizer was applied in the same split-plot layout as was used for the watering treatment in 1989. The main reason for the fertilization treatment was to determine whether or not nitrogen was limiting to growth on this site, and whether there were any differences in nitrogen status and response to fertilization between the seven treatments. Although this site had a thick forest floor, no doubt containing high levels of nitrogen, it is possible that very little nitrogen was in an available form, due to the slow mineralization rates resulting from low soil temperature.

In August 1989, a number of slightly chlorotic seedlings had been observed, particularly in the F-layer treatments and rotten wood. In most cases the seedlings appeared otherwise healthy, but were paler green than seedlings in the H-layer and mineral soil. If nitrogen deficiency was causing the chlorosis, then fertilization could be expected to improve growth and survival.

Results are reported as cg/g foliar nitrogen on a dry-mass basis (Table 4.4.0.2), and also as percentage of seedlings having adequate nitrogen (Table 4.4.0.3), using the values given by Ballard and Carter (1985). According to this publication, foliar nitrogen levels of 1.55 cg/g are adequate for white spruce.

Fertilization with ammonium nitrate did significantly improve seedling growth for all of the pamameters except shoot to root ratio. There was also increased survival in the fertilized subplot as compared to the unfertilized subplot, although this difference may be due more to the presence of the fungus Rhizina undulata in the unfertilized subplot, than to the benefits of increased levels of available nitrogen in the fertilized subplot. Unfortunately, there was no way to quantify mortality that could be attributed to Rhizina rather than to other causes. Differences in growth that resulted from fertilization will be discussed fully in Section 5.4.

As expected, foliar nitrogen levels were found to be significantly higher in the fertilized subplot at 2.32 cg/g N than in the unfertilized subplot at 1.78 cg/g N. In the fertilized subplot 75.4% of seedlings sampled had adequate nitrogen levels, as opposed to 57.9% of the unfertilized seedlings.

Seedlings in the seven substrate/screef treatments had significantly different foliar nitrogen levels, and this was apparent for both the fertilized and unfertilized subplots, as can be seen in Figure 4.4.0.A. Highest foliar nitrogen levels were found in seedlings from treatments 6 and 5 (F-layer) at 2.64 cg/g and 2.54 cg/g respectively. Seedlings growing in rotten wood (treatment 7) had foliar nitrogen levels of 2.26 cg/g, followed by seedlings growing in treatments 4 and 3 (H-layer), with 2.17 cg/g and 1.91 cg/g respectively. The lowest foliar nitrogen levels were found in seedlings growing in mineral soil, with treatment 2 seedlings (small screef) at 1.67 cg/g, and treatment 1 (large screef) at 1.31 cg/g. The only significant differences were that seedlings in treatments 6, 5, and 7 had higher N levels than treatment 1 seedlings, and treatments 6 and 5 also had significantly higher N levels than treatment 2 seedlings.

Foliar nitrogen levels have been shown to be correlated with levels of mineralizable N in soil (Zöttl 1960, as cited by Ballard and Carter 1985) indicating that available nitrogen levels were higher in organic materials, particularly the F-layer, than in mineral soil. This is to be expected, since most fungal activity takes place in the F-layer. In addition, since soil temperature is highest in the F-layer, the rate of decomposition by fungi is higher than in lower horizons.

Low levels of foliar nitrogen in seedlings planted in mineral soil could also be related to the presence of water-logged conditions, since standing water was sometimes observed in the mineral soil screefs, particularly early in the season. Zinkan *et al.* (1974) found that reduced oxygen content in the soil solution resulted in foliar nitrogen deficiency in white spruce seedlings.

The foliar nitrogen results indicate clearly that the cause of chlorosis in seedlings growing in F-layer material and rotten wood was not nitrogen deficiency. Fertilization did not noticeably improve the slight chlorosis observed in seedlings in the F-layer and rotten wood. These seedlings were, however, the ones that showed the highest levels of foliar nitrogen before fertilization, when adequate levels were found in 71% of seedlings sampled from the F-layer and 83% of the seedlings in rotten wood, as opposed to only 20% in mineral soil. Sixty-one percent of seedlings sampled in the H-layer had adequate nitrogen levels. Figure 4.4.0.B shows the improvement in the percentage of seedlings having adequate nitrogen levels after fertilization. Seedlings in small screef treatments appeared to show a better response to fertilization, possibly because they may have received higher concentrations of fertilizer at the time of fertilization. It was difficult to achieve even

not enough fertilizer added?

application of the solution for seedlings in deep screefs, where the solution tended to pool in the bottom of the hole when applied.

A problem with the analysis of foliar nitrogen levels in this study was the small number of seedlings sampled. It was only decided to do foliar nitrogen analysis after the first growing season, and there was not an adequate number of seedlings in the experiment, after destructive sampling for growth measurements, to allow for more than three seedlings from each experimental unit to be sampled for foliage. In some cases, particularly in block B where mortality had been highest, only one or two seedlings were sampled, whereas Ballard and Carter (1985) recommend a mimimum sample size of 20. However, the total sample size was adequate to measure the overall effect of fertilization. Further research could be done to study the relationship between planting material and foliar nitrogen levels.

Since low nitrogen levels were not shown to be responsible for chlorosis on this site, the paler foliage colour may have been due to pigment degradation resulting from intense sunlight. Seedlings in F-layer material and rotten wood were the most chlorotic, and they were also the seedlings that received the most direct sunlight, due to their elevated position in the microtopography, and the lesser amount of competing vegetation on mounds. Binder *et al.* (1987) report that optimum light intensity for growth of white spruce seedlings is provided by about 30% shading by competing vegetation.

5.4 SEEDLING GROWTH RESULTS

Destructive sampling of seedlings was carried out twice, once after the first growing season in August 1989, and once after the second growing season in August 1990. Height, diameter, root mass, shoot mass, total seedling mass, and shoot mass to root mass ratio were determined, and analysed for significant differences at $\alpha=0.05$. The increase in size/mass from time of planting to time of sampling was also calculated.

The main trend in the data shows a better growth response for seedlings planted in any of the forest floor materials than in mineral soil, especially for the mineral soil/small screef treatment. This is more pronounced for the mass measurements than for height and diameter.

The most obvious correlation between seedling environment and seedling growth is for maximum soil temperature and root, shoot, and total mass. All of the organic materials were warmer than mineral soil, and seedlings growing in these substrates were heavier by August 1990 than seedlings growing in mineral soil.

A second relationship is between seedling mass and soil moisture content, where lower moisture content appears to be correlated with greater seedling weight. This is probably due to the effect of soil moisture content on soil temperature, as well as to the inhibition of root growth and water uptake resulting from water-logged or flooded conditions.

A third factor that may be involved, especially with regard to poorer growth response in mineral soil, is lack of available nitrogen. This relationship is more striking when considering the small percentage of seedlings with adequate nitrogen levels in mineral soil, than it is when considering average foliar nitrogen content.

The watering treatment carried out in 1989 had no significant effect on any of the growth parameters, whereas fertilization with ammonium nitrate in May 1990 produced significant differences for all growth parameters except shoot to root ratio.

Particularly in August 1990, block A produced seedlings of greater size/mass than seedlings in block C, and sometimes block B. This may be partly due to the significantly higher water content of soils in block C. Because of its effect on volumetric heat capacity and thermal conductance, higher moisture content of soils in block C probably resulted in slightly colder temperatures than in blocks A and B. In addition, the higher water content is an indicator of a higher water table relative to the height of the various horizons, and it is possible that flooded or waterlogged conditions were in effect for more of the year than in other blocks, which according to Grossnickle (1986) has an adverse effect on root growth in white spruce. Block A, however, had a significantly higher water content than block B, but in general also produced larger, heavier seedlings, indicating that some other factors must be involved, but are not apparent in the data. The total depth of the forest floor was also greater for block C than for block B, which means that it would have more effectively insulated lower horizons, resulting in lower soil temperature, particularly for small screef treatments. Again, this helps to explain differences in seedling growth between blocks C and B, but does not help in explaining why block A seedlings did better than either of the other blocks. Having the resources to monitor soil temperature in all three blocks would have helped in identifying differences in temperature that resulted from variations in moisture content and forest floor depth.

Analysis of the growth data for August 1989 showed that the error term E2 (interaction between blocks and watering, within treatment), was significant for all growth parameters except height. This is hard to explain except in terms of the residual error term, which E2 is tested against. The residual is very small due to the large number of seedlings sampled and the small variation between them at this sampling date, and this allowed small differences in E2 to be significant. This source of variation was only significant for the August 1989 data.

Transformations were carried out on data sets having unequal variances, as shown in Appendix B. In August 1990, data sets for all growth parameters required transformations. This indicates that within some treatments there was a greater variation in seedling growth response than within other treatments. This can be expected in a field experiment by the end of the second growing season, because small differences in environment exist within a block, and do not affect seedlings in different treatments the same way.

5.4.1 ROOT MASS, SHOOT MASS, & TOTAL MASS

Root mass, shoot mass and total seedling mass all show similar trends in significant differences between treatments, and these trends are more pronounced in August 1990 than in August 1989. Mass differences between seedlings in the seven screef size/substrate treatments show clearly that more growth occurred in seedlings planted in the three organic substrates than in mineral soil.

The most highly significant results were found in the analysis of root mass, and these differences can be explained very well in terms of variations in soil temperature and soil moisture for the seven treatments. Mass of oven dried roots in August 1990 varied from 3.54 g for seedlings in treatment 6 (small screef/F-layer) to 1.41 g for seedlings in treatment 2 (small screef/mineral soil). Seedlings from treatment 2 had significantly less root growth than seedlings in any of the other six treatments, a trend that is found for both dates of sampling, and is also noticeable for shoot mass and total seedling mass. Treatment 1 seedlings (large screef/mineral soil) had significantly greater root mass in August 1990 than seedlings in treatment 2 (small screef/mineral soil), but less than seedlings in any of the organic material treatments except treatment 4 (small screef/H-layer).

Examination of Figure 4.1.3.A along with Figure 4.5.0.A reveals the strong relationship between soil temperature and root growth. Treatments with higher soil temperatures produced seedlings with greater root mass, and in relative terms the variation in root growth between the seven treatments is very similar to the variation in maximum daily temperature. This correlation is further emphasized by the fact that in both mineral soil and H-layer material, large screef treatments, being warmer than small screef treatments, produced seedlings with greater root mass than those in small screef treatments. This difference did not show up between treatments 5 and 6 (F-layer), but there was very little temperature difference between these two treatments. According to Heninger and White (1974), the optimum temperature for root growth in white spruce is 19°C. Dobbs and McMinn (1977) also found that all aspects of white spruce seedling growth were best at a soil temperature of 20°C and were very poor at 10°C.

Further examination of Figures 4.1.3.A and 4.5.0.A show that the relative difference in root mass between seedlings planted in mineral soil (treatments 1 and 2) and seedlings in forest floor materials (treatments 3, 4, 5, 6, 7) is somewhat greater than the relative differences in soil temperature for those treatments. This may be partly due to soil moisture levels, which show an inverse relationship to root growth, particularly in the case of the mineral soil treatments. This can be seen by comparing Figure 4.1.3.A with Figure 4.6.0.A. In addition to contributing to low soil temperature, high soil water content can adversely affect root growth. Grossnickle (1986) flooded the roots of cold-stored white spruce seedlings for 14 days, and found that no root growth occurred in these seedlings even after flooding subsided, for the entire 42 days of the study. The height of the water table on this site was very near the surface of the mineral horizon, and in some cases, such as at the beginning of the growing season and after heavy rainfall, standing water could be observed in the bottom of the screefs in treatments 1 and 2. In addition, a rotting smell indicative of anaerobic conditions was observed in some of the wetter screefs when the mineral soil was disturbed. If anaerobic conditions did exist for some of the seedlings, there could have been an adverse effect on seedling root growth as a result of low oxygen content (Zinkan *et al.* 1974) or toxic conditions (Sanderson and Armstrong 1980).

In addition to inhibiting root growth, conditions of excessive moisture may also interfere with water uptake in cold soils. Grossnickle (1986) found indications of greater internal water stress in flooded sedlings than non-flooded seedlings. White spruce is known to be very sensitive to internal water stress, and responds by stomatal closure, thus reducing photosynthesis (Grossnickle and Blake 1987). Van den Driessche (1987) was also able to show that for Sitka spruce, current photosynthate is the primary carbon source for new root development, so that reduced photosynthesis could in turn inhibit root growth. These findings help account for the overall poorer growth of seedlings in mineral soil.

In addition to growing in conditions of low soil temperature and high soil water content, seedlings in mineral soil were found to have lower levels of foliar nitrogen than seedlings growing in forest floor materials. Lower N levels would contribute to their overall poorer growth response, which is supported by the fact that fertilization resulted in a significant increase in all seedling growth parameters except shoot to root ratio. Seedlings in the fertilized subplot had an average root mass of 3.30 g versus 2.36 g in the unfertilized subplot.

The much lower bulk density of the organic substrates than mineral soil would also seem to partially account for the greater root growth in forest floor materials.

In both August 1989 and August 1990, seedlings in block A had significantly greater root mass than seedlings in block C. This is assumed to be due mainly to the higher water content of material in block C.

During excavation of roots, differences were noted in root form for seedlings growing in the four soil materials. Although they were not quantified, these differences are worth mention as a possibility for future study, and because they help in interpreting the growth results. Seedlings growing in treatment 2 (mineral soil/small screef) produced the least root weight, and in most cases, new roots formed on these seedlings were adventitious roots on the lower portions of the shoot. The deep screefs collected loose organic material, and although some attempt was made to keep them cleaned out, there was usually a few centimeters of debris at the bottom of these holes, and this is where root growth took place. If the spot happened to be fairly well drained, there was some root development in the mineral soil. The same was true of seedlings grown in large screefs in mineral soil (treatment 1). When a high water table was apparent, the little root growth that occurred was at the very surface of the soil. If the large screef spot was in a more well drained area, the root mass tended to be bushy, and many branched, with most of the tips appearing to be mycorrhizal. Generally, roots did not extend more than 10 cm from the plug, except along the surface of the soil. H-layer material also produced a bushy, multibranched root, but with many more fine root tips than in the mineral soil. There were also some long roots extending away from the plug, up to 0.5 m in length, particularly in the large screef treatment. Root tips in this material also appeared to be mycorrhizal. F-layer material produced seedlings with root forms that were much less bushy, but with a great many more long coarse roots extending up to 0.75 or 1.0 m from the plug. They were not branched as many times close to the root plug, and it is estimated that the unsuberized root surface area, that is associated with water and nutrient absorption, was less for this type of root than for the finer root system in the H-layer, even if the total root weight may have been greater. Again, root tips appeared to be mycorrhizal. These seedlings also produced a great many roots at the base of the root plug, which grew down into the H-layer material, and were finer than those growing in the F-layer. Seedlings growing in rotten wood produced variable root forms. In some cases very few roots developed, and those few did not appear to be mycorrhizal. These seedlings were generally chlorotic and unhealthy looking. Seedlings of better vigour produced roots that appeared to be mycorrhizal, and were similar to those described for F-layer seedlings; long, coarse roots that grew through the rotten wood into F-layer material, or finer roots that grew downward into H-layer material. Further study of the relationship between root form and planting material in relation to ability for water and nutrient uptake could help interpret growth responses in different substrates.

Trends in seedling shoot mass are similar to those discussed for root mass, except for some differences between August 1989 and August 1990. In August 1989, seedlings in treatment 3 (large screef/H-layer) were significantly larger at 3.78 g than seedlings in any other treatment. There were no other significant differences in August 1989, except that seedlings in rotten wood (treatment 7) had greater shoot mass at 3.44 g than seedlings in treatment 2 (small screef/mineral soil) at 3.08 g.

By August 1990, seedlings in treatments 6 and 4 (small screef/F-layer and small screef/H-layer) had attained greater shoot mass than treatment 3 seedlings. All three of these treatments had significantly heavier shoots than seedlings in mineral soil (treatments 1 and 2), and seedlings growing in treatment 5 (large screef/F-layer) also had greater shoot mass than seedlings in treatment 2. In August of 1990 shoot mass ranged from 12.00 g in treatment 4 to 7.32 g in treatment 2. The trend in shoot mass for August 1990 reflects that of root mass closely, except in the case of treatment 4 (small screef/H-layer), and it follows that seedlings with the most well developed root systems would be capable of supporting the greatest shoot development, as well as vice-versa because of the relationship between current photosynthate and new root growth (van den Driessche 1987).

The correlation between soil temperature and root growth has been discussed, and seems to hold for shoot growth as well. The only slight difference in response is for seedlings in treatment 4, which started out slowly in 1989 in terms of both root and shoot growth, but by August 1990 had the greatest shoot weight, but had not increased proportionally in root weight, resulting in an increased shoot to root ratio. There is no ready explanation for the increase in shoot weight in this particular treatment.

Seedlings in the fertilized subplot had an average shoot mass of 11.50 g, which was significantly higher than the shoot mass of 8.31 g for unfertilized seedlings. This is proportional to the increase in root mass, since the shoot mass to root mass ratio was not changed significantly by fertilization.

Shoot mass in block A was significantly higher than shoot mass in block B, which was significantly higher than shoot mass in block C. As with root mass, it is difficult to explain this, except in terms of the higher water content of block C, which still does not shed light on the overall superior growth of seedlings in block A.

Seedling total mass was calculated as the sum of root mass and shoot mass for each seedling, and because of the generally higher mass of shoots than roots, trends in total mass reflect closely those of shoot mass. Total seedling mass in August 1990 ranged from 8.73 g in treatment 2 (small screef/mineral soil) to 15.40 g in treatment 6 (small screef/F-layer). Significant differences between treatments are nearly identical to those for shoot mass, as are significant differences for the fertilization treatments, and between blocks.

5.4.2 SHOOT MASS TO ROOT MASS RATIO

The trend in shoot mass to root mass ratio was similar in August 1989 and August 1990, and shows that seedlings from treatment 2 (small screef/mineral soil) had a much higher shoot to root ratio than any of the other treatments. In August 1990, the shoot to root ratio was 7.01 for seedlings in treatment 2. The next highest was treatment 4 (small screef/H-layer), with a shoot to root ratio of 5.13. The other treatments all had fairly similar shoot to root ratios, ranging from 4.04 for seedlings in treatment 1 (large screef/mineral soil), to 3.51 for seedlings in treatment 7 (rotten wood). The obvious trend here is that seedlings planted in small screef treatments had higher shoot to root ratios than seedlings in large screef treatments. This is apparent in August 1989, but is much more pronounced by August 1990. Seedlings in small screefs got taller, possibly in response to low light levels. The higher shoot to root ratios for treatments 2 and 4 could be due to colder, wetter soils inhibiting root growth, while height growth increased shoot weight disproportionally to root weight. As previously discussed, it is also possible that small screef treatments received somewhat higher nitrogen levels, due to uneven fertilizer application, which could have caused a greater increase in shoot growth than root growth. However, there were no significant differences between fertilized and unfertilized subplots to support this idea.

It is generally considered that nursery stock, particularly container stock, is out of proportion as far as shoot to root ratio is concerned. However, it is not just the mass of roots that is important, but the morphology as well, since plugs expose a relatively small root surface area to the soil. In this study, shoot to root ratio increased somewhat from the time of planting to the times of sampling, but for seedlings planted in the organic materials this increase was relatively small, and was not associated with a decline in seedling health. In fact, it was obvious that although the shoot to root ratio was somewhat higher, seedlings that had experienced significant root growth were exploiting a much greater volume of soil than was the case for the original plugs.

5.4.3 DIAMETER AND HEIGHT

There were no significant differences in diameter and height of seedlings in the seven treatments, but figures 4.1.1.A and 4.1.1.B show that by August 1990, there was a trend toward larger diameters for seedlings growing in organic materials, as compared to mineral soil. Diameters in August 1990 ranged from 0.63 cm for seedlings in treatment 2 (small screef/mineral soil) to 0.99 cm for seedlings in treatment 6 (small screef/F-layer). Although the differences were not significant, they reflect the tendency shown in seedling mass for better growth in forest floor materials than in mineral soil. Fertilization increased diameter significantly.

During the period of June 1989 to August 1990, seedlings in treatment 2 (small screef/mineral soil) showed the greatest height increase, followed by seedlings in treatment 4 (small screef/H-layer). Seedlings in small screef treatments were in very shaded conditions, and the height increase was probably a response to this. By August 1990, the tallest seedlings were found in treatment 4 and 3 (H-layer), and in treatment 2 (small screef/mineral soil). Treatment 2 seedlings were tall, but they had the lowest shoot mass of all the treatments. Treatment 4 seedlings on the other hand, were tall, but had the greatest shoot mass.

It is clear from the data that although an increase in height will result in a slight increase in shoot mass, it is not the main factor involved in shoot mass increase. Seedlings growing in mineral soil weighed less than those in organic materials, but were at least as tall. Height seems to have been influenced more by light levels than by soil temperature or moisture levels, or even by foliar nitrogen levels.

As with the other growth parameters, fertilization did result in a significant increase in height, as would be expected where overall seedling growth was improved.

In August 1990, seedling height in block A was significantly greater than in blocks B or C, as was the case for all other growth parameters except shoot to root ratio, and again is not readily explained.

5.5 SEEDLING SURVIVAL RESULTS

Seedling survival was assessed at three dates: August 1989, May 1990, and August 1990, the results of which are presented in Figure 4.3.0.A. Survival was close to 100% for all treatments in August 1989, but by May 1990 it had declined somewhat. Although there were still no significant differences ($\alpha=0.05$) in survival between treatments, it can be seen that mortality was slightly higher in F-layer material and rotten wood (treatments 5, 6, 7). By August 1990, survival had declined again, ranging from 77.4% in treatment 1 (large screef/mineral soil) to 55.9% in treatment 4 (small screef/H-layer), but again, differences were not significant.

Unfortunately, these results do not reflect seedling survival as a result of the inherent differences in the four substrates, since much of the mortality can be attributed to the root pathogen Rhizina undulata. This fungus occurs in patches on burned sites, and results in death of infected seedlings. Apothecia of the fungus were first noted in forest floor materials in August 1989, one year following burning. Both Ginns (1974) and Thies *et al.* (1977) used the presence of apothecia as evidence of pathogenicity, since the fungus is difficult to isolate from seedlings. By May 1990 there were some dead seedlings, and more by August 1990. According to Ginns (1974), most mortality caused by Rhizina occurs in the first year after planting, and although these results were for Douglas-fir, the effect on white spruce would be similar. It can therefore be expected that no further mortality as a result of Rhizina would occur on the research site after the 1990 growing season. Occurence of the fungus in forest floor materials, particularly the F-layer, can be explained in terms of the life cycle of the fungus. Rhizina requires fire to trigger germination of spores, and since the heat of slash fires penetrates only a few centimeters into the F-layer, that is where one would expect the fungus to grow. This suggests that Rhizina caused a higher proportion of mortality in the surface F-layer and rotten wood materials, than in the H-layer and mineral soil. This is supported by the trends in survival over the three sampling dates, where there was a greater decrease in survival from August 1989 to May 1990 in the F-layer and rotten wood than in mineral soil and the H-layer, but between May 1990 and August 1990, the decrease in mortality was greater in mineral soil and H-layer material than in the F-layer and rotten wood. It is speculated than most of the mortality that occured during the period of August 1989 to May 1990 was due to the fungus, whereas mortality occurring from May 1990 to August 1990 could have been mainly due to other causes.

Rhizina occurred on this site in two main patches, the largest one in the unfertilized subplot of block B, and a smaller one in block C that was in both the fertilized and unfertilized subplots. This is thought to be the main cause of the significant differences in survival between blocks, and in May 1990 block A had higher survival than either block B or block C. In August 1990, block A had higher survival than block C, which had higher survival than block B. No signs of Rhizina were observed in block A, and survival was 81%, as opposed to 69% in block C, and 53% in block B (refer to Table 4.3.0.4), giving an indication of the amount of mortality that could be attributed to the fungus.

There were also significant differences in survival between the fertilized subplot at 75%, and the unfertilized subplot at 61%, however it is impossible to say how much of this is really due to higher nitrogen levels. The largest patch of Rhizina was found in the unfertilized subplot of block B, and accounts for much of the higher survival that is attributed to fertilization in the analysis.

It is unfortunate that Rhizina occured in the study area, because there is no way of saying accurately how much seedling death was due to factors other than the fungus. A guess is that if the fungus had not been present, there would have been less mortality in F-layer material, and possibly rotten wood. Also, given the poor state of root development for seedlings in treatments 1 and 2, particularly those in small screefs, it is expected that by the third growing season mortality in mineral soil would have increased relative to other substrates, where a greater percentage of the surviving seedlings appeared to be well established.

6.0 CONCLUSIONS

The results of this study show clearly that, after two growing seasons, Interior spruce seedlings planted in F-layer and H-layer material were heavier than seedlings growing in mineral soil. This is true of root, shoot, and total mass, and is most pronounced in the comparison of seedlings growing in organic materials with those growing in the small screef/mineral soil treatment. Results were less clear for seedlings growing in rotten wood, but the trend was for better growth in rotten wood than in mineral soil. Height and diameter did not show significant differences.

Better growth in organic materials on this site can be attributed mainly to higher soil temperature in combination with lower water content. Higher soil temperature was clearly associated with greater seedling mass, and particularly with greater root mass. Because of the high water table on this site, and the fact that the most negative soil water potential was only about -30 kPa, it is safe to say that lack of moisture was not limiting to growth or survival, even in the F-layer. Excess water, on the other hand, could have been a limiting factor to growth and survival for seedlings planted in mineral soil, since standing water was observed at times in the bottom of screef holes, and there was something of an inverse relationship between soil moisture and seedling mass. High water content increases the heat capacity of soils, which on this site would negatively impact soil temperature.

Low foliar nitrogen levels also appear to be related to poor growth in mineral soil. Although average nitrogen contents for seedlings in the various treatments showed deficiency only for seedlings in the large screef/mineral soil treatment (according to levels reported by Ballard and Carter (1985)), the percentage of seedlings sampled with adequate nitrogen levels was much lower in mineral soil than in other materials. Fertilization with ammonium nitrate also increased seedling growth for all parameters except shoot mass to root mass ratio, indicating that even if foliar nitrogen content was adequate, it was less than optimum for growth of white spruce.

It is concluded that nitrogen deficiency was not the cause of the slight chlorosis observed in seedlings in the F-layer and rotten wood, since these substrates produced seedlings with the highest foliar nitrogen levels, and the highest percentage of seedlings with adequate N levels. A possible explantation for the paler green foliage of seedlings growing in these substrates is chlorophyll degradation resulting from over intense light levels. Binder *et al.* (1987) suggest that 30% shading by competing vegetation provides optimal light conditions for white spruce seedlings.

Shoot mass to root mass ratio was lower for seedlings growing in organic materials than in mineral soil, with the exception of the H-layer/small screef treatment. Seedlings growing in forest floor materials were better able to achieve an appropriate balance between shoot and root after planting than were seedlings growing in mineral soil, where low soil temperature and high soil water content in the deep screef holes inhibited root growth, and low light levels induced height growth away from the shaded conditions.

While this study expresses the differences in growth for seedlings planted in different materials and in different screef sizes, it is restricted in its ability to state conclusively what the limiting factors were, and to what degree they were interrelated. Further study needs to be done with regard to growth limiting characteristics of forest floor materials, and the results need to be tested on different sites.

Seedling survival was not significantly different for any of the treatments, but results were complicated by the presence of the fungus Rhizina undulata, since it is thought that it increased mortality in forest floor materials, particularly the F-layer and rotten wood, more than in mineral soil.

The implication of this study, in practical terms, is that for sites in the ICHmc1 that have a thick forest floor and a high water table, planting on elevated materials, with a minimal screef, will produce better growth results than screefing down through the F-layer material in an effort to get to mineral soil, or even H-layer material. Planting substrate itself appears to be less important than the temperature and moisture conditions of the material. It is interesting that even rotten wood, which has long been considered an unsuitable planting material for white spruce seedlings, produced better growth results than mineral soil.

This study is particularly applicable in the treatment of small areas of larger cutblocks, where it is not logistically feasible to employ mechanical site preparation techniques to improve the availability of suitable microsites.

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APPENDIX A

ANALYSIS OF VARIANCE TABLES

Diameter 1989

Source	SS	DF	MS	F	p	Test term
Block	0.0496	2	0.0248	5.9475	0.0029	Resid.
Trmt	0.1096	6	0.0183	2.0981	0.1294	Bl*Tr
Bl*Tr	0.1045	12	0.0087	2.0866	0.0173	Resid.
Water	0.0187	1	0.0187	1.8723	0.1928	Bl*W(Tr)
W*Tr	0.0664	6	0.0111	1.1061	0.4065	Bl*W(Tr)
Bl*W(Tr)	0.1401	14	0.0100	2.3981	0.0033	Resid
Resid.	1.4018	336	0.0042			
Total	1.8907	377				

Height 1989

Source	SS	DF	MS	F	p	Test term
Block	71.05	2	35.523	2.4817	0.0851	Resid.
Trmt	408.76	6	68.127	2.7065	0.0671	Bl*Tr
Bl*Tr	302.05	12	25.171	1.7585	0.0539	Resid.
Water	7.74	1	7.743	0.4729	0.5029	Bl*W(Tr)
W*Tr	50.23	6	8.373	0.5113	0.7901	Bl*W(Tr)
Bl*W(Tr)	229.24	14	16.374	1.1439	0.3181	Resid
Resid.	4809.50	336	14.314			
Total	5878.60	377				

Root weight 1989

Source	SS	DF	MS	F	p	Test term
Block	0.889	2	0.4444	5.1914	0.0060	Resid.
Trmt	6.694	6	1.1157	9.0265	0.0007	Bl*Tr
Bl*Tr	1.483	12	0.1236	1.4437	0.1443	Resid.
Water	0.402	1	0.4022	1.6923	0.2143	Bl*W(Tr)
W*Tr	1.465	6	0.2441	1.0273	0.4477	Bl*W(Tr)
Bl*W(Tr)	3.327	14	0.2377	2.7760	0.0006	Resid
Resid.	28.766	336	0.0856			
Total	43.026	377				

Shoot weight 1989

Source	SS	DF	MS	F	p	Test term
Block	0.075	2	0.0376	0.0720	0.9306	Resid.
Trmt	17.959	6	2.9931	5.6315	0.0055	Bl*Tr
Bl*Tr	6.378	12	0.5315	1.0166	0.4329	Resid.
Water	0.266	1	0.2661	0.2848	0.6019	Bl*W(Tr)
W*Tr	4.105	6	0.6842	0.7322	0.6319	Bl*W(Tr)
Bl*W(Tr)	13.082	14	0.9344	1.7872	0.0392	Resid
Resid.	175.670	336	0.5228			
Total	217.540	377				

Total weight 1989

Source	SS	DF	MS	F	p	Test term
Block	1.432	2	0.7160	0.9415	0.3911	Resid.
Trmt	41.776	6	6.9626	8.2468	0.0011	Bl*Tr
Bl*Tr	10.131	12	0.8443	1.1101	0.3507	Resid.
Water	1.323	1	1.3227	0.7319	0.4067	Bl*W(Tr)
W*Tr	7.769	6	1.2948	0.7165	0.6429	Bl*W(Tr)
Bl*W(Tr)	25.300	14	1.8072	0.7165	0.0037	Resid
Resid.	255.550	336	0.7606	2.3761		
Total	343.280	377				

Shoot to root ratio 1989*

Source	SS	DF	MS	F	p	Test term
Block	0.921	2	0.4605	4.4377	0.0125	Resid.
Trmt	3.876	6	0.6461	5.0942	0.0081	Bl*Tr
Bl*Tr	1.522	12	0.1268	1.2222	0.2659	Resid.
Water	0.246	1	0.2464	1.1752	0.2966	Bl*W(Tr)
W*Tr	1.739	6	0.2899	1.3828	0.2879	Bl*W(Tr)
Bl*W(Tr)	2.935	14	0.2096	2.0202	0.0159	Resid
Resid.	34.865	336	0.1038			
Total	46.105	377				

* data transformed by log(SR)

Diameter 1990*

Source	SS	DF	MS	F	p	Test term
Block	1.380	2	0.6898	3.1780	0.0432	Resid.
Trmt	3.688	6	0.6147	2.0237	0.1407	Bl*Tr
Bl*Tr	3.645	12	0.3037	1.3994	0.1655	Resid.
Fert	0.115	1	0.1148	0.3468	0.5653	Bl*F(Tr)
F*Tr	1.297	6	0.2162	0.6531	0.6878	Bl*F(Tr)
Bl*F(Tr)	4.634	14	0.3310	1.5249	0.1015	Resid
Resid.	59.908	276	0.2171			
Total	74.539	317				

* Unequal variances, but unable to transform.

Height 1990*

Source	SS	DF	MS	F	p	Test term
Block	1.046	2	0.5232	15.0020	0.0000	Resid.
Trmt	0.813	6	0.1355	2.3272	0.1004	Bl*Tr
Bl*Tr	0.699	12	0.0582	1.6699	0.0731	Resid.
Fert	0.508	1	0.5085	12.0430	0.0037	Bl*F(Tr)
F*Tr	0.342	6	0.0570	1.3495	0.3002	Bl*F(Tr)
Bl*F(Tr)	0.591	14	0.0422	1.2106	0.2669	Resid
Resid.	9.626	276	0.0349			
Total	13.647	317				

* transformed by log(ht)

Root weight 1990*

Source	SS	DF	MS	F	p	Test term
Block	1.889	2	0.9445	3.5350	0.0305	Resid.
Trmt	16.674	6	2.7789	12.2470	0.0002	Bl*Tr
Bl*Tr	2.723	12	0.2269	0.8493	0.5995	Resid.
Fert	3.507	1	3.5069	12.7000	0.0031	Bl*F(Tr)
F*Tr	3.595	6	0.5992	2.1700	0.1090	Bl*F(Tr)
Bl*F(Tr)	3.866	14	0.2761	1.0335	0.4199	Resid
Resid.	73.742	276	0.2672			
Total	107.000	317				

* transformed by $(\text{root wt.})^{0.5}$

Shoot weight 1990*

Source	SS	DF	MS	F	p	Test term
Block	23.081	2	11.541	17.295	0.0000	Resid.
Trmt	23.976	6	3.996	4.211	0.0164	Bl*Tr
Bl*Tr	11.386	12	0.949	1.422	0.1552	Resid.
Fert	16.615	1	16.615	23.347	0.0003	Bl*F(Tr)
F*Tr	6.556	6	1.093	1.535	0.2377	Bl*F(Tr)
Bl*F(Tr)	9.963	14	0.712	1.066	0.3882	Resid
Resid.	184.170	276	0.667			
Total	278.370	317				

* transformed by (shoot wt.)$^{0.5}$

Total weight 1990*

Source	SS	DF	MS	F	p	Test term
Block	26.315	2	13.1570	14.8310	0.0000	Resid.
Trmt	36.052	6	6.0087	4.9473	0.0091	Bl*Tr
Bl*Tr	14.575	12	1.2146	1.3690	0.1803	Resid.
Fert	21.732	1	21.7320	23.1660	0.0003	Bl*F(Tr)
F*Tr	9.225	6	1.5375	1.6389	0.2088	Bl*F(Tr)
Bl*F(Tr)	13.134	14	0.9381	1.0574	0.3968	Resid
Resid.	244.860	276	0.8872			
Total	369.88	317				

* transformed by (total wt.)$^{0.5}$

Shoot to root ratio 1990*

Source	SS	DF	MS	F	p	Test term
Block	0.648	2	0.3240	2.1190	0.1221	Resid.
Trmt	15.411	6	2.5685	19.3360	0.0000	Bl*Tr
Bl*Tr	1.594	12	0.1328	0.8687	0.5795	Resid.
Fert	0.042	1	0.0424	0.1985	0.6628	Bl*F(Tr)
F*Tr	0.959	6	0.1599	0.7491	0.6202	Bl*F(Tr)
Bl*F(Tr)	2.989	14	0.2135	1.3960	0.1542	Resid
Resid.	42.204	276	0.1529			
Total	63.850	317				

* transformed by log(SR)

Seedling survival August 1989

Source	SS	DF	MS	F	p	Test term
Block	25.424	2	12.712	3.0000	0.0823	Bl*W(Tr)
Trmt	86.051	6	14.342	1.3750	0.3001	Bl*Tr
Bl*Tr	125.170	12	10.430	2.4615	0.0554	Bl*W(Tr)
Water	1.304	1	1.304	0.3077	0.5878	Bl*W(Tr)
W*Tr	7.823	6	1.304	0.3077	0.9225	Bl*W(Tr)
Bl*W(Tr)	59.323	14	4.237	0.0000	1.0000	Resid
Resid.	0.000	0	0.000			
Total	305.090	41				

Seedling survival May 1990

Source	SS	DF	MS	F	p	Test term
Block	1731.60	2	865.800	11.8080	0.0010	Bl*F(Tr)
Trmt	1787.90	6	297.980	2.9012	0.0550	Bl*Tr
Bl*Tr	1232.50	12	102.710	1.4008	0.2710	Bl*F(Tr)
Fert	52.66	1	52.662	0.7182	0.4110	Bl*F(Tr)
F*Tr	27.99	6	4.665	0.0636	0.9986	Bl*F(Tr)
Bl*F(Tr)	1026.50	14	73.325	0.0000	1.0000	Resid
Resid.	0.00	0	0.000			
Total	5859.20	41				

Seedling survival August 1990

Source	SS	DF	MS	F	p	Test term
Block	5581.20	2	2790.60	19.926	0.0001	Bl*F(Tr)
Trmt	1810.70	6	301.79	2.119	0.1263	Bl*Tr
Bl*Tr	1708.70	12	142.39	1.017	0.4826	Bl*F(Tr)
Fert	2142.90	1	2142.90	15.301	0.0016	Bl*F(Tr)
F*Tr	584.68	6	97.45	0.696	0.6574	Bl*F(Tr)
Bl*F(Tr)	1960.70	14	140.05	0.000	1.0000	Resid
Resid.	0.00	0	0.00			
Total	13789.00	41				

Foliar nitrogen levels August 1990

Source	SS	DF	MS	F	p	Test term
Block	2.212	2	1.1060	2.6505	0.0780	Resid.
Trmt	23.087	6	3.8479	4.0923	0.0182	Bl*Tr
Bl*Tr	11.283	12	0.9403	2.2533	0.0183	Resid.
Fert	6.610	1	6.6100	8.0436	0.0132	Bl*F(Tr)
F*Tr	5.679	6	0.9466	1.1519	0.3841	Bl*F(Tr)
Bl*F(Tr)	11.505	14	0.8218	1.9693	0.0340	Resid
Resid.	27.958	67	0.4173			
Total	89.619	108				

Maximum soil temperature 1989*

Source	SS	DF	MS	F	p	Test term
Trmt	7.960	6	1.327	76.842	0.0000	Resid.
Resid.	7.856	455	0.017			
Total	15.817	461				

* data transformed by log(max)

Minimum soil temperature 1989*

Source	SS	DF	MS	F	p	Test term
Trmt	3.216	6	0.536	23.632	0.0000	Resid.
Resid.	10.320	455	0.0238			
Total	13.535	461				

* data transformed by log(min)

Average soil temperature 1989*

Source	SS	DF	MS	F	p	Test term
Trmt	4.906	6	0.818	45.820	0.0000	Resid
Resid.	8.120	455	0.018			
Total	13.027	461				

* data transformed by log(avg)

Soil temperature range 1989*

Source	SS	DF	MS	F	p	Test term
Trmt	212.110	6	35.352	335.44	0.0000	Resid.
Resid.	47.952	455	0.105			
Total	260.060	461				

* data transformed by log(range)

Soil moisture content before watering treatment 1989

Source	SS	DF	MS	F	p	Test term
Block	0.073	2	0.0368	2.250	0.1448	Resid.
Trmt	0.763	6	0.1272	24.472	0.0000	Bl*Tr
Bl*Tr	0.062	12	0.0052	0.317	0.9723	Resid.
Water	0.038	1	0.0381	2.329	0.1509	Bl*W(Tr)
W*Tr	0.079	6	0.0132	0.804	0.5843	Bl*W(Tr)
Bl*W(Tr)	0.213	13	0.0164	0.000	1.0000	Resid
Resid.	0.000	0	0.0000			
Total	1.209	40				

Soil moisture content during watering 1989

Source	SS	DF	MS	F	p	Test term
Block	0.234	2	0.1172	19.467	0.0000	Resid.
Trmt	6.747	6	1.1246	43.370	0.0000	Bl*Tr
Bl*Tr	0.311	12	0.0259	4.307	0.0000	Resid.
Water	0.030	1	0.0302	1.553	0.2332	Bl*W(Tr)
W*Tr	0.089	6	0.0150	0.770	0.6061	Bl*W(Tr)
Bl*W(Tr)	0.272	14	0.0194	3.228	0.0001	Resid
Resid.	1.505	250	0.0060			
Total	9.178	291				

APPENDIX B

RESULTS OF HOMOGENEITY OF VARIANCE TESTS

Growth data 1989*

Parameter	p	Transformed by	p
Diameter	0.17195	-	-
Height	0.02008	-	-
Root wt.	0.07513	-	-
Shoot wt.	0.54199	-	-
Total wt.	0.30481	-	-
Shoot:root	0.00000	log(SR)	0.02327

* based on the Chi-square statistic. Reject hypothesis that variances are equal if probability is less than 0.05.

Growth data 1990*

Parameter	p	Transformed by	p
Diameter	0.00000	log(diam)	0.00000
Diameter	0.00000	$(diam)^{0.5}$	0.00000
Height	0.00423	log(ht)	0.08344
Root wt.	0.00036	$(rtwt)^{0.5}$	0.59223
Shoot wt.	0.00009	$(shwt)^{0.5}$	0.12070
Total wt.	0.00117	$(totwt)^{0.5}$	0.30242
Shoot:root	0.00000	log(SR)	0.09303

* based on the Chi-square statistic. Reject hypothesis that variances are equal when probability is less than 0.05.

Soil temperature data*

Parameter	p	Transformed by	p
Maximum	0.00000	log(max)	0.12761
Minimum	0.03198	log(min)	0.46075
Average	0.00119	log(avg)	0.70652
Range	0.00000	log(range)	0.00070

* based on the Chi-square statistic. Reject hypothesis that variances are equal when probability is less than 0.05.

Soil moisture data*

Parameter	p	Transformed by	p
VW(wk 1)	0.00178	$(VW)^{0.5}$	0.01420
	0.00178	log(VW)	0.05758
VW(wk 2-8)	0.00000	$(VW)^{0.5}$	0.00000
	0.00000	log(VW)	0.00000

* based on the Chi-square statistic. Reject hypothesis that variances are equal when probabilities are less than 0.05. This set of transformations was unsuccessful, and none of it was used in the analysis.

APPENDIX C

RESULTS OF NORMALITY TESTS

Growth data 1989 probabilities*

Trmt* Water	Ht.	Diam.	Root wt.	Shoot wt.	Total wt.	Shoot: root*
1-NW	0.377	0.051	0.298	0.543	0.452	0.541
1-W	0.806	0.305	0.084	0.728	0.737	0.807
2-NW	0.563	0.169	0.687	0.358	0.118	<0.010
2-W	0.014	0.500	0.990	0.814	0.485	0.485
3-NW	0.605	0.504	0.942	0.308	0.406	<0.010
3-W	0.295	0.645	0.417	0.472	0.679	0.560
4-NW	0.373	0.353	0.049	0.341	0.541	0.706
4-W	0.662	0.152	0.240	0.022	0.100	0.502
5-NW	0.277	0.123	0.575	0.876	0.381	0.927
5-W	0.456	0.491	0.595	0.444	0.066	0.073
6-NW	0.343	0.752	0.227	0.326	0.789	0.753
6-W	0.296	0.663	0.610	0.459	0.363	0.324
7-NW	0.102	0.774	0.335	0.346	0.271	0.297
7-W	0.808	0.605	0.581	0.046	0.252	0.324

* Based on the Shapiro-Wilk statistic. Reject hypothesis that data is normally distributed if probability is below 0.05.

Growth data 1990 probabilities*

Trmt* Water	Ht.	Diam.	Root wt.	Shoot wt.	Total wt.	Shoot: root*
1-NW	0.027	0.365	0.365	0.443	0.412	0.904
1-W	0.020	0.538	0.951	0.546	0.653	0.188
2-NW	0.025	0.274	0.083	0.097	0.085	0.676
2-W	0.243	0.400	0.034	0.042	0.045	0.323
3-NW	0.031	0.630	0.765	0.205	0.349	0.724
3-W	0.096	0.346	0.832	0.069	0.107	0.235
4-NW	0.096	0.441	0.845	0.623	0.739	<0.010
4-W	0.245	0.559	0.557	0.470	0.452	1.000
5-NW	0.414	0.154	0.541	0.402	0.373	0.093
5-W	0.349	0.287	0.492	0.022	0.084	0.156
6-NW	0.098	<0.010	0.344	0.858	0.612	0.095
6-W	<0.010	0.498	0.450	0.493	0.724	0.117
7-NW	0.292	0.039	0.261	0.286	0.140	<0.010
7-W	0.513	0.962	0.475	0.261	0.262	0.471

* Based on the Shapiro-Wilk statistic. Reject hypothesis that data is normally distributed if probability is below 0.05.

Soil temperature data probabilities*

Trmt	Daily maximum	Daily minimum	Daily average	Daily range
1	<0.01	<0.01	<0.01	<0.150
2	<0.01	<0.01	<0.01	0.087
3	<0.01	<0.01	<0.01	<0.150
4	<0.01	<0.01	<0.01	<0.150
5	<0.01	<0.01	<0.01	0.028
6	<0.01	<0.01	<0.01	<0.150
7	<0.01	<0.01	<0.01	<0.150

* based on the Kolomogrov D statistic. Reject hypothesis that data is normally distributed if probability is less than 0.05. Except for 'daily range', this data was not normally distributed.

Soil moisture data probabilities*

Trmt*water	Water content week 1	Water content weeks 2-8
1-1	0.172	0.747
1-2	0.397	0.801
2-1	1.000	0.039
2-2	0.758	0.311
3-1	0.210	<0.010
3-2	0.464	0.519
4-1	0.785	0.129
4-2	0.194	<0.010
5-1	0.966	0.392
5-2	0.650	0.393
6-1	0.465	0.366
6-2	0.124	0.351
7-1	0.430	0.653
7-2	0.291	0.742

* based on the Shapiro-Wilk statistic. Reject hypothesis that data is normally distributed if probability is less than 0.05