



EFFECTIVENESS OF REFLECTIVE TARPAULINS IN PROTECTING TREE SEEDLINGS AGAINST HEAT STRESS

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Abstract

Reflective tarpaulins are used extensively in Western Canada to protect tree seedlings against solar radiation during transportation and on-site storage prior to planting. This report outlines heat transfer characteristics of new and used reflective tarpaulins, and a FIST (Fiberglass Insulated Seedling Transporter) canopy. Containerized white spruce (*Picea glauca* (Moench) Voss) seedlings were exposed to heat while stored in boxes under tarpaulins. In a separate laboratory experiment, seedlings were pre-conditioned and exposed to heat. All seedlings were outplanted in nursery plots, and survival and growth were monitored.

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Summary

Millions of tree seedlings are planted in Western Canada each year. Most are stored in central field caches near the planting area for several days, and then transported by pickup trucks or all-terrain vehicles (ATVs) to the planting site. Reflective tarpaulins are used extensively to protect seedling boxes from direct solar radiation in both central and field caches, and during transportation operations in the field.

The main objectives of this study were to determine the effectiveness of new and used reflective tarpaulins of various qualities in resisting heat transfer, and to determine if survival and growth of seedlings are affected significantly when seedlings are stored under such tarpaulins for various lengths of time. A FIST (Fiberglass Insulated Seedling Transporter) canopy and an unprotected seedling box were included among the treatments.

Three experiments were carried out by the author: a field experiment at Red Rock Research Station in June 1992; a controlled conditions experiment at FERIC in January 1993; and a laboratory experiment at the University of British Columbia and Red Rock Research Station in June 1993.

The field experiment consisted of storing white spruce container seedlings in standard seedling boxes under various types of tarpaulins for up to six days, while temperatures in the boxes were monitored continuously. Each day, seedlings were withdrawn and outplanted in a nursery plot. Needle samples were collected after storage, but before planting, and the electrical conductivity of these needles was measured. Survival and growth of the seedlings were measured for three growing seasons.

In the controlled conditions experiment, three pieces were removed from each of the new and used tarpaulins used in the field experiment. Each piece was tested for its ability to resist the transfer of heat applied to the tarpaulin surface by two photographic lights.

The laboratory experiment was designed to investigate if pre-conditioning the container-grown white spruce seedlings to higher temperatures significantly affects survival and growth of heat-stressed seedlings. Seedlings were pre-conditioned for four and eight days prior to being exposed to three temperature levels for two time periods. Electrical conductivity of needles was measured following heat-stress treatments. Seedlings were then outplanted adjacent to those in the field experiment, and survival and growth were measured for two growing seasons.

The results of the temperature monitoring in the field test and the heat transfer testing under controlled con-

ditions showed that using one particular type of tarpaulin (Silvicool® 2) was not significantly different from leaving the boxes unprotected. No significant differences in performance were found between the types of new tarpaulins with respect to heat transfer, but the new ones were significantly different than the used tarpaulins. The FIST canopy had a higher accumulated heat sum than the new tarpaulins because the heat inside the canopy dissipated more slowly, once the temperature in the canopy had risen. Seedlings boxes loaded directly from cool storage can be expected to maintain lower temperatures for longer in the FIST canopy than in boxes protected by tarpaulins because heat transfer through the canopy insulation is slower.

Relative conductivity analysis indicated no damage occurred to cell membranes in white spruce needles as a result of being exposed to temperatures up to 35°C, and being stored up to six days.

The storage of white spruce seedlings at temperatures ranging up to 35°C for up to six days did not cause mortality in seedlings outplanted in nursery beds. In fact, the mortality of the test seedlings was lower than normal for seedlings planted in these beds.

Statistical analysis of the growth in total seedling volume after two growing seasons indicated that there were no significant differences between treatments. Neither was growth in each of the first, second, and third growing seasons significantly different between treatments. Also, no significant differences in seedling volumes after three growing seasons were observed regardless of length of seedling storage, up to six days.

Results from the laboratory experiment indicate that containerized white-spruce seedlings are very heat tolerant. Temperatures of up to 40°C for 48 h did not kill the seedlings and did not reduce growth; rather, growth was actually enhanced. Pre-conditioning of seedlings may have been beneficial in the short term for seedlings exposed to the 48-h heat stress. However, the seedlings were outplanted in a nursery bed; had the seedlings been planted on a harvested site, the results may have been different.

Very few incidents occur where stored seedlings are accidentally heated for more than a day as a result of a malfunctioning refrigeration unit, and subsequently disposed of; however, it does occur and the practice should be re-evaluated in the case of container-grown white spruce seedlings.

Further studies to confirm the findings of this project and to determine the heat tolerance of other species would be valuable in order to define acceptable heat stress limits for planting stock.

Sommaire

Des millions de semis sont plantés dans l'ouest du Canada chaque année. La plupart d'entre eux sont entreposés pendant plusieurs jours dans des abris situés à un endroit central près de la superficie à reboiser, puis transportés par camionnette ou par véhicule tout terrain (VTT) sur le site de plantation. L'emploi de bâches réfléchissantes est très répandu pour protéger les boîtes de semis contre les rayons directs du soleil tant dans les abris centraux que sur le terrain, ainsi que durant les opérations de transport sur le site.

Les principaux objectifs de cette étude visaient à déterminer l'efficacité de bâches réfléchissantes neuves et usagées de diverses qualités à résister à la transmission de chaleur, et à déterminer si la survie et la croissance des semis sont affectées de façon significative quand ceux-ci sont entreposés sous les bâches pendant des périodes de temps variées. Un pavillon FIST (pavillon à mousse isolante pour le transport des semis) et une boîte de semis non protégée faisaient partie des traitements.

Trois expériences furent effectuées par l'auteur : une expérience sur le terrain à la station de recherche de Red Rock en juin 1992; une expérience dans des conditions contrôlées à FERIC en janvier 1993; et une expérience en laboratoire à l'Université de Colombie-Britannique et à la station de recherche de Red Rock en juin 1993.

L'expérience sur le terrain consistait à entreposer, jusqu'à six jours, des semis d'épinette blanche en récipients dans des boîtes standard de semis sous divers types de bâches, en surveillant continuellement la température dans les boîtes. Chaque jour, des semis étaient retirés des boîtes et mis en terre dans une placette en pépinière. Des échantillons d'aiguilles furent recueillis après l'entreposage, mais avant la plantation, et la conductivité électrique de ces aiguilles fut mesurée. La survie et la croissance des semis furent mesurées pendant trois saisons de croissance.

Dans l'expérience en conditions contrôlées, trois pièces furent prélevées sur chacune des bâches neuves et usagées utilisées dans l'expérience sur le terrain. Chaque pièce fut soumise à des épreuves pour déterminer sa capacité à résister à la transmission de chaleur appliquée à la surface de la bâche par deux lampes photographiques.

L'expérience en laboratoire consistait à étudier si un conditionnement préalable à des températures plus élevées, de semis d'épinette blanche cultivés en récipients, affectait de façon significative la survie et

la croissance des semis exposés à un stress thermique. Les semis furent soumis au conditionnement préalable pendant quatre et huit jours avant d'être exposés à trois niveaux de température pendant deux périodes de temps. La conductivité électrique des aiguilles fut mesurée après les traitements de stress thermique. Les semis furent ensuite mis en terre à côté de ceux qui provenaient de l'expérience sur le terrain, et la survie et la croissance furent mesurées pendant deux saisons de croissance.

Les résultats des suivis de température dans l'essai sur le terrain et de l'épreuve de transmission de chaleur en conditions contrôlées montrèrent que l'utilisation d'un type particulier de bâche (Silvicool® 2) n'était pas différente de façon significative de celle de boîtes sans protection. Aucune différence significative de performance ne fut constatée entre les types de bâches neuves en fait de transmission de chaleur, mais les bâches neuves étaient différentes de façon significative des bâches usagées. Le pavillon FIST avait une quantité de chaleur accumulée supérieure à celle des bâches neuves parce que la chaleur à l'intérieur du pavillon se dissipait plus lentement, une fois que la température dans le pavillon avait augmenté. Les boîtes de semis chargées directement à partir de chambres froides peuvent probablement maintenir des températures plus basses plus longtemps dans le pavillon FIST que dans les boîtes protégées par des bâches parce que la transmission de chaleur à travers l'isolation du pavillon se fait plus lentement.

L'analyse de conductivité relative n'indiquait aucun dommage aux membranes des cellules dans les aiguilles d'épinette blanche, par suite de l'exposition à des températures allant jusqu'à 35 °C, et de l'entreposage jusqu'à six jours.

L'entreposage de semis d'épinette blanche jusqu'à six jours à des températures allant jusqu'à 35 °C n'a pas entraîné de mortalité des semis plantés dans les planches de pépinière. En fait, la mortalité des semis de l'essai était plus faible que la normale pour les semis plantés dans ces planches.

L'analyse statistique de la croissance en volume total des semis après deux saisons de croissance indique qu'il n'y avait aucune différence significative entre les traitements. La croissance dans chacune des trois saisons n'était pas non plus différente de façon significative entre les traitements. De plus, aucune différence significative ne fut observée dans les volumes de semis après trois saisons de croissance, peu importe la durée d'entreposage des semis, jusqu'à six jours.

Les résultats de l'expérience en laboratoire indiquent que les semis d'épinette blanche en récipients sont très

tolérants à la chaleur. Des températures jusqu'à 40 °C pendant 48 heures ne tuèrent pas les semis et ne réduisirent pas la croissance; en fait, celle-ci se trouva plutôt favorisée. Le conditionnement préalable peut avoir été bénéfique à court terme aux semis exposés au stress thermique de 48 heures. Cependant, les semis étaient plantés dans une planche de pépinière; s'ils avaient été plantés sur un parterre de coupe, les résultats auraient pu être différents.

Il se produit très peu d'incidents où les semis entreposés subissent accidentellement un échauffement pendant plus d'une journée par suite du mauvais fonctionnement d'un appareil de réfrigération, et sont subséquemment mis de côté; cependant, cela arrive et la pratique devrait être réévaluée dans le cas de semis d'épinette blanche cultivés en récipients.

D'autres études pour confirmer les conclusions de ce projet et déterminer la tolérance à la chaleur d'autres essences seraient importantes afin de définir des limites acceptables de stress thermique pour les stocks de plantation.

INTRODUCTION

Several hundred million coniferous tree seedlings are grown and planted in Western Canada every year. The vast majority of these seedlings are grown in containers, mostly of the Styroblock® type. Seedlings slated for spring planting are lifted in late fall, sorted and put into bundles that are then packed in paper or polyethylene bags and placed inside waxed cardboard boxes for overwinter freezer storage. In the spring, the boxes are removed from the freezer and the seedlings are allowed to thaw for a short period. They are then shipped in temperature-controlled semitrailers or trucks to a central cache at or near the planting area. Seedling boxes are stored at the central cache until distributed to satellite caches in the planting area, where planters replenish their supplies of seedlings. Field storage of seedlings may last a week or longer depending on the progress of the planting program.¹

Seedling performance may be affected by root exposure to drying conditions, handling, storage conditions and length, shipping, temporary storage in the field, and planting (particularly microsite selection) (DeYoe 1986, Rietveld 1989). Although high temperatures can occur in the absence of other environmental stresses, they are commonly accompanied by both atmospheric and edaphic water stress (Hällgren et al 1991). Some research results indicate that seedlings should be kept at temperatures below 10°C at all times until planted to avoid the damaging effects of high temperature and to reduce evaporative demand (Baker 1929, Binder and Fielder 1995, Levitt 1980, Seidel 1986) (see Stjernberg 1995 for a full literature review). Covering boxes with reflective tarpaulins is one technique used to protect seedling boxes from direct solar radiation and slow the rise of temperature within the boxes. They are used extensively in all planting operations in Alberta, British Columbia, and Saskatchewan, to cover boxes in seedling caches and during local transportation of seedlings.

Different brands and qualities of tarpaulins are commercially available. When new, all reflective tarpaulins are white on one side and silver coloured on the other side. Tarpaulins should be used with the white side facing upwards/outwards. However, as a tarpaulin is folded, stretched, scuffed, and exposed to the elements in normal use, delamination, decreased reflectance of the white surface, and general deterioration occurs. When this happens, the tarpaulin's ability to resist heat transfer may be reduced, thereby decreasing its effectiveness in protecting seedling boxes from solar radiation.

The British Columbia Ministry of Forests' (BCMOF) Silviculture Contracts specify that only reflective tarpaulins, in good repair and approved by a BCMOF Officer,

can be used to cover seedling boxes (BCMOF 1989). Otherwise, however, no standards exist for the quality of the reflective tarpaulins to be used by planting contractors. As a result, some very poor quality, worn out tarpaulins are in use; very little is known about how effective the tarpaulins are after one or more years of use in the field. This project was designed in 1991 to provide information about various types of tarpaulins, and to determine if there are any measurable effects on the stored seedlings. The project was extended with a laboratory experiment after preliminary analysis of first-year seedling growth.

OBJECTIVES

- Determine the effectiveness of new and used reflective tarpaulins of various qualities in resisting heat transfer.
- Determine if immediate and measurable detrimental biological responses occur in seedlings stored under these tarpaulins for different lengths of time and at different temperatures.
- Determine if survival and growth of seedlings are significantly affected when stored for different lengths of time and at different temperatures.
- Determine if pre-conditioning seedlings to higher temperatures significantly affects survival and growth of heat-stressed seedlings. (This objective was added after the first year.)

EXPERIMENTS

Field Experiment

Materials, Methods, and Instrumentation. The project was designed to test a number of different types of reflective tarpaulins, by recording temperatures in seedling boxes stored beneath them for a number of days, and to determine if seedling survival and growth are affected by storage for different lengths of time. The materials selected for testing are described in Table 1.

Seedling Shelters. Seedling shelter frames² were covered with reflective tarpaulins (Table 1), extending to the ground on all sides. Two shelters were constructed from each test material. The shelters and the FIST canopy were set up in three rows on a grassy area beside the Red Rock Research Station, 15 km south of Prince George, British Columbia (Figure 1).

Container-grown white spruce (*Picea glauca* (Moench) Voss) seedlings in a standard box were placed in each of the shelters. Two boxes were placed in the FIST

¹ R.F. Bowden, Regeneration Specialist, BCMOF, Victoria, B.C.; personal communication, September 1995.

² Made of 1 x 2" wood, 120 x 90 x 50 cm in size.

Table 1. List of Treatments and Test Materials in the Field Experiment

Treatment	Test material	Type ^a	Status
1	Lightweight Silvicool®3 ^b	8x8	New
2	Standard Silvicool®3	12x10	New
3	Original Silvicool®type ^c	18 oz.	New
4	Econocool	8x8	New
5	Silvicool®2	12x12	2-years old
6	Original Silvicool®type	18 oz.	7-years old
7	Original Silvicool®type	10 oz.	1-year old
8	Unprotected box	N/A	New
9	FIST canopy ^d	N/A	New
10	Silvicool®2 shelter ^e	12x12	3-years old

^a Reflective tarpaulins are distinguished in two ways, i.e. by the weight, in ounces per square foot (e.g. 18 oz), and in the case of woven materials, by the number of strands per inch in two directions (e.g. 8x8). ^b Silvicool® is a registered trademark of Bushpro Supplies Ltd., Anmore, B.C. ^c The Original Silvicool® reflective tarpaulin was a custom-made 12 oz. vinyl material. ^d The Fiberglass Insulated Seedling Transporter (FIST) canopy has a sandwich construction consisting of two fiberglass skins (each 2.5 mm thick) covering 35 mm of solid insulation (R12), reinforced with 2 x 2" wood. It is manufactured by the Horizon Fiberglass Products Ltd., Delta, B.C and was loaned to FERIC by the manufacturer. ^e Treatment 10 consisted of a commercially purpose-built shelter made of Silvicool® 2 tarpaulin material. The dimensions of this shelter was somewhat larger than for those set up for this trial.

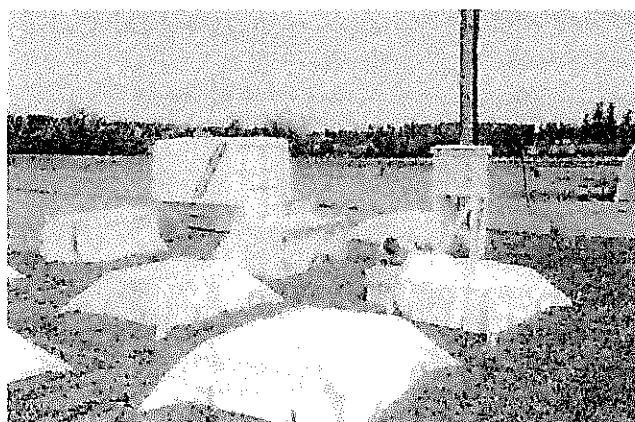


Figure 1. Reflective tarpaulin shelters set up outside the Red Rock Research Station, Prince George, in June 1992. The Fiberglass Insulated Seedling Transporter (FIST) canopy is seen in the far left corner. The shelter to the left of the canopy is Treatment 10—the commercially purpose-built shelter. The ambient temperature was recorded inside the weather station shown on the right.

canopy, and two were left unprotected as controls. Seedlings were stored at +5°C until placed in the shelters.

To maintain the same physical environment in the boxes after seedlings had been withdrawn for planting, the vacated space was filled by other seedlings.

Seedling Box Temperatures. The temperatures inside the boxes were measured on a continuous basis using one thermocouple placed in the physical center of each box. All thermocouples were scanned every 10 seconds and the average value for each 15-min period was recorded by a data logger. Recordings started at 2100 h on June 8, 1992, and continued uninterrupted for 144 h.

Environmental Measurements. The ambient temperature was measured with a thermocouple placed inside the Stevenson Screen at Red Rock Research Station. Ambient air temperature, wind speed, and solar irradiance were measured at the same intervals as the temperatures in the seedling boxes, using the same data logger.

Electrical Conductivity Measurements. Any damage to cell membranes may cause the cell contents to leak, and this can be measured in an electrical conductivity test. Needle samples for conductivity tests were collected each day (Times 1-6) at a rate of 120/day (Figure 2). The conductivity measurements to be used as the control were obtained at Time 1, i.e. before the seedling boxes were placed in the shelters. Conductivities were measured and analyzed according to methods used by the Research Laboratory of the BCMOF and others (Colombo et al 1984).

Outplantings. The experiment had a split-plot randomized complete block design with repeated measurements within the experimental units. The sample plot layout is shown in Figure 3. Seedlings were outplanted in prepared nursery beds at the Red Rock Research Station. The first outplanting, i.e. Time 1 used as Control for the experiment, was removed from seedling boxes

and planted on June 8 before the boxes were placed in the shelters. The following day, June 9, was rainy and cold, and no planting was done. Samples of seedlings were then withdrawn from the stored seedling boxes daily on the next five days, i.e. Times 2 (= June 10, etc.), 3, 4, 5 and 6, and planted according to the layout shown in Figure 3 (Figure 4).



Figure 2. Collecting needle samples for conductivity tests.

Root collar diameter and total height of each seedling were measured and recorded immediately after planting. These measurements were repeated after the first, second and third growing seasons. In addition, survival surveys were done each spring.

Statistical Analysis. Statistical covariance analyses of the growth data were carried out in SAS[®].³

Conductivity data were statistically analyzed using analysis of variance⁴ (ANOVA) in SAS[®]. The statistical model used for growth data analysis, minus the Block⁵ factor, was also used for the conductivity data analysis.

³ SAS[®] for Windows, Version 6.08, SAS/STAT Module, SAS[®] Institute Inc., Cary, NC.

⁴ The variance is a measure of variation which considers the position of each observation relative to the mean of all the observations. The square root of the variance is called the standard deviation.

⁵ The Block factor is a part of the statistical model which considers the effects of having seedlings planted in different blocks within the sample plot.

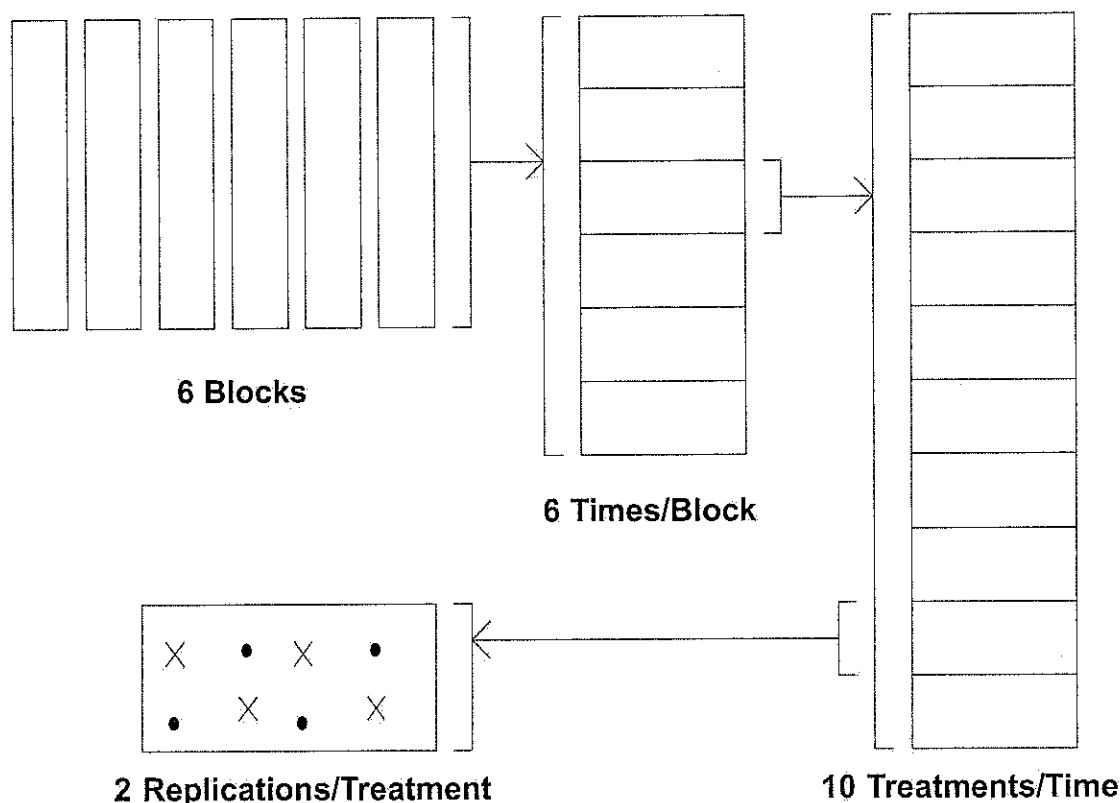


Figure 3. Schematic layout of sample plot with a split-plot randomized complete block design, with repeated measurements of the experimental units. Each of the six blocks was divided into six time zones; each time zone was divided into ten treatment parts and each part was planted with two replications of four seedlings, in an alternate fashion.



Figure 4. Outplanting of seedlings in sample plot.

Controlled Conditions Experiment

Three 40 x 40 cm squares of material, removed from each tarpaulin used in the field testing, were tested under controlled indoor conditions at the FERIC office. The squares were placed over the opening of a heavily-insulated wooden box. Two 250-W photographic lights were directed at the surface of the tarpaulin and turned on for 30 min. Thermocouples, located 2.5 cm below the surface of the tarp and 2.5 cm above it, were attached to a data logger and scanned every five seconds. The average temperature for each minute was recorded. The ratio of heat sums below the tarpaulin to those above it was used in the statistical analysis of the data.

Laboratory Experiment

This experiment was added after first-year results of the field experiment indicated a possible pre-conditioning effect on the seedlings resulting from storage under the tarpaulins.

Materials and Methods. White spruce container seedlings, from the same seedlot as used in the field experiment, were used for this experiment. One-third of the seedlings were not pre-conditioned, one-third were pre-conditioned at 30°C for three h/day for 4 consecutive days, and one-third were pre-conditioned at 30°C for three h/day for 8 consecutive days. The heat stress treatments were applied immediately after pre-conditioning; seedlings in paper bags were placed into incubators for 8 h and 48 h at temperatures of 30°C, 35°C, and 40°C. The control seedlings were left in the cool storage facility at 5°C. The seedlings, which had been shipped by courier from Prince George to the Forest Sciences Department

of the University of British Columbia in Vancouver for the experiment, were returned after heat stressing and then outplanted in prepared nursery beds at Red Rock Research Station. Seedlings were planted in one plot with an irrigation facility (Plot I) and in one without (Plot NI). The plots had a completely randomized design.

RESULTS

Field Experiment

Environmental Conditions. On the first day (June 9), the weather was cool and cloudy with rain most of the day. The weather then improved for the remainder of the test, and the last three days were sunny with cloudy periods. Solar radiance peaked at about 1000 W/m² during the last four days. The wind increased as the experiment progressed and reached a maximum of about 5 m/s during the fifth day.

Seedling Box Temperatures. The minimum temperatures (Figure 5) were generally reached between 0600 and 0700 h while the maximum temperatures (Figure 6) occurred approximately between 1600 and 1700 h. Daily temperatures within the boxes followed the same pattern. Figure 6 shows that the first two days (June 9 and 10) were substantially cooler than the following days. Treatment 8 (unprotected seedling box) predictably had the highest daily maximum temperature, while Treatment 9 (FIST canopy) usually had the lowest daily maximums. This was expected since the FIST canopy is insulated and the inside temperature increases at a slower rate. On the other hand, the temperature also decreases more slowly at night, reflected in the highest minimum temperatures (Figure 5).

Heat sums,⁶ in degree-hours, were calculated for each treatment using a base temperature of 10°C (Table 2). Outplanted seedlings were exposed to less heat than is shown in Table 2 since the samples were removed gradually over a period of six days.

An analysis of variance of the heat sums indicated significant differences between the treatments. In Table 2, heat sums shown with the same letter are not significantly different ($\alpha=0.05$).

Treatments 1, 2 and 3, all new tarpaulins, have the lowest heat sums. The new tarpaulin in Treatment 4 was not as effective in resisting heat transfer as the other three although there was no statistically significant difference between the four new tarpaulins. Treatment 8 (unprotected box) has the highest heat sums, while Treatments 5 and 10 are only slightly lower. The heat sum for Treatment 5 was

⁶ Heat sum = (T - 10°C) • No. of hours at the temperature T.

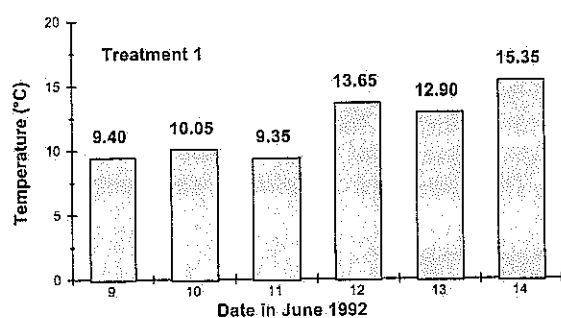
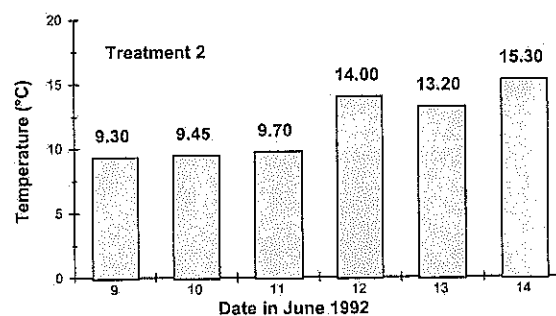
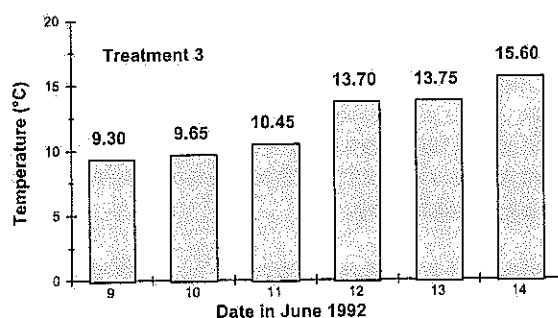
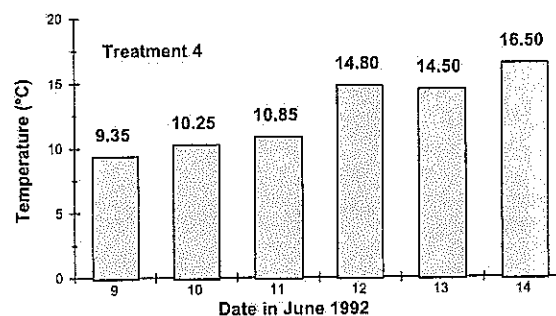
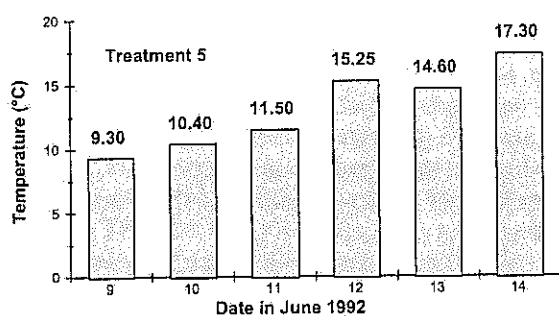
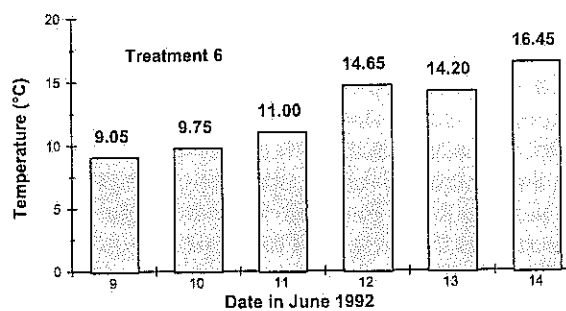
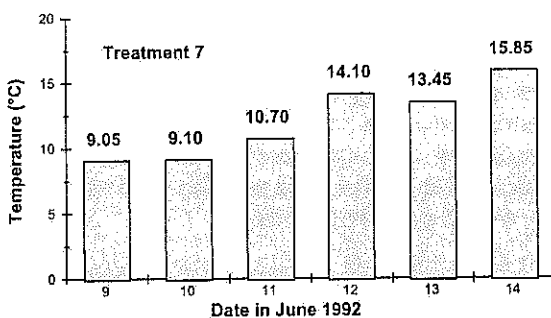
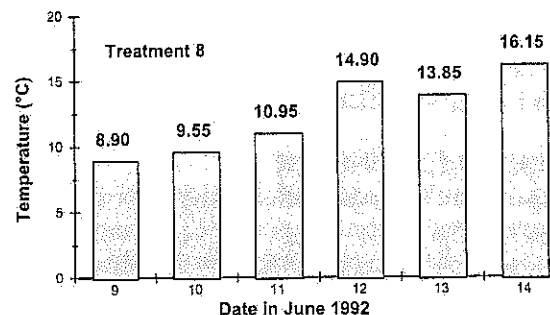
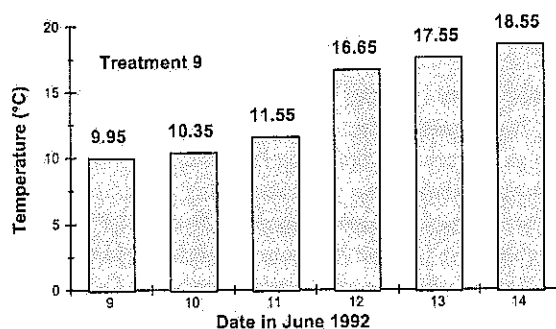
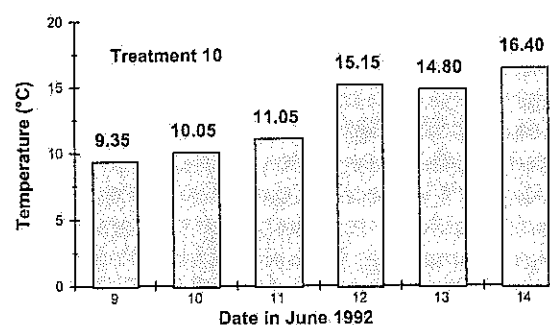


Figure 5. Daily minimum seedling-box temperatures for the 10 treatments in the field experiment.

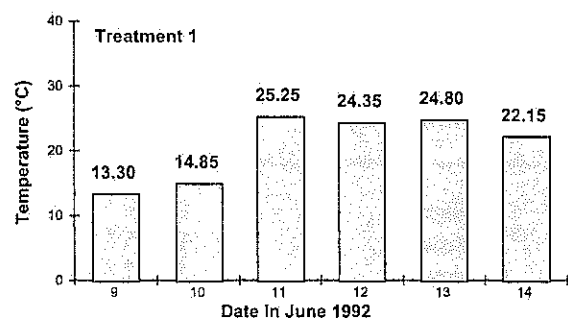
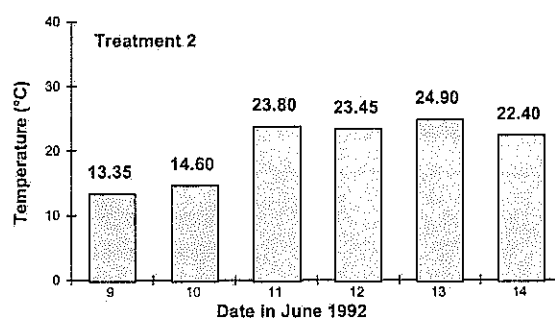
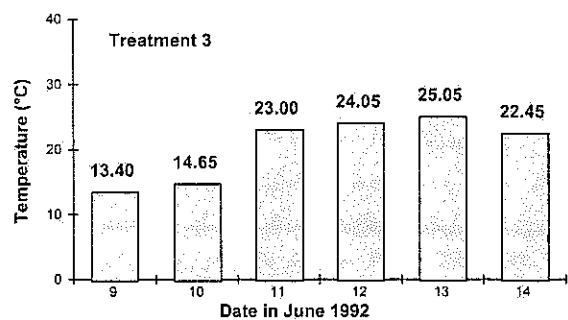
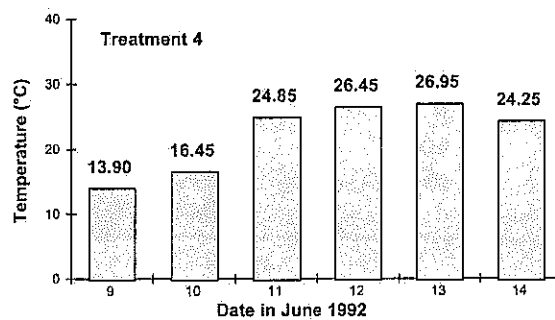
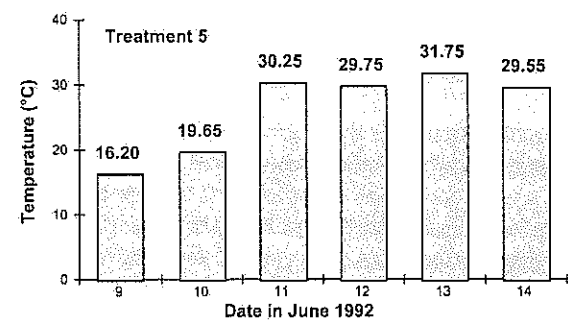
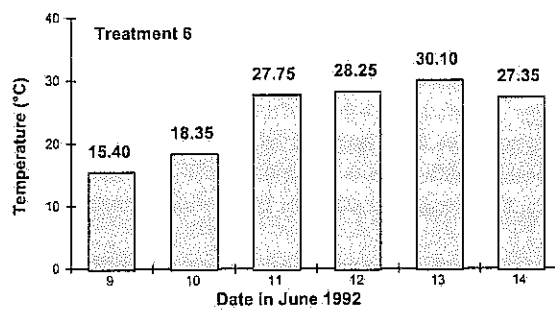
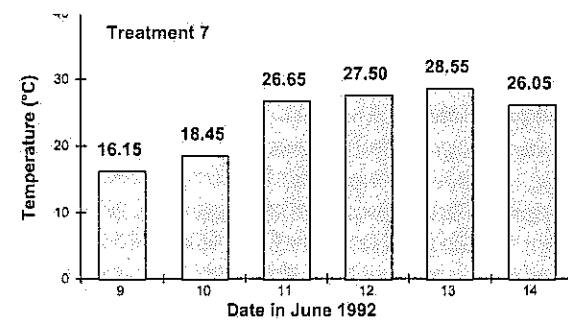
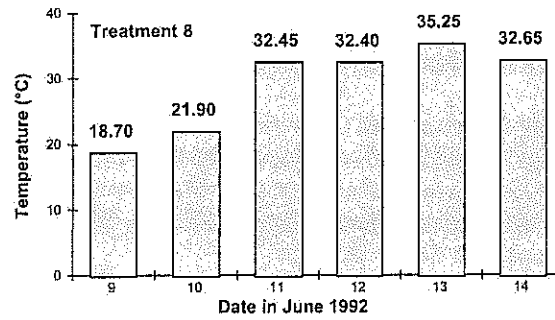
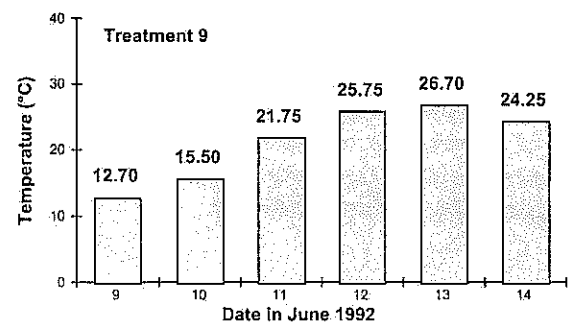
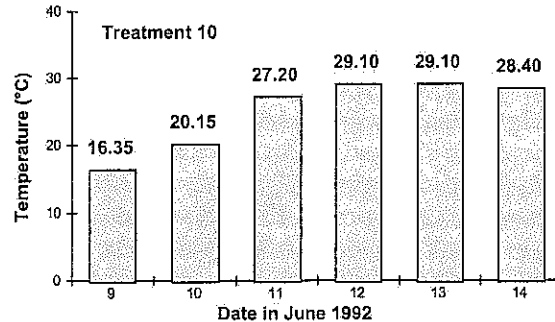


Figure 6. Daily maximum seedling-box temperatures for the 10 treatments in the field experiment.

Table 2. Heat Sums after 144 Hours for Treatments 1-10. Heat sums shown with the same superscript letter in this table are not significantly different.

Treatment	Test material	Status	Heat sum (°C-h)
1	Lightweight Silvicool®3	New	844.9 ^f
2	Standard Silvicool®3	New	840.5 ^f
3	Original Silvicool® type	New	832.2 ^f
4	Econocool	New	985.1 ^{def}
5	Silvicool® 2	2-years old	1262.2 ^{ab}
6	Original Silvicool® type	7-years old	1116.8 ^{bcd}
7	Original Silvicool® type	1-year old	1045.5 ^{cde}
8	Unprotected box	New	1373.0 ^a
9	FIST Canopy	New	1025.2 ^{cde}
10	Silvicool® 2	3-years old	1193.2 ^{bc}
cf.	Ambient air temperature in Stevenson Screen		912.6 ^{cf}

not significantly different from the unprotected box in Treatment 8.

Heat sums for outplanted seedlings are shown in Figure 7. These heat sums are calculated from the time the seedlings entered storage (Time 1) until the time they were withdrawn for planting. Since the seedlings from the various treatments were planted in a random order each day, the times of removal from the shelters varied.

Electrical Conductivity. Relative conductivities (RC) for all 720 samples ranged from 5.7 to 12.4, with an average of 8.4 (standard deviation = 1.2). Interaction between Time and Treatment was significant at the $\alpha = 0.05$ level but no pattern can be established.

Seedling Survival and Growth. Seedling survival was very high. Of the 2 880 seedlings in the field experiment, only seven had died after three growing seasons. There was no discernible pattern in terms of Times, Blocks and Treatments for dead seedlings.

Growth in the second growing season (G2) (see Terminology in Appendix I), and total volume after the second year (V3) were analyzed. Results showed significant interactions between Time, Block, and Treatment for both V3 and G2. The presence of significant interactions in the analysis signifies that treatments gave different results in different blocks, and that seedlings from the same time period grew differently in different blocks. Had there been a treatment effect it would have been equally evident in all blocks. Also, had there been a time-in-storage effect, it would have been similar in all blocks. However, growth of the seedlings was different for all times and treatments depending on where within the plot the seedlings were located. Generally growth increased

towards the western side of the plot and towards the northern side (Figure 8). This variance within and between blocks was unexpected and unpredictable, resulting in a complicated analysis which has been reported elsewhere (Stjernberg 1995).

Data obtained after three growing seasons were also statistically analyzed. Each block was analyzed separately since each contained complete sets of time and treatment combinations. There were no particular patterns to the volume differences that caused the interactions. This indicates that treatments gave different results for different storage times and location in the block. No particular pattern can be established which would explain the treatment differences for different lengths of storage.

Soil and Foliage Analysis. To determine what may have caused the growth differences in the various parts of the plot, soil and foliage samples were collected and commercially analyzed.⁷ Foliage samples were collected from seedlings adjacent to the soil sample locations. The results indicate that the differences in growth are related to available soil nutrients. Most nutrients analyzed showed increased levels to the west and north of the plot, consistent with growth differences. One foliage sample from the southeast corner of the plot showed a toxic level of iron and higher than average level of aluminium. The corresponding soil sample had lower than average levels of copper, zinc, iron and manganese. Growth in this corner was lower than further west and north in the plot, suggesting a nutrient imbalance.

⁷ Pacific Soil Analysis Incorporated, Richmond, B.C.

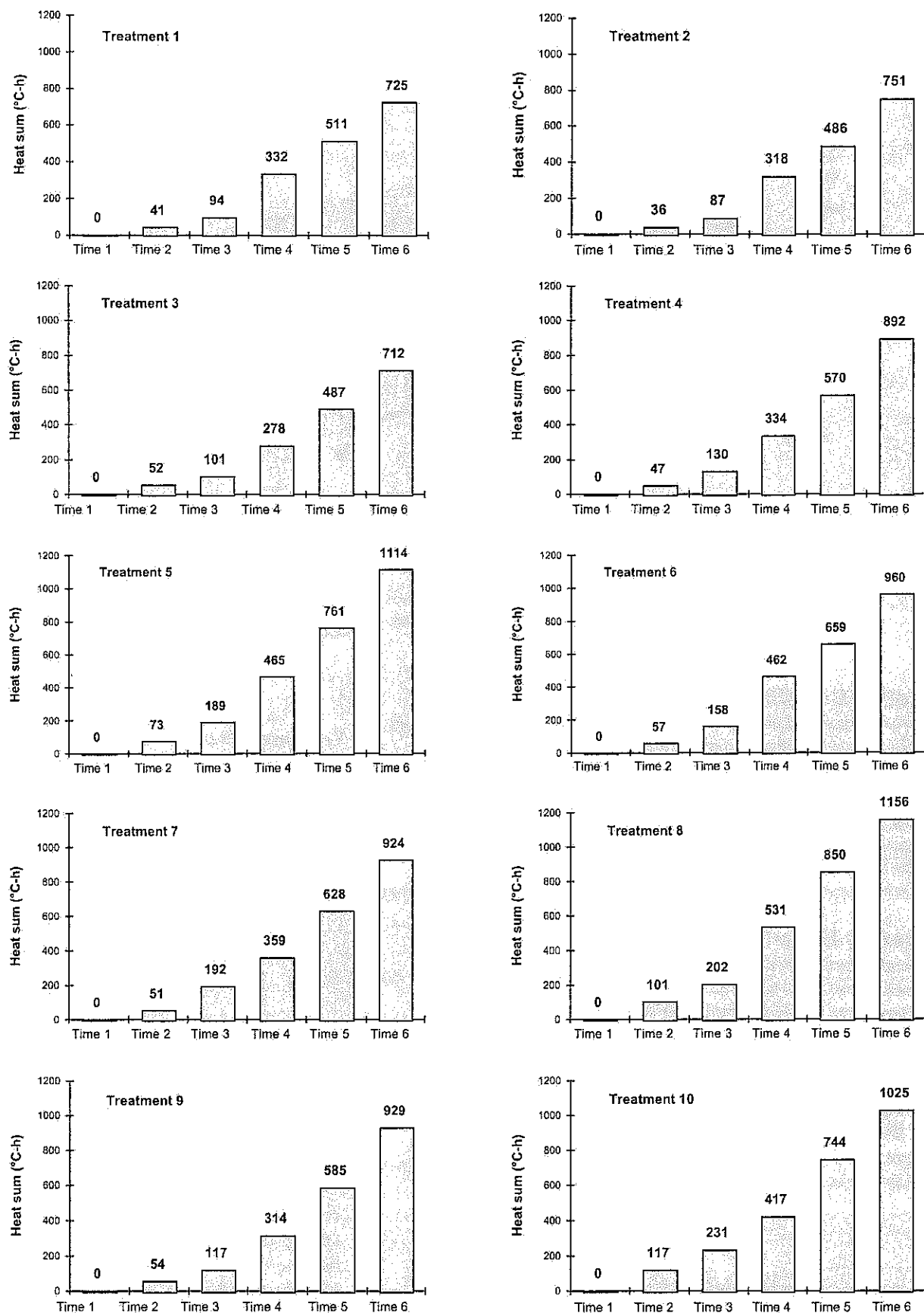


Figure 7. Heat sums for seedlings planted in sample plot, by treatment. Heat sums began accumulating at 2100 h on June 8, 1992 and ended at the time of planting. Time 1 has a heat sum of zero for all treatments.

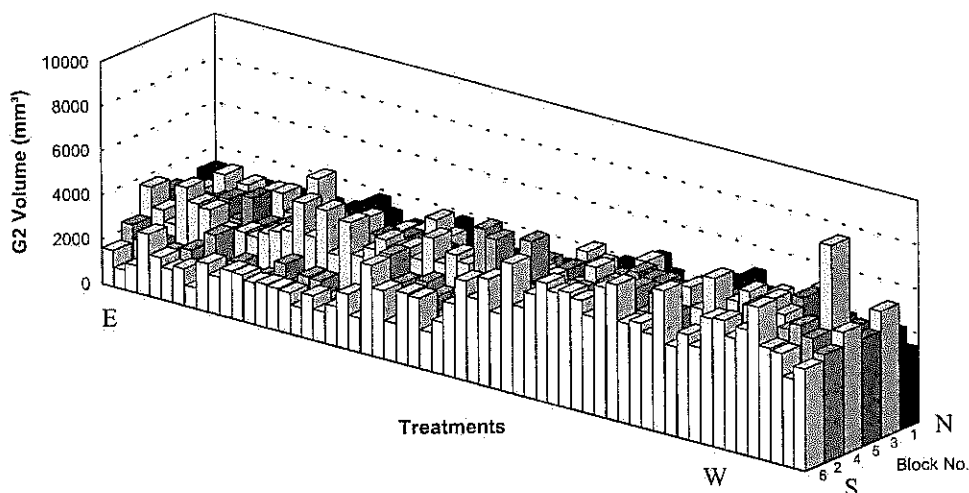


Figure 8. The mean growth in the second growing season (G2), plotted in the sequence that treatments were located in each block. Blocks are in the same order as in the plot.

Controlled Conditions Experiment

The test of tarpaulins under controlled conditions determined the relative heat transfer characteristics between samples of seven of the tarpaulins used in the field experiment. The average ratios for the samples from each tarpaulin type were expressed relative to Treatment 1, i.e. the new lightweight Silvicool®3 tarpaulin. Treatment 1 had the lowest heat transfer of all the samples tested. The relative heat sum ratios are shown in Figure 9.

Laboratory Experiment

Electrical Conductivity. The absolute values for relative conductivity⁸ were about double those found in the field experiment, i.e. 16 compared to 8. Statistical analysis of the data showed significant two-way and three-way interactions between Pre-conditioning, Heat, and Time, but there does not appear to be a pattern of treatment effects. However, relative conductivity did increase for seedlings pre-conditioned 4 and 8 days in the 48-h treatment at 35°C, and in the 48-h treatment at 40°C, regardless of the pre-conditioning treatments.

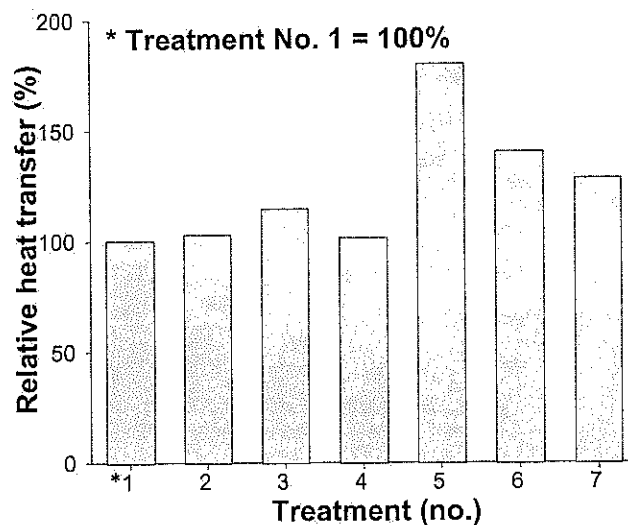


Figure 9. Ratios of relative heat transfer for pieces of reflective tarpaulins taken from Treatments 1 - 7. Treatment 1 was set at 100%. Tarpaulins in Treatments 1 - 4 were new, while those in Treatments 5 - 7 had been used. This test was carried out under controlled conditions, using floodlights as a heat source.

⁸ Relative conductivities are an indication of the state of the cell membranes. If the membranes get damaged, the contents of the cells leak, indicated by an increase in measured electrical conductivity.

Seedling Survival and Growth. Survival of the seedlings was very high. After the first growing season, only one seedling had died, and five were dead after the second season (<1%)—two in Plot I and three in Plot NI.

Growth in the first and second growing seasons for Plots I and NI were analyzed. The significant factors in the mean growth in the first year were interactions Plots•Pre-conditioning•Time and Plots•Time. Pre-conditioned seedlings grew better than those without pre-conditioning in both plots after a 48-h heat stress treatment. Seedlings with the 48-h stress treatment and no pre-conditioning in Plot I had higher mean growth than those with the 8-h stress treatment. Regardless of pre-conditioning, mean growth in the two plots was different for the two exposure times. Growth in Plot I increased for the 48-h heat stress treatment compared to the 8-h treatment, while in Plot NI it decreased slightly.

Mean growth in the second year was significantly different for the two plots, with significantly less growth of seedlings in Plot NI compared to those in Plot I.

In Plot I, seedlings exposed to the heat stress for 48 h had higher mean volume (data not shown). No significant differences were present for the growth in the second growing season.

In Plot NI, pre-conditioned seedlings had higher growth when exposed to 48 h of heat stress compared to 8 h of exposure.

DISCUSSION

Field Experiment

Environmental Conditions. The environmental conditions recorded during the field experiment are typical of conditions in late spring or early summer at planting sites in the Central Interior of British Columbia. Temperatures on June 9 and 10 were low compared to the following four days and below the 30-year mean daily temperature in June for Prince George airport—12.9°C (Environment Canada n.d.). The highest levels of solar radiation occurred during the afternoon hours and the wind speed typically peaked in the early evening hours each day. Some wind was present during the early part of the night. While solar radiation is the source of any heat buildup in the seedling boxes, the presence of a wind will affect the rate of the accumulation and subsequent decrease of heat during the night.

Reflective Tarpaulins and Seedling Box Temperatures. Minimum seedling-box temperatures varied little among treatments during the first 72 h. The FIST canopy had the highest minimum temperatures each day of the experiment (Figure 5). This unit has 35 mm of foam insulation

between the outside and inside fiberglass skins. The effect of the FIST insulation can be seen in its daily maximum seedling-box temperatures which were some of the lowest recorded (Figure 6). Because heat transfer always proceeds from a warmer to a colder region (Gates 1980), heat is transferred into the FIST canopy during the day, and out during the night provided the outside temperature is lower than the inside temperature at that time. However, because of insulation in the walls and roof of the FIST canopy, heat transfer is slower in both directions compared to heat transfer in the tarpaulin shelters.

Heat sums for Treatments 1 - 4, all new tarpaulins, are the lowest and significantly different ($\alpha=0.05$) from the rest. Though the heat sum for the new tarpaulin in Treatment 4 is higher by about 17% than the heat sums for the other three, the difference is statistically not significant. The heat sum in Treatment 5 was not significantly different from the unprotected box which recorded the highest heat sum. The reflective tarpaulin in Treatment 5 had a layer of black plastic between the white outer surface and the scrim (Stjernberg 1991). This layer was expected to make the tarpaulin completely opaque even when well-used. However, the black plastic acted as a heat sink and retained heat conducted from the white outer layer. This resulted in a heat sum for Treatment 5 about 50% greater than for the best three new tarpaulins. Treatment 10 was a commercially purpose-built shelter somewhat larger in size than the other shelters. Although the tarpaulin material was the same as for Treatment 5 and appeared to be in better condition, there was no significant heat sum difference between the two.

The heat sum for Treatment 9 (the FIST canopy) was about 25% higher than for the three tarpaulins with the lowest heat sums, but was not significantly different from Treatments 6 and 7. The higher heat sum for the FIST canopy is a direct result of the rate of heat transfer through the canopy insulation. However, in a typical planting operation the FIST canopy would normally be loaded with many more boxes of seedlings than was the case in this experiment. The amount of heat required to increase the temperature in a fully loaded canopy would be much higher, and as consequence the buildup of heat during the day would not be as high as shown here. If the inside temperature remains below the outside temperature for all or a portion of the night, less or no heat would be transferred to the outside. Operationally, the FIST canopy can be expected to have a much lower heat sum than reported in this experiment. Von der Gonna (1990) found that the temperatures inside the canopy remained well below ambient air temperature when the canopy was carrying a full load of seedling boxes. In this experiment, the FIST canopy attained greater heat sums than ambient air temperature.

The tarpaulins used in Treatments 6 and 7 were both of the Original Silvicool® type, but were different ages. However, the difference in their heat sums was not significant. There were significant differences between new and used tarpaulins but the differences within each group were small, and not significant in the case of new tarpaulins. It is shown that tarpaulin usage resulted in increased heat transfer and thus decreased the efficiency of the tarpaulins. However, age by itself is not necessarily a good indicator. It is the quality of the material, and the abuse it has taken, which will determine the efficiency of the tarpaulin.

Seedlings were withdrawn daily, and at different times during the day for each treatment in a randomized order with the result that heat sums for outplanted seedlings differed (Figure 7). The first two days of storage did not add much to the heat sums but by Time 4, the differences between treatments were clearly established. The heat sum increments after Time 4 are very similar in size for all treatments. The heat sum differences between Treatment 8 (unprotected box, i. e. control) and Treatments 5 and 10 are small. If high heat sums, with a base temperature of 10°C, induce physiological perturbations in the seedlings, one could have expected this to be displayed in relative conductivities, and perhaps in survival and growth in Treatments 5, 8 and 10.

Electrical Conductivity. The relative conductivity test determined if cell membranes were damaged by the heat buildup (heat sums) in the seedling boxes. Damaged cell membranes would allow the cell contents to leak. This would be indicated by an increase in the electrical conductivity of the leachate. This technique is commonly used to determine frost hardiness in seedlings (Colombo et al 1984, Hawkins and Binder 1990) and has been used by Binder and Fielder (1995) to detect heat damage in seedlings. Preliminary heat exposure tests done before the field experiment indicated that a relative conductivity of above 30 should be expected after significant damage to cell membranes.

The results from the electrical conductivity measurements in the field experiment gave a relative conductivity in the range of 6 to 12. While there was statistically significant interaction between Time and Treatment, the relative conductivities were too low to signify any cell membrane damage. Natural variations among the seedlings could account for the small but significant differences in relative conductivity. Analyses of the relative conductivities for time in individual treatments do not show a pattern that can be correlated with the heat stress received over time.

Treatments 8, 10 and 5, which had the greatest heat sums by the last planting (Figure 7), did not have the highest

relative conductivity (RC) at Time 6. In fact, Treatment 3 with the lowest heat sum had the greatest RC. This further suggests the present RC data were indicative of natural variations among the seedlings rather than physiological damage induced by heat. In short, it appears the level of heat sums observed in this experiment did not result in any cellular membrane damage for seedlings of this spruce seedlot.

Seedling Survival and Growth. In the field study, all but seven seedlings were alive after three growing seasons—a survival rate of 99.8%. No pattern relating the dead seedlings to any time or treatment effect is discernible. Three-year survival rates of this order suggest the heat treatments had induced no physiological perturbation in the stock. Mortality of 1 to 2% in the first season is usually expected in this common garden at Red Rock Research Station.⁹ High survival as observed could result if the seedlot had a high degree of heat tolerance, if it was of exceedingly high physiological quality at the time of planting, or if the heat treatments were of no physiological significance. The best, or any, hypothesis cannot be selected at this time.

Analyzing the growth of the seedlings presented a statistical challenge. The experiment was designed as a split-plot randomized complete block with repeated measurements within experimental units. The statistical model included all main effects (Block, Time, Treatment) but also two-way and three-way interactions between these effects. All significant interactions must be explained. The total stem volume after two growing seasons (V3) and the stem growth in the second growing season (G2) were chosen as starting points.

Unfortunately, there were significant three-way interactions between Block, Time and Treatment both in G2 and V3. Analysis showed distinct differences between the blocks from south to north in the plot (Figure 8). The plot was established in a bareroot forest-seedling nursery field where soils have been regularly cultivated, and where there were no visual differences among blocks. However, when volumes for the treatments were compared to the volume of the control there were obvious differences between the blocks. An examination of G2 found no pattern until treatments were plotted in the same sequence that had been randomly selected for the outplanting in the blocks. The data then clearly indicate the increase in growth toward the west end of the blocks. This was confirmed by regression analysis, which shows more effects on growth from microsites than from any heat treatment or storage time.

⁹ C. Hawkins, BCMOF, Red Rock Research Station, Prince George B.C.; personal communication, May 1994.

When the three-way interaction effect was included in the error term, analysis still showed significant Time and Treatment interaction, and Time and Block interaction for the total volume after two growing seasons (V3). However, when the mean volumes are plotted in the same order as the treatments were planted, the variations within the blocks are reduced. This indicates that where in the plot the treatment was located had an effect rather than the treatment - time combination. Again, analysis showed planting microsite had greater influence than all other variables.

When more data had been collected, growth in the third growing season (G4) was analyzed block by block. Time and Treatment interactions were present in most blocks. However, there were no significant interactions in Block 6 and the growth in the third growing season confirms the previous trend of increasing growth towards the west part of the plot. Not unexpectedly, the analysis of G4 and G5 further confirmed the observation of the first two analyses: planting location had a far greater effect than did treatment and storage duration. Therefore, it was decided to do soil and foliar analyses to see if site-related growth differences may be related to nutrient deficits or excesses.

Soil and Foliage Analysis. Most of the soil and foliage nutrients increased towards the west and north, the same trend as demonstrated with the seedling growth (Figure 8). This may help explain microsite growth differences. A foliage sample taken at the southeast corner of the plot showed anomalous readings of iron (408 ppm) and aluminium (468 ppm). These are very high compared to the readings from seven other nearby samples that averaged 134 ppm for iron and 205 ppm for aluminium. While references to aluminium levels are not readily available, foliar iron was at a toxic level and is a likely cause for the depressed growth (van den Driessche 1989). The soil sample taken from the same location in the plot also showed levels of copper, zinc, iron, and manganese that were lower than the average from 15 other locations in and adjacent to the plot. Further, total nitrogen, sulphur and organic matter were lower in this corner than the averages from samples in other parts of the plot. This may explain why seedling growth in this corner was much lower than in the rest of the plot. The soil sample values are not easily interpreted because different nutrients may have off-setting or compensating effects at different levels.¹⁰ These data indicate the importance of knowing your site prior to planting. Ideally, soil sampling should have been done before block layout. That would have shown the differences in uniformity among the blocks and could have minimized microsite differences.

Controlled Conditions Experiment

The test of the tarpaulin samples resulted in the same ranking of the tarpaulins as in the field experiment (Figure 9), though two tarpaulins were in reverse order

(Treatments 3 and 4). The light spectrum for the floodlights contains more infrared light than solar radiation¹¹ and this is most likely the cause for differences in the two experiments. If deemed crucial by the silviculture industry, tarpaulins could be tested for their efficiency before decisions are made to retain or dispose of them. However, based on the present results obtained under longer than normal operational durations, there is no biological evidence to suggest tarpaulin quality was an issue in this one spruce seedlot experiment.

Laboratory Experiment

Electrical Conductivity. Based on tests carried out prior to the field experiment, relative conductivities above 30 would be indicative of cell membrane damage. Because relative conductivities were low, survival was high and no obvious treatment or storage duration effects were evident for the initial planting in 1992, it was postulated that the diurnal fluctuation of temperatures pre-conditioned the seedlings prior to planting. This possibility was alluded to earlier in this report when alternative explanations suggested that the seedlot had a high degree of heat tolerance, the heat treatments were not physiologically significant or the seedlot was of exceedingly high physiological quality. A laboratory pre-conditioning experiment was conducted to assess if this phenomenon was present.

Relative conductivities observed during the laboratory experiment were in the 15 to 20 range, indicating very little, if any, damage to the cell membranes as a result of the treatments. These values were about 7 to 10 relative units greater than for the field trial. There may be seasonality in relative conductivity even when the same seedlot is grown in the same nursery with only the year different. As with relative conductivities in the field experiment, natural variations among seedlings would explain the small differences that did occur and the interactions shown in the data. There was no demonstrated effect from the pre-conditioning treatments or from the 8-h treatment at any temperature. Several readings for the 48-h treatment stand out, but their standard deviations were large (i.e. 19.9 $\pm$ 4.1 and 21.0 $\pm$ 7.1). It is therefore reasonable to conclude that the heat stress treatments did not cause significant cell membrane damage. This conclusion is supported by the results of other studies (Alexandrov 1964, Helgerson 1990, Burr et al 1993). Alexandrov found that the temperature of irreversible damage to cell components ranged from 48.5 to 56.4°C in eight different species. Burr et al (1986)

¹⁰ R. van den Driessche, BCMOF, Victoria, B.C.; personal communication, March 1995.

¹¹ Michael Norris, General Electric; personal communication, April 1995.

recorded much higher electrolyte leakage in cell membranes when the temperature increased from 48 to 52°C. Binder and Fielder (1988) reported that conductivities increased in needle segments in 30 and 40°C treatments after 72 h. Increased relative conductivities could have been expected, had the present experiment continued past 48 h.

Seedling Survival and Growth. In the laboratory experiments, the seedling survival, 99.5% after 2 growing seasons, is high given the heat stress treatments applied. At the least, this particular seed source is very tolerant to heat stress. Binder and Fielder (1995) recorded less than 10% mortality in white spruce seedlings after one growing season when they exposed the seedlings to a 48-h 40°C heat treatment. Mortality increased to above 50% when the duration was extended to 72 h. In the present laboratory experiment the maximum duration was 48 h. The length of exposure to the heat stress is therefore important and has been confirmed in other studies (Baker 1929, Binder and Fielder 1988, Colombo and Timmer 1992, Ingram et al 1990).

The seedlings in this experiment were exposed to two transportation segments of 800 km each—before and after the various pre-conditioning and heat stress treatments—by courier in vehicles that were not temperature controlled. Transportation distances for seedlings in British Columbia and Alberta typically average less than 400 km, with most of it in a temperature-controlled environment. Very few seedlings are transported in excess of 1000 km in total (Stjernberg 1996). Thus, the seedlings in this experiment were exposed to extreme shipping and handling conditions, although the conditions are assumed to be equal across treatments.

When the field experiment data for the first growing season were analyzed, the data suggested a pre-conditioning effect for seedlings at temperature exposures of up to 35°C. Reports indicate that seedlings can withstand temperatures that normally would be fatal, if they have been pre-conditioned by higher-than-normal temperatures (Burke 1990, Colombo et al 1992, Howarth and Ougham 1993, Koppelaar et al 1991).

When the interaction Plots•Pre-conditioning•Time data for growth in the first growing season (G1) are plotted, pre-conditioned seedlings that were heat stressed for 48 h appear to have grown better than seedlings that were not pre-conditioned. However, even the seedlings not pre-conditioned grew better in one plot. There were no significant differences in growth between pre-conditioned and non-pre-conditioned seedlings exposed to the 8-h stress treatment. This indicates that the differences lie only in the length of exposure. A significant Plots•Time interaction suggests that seedlings in the “irrigated” Plot I grew better than in the other plot, even though there

was no actual irrigation. The distinct differences in soil nutrients within the adjacent field experiment plot may also be present between the Plots I and NI, though this was not investigated. However, the non-irrigated plot was more exposed to desiccating winds, particularly in the late fall and early spring when the soil was frozen and there was no snow to offer protection. Over-winter foliar injuries were observed in the NI plot. Seedlings with the longer 48-h heat stress exposure had better growth than did those with the 8-h exposure.

The Pre-conditioning•Heat interaction for the second growing season growth (G2) was significant but without consistency between the various combinations. At temperatures at and below 30°C there was no effect from pre-conditioning. However, at 35 and 40°C a pre-conditioning effect was indicated, albeit without pattern. The analysis does show a significant difference between G2 in Plot I and G2 in Plot NI. As discussed above, the most likely cause is related to the winter injury acquired in Plot NI. Plot NI seedlings had considerably more winter injury than any other seedlings planted in 1993 at Red Rock Research Station.¹²

To eliminate the confounding differences between plots, the data for each plot were analyzed separately. This is valid because there was no irrigation done and the plots were therefore equally treated with respect to irrigation. Interpretation of results from Plot I are straightforward. Only a time effect is significant, confirming that the longer heat stress duration resulted in higher growth. However, it does not explain why. The clearly indicated pre-conditioning effect in Plot NI for the growth in the first growing season (G1) is not present in the second growing season (G2). This could result if winter injury in 1993/94 was so severe it became the major factor regulating seedling growth. The pre-conditioning effect is also difficult to interpret when it is interacting with the levels of heat stress, although this interaction is very similar for both growing seasons. In the first year, the 8-day pre-conditioning appears to increase the volume growth with increasing temperature, but some of this effect is lost in the second year. Again, this may in part be attributable to winter injuries in Plot NI.

The overall interpretation of the data suggests that the 48-h stress duration increased growth in the first year. This is opposite to what other studies have found (Binder and Fielder 1995) and also contrary to what was intuitively expected in this experiment. The reasons are elusive. Seedlings that underwent the 8-day pre-conditioning and 48-h heat stress treatment had several noticeable

¹² C. Hawkins, BCMOF, Red Rock Research Station, Prince George, B.C.; personal communication, March 1995.

physical features: buds on the lower laterals had started to flush; needles on upper laterals had turned yellow; seedlings had no or a limited number of white roots and very brittle needles. Many of the seedlings with the shorter pre-conditioning and heat stress treatments had white roots growing after the treatments were finished. Light is obviously not required to initiate root growth in white spruce. Binder et al (1995) report the same to be true for Sitka spruce (*Picea sitchensis* (Bong.) Carr.).

Temperatures in the incubators were stable and varied only within a few tenths of a degree from the settings. However, the temperatures dropped slightly when the bags of seedlings were placed in the incubators, with a delay before the temperatures again reached their targets. No formal measurements of the bag temperatures were made. This decrease in temperature is difficult to avoid and has been reported in other similar experiments (Binder and Fielder 1988). However, it is not likely to have influenced the results.

CONCLUSIONS

Field Experiment and Controlled Conditions Experiment

The results of the temperature monitoring in the field test and the heat transfer testing under controlled conditions show that using tarpaulins made from the Silvicool® 2 material would not be significantly different from leaving the seedling boxes unprotected.

The new tarpaulins showed no significant differences in performance with respect to heat transfer. The determining factors for purchase should be the quality of the material.

The insulated FIST canopy had a higher accumulated heat sum than the new tarpaulins, mainly because the heat dissipated more slowly once it had accumulated inside. A FIST canopy loaded with seedling boxes directly from cool storage will have a lower initial temperature and can be expected to maintain low box temperatures longer than boxes protected by tarpaulins, because of the slow rate of heat transfer through the insulation.

There is a definite increase in heat transfer capacity after a tarpaulin has been used for a period of years, though differences between different types of used tarpaulins are not great.

Relative conductivity analysis indicated no cell membrane damage in the needles of seedlings as a result of exposure to temperatures up to 35°C, and storage time of up to 6 days.

Storage of white spruce seedlings at temperatures ranging up to 35°C for up to 6 days did not cause mortality

in seedlings outplanted in nursery beds. In fact, the mortality of the test seedlings was lower than normal for seedlings planted in these beds.

Results of the statistical growth analysis are interpreted as showing no significant differences between treatments in total seedling volume after 2 growing seasons, or in the growth in each of the first, second and third growing seasons. Furthermore, interpretation of the data indicate no significant differences in seedling volumes after three growing seasons, regardless of length of seedling storage which ranged up to 6 days.

The survival and growth results apply only to containerized white spruce seedlings planted in a nursery bed environment. Different results may have been obtained if seedlings had been outplanted on a harvested site.

Laboratory Experiment

The results of this experiment indicate that containerized white spruce seedlings are very heat tolerant. Temperatures of up to 40°C for 48 h did not kill the seedlings and did not reduce growth. Such temperatures actually enhanced growth. Pre-conditioning of seedlings may have been beneficial in the short term for seedlings exposed to 48-h heat stress. However, the seedlings were outplanted in nursery bed conditions, and the results may have been different had the seedlings been outplanted on a harvested site.

The results suggest that further studies should be made to confirm the findings of this study with respect to heat tolerance and pre-conditioning effects. Heat tolerance limits for containerized white spruce and other major species used for reforestation in Western Canada should be established for seedlings outplanted in field conditions.

Implications for the Forest Industry

Some implications for the forest industry from this research project are:

- The Silvicool® 2 type of reflective tarpaulins should not be used if heat exposure is a concern.
- The effectiveness of reflective tarpaulins deteriorates significantly with usage though it is not a linear relationship. Better quality tarpaulins are more effective than lower quality ones.
- The FIST canopy is effective in protecting seedlings against solar radiation. However, it should not be used for longer-term storage since heat slowly builds up and then does not dissipate as quickly as it would under a tarpaulin. The more boxes in the canopy, the longer they will stay cool, if they are cool to start with.
- Though rare, stored seedlings may be destroyed when they have been heated for more than a day as

a result of a malfunctioning refrigeration unit on the semi-trailer. Prior to disposal of the seedlings, extensive testing is normally carried out. However, a load of seedlings may represent a value of \$35,000 to \$40,000 (in 1994); any disposal of container-grown white spruce should be re-evaluated in light of their apparent heat tolerance demonstrated in this project.

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APPENDIX I

Terminology

Seedling volume (V) was estimated by the formula: $V = \text{diameter} \cdot \text{diameter} \cdot \text{height} \cdot 0.2618$. This formula assumes that seedling stems are cone-shaped.

All volumes shown are LSMEAN (Least Square Mean) as calculated by the SAS/STAT^a program, and are expressed in mm³.

V1 = seedling volume at time of planting. V1 is used as covariate in the statistical analysis to remove the influence different seedling sizes may have had on the volume growth of the seedlings.

V2 = seedling volume after the first growing season.

V3 = seedling volume after the second growing season.

V4 = seedling volume after the third growing season.

G1 = $V2 - V1$; growth in the first growing season only.

G2 = $V3 - V2$; growth in the second growing season only.

G3 = $V3 - V1$; growth in the first and second growing seasons.

G4 = $V4 - V3$; growth in the third growing season only.

G5 = $V4 - V1$; growth in the first, second and third growing seasons.

Time = length of storage in days.

Time 1 = no storage; seedling used as controls.

Time 2, 3, 4, 5, 6 = seedlings stored for 2, 3, 4, 5 and 6 days

Block = position in sample plot (B1, B2...B6). Blocks consisted of nursery beds with four seedlings planted abreast.

Treatment = protection method (Treatment 1, 2...10).

NOTE: Each block (B 1, 2...6) was randomly divided into six time zones (T1, T2...T6), which in turn was randomly divided into ten treatment parts (TR 1, TR 2... TR10). Each block consisted of 480 seedlings; each time zone consisted of 80 seedling, and each treatment consisted of eight seedlings (four seedlings in each of two replications) per time zone per block (Figure 3).

^a SAS® for Windows, Version 6.08, SAS/STAT Module, SAS® Institute Inc., Cary, NC.



**PACIFIC REGENERATION
TECHNOLOGIES INC.**

PLANTING HANDBOOK

FOR INTERIOR REGIONS



WINTER 2003 EDITION

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This handbook is for all those involved in reforestation, from ordering seedlings right up to planting. The section on stock type selection is geared for the silvicultural forester or anyone else involved in ordering seedlings. The latter sections are designed for those actually planting the tree seedlings, although the information should prove useful to all involved in the forest regeneration process. As a tree planter, the goal of this handbook is to provide you with information that will enable you to consistently plant seedlings yielding high growth plantations. If you understand the principles governing seedling growth limiting factors and associated microsite influences, you will be in a better position to make the most productive decisions. Thoughtful adherence to the philosophy within these pages, in combination with careful observation of what is going on around you at the planting site, will result in many rewards for your efforts. You have now become part of a most worthwhile endeavour, that of renewing the forest for the future. The results of your contributions to this effort will be apparent and around for many generations, something in which you can take a healthy measure of pride!

If you have any questions or concerns, please ask your foreman or supervisor for further information or clarification. General information may also be obtained from your nearest PRT nursery.

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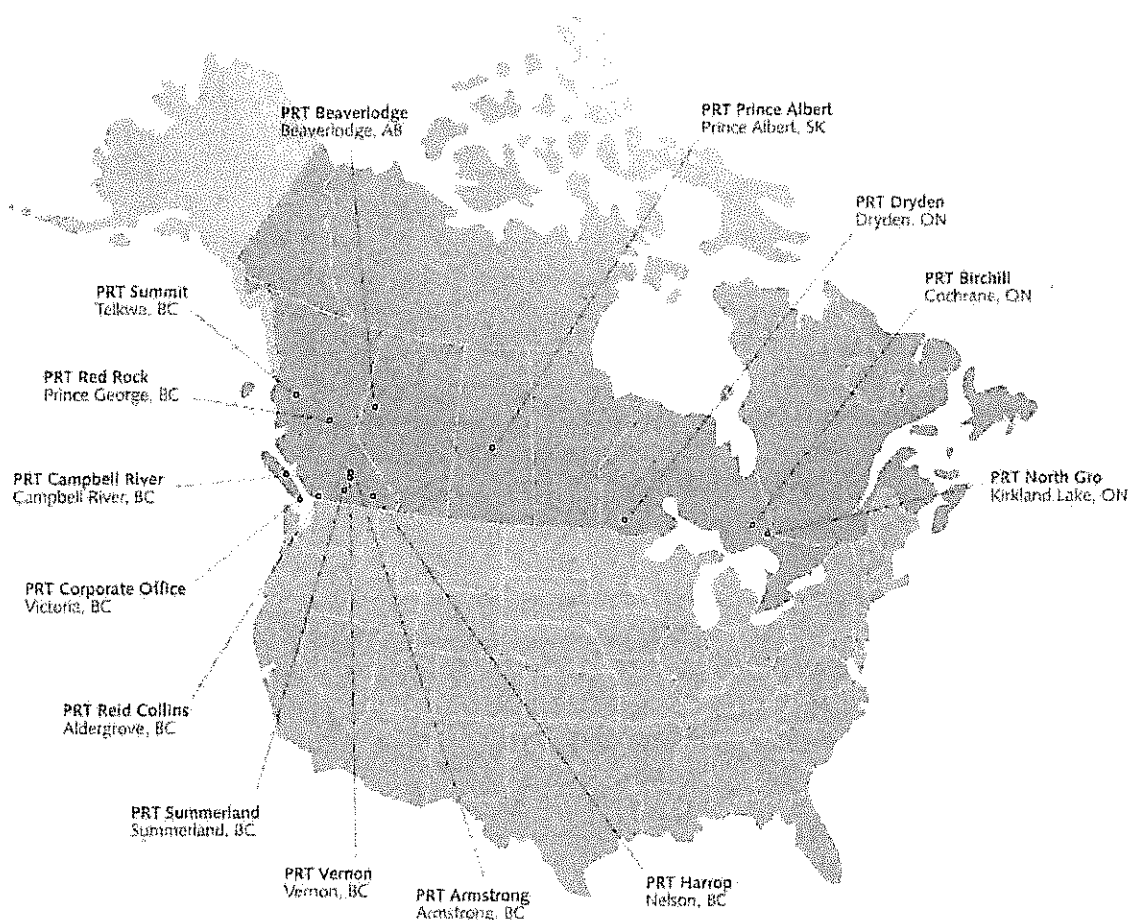
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PART I Introduction

PRT Background

PRT Beaverlodge Nursery is a member of the Pacific Regeneration Technologies Inc. (PRT) group of companies. PRT is comprised of thirteen nurseries located across Canada in Ontario, Saskatchewan, Alberta and British Columbia. PRT was an employee owned company founded in 1988 in response to the British Columbia government privatization initiative. Since 1988, PRT has increased production from 50 million to over 120 million seedlings, providing stock for western Canada, Alaska, and the US Pacific Northwest. Greenhouse capacity has increased tenfold to more than 2 million square feet. PRT also has extensive open compound growing areas, and bareroot facilities. These capital expenditures have allowed PRT to remain current in an evolving forest industry. In 1997 PRT became a public company as an Income Trust Fund on the Toronto Stock exchange.

Location of PRT Facilities



The main services offered by PRT include:

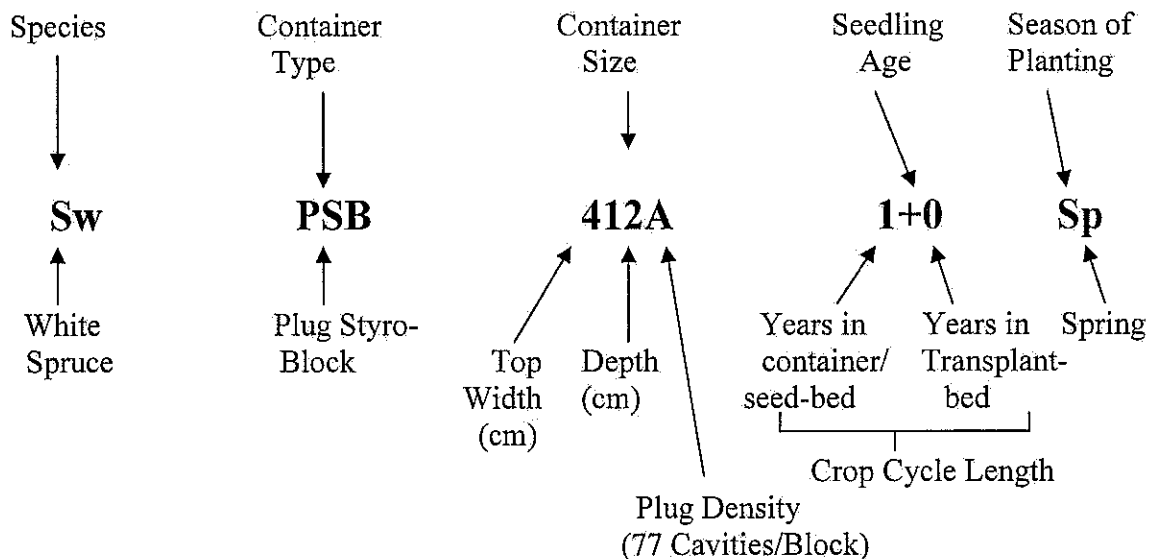
- Seedling production - commercial forest trees and native plants
- Seed processing, storage and specialized seed treatments
- Cold (frozen) storage
- Seedling transportation
- Seed orchard management
- Seedling field performance assessment and enhancement - Field Agrologist
- Tree Planting – Frontier Resource Management (Ontario)

PART II Stock Type Selection

Types of Nursery Stock

- Three types of nursery stock
 - 1) Container – Plug Styroblock™ (PSB), Copperblock™ (PCT), Plug Airblock (PAB)
 - frozen stored vs hot lift
 - greenhouse vs open compound
 - 1+0 vs 2+0
 - 2) Bareroot (BBR)
 - 3) Plug Transplanted Bareroot (PBR)
- Two types of container stock available, although in B.C. only Styroblocks™ grown
 - a) rigid-walled containers, removed before planting exposing a firm root plug
 - e.g. Styroblock™, and Multi-pot, Panth, Spencer-Lemaire
 - b) soft-walled containers which remain intact at planting
 - e.g. Jiffy (first forestry use was in 1985)

Styroblock™ Stock Type Nomenclature



Container Modifications – Copper-treated Styroblock™ (Copperblock / PCT)

- Concern over perceived toppling in planted container grown (Styroblock™) lodgepole pine in B.C. led to container modification via chemical root pruning by coating the inside of the growing container walls with copper

- The copper promotes the formation of a more fibrous root system, which results in “softer” plugs than those grown in regular Styroblocks™.

Despite their wide acceptance, the long-term benefits of copper root pruning have never been proven. Since the introduction of Copperblocks™, vertical ribs to prevent root spiraling have been introduced; the media bulk density has decreased allowing vigorous root growth without plug compaction; and sowing dates have been refined such that stock is not held any longer than necessary, preventing rootbound plugs. [For more information see the *Copper Root-Pruning of Coniferous Forestry Seedlings* article in *Notes from the Field* on the PRT website at http://www.prtgroup.com/customersupport/resources/field/prtkiiskila_article5.html].

Pine Needle Morphology – Primary vs Secondary or Mature Needles

Pine may also be ordered with primary or secondary (i.e. fascicle) foliage. Even though primary needle pine has less foliage, and thus less transpirational area, secondary needle pine is often considered more resistant to drought stress. Presently this is based more on looks than anything, as there is no significant evidence in the literature to support enhanced field performance of one needle type over the other. Along with fascicle needles, secondary needle pine has a whorl of buds at the apex vs the single terminal bud usually found in primary needle pine.

How Big are the Seedlings?

Common¹ Specifications of Various White Spruce (Sw) Stock Types

Stock Type	Cavity/Block	Volume ml	Age	TARGET Ht	TARGET RCD	MINIMUM Ht	MINIMUM RCD	MAX Ht	Ht: RCD
1+0 Stock									
313B	160	65	1+0	18	3.0	11	2.2	25	60
410	112	80	1+0	20	3.2	12	2.3	28	63
415B	112	105	1+0	22	3.5	13	2.6	30	63
412A	77	125	1+0	24	3.8	14	2.8	35	63
415D	77	160	1+0	26	4.0	15	3.0	40	65
512A	60	220	1+0	30	4.2	15	3.2	45	71
615A	45	213	1+0	35	5.0	20	3.5	50	70
2+0 Stock									
415B	112	105	2+0	27	4.8	14	3.5	40	56
412A	77	125	2+0	27	5.0	15	3.8	45	54
415D	77	160	2+0	30	5.3	15	3.8	45	57
515A	60	284	2+0	35	5.8	17	4.2	50	60

¹ For comparison purposes only, actual contract specifications may differ – contact the nursery manager for more details.

Planting Season - Spring (Frozen Stored)

- Frozen stored stock can be “custom” thawed for delivery as sites are available for planting
- Once thawed, seedlings rapidly lose dormancy and hardiness and flush shortly after planting
- Prior to flushing, root activity is high, thus under favorable soil conditions roots quickly egress into the surrounding soil, reducing seedling reliance on plug conditions
- During flushing seedlings are very sensitive to stresses (e.g. drought, frost, high temperature)
- It is recommended you do not plant later than mid-June, as seedlings will be out of sync with the natural environment

Planting Season – Summer (Hot Lift)

- Seedlings are still physiologically active, thus speedy stock handling from nursery to planting site is essential
- Height growth has ceased (seedlings are generally considered too succulent for shipment during active shoot growth), and seedlings are moving into dormancy and therefore have developed some hardiness (e.g. resistance to drought, frost)
- In general, stock will not flush after planting - thus has lower water requirements and is better able to control moisture loss
 - majority of seedling resources are put into roots and stem growth
- Planting date is dictated by environmental conditions at planting
- The key to a successful summer plant is communication

Stock Type Selection

Stock type selection can be broken down as follows:

1. Identify the general site ecotype (e.g. nutrients, soil, moisture, etc.)
2. Select the desired species and seed source for the area
3. Determine the appropriate planting window for the site
4. Assess the specific site limiting factors
5. Review available site preparation methods to alleviate the limiting factors
6. Determine which stock type is best suited to the site's limiting factors

7. Compare the cost effectiveness of the various site treatment/stock combinations
8. Select the *optimum seedling*

1. Identify the Site Ecotype; 2. Select the Desired Species and Seed Source; and 3. Determine the Planting Window

Identifying the site ecotype and selecting the appropriate species and seed source are generally done early on in the process, prior to logging. In most cases, your choices at this stage are limited and dictated by site and management factors. After the desired species and seed source has been chosen, the planting window must be determined. This will dictate whether frozen stored/overwintered stock for spring planting, or hot-lift/current crop stock for summer planting will be needed. If the planting sites have spring access, the ground never freezes or thaws early, and the probability of late spring frosts are low, then spring planting can begin as soon as feasible and continue till the summer solstice in the third week of June. For sites with late spring access (e.g. high elevation cutblocks), hot-lift stock can be planted from late June until late July, as long as the site is not subject to summer drought. In selecting a planting window, operational logistics will play a role, but they should never be allowed to compromise the seedling's biological requirements.

4. Assess the Specific Site Limiting Factors

The next step is to assess the specific factors which limit plant growth on the site in question, or in the general area if it is not feasible to order stock types specifically for each individual planting site. Common site limiting factors and appropriate planting stock for these conditions are listed below:

- Vegetation Competition - select large stock
- Snow/Vegetation Press - select large, sturdy, well branched stock
- Cold Soils - select stock grown in shorter containers
- Drought - select smaller, well balanced stock
- Shallow Soils - select stock grown in shorter containers
- Frost - no stock type can fully avoid frost damage, although species differ in tolerance of frost (e.g. lodgepole pine will withstand frost much better than white spruce)
- Wet Soils - no stock type can be used to alleviate wet planting spots. In fact, the use of mechanical site preparation may be your only option of enhancing growth on very wet sites.

5. Review Available Site Preparation Methods to Alleviate the Limiting Factors

After the site limiting factors have been assessed, available site preparation methods to alleviate the growth limiting factors should be examined. Examples include tools such as chemical and mechanical site preparation, the use of which is usually governed by environmental and/or monetary factors.

6. Determine Which Stock Type is Best Suited to the Site's Limiting Factors

Taking into account the use of any planned site preparation, the stock type best suited to the site's limiting factors needs to be determined. Keep in mind that there are limits as to what

any stock type can overcome. Under favourable conditions, large seedlings generally grow larger in absolute terms than comparable smaller seedlings. They do not have any additional physiological attributes to enhance performance, but simply occupy a greater area within the planting spot. A greater photosynthetic area equals quicker growth and access to the site's resources. This is coupled with a greater number of branches and buds which equals more places for new shoot growth. Once site-limiting factors (e.g. vegetation competition) are overcome, both small and large stock grow at the same rate governed by the site. However, where moisture is limited, large stock often does not survive as well as smaller stock due to the greater transpirational demand. Also, on sites with minimal or no vegetation competition, initial stock size differences are not as important as the large stock does not offer as much of an initial advantage over the smaller stock.

A clear understanding of the various types of nursery stock available will allow you to make the most productive stock selection decision. From a nursery perspective, the ideal container is one in which the nursery can economically grow seedlings of the desired size, consistently and reliably. From a field perspective, the ideal container is one which produces seedlings of a desired size capable of vigorous cost effective growth after planting. After container type and size, stock type is primarily characterized by: i) height; and ii) root collar diameter (RCD). Also, dividing height by RCD gives you the height: to: diameter ratio, which gives an indication of the seedling sturdiness. For the most part, seedling specifications typically consisting of minimum, target and maximum height, along with minimum and target RCD are included in the initial seedling contract drafted when ordering seedlings. In the nursery, there are biological limitations as to what can be produced in any given container size for each species. Taking into account seedling recovery, optimum seedling specifications reflecting what can be reliably grown in the various container sizes in a cost-effective manner have been developed. The nursery grows to the target specifications of the particular stock type, but there will always be some variation as seedlings are biological organisms (i.e. we're all familiar with the basic bell curve). Stock type selection should be based on target seedling specifications for a particular container size, specifications based on what can be produced in the nursery. If a larger seedling is desired, rather than increasing the specifications of your current stock type, a larger container size with correspondingly larger height and RCD specifications should be chosen. **In essence, after assessing the site's limiting factors and determining what size stock you require, you would order stock in the container size that has target seedling specifications which match your previously determined stock size requirement.**

7. Compare the Cost Effectiveness of the Various Site Treatment/Stock Combinations

After the stock type best suited to the site has been determined, then the cost effectiveness of the various available site treatment/stock combinations must be compared. This is the final step in determining your *optimum seedling*. To compare effectiveness we need survival and initial growth goals, which in some cases have already been set by stocking and free growing height requirements. Analysis of regeneration costs requires evaluation of these goals and cost in relation to site preparation, stock type, and post-planting vegetation control. At this point, you must remember to consider total establishment costs – initial savings upfront may result in having to spend more later (e.g. what is the cost of fill-planting?). Alternatively,

initial investments in nursery culture may reduce overall costs in the long run, through a reduction in subsequent silvicultural treatments.

8. Select the *Optimum Seedling*

Finally, rank the silvicultural treatment/stock combinations by total cost per hectare. Which combination meets your free growing requirements at the lowest cost? This is the difficult part, as we usually do not have all the data we would like. Often it comes down to the level of risk you are comfortable with. Nonetheless, after comparing the above, you will be in a better position to choose your *optimum seedling* or stock type. The term *optimum seedling*, defined as the seedling which will minimize overall reforestation costs while achieving established goals for initial survival and growth, was coined by South and Mitchell in 1999.

PART III Storage and Handling

Physiological Aspects of Frozen Storage and Thawing

- Frozen storage is the least stressful way of overwintering seedlings
 - provides a stable, reliable, controlled environment
- Low storage temperatures slow, but do not stop metabolic processes such as respiration
 - frozen storage (-2°C) is used as it reduces respiration further and reduces storage molds
 - reserves are important as dark conditions of storage prevent their replenishment by photosynthesis
- Seedlings must be physiologically ready for frozen storage
 - during dormancy, conifers are most resistant to stress
 - accumulation of a couple hundred hours of low ($0-10^{\circ}\text{C}$) temperatures (i.e. chilling hours) is required for boreal species to become frost hardy to -18°C
- Readiness for storage is determined through frost hardiness testing
 - controlled freezing to -18°C , followed by a visual assessment for foliage damage or chlorophyll fluorescence measurement
- Stock is also assessed toward the end of frozen storage well in advance of shipping
 - samples of each seedlot are potted and grown under favourable conditions in a greenhouse
 - bud flush and root growth are measured to assure viability
 - if problems are apparent, this information is reported ASAP
- After thawing:
 - seedling dormancy, hardiness and tolerance to water stress are lost rapidly

- as seedlings have previously accumulated chilling units they will break bud after sufficient heat sums have been accumulated
- between 300-400 hours of heating at 10°C is required for spring bud flush

Trees per Box – Common Amounts

Container Size	Seedlings per Box		Box Size (length x width x height)
	Hot Lift	Frozen Storage	
211A	400	400-500 ¹	16 x 12 x 24 or 16 x 12 x 18 ²
312	360	360-400	16 x 12 x 24 or 16 x 12 x 18
313B	360	360-400	16 x 12 x 24 or 16 x 12 x 18
410	270	270-360	16 x 12 x 24 or 16 x 12 x 18
415B	270	270-360	16 x 12 x 24
412A	180	180-200	16 x 12 x 24
415D	180	180-200	16 x 12 x 24
512A	120	120	16 x 12 x 36
615A	90	90	16 x 12 x 36
½ + 1½		180	16 x 12 x 36

¹ The range results from stock packaged upright vs lying down. Hot lift summer plant is packaged upright whenever possible, and no box liner is required.

² “Stubby” box

Frozen Storage Guidelines

- Freezing
 - once seedlings are frozen, storage facility initially set at an ambient temperature of -5°C to ensure rapid freezing
 - ambient temperature set at -2°C
 - PRT cooler temperatures are continuously monitored by environmental computers
 - stock monitoring programs are in place at appropriate intervals

Thawing Seedlings

- Several ways of thawing seedlings:
 - 1) traditional slow thaw where all the stock in a particular cooler is thawed simultaneously
 - 2) rapid or quick thaw where particular requests are thawed a day or two before being shipped to the field
 - most stock is thawed somewhere in between these two extremes

- Good planning is essential to be able to custom thaw orders whenever possible
- The sooner the seedlings are shipped to the field after being thawed
 - the less chance there is for the development of storage moulds and carbohydrate depletion

Slow Thaw

- Slow thaw can take up to several weeks to completely thaw container seedlings. Cooler ambient temperature is set initially at 8°C for 5-7 days, then lowered to 3°C
 - do not allow inside carton temperature to rise above 5°C
 - keep an eye on the uppermost boxes in the cooler
 - minimize seedling exposure to temperature fluctuations
 - inspect seedlings daily for temperature, disease, moisture, root and shoot activity
- Once thawed, cooler temperatures can be lowered to just above freezing to reduce carbohydrate depletion and disease potential
- Once thawed seedlings should be planted ASAP, with priority given to diseased or damaged stock

Quick or Rapid Thaw

- Rapid thawing of seedlings over a couple of days is not harmful to seedlings, but is more labour intensive
- Requires approximately 3-5 days, but can be done more quickly by removing seedlings from the boxes and repackaging after thawing.
- Larger plugs hold more water, thus take longer to thaw than stock types with less plug volume
- Various temperature regimes in use (e.g. facility ambient temperature set at 12-15°C for 2 days, then lowered to 3°C)
- Cartons are spaced 8-10 cm apart, and fans may be used to ensure there is sufficient air flow around the cartons

Thawing Seedlings in Other Facilities (e.g. Curling Rink)

- Thawing seedlings in a curling rink is no different than in a cooler (i.e. the same

principles apply)

- however, when thawing in a curling rink you lose some flexibility
 - depending on how the curling rink is equipped, rapid thaw is difficult so planning and scheduling have to be good
- If you choose to thaw your stock at the curling rink:
 - place cartons 4-8 cm apart on pallets for proper air flow
 - do not place cartons directly on the floor (e.g. keep them off the ice)
 - except for inspections, keep the cartons closed
 - ensure there is continuous air movement inside the facility
 - rotate boxes as the upper boxes will thaw more quickly

Snow Cache

On sites that are difficult to reach during the spring, a snow cache may have been built to overwinter the seedlings

- The inside temperature will remain very stable at just below freezing
- The cache may be opened and seedlings removed as needed. Open the shaded side first to minimize snow melt
- Once opened, use a plastic sheet or tarp to keep the cold in

Seedling Stress

- Stress is generally cumulative, once weakened, the seedling's resistance to further stress and its ability to recover is compromised
 - however, not all stresses accumulate in the same way
 - damage from desiccation and moderate temperatures accumulate
 - damage from rough handling or very high or low temperatures occurs rapidly once a critical threshold is reached
- Stress triggers a survival response, shifting resources from growth to repair and adjustment
 - amount of stress required to cause a detectable growth reduction is related to site and weather conditions after planting
 - seedling stock type and physiological condition influence

Seedling Loading Guidelines

- Do not throw or drop cartons, or lay on their side (keep boxes upright until completely

empty)

- seedlings are live plants, handle with care
- many small shocks are not as damaging as a few large ones - the maximum force experienced by the plant is more important
- Load all boxes with carton labels facing the rear doors for easy identification
 - to ensure that the reefer is loaded as desired, it is a good idea to supply a reefer layout map
 - mark changes in seedlots appropriately with flagging tape, spray paint, etc.
- Dunnage such as plywood, 1x4 slats, or ¼ wafer board MUST be placed between the 2nd and 4th layers of boxes to stabilize the load and prevent boxes from being crushed
- Load boxes so that there is at least 30 cm (1 ft) between the boxes and roof for proper air circulation
 - boxes directly in front of the cooling unit air flow will freeze
- Ensure cartons are well secured
 - tie down if necessary
 - drive appropriately on gravel (bumpy) roads
- Check seedling moisture in damaged boxes, and repair boxes as necessary
- Keep records (e.g. reusable HOBO Temp data loggers) of temperature during transport and while on site [*contact Glenn at PRT Beaverlodge for more information*]

Seedling Temperature

- Respiration rates increase with increasing temperature, giving off more heat, further increasing respiration and the cycle continues
 - in a closed box, this results in a depletion of seedling carbohydrates
- Length of time that seedlings must be exposed to warm temperatures to cause a noticeable reduction in field performance depends on many factors
 - e.g. box temperatures of 20°C for four days after thawing were found to have no measurable effect on the survival and growth in white spruce seedlings planted into a hand weeded, farm-field site
 - on a more severe site, the results may have been different
- As maintaining proper temperature is critical for shipping, especially current crop seedlings, some form of temperature monitoring and record keeping is a good idea

Monitoring Seedling Temperature

- Dial thermometers are available for inserting through seedling boxes to monitor internal box temperatures
- Min-Max thermometers are useful for monitoring temperature extremes
- Some forest companies are now using small, reusable data loggers for monitoring temperature during:
 - shipping, storage and planting
 - silvicultural treatments
 - early establishment
 - *[contact Glenn at PRT Beaverlodge for more information]*
- If you find a data logger in your seedling box or within a seedling bundle, please return to your supervisor and collect your finders reward :-)

Transportation Guidelines - Frozen Storage

- Seedlings that have been freezer stored may be shipped in either frozen or thawed condition
 - frozen stock will not overheat during normal shipping, thus can be packed tight
 - typically stacked eight boxes across, five high
- Refrigerated vans are recommended
 - mass of a trailer load of (cool) seedlings has a large effect on the reefer temperature, it will take a while to heat up, especially in an insulated reefer
 - however, use of refrigerated vans on short hauls provides extra insurance against the possibility of breakdowns and delays
- Reefer temperatures are commonly set at -2°C (28°F) when transporting frozen stock, and $2-4^{\circ}\text{C}$ ($36-39^{\circ}\text{F}$) for thawed stock. Do not freeze thawed stock.
- Roots can be damaged by temperatures of only -10°C (14°F), ensure that seedling roots are not exposed to these cold temperatures

Transportation Guidelines – Hot Lift or Current Crop

- Success requires good communication between the forester, nursery, planting contractor, and trucking company

- Hot lifted seedlings should be irrigated thoroughly prior to packaging - may be the last water they get for some time
- Depending on trailer capacity and box size, hot lift boxes are typically stacked seven boxes across, five high
 - stack boxes so that there are continuous tunnels throughout the load to allow for proper air circulation
 - Refrigerated vans should be used, with the temperature set to at 6°C (43°F) to maintain internal box temperatures of approximately 10°C (14°F)
 - hot lift stock is physiologically active, respiring and creating its own heat
 - the cooling unit on a fully loaded trailer can maintain, but not cool down warm stock
- Internal box temperatures should not be above 12°C (54°F) at loading
 - to avoid overheating, freshly lifted stock can be precooled by placing seedling boxes in a cooler set around 4°C for 4 to 6 hours prior to shipping

Shipping

- Prior to loading, ask the driver to start the cooling unit and set the appropriate temperature
 - **Verify Celsius vs. Fahrenheit**
 - do not load a truck with a cooling unit that cannot be started prior to loading
- During transport, operation/warning lights on the cooling unit should be checked regularly
- Ensure that proper instructions have been provided for additional pickups, the final delivery destination, and the expected time of arrival
- If the expected time of arrival will not be met, the contact **MUST** be informed

Transportation Guidelines – Pick-up Trucks

- Preferably use an insulated canopy (e.g. FIST), or cover the boxes securely with reflective tarps (e.g. SILVACOOOL) in good condition, keeping the white side up
 - further reduce heat by insulating the truck bed from exhaust system heat
 - if possible, travel early in the morning, or late in the day
- Reflective tarps:
 - maintain existing temperature in boxes by preventing heat from entering
 - tarp effectiveness deteriorates significantly with age
 - keep tarps clean for maximum effectiveness
 - use a tarp large enough for the job
 - not all reflective tarps are created equal, tarp effectiveness has been shown to vary

Spring Plant Strategy

- Desired that root growth is initiated before bud burst, so the tree can better deal with the high moisture demands of the new flush
 - how soon the seedling flushes after planting is related to the temperatures it receives after thawing
 - seedlings exposed to warm temperatures will break bud sooner
- Warm temperatures may also result in root elongation in the box
 - root elongation prior to planting spring stock is not desired due to the sensitivity of the new root tips to breakage and desiccation
- In some instances field practitioners have purposely warmed up spring plant stock prior to planting
 - the goal is to hasten bud burst of late planted spring stock, so that it will not be out of sync with the natural environment
 - benefits of a brief conditioning period are not known

On Site Storage of Spring Plant Seedlings

- Reefers set at 2-4°C provide ideal conditions for storage
- Field cache - select location in the shade (e.g. timber, north slope, near streams, ditch with moving water, patches of snow) with good air circulation
 - locate cache accessible to the working plant site
 - to avoid crushing, alternate box direction and don't stack too high
- If sufficient shade is not available, shelter can be provided by stringing a tarp above the cache
 - it is important to be careful how you provide shade, or you can do more harm than good
 - leave enough space (e.g. 60 –90 cm, 2-3 ft.) between the tarp and boxes to allow for air circulation
 - canvas tarps are not desired as they are very effective at trapping heat
- While internal box temperatures are low, seedling boxes can be directly covered (i.e. no air space) with a reflective tarp to maintain low temperatures
- Check daily to monitor internal box temperature, moisture content, root and shoot activity (i.e. white root tips and swelling buds), and for the presence of grey mould
 - after a while, if internal box temperatures start to rise, the reflective tarp can be removed and the seedlings treated more like hot lift current stock (e.g. overhead tarp, space, open boxes)

- If seedlings are still partly frozen, sort bundles and finish thawing in the shade, never in the direct sun or near a heat source
 - if thawed in the sun, the seedling will lose water through the foliage, but since it is unable to take up water as the roots are frozen, it will desiccate
 - do not try to separate frozen seedling bundles, as you will damage the delicate roots

On Site Storage of Hot Lift or Current Crop Seedlings

- The essence of "hot-planting" is speed
 - after lifting, ship seedlings to the field and planted ASAP
- If field cached, boxes **MUST** be opened to prevent heat buildup, facilitate watering, and allow light to reach the seedlings
 - allows photosynthesis, and prevents another blackout, which may reduce subsequent diameter and root growth after planting
 - if packaged horizontally seedlings must be placed upright
- Keep seedlings out of direct sunlight - select location for field cache under dappled light through the forest canopy, or suspend a tarp a couple feet above the boxes (allow for air circulation)
 - dark coloured interiors of most opened boxes will absorb radiation

Troubleshooting - Reefer Problems

- Reefer cooling units transporting/storing spring plant seedlings have been known to malfunction (i.e. mechanical or human error)
 - potential for seedling damage depends on the maximum or minimum temperature obtained, how long it lasted, and the seedling condition at the time of the incident
- Seedling boxes exposed to high temperatures **MUST** be removed from the reefer, spaced and opened to cool due to high seedling respiration
 - severely damaged tissue will soon show symptoms, however less severe, but still deleterious damage is difficult to detect
 - stock can be evaluated at the nursery via a potting test, but results take approximately a week
 - results can be obtained sooner via a portable chlorophyll fluorescence meter, SIVE, etc. [*contact Glenn at PRT Beaverlodge for more information*]

Troubleshooting - Grey Mould

- Stock with a lot of dead foliage prior to freezer storage is subject to grey mould or *Botrytis* infection
 - often confused with mycorrhizal seedling roots

- Proper water management and the use of fungicides can prevent/limit its occurrence
- If it occurs, its severity must be assessed (e.g. where, how much?)
- If noticed while in freezer storage, the stock should be kept frozen, then quick thawed just before planting
- Infected stock should be planted first if at all possible
 - once planted, a light *Botrytis* infection usually burns off in a couple of hours once exposed to sunlight

Pesticides

On the whole, pesticide use in the nursery industry has declined substantially in the last ten years. However, pesticides may have to be used on stock from time to time. If this is the case, the seedling purchaser is informed, all seedling boxes are clearly marked as such, and a copy of the applicable pesticide use form is included with each seedling shipment. Although all pesticides are used according to current government regulations and have been shown to be safe if used as directed, it is recommended that gloves be worn when handling seedlings, and that hands be washed before eating or going to the washroom. As well, seedling boxes should not be used for storage of personal items such as clothes.

Seedling Moisture Status in the Field

- A dry tree is a dead tree
- Desiccation stress is accumulative and interacts with other stresses
- Cooling systems dehydrate, although its usually not a problem in spring stock
 - properly close bags/boxes and repair or replace punctured boxes
- Current crop stock moisture status **MUST** be monitored closely as it may dry out, depending on storage conditions, and storage time
 - feeling the seedling plug (i.e. the "squeeze test") is subjective
 - using seedling box weights is more quantifiable
 - λ use average box weight per stock type like block weights [*contact Glenn at PRT Beaverlodge for more information*]
 - λ don't want to plant a seedling with a dry plug, keep moist
 - overwatering is a concern
 - surplus water left in the boxes after watering should be drained

Care of Seedlings During Planting

- Follow general principles outlined for transportation and storage
 - rough grabbing from the box can break off seedling tops
 - do not squeeze or step on bundles to remove excess moisture – this not only removes the last water the seedling may have for some time, it also damages delicate seedling roots!
 - handle and unwrap bundles gently
 - work with one tree at a time
- Limit amount of seedlings stored outside of field cache (½ day)
 - store boxes under a reflective tarp in the shade, under logs or brush, not out in the open without protection
 - boxes (spring plant) should be kept shut to retain moisture
 - plan breaks when planting bags are empty, or place in the shade during breaks
- Keep planting bags in good condition
 - torn or punctured bags will allow air to dry the roots
 - use reflective inserts
 - with exception of the feeder bag, keep closed to prevent drying
 - place sponge, carpet underlay or moist layer of peat moss in bag bottom
 - don't cram planting bag with too many seedlings

Handling of Bareroot and Transplant Seedlings

- The previous guidelines apply to field grown bareroot and transplant seedlings as well, but as more of their roots have direct exposure to air and have little protection from desiccation, extra care is required when working with these stock types
 - bags within the seedling box aid in conserving moisture, the opening of which may result in moisture loss, requiring that stock be misted
 - peat moss may have be placed in the box during the packaging of current crop stock at the nursery, to provide a moisture source to maintain high humidity levels within the box
- Limiting the amount of seedlings carried in the planting bag, especially during hot weather, is a good practice for transplant and bareroot seedlings
- Roots of bareroot and transplant stock are often tangled together, and must be gently separated to prevent damage.
 - this must also be done in the shade, for the only time seedlings should be exposed to direct sunlight and dry air is when they are taken from the planting bag to the planting hole

- Optional procedures for bareroot stock often consist of dipping the roots in warm water for no more than one minute prior to planting
- Similarly, rootdips have been used in hot, dry areas to protect bareroot seedling roots against exposure prior to planting; and to aid after planting by initially holding water in the seedling's root zone
 - rootdips have consisted of soil slurries, vermiculite or sphagnum peat moss slurries, and hydrophilic gels
 - a recent review of over 25 years of published literature on root dipping found that when seedlings are handled properly during storage and planting, rootdips do not increase their survival or growth

PART IV Planting

Selecting Favourable Microsites

- Specific requirements of newly planted seedlings can often be met to varying degrees on the same site
- Optimum seedling location will vary (e.g. on cold wet site - plant high... on dry, southern exposures - plant for shelter...)
- Since there is usually an allowable deviation from the prescribed spacing, it is critical that optimum planting spots are chosen, rather than adhering rigidly to some fixed spacing
 - by choosing the optimum microsite, seedling requirements can be more readily met, increasing seedling survival and early growth
- Generally, the best microsite is the easiest to plant. The key to productive planting is acquiring an eye for recognizing the best planting spots
 - microsites as little as 20 cm apart can vary drastically in their growing conditions.

Forest Floor Planting

- Forest floor or duff planting is commonly used to describe low impact tree planting where seedlings are planted directly into the forest floor without mechanical site preparation or boot screening
 - there are numerous variations on this theme (F-layer vs H-layer vs rotten log vs live moss on a newly harvested site)
 - is practiced in conjunction with proper microsite selection, and planting depth
 - the size, depth and type of soil classified as "good planting medium" will be specified by your supervisor

- Advantages of forest floor planting
 - majority of roots are placed in a warmer, drier, more nutrient rich substrate, will result in better growth
 - maintenance of the forest floor or organic layer reduces erosion, minimizes frost heaving on silty soils, reduces the potential for desiccation on clayey soils, and retains nutrients
- If mechanical site preparation is not required (i.e. raw plant)
 - can plant in year one and get a jump on vegetation competition (for sites prone to severe vegetation competition, site preparation may be required)
 - planting and site preparation costs will be reduced
 - less site disturbance reduces the possibility of site degradation
- Exceptions:
 - on sites with a thick humus layer, it may be desirable to remove some of the feathermosses or upper organic matter
 - whether a rotten log (i.e. red rot) makes a suitable planting spot must be judged on a case by case basis, but the general rule is that the wood must be broken down enough that the structure no longer consists of cubical chunks
 - on hot, dry sites where lack of moisture is the main growth limiting factor, forest floor planting is risky and not recommended unless a portion of the root plug can be placed into mineral soil
 - leaving a shallow layer of humus on top of the mineral soil is desirable on dry sites, as it will act like a mulch, reducing drying of the mineral soil
 - on coarse loamy soils, preferred planting spots also include exposed mineral soils and mineral/organic mixtures

Structure and Moisture Characteristics of the Forest Floor or Duff

- Structure of forest floor materials (i.e. duff)
 - depends on the original litter, and the state of its decomposition by fungi or insects
 - Fermenting (F-layer) has loose structure and large pore spaces, Humus (H-layer) has smaller pore spaces, rotten wood is similar to the H-layer but quite variable
 - the duff has low bulk density ($125 - 170 \text{ kg/m}^3$) compared to mineral soil ($1,500 \text{ kg/m}^3$), which allows for better root egress
- Moisture characteristics of the forest floor or duff
 - depends on its thickness
 - the forest floor has low water holding capacity compared to mineral soil
 - the forest floor has low hydraulic conductivity because of its large pore spaces
- Nutrient characteristics of the forest floor
 - depends on its state of decomposition (e.g. the Carbon: Nitrogen ratio of a rotten log may be $> 100:1$ vs. $30:1$ for mineral soil)

- nutrients increase from: F-layer and rotten wood > H-layer > mineral soil
- duff has a high cation exchange capacity (i.e. it has a high nutrient holding ability)
- there is increased biological activity and abundant mycorrhizae in the duff

Planting Near Stumps

- Why?
 - stumps are raised microsites, which on cold, wet sites equals a warmer planting spot
 - there is reradiation of heat
 - they can help in preventing vegetation press and snow creep
 - they help in preventing animal (e.g. cattle) trampling
- Distance from stumps
 - depending on the stump size (larger stumps may have air pockets at their base), seedlings may be planted quite close to the stump (e.g. 15 cm), but never on the stump
 - depending on the species and planting site, this practice is not always recommended due to the potential for root rots
 - there has been some concern over poor root asymmetry resulting in instability leading to toppling, although the actual risk is not known at this time

Planting Spot Selection Summary

- Choice of substrate is not as important as its temperature and moisture conditions which are influenced by microsite (i.e. duff planting places seedlings into warm/dry spots)
- Evaluate growth limiting factors on a site-by-site basis
- Is the required number of plantable spots available?
- Spacing of microsite planting is more irregular
 - this makes it mentally more difficult for planters and checkers
 - minimum spacing becomes the main concern

Planting Depth

- Studies from the early 1900's warned against planting too deeply - "the greatest hazard to plantation survival"
 - more recent literature based primarily on pines in the southern U.S. recommends deep planting, due to increased stability, drought avoidance and protection of the root collar from heat damage
- The current thought in boreal regions is to plant to the depth of the root collar (i.e. so that the seedling will grow at the same depth it did in the nursery)

- when discussing planting depth, your point of reference must be established (i.e. mineral soil vs. H-layer vs. F-layer vs. litter layer)
- on hot, dry sites where the duff layer is left intact to act as a mulch, the root collar should be planted flush with the surface of the underlying mineral soil
- Deep planting (e.g. “two fingers”)
 - is recommended where there is potential for soil sloughing (e.g. mechanically prepared planting spots such as mounds or berms on trenches)
 - has been recommended on dry sites to increase seedling access to water, although proper stock type selection and possible site preparation are better options in the long run
- Certain species such as spruce put out adventitious roots on the stem and branches if planted deeply, aiding in anchorage and nutrient/water uptake
 - however, if the proper stock type for the site is planted correctly in warm, moist, well drained nutrient rich substrates, then the benefit to the new root system from additional adventitious roots will be minimal
 - as most pines do not put out adventitious roots, the decision to deep plant must be carefully considered
- Shallow planting
 - if the proper stock type has been selected and suitable planting equipment is being used, there are no reasons to shallow plant
 - however, as peat (i.e. the duff or forest floor) has large, non-capillary pores which impede the upward movement of water, having the top of the plug exposed does not necessarily mean that the seedling will dry up and die

Closing the Planting Hole

- Concern about poor root-soil contact leading to moisture stress has resulted in stomping around the seedling to close the planting hole (i.e. “The Death Stomp”)
 - if you see your boot tread, you’re applying too much pressure
 - stomping breaks down forest floor texture leading to soil compaction, which reduces subsequent seedling growth
 - stomping also increases the possibility of damaging the root collar and lower branches
- Evaluation of planting firmness on conifer seedlings includes the “three needle test”, in which the seedling is pulled by grabbing onto three needles, which should tear off from the seedling rather than move the seedling from the ground

- A balance between the use of excessive force and the creation of air pockets must be reached
 - air pockets are not desirable, as they reduce the amount of root: soil contact, which is necessary for the seedling to access soil water and nutrients
 - depending on the soil type, the planting hole may be adequately closed through gentle pressure from your shovel, toe of your boot, or hand
 - gentle backcuts may be used to close the planting hole, and in no circumstances should they be left open (this shows the planting checker that an effort was made)
 - the seedling plug should not be flattened, so that it is less than three quarters of its original dimension

Fertilization-at-Time-of-Planting

- Limited height growth for the first couple of years after planting compromises plantation productivity. Suppressed seedlings may also be damaged by competing vegetation, insects, animals
 - possible causes include nutrient poor soils, cold wet soils, improper handling, and poor planting spot selection and/or technique
- As seedlings often become chlorotic after planting, fertilization-at-time-of-planting (FAP) has been prescribed to minimize planting check, as well as ameliorate the site limiting factors of nutrient deficiency and vegetation competition
- FAP is generally carried out on nutrient demanding species such as spruce
- Areas of artificially induced low nutrient availability including landings, roadways, and mechanical site prepared planting spots such as mounds are also considered candidates for FAP
- In some instances, increased animal damage has been reported after FAP
 - future implications depend on the type of damage (e.g. girdling vs. browse)
 - FAP may result in greater seedling biomass which may be better able to recover from browse
- FAP is not recommended on hot, dry sites due to risk of fertilizer burn
 - there have been instances of high mortality in the past
- At planting, individual seedlings are fertilized as they only occupy a small portion of the total site
 - at present, most common method of FAP involves placing controlled release fertilizer in or adjacent to the planting hole at the time of planting
 - various products are available (e.g. *tea bags*, planting tabs, loose controlled release fertilizer prills)

- to be most effective, fertilizers must be placed within the area of root growth (i.e. don't put fertilizer in bottom of planting hole on a cold, wet site)
- nutrient release governed by temperature or microbial decomposition
- FAP is an expensive option
- Alternative – long term controlled release fertilizer injected into the seedling plug during seedling harvest at the nursery (Nutri-PlugTM FAL))
 - ensures correct fertilizer placement
 - no additional labour required at planting
 - less costly [*contact Glenn at PRT Beaverlodge for more information*]

NOTES