

**TEMPERATURE, NUTRITION, LIGHT
AND MOISTURE REGIMES USED AT
RED ROCK RESEARCH STATION
TO PRODUCE CONTAINER
1+0 SPRUCE SEEDLINGS**

by
R.Y.N. Eng

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REPORT

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Temperature, Nutrition, Light and Moisture Regimes Used at Red Rock Research Station to Produce Container 1+0 Spruce Seedlings

by
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ABSTRACT

This report describes the environmental conditions used to grow containerized 1+0 spruce seedlings at Red Rock Research Station. Temperature, nutrition, light and moisture are discussed.

Seedlings are germinated at 20°C in March and gradually lowered towards the end of the growing season. They are fertilized with 20-8-20 at concentrations ranging from 30 to 85 ppm N. Photoperiodic lighting is provided during the early part of the growing season to prevent budset. After photoperiodic lighting ends, blackout, rather than nutritional and moisture stress, is used to induce budset.

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1 INTRODUCTION

1.1 Objectives

There are many environmental factors in the greenhouse that affect plant growth. Temperature, nutrition, light and moisture are perhaps of greatest importance to the grower since they can be manipulated to influence plant growth and quality. How these factors are manipulated to produce container 1+0 spruce seedlings at Red Rock Research Station is described in detail here, with results from experiments conducted between 1987 and 1990. This report presents:

- the temperature, nutrition, light and moisture regimes used at Red Rock;
- an explanation of why these environmental conditions are used at Red Rock;
- a comparison of the practices used at Red Rock with those recommended by researchers and those used by other growers in British Columbia;¹
- a description of how temperature conditions and natural light conditions may have a different effect on nurseries located in different areas of the province; and
- proposed modifications to the present environmental conditions at Red Rock aimed at providing better growing conditions for container conifer production.

1.2 Greenhouse Facilities

The four polyethylene/fibreglass research greenhouses at Red Rock were constructed in 1986. They are computer-controlled by an Atenta Control System.² Unit heaters, exhaust fans and intake louvres are automatically activated and deactivated by the computer-controlled system to maintain the desired greenhouse temperature. The computer-controlled system also regulates the travelling boom system to control irrigation, misting and fertilization. The blackout/energy curtains are automatically opened and closed at the desired times as programmed by the operator. A more detailed discussion of the greenhouse facilities is described by Eng (1989).

2 TEMPERATURE

2.1 Germination

2.1.1 Temperature range

A constant temperature of 21°C is well suited for the germination of many conifer species (Matthews 1971; Tinus and McDonald 1979), although a temperature between 18 and 21°C is acceptable (Tinus and McDonald 1979). Even though germination is usually faster at temperatures above 21°C, it is not recommended. These higher temperatures not only reduce relative humidity, thus drying out the block surface, but they also promote excessive hypocotyl elongation (Tinus and McDonald 1979).

Many of the growers in British Columbia have heat setpoints ranging from 18 to 22°C to provide a favourable environment during the germination period March-April. Growers in the milder regions of the province, such as the Lower Mainland, usually have no difficulty obtaining the desired heat setpoint (Table 1). Growers in the northern Interior, however, often have problems achieving the desired temperature because of the low outdoor temperatures that can occur in March and April. At Red Rock, when the outside night temperature is below -5°C, a unit heater providing 280 000 BTUH cannot

¹ The author visited nurseries and/or conducted a survey to become familiar with the environmental conditions provided by growers in British Columbia.

² Atenta Control Systems B.C. Inc., Victoria, B.C.

maintain the desired night temperature of 20°C within a 600 m³ greenhouse with skirted under-bench heating. Without an additional source of heat, the night temperature within the greenhouse can only be maintained at 12-15°C. At these low greenhouse temperatures, germination may be delayed (Draper and Hawkins 1989). In addition, the lower temperatures and delayed germination promote pests and diseases such as algae, molds and damping off. Fortunately, low germination temperatures can be avoided if space heaters are used to provide supplemental heat during periods of low outdoor temperatures. Alternatively, the greenhouses can be equipped with thermal curtains to reduce fuel consumption (Draper and Hawkins 1989).

TABLE 1. Temperature data for Prince George and Langley (Environment Canada 1981)

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Prince George												
Daily max.	-7.5	-1.0	3.6	10.3	16.1	19.5	22.0	20.8	15.9	9.6	0.9	-3.9
Daily min.	-16.6	-11.2	-7.2	-1.7	2.5	6.2	8.1	7.2	3.5	-0.1	-6.6	11.9
Daily mean	-12.1	-6.1	-1.8	4.3	9.3	12.9	15.1	14.1	9.7	4.8	-2.9	-7.9
Extreme max.	12.8	12.8	17.8	29.7	32.2	33.9	34.4	33.3	28.9	25.0	16.1	11.7
Extreme min.	-50.0	-45.0	-37.8	-25.6	-8.3	-2.8	-1.7	-3.9	-12.2	-25.6	-41.7	-45.6
Langley												
Daily max.	4.7	7.9	10.0	13.2	17.1	19.8	23.0	22.8	19.7	14.5	6.6	6.0
Daily min.	-0.7	1.5	1.8	3.8	6.6	9.3	10.8	10.9	9.0	5.9	2.5	0.8
Daily mean	2.0	4.7	5.9	8.5	11.9	14.6	16.9	16.9	14.4	10.2	5.6	3.4
Extreme max.	14.4	16.7	20.0	24.5	31.7	32.2	35.6	36.1	33.3	27.5	19.0	16.1
Extreme min.	-13.9	-8.0	-8.3	-2.8	-0.6	1.7	3.9	3.3	-1.7	-2.8	-8.9	-19.4

At Red Rock, a constant heat setpoint of 20°C is maintained during the first 5 days of germination (Table 2). After that, the night heat setpoint is reduced to 11°C for the next 4 weeks to:

1. reduce fuel consumption (Draper and Hawkins 1989);
2. reduce excessive hypocotyl elongation (Tinus and McDonald 1979); and
3. reduce epicotyl length (Thompson 1981).

These benefits are obtained without algae, mold or damping off becoming a problem.

Except in 1990, germination under these temperature conditions was comparable to that obtained under laboratory conditions. In 1990, germination in the greenhouse was approximately 10% lower than that in the laboratory. This may have been due to slower germination rates of the seedlots used in 1990. To take into account that seedlots may have different germination rates, the germination temperature regime has been changed. The heat setpoint will be maintained at 20°C until the germination stage has been completed, and then reduced to 11°C.

2.1.2 Under-bench heating vs. above-bench heating

The use of under-bench heating during germination helps maintain greenhouse air temperatures closer to the heat setpoint. The desired greenhouse air temperature at crop height can be maintained at lower outdoor air temperatures with under-bench heating than with above-bench heating. With under-bench heating, the heated air spends more time within the greenhouse and less heat is lost through the ridge. As a result, bottom heating can reduce energy consumption (Harlass and Bartok 1988; Draper and Hawkins 1989). It is therefore best to distribute heat as close to the floor and crop as possible, rather than to displace cold air near the floor with lighter heated air (Bartok 1989).

TABLE 2. Heat and vent setpoints used for growing spruce seedlings at Red Rock Research Station

Date	Growth stage	Setpoint ^a		Day	Night
		Heat (°C)	Vent (°C)		
March 16 ^b	germination	20/20	23/23	600-1900	1901-559
March 21	germination	20/11	23/23	600-1900	1901-559
April 19	juvenile	19/13	23/23	600-2200	2201-559
May 3	juvenile	19/13	23/23	600-2200	2201-559
May 12	exponential	19/13	23/23	600-2200	2201-559
May 29	exponential	19/13	23/23	430-2230	2231-429
June 21	exponential	19/13	23/23	430-2230	2231-429
July 19	budset	17/11	19.5/19.5	500-2200	2201-459
August 16	budset ^c	17/9	19.5/19.5	600-2200	2201-559
August 30	budset	17/9	19.5/19.5	630-2130	2131-629
Sept. 6	budset	15/8	19.5/19.5	630-2130	2131-629
Sept. 13	budset	14/7	19.5/19.5	700-2100	2101-659
Sept. 20	budset	14/7	19.5/19.5	715-2045	2046-714
Sept. 27	hardening off	13/6	19.5/19.5	715-2045	2046-714
Oct. 4	hardening off	12/5	19.5/19.5	730-2030	2031-729
Oct. 11	hardening off	11/4	19.5/19.5	745-2015	2016-744
Oct. 18	hardening off	10/2	14/14	815-1945	1946-814
Oct. 25	hardening off	9/1	14/14	830-1930	1931-829
Nov. 1	lift	-	-	-	-

^a Temperatures separated by a slash represent day/night temperatures, respectively.

^b Sowing date.

^c Late budset is primarily observed in the sitka-interior hybrid.

Under-bench heating, especially if skirted, is also a more effective method of warming the growing medium than over-bench heating. As warm air rises, the passage of heat through the blocks maintains a uniform medium temperature closer to the heat setpoint. At Red Rock, when the low outdoor temperatures prevent the heaters from maintaining a 20°C air temperature within the under-bench heated greenhouse, the growing medium temperature is 18-20°C even though the greenhouse air temperature at crop level is 12-15°C. If the growing medium is kept at the desired temperature, germination is not hindered even though the air temperature may be suboptimal (Harlass and Bartok 1988). The warm growing medium temperature also encourages root growth in the germinants (Maher 1978). However, if the same greenhouse at Red Rock were heated overhead, the growing medium temperature — in addition to the greenhouse air temperature — would probably be below the 20°C heat air setpoint.

2.2 Juvenile and Exponential Stage

2.2.1 Temperature range

Seedlings during the juvenile and exponential stage can be grown at day/night temperatures of 20-24/13-26°C (Tinus and McDonald 1979). At Red Rock, the heat and vent setpoints selected are 19/13°C and 23/23°C, respectively (Table 2). The day temperature chosen is a compromise between high temperatures which promote excessive shoot growth (Tinus and McDonald 1979) and low temperatures which reduce photosynthesis (Brix 1967; Mastalerz 1977). The night temperature chosen is a compromise between high temperatures which increase plant respiration (Brix 1967; Mastalerz 1977; Toki *et al.* 1978) and low temperatures which reduce root growth (Maher 1978; Lavender 1984; Andersen *et al.* 1986).

Unlike in the germination stage, there is no difficulty in heating the greenhouse to meet heat setpoints during the juvenile and exponential stages. In fact, with warmer outdoor temperatures and higher light intensities, maintaining temperatures below the vent setpoint can be difficult. Areas in the province where the outdoor temperature is cool or the light intensity low, the problem of high greenhouse temperatures will

not be serious. Growers who remove their greenhouse covering will also experience fewer problems with high temperatures but will no longer be growing their seedlings in a controlled environment. In contrast, areas where the outdoor temperature is high or light is intense for several weeks during the growing season, the temperature within an enclosed greenhouse may reach undesirably high levels. For several weeks from spring to fall, it is common to find temperatures in the mid-30°C's within the greenhouses at Red Rock, even when the side walls are rolled down, regardless of whether there is a single or double layer of polyethylene covering. At such high temperatures, respiration exceeds photosynthesis (Mastalerz 1977) due to stomata closure (Hawkins 1991). In addition, the higher temperatures reduce relative humidity, subjecting the seedling to greater water stress. The high daytime temperatures may also produce undesirably tall seedlings as discussed in Section 2.3.2.

2.2.2 Transition between day and night heat setpoints

The transition between day heat setpoint and night heat setpoint may be gradual (ramped) or abrupt (stepped). At Red Rock, the transition between day and night heat setpoints is ramped at a rate of 0.1°C·min⁻¹, rather than stepped.

Recent research has indicated that an abrupt increase in temperature at sunrise promotes stem elongation (Heins *et al.* 1988), which would be undesirable in conifer production. Instead, a sudden drop rather than a gradual increase in temperature at sunrise may be preferable if height control is desired. Heins *et al.* (1988) found that a temperature drop at sunrise is an effective means of reducing stem elongation in ornamental plants. Their research further suggested that there is no need to gradually open thermal curtains. Instead, it may be advantageous to open the curtains rapidly so that the plants are exposed abruptly while the greenhouse air temperature drops as heat is lost from the uninsulated greenhouse. Whether a sudden drop in temperature at sunrise is effective in controlling the height of conifer seedlings without adverse effects remains to be investigated.

2.3 Dormancy and Hardening

2.3.1 Temperature range

In nature, the annual cycle of conifers begins with germination in spring, followed by the completion of shoot elongation, and finally dormancy and cold hardiness. The last stages of the annual cycle, dormancy and hardiness, are important to achieve to ensure successful overwintering and vigorous shoot growth the next spring. In container spruce culture, these stages are often difficult to obtain.

Conifer growers try to provide optimal conditions in the greenhouse to encourage budset and dormancy induction, and so prepare the seedlings for cold storage at 2 to -2°C. At Red Rock, the daytime/nighttime heat setpoints of 19/13°C are provided from the end of germination until mid-July. By mid-July, blackout application is near completion or has been completed. The heat setpoints provided at this time are a compromise between providing low temperatures to reduce respiratory losses (Brix 1967; Mastalerz 1977; Toki *et al.* 1978) and mild temperatures to enhance the short day effect on dormancy and cold hardiness (Lavender 1984).

After mid-July, the heat setpoint is gradually lowered from 19/13°C to 9/1°C by the end of October (Table 2). The lowered heat setpoints, especially during the night, greatly reduce fuel consumption. Similarly, the vent setpoint is lowered from 23°C/23°C to 14°C/14°C by the end of October (Table 2). The gradual reduction in temperature encourages hardening off (Tinus and McDonald 1979; Lavender 1984), but does not drastically reduce photosynthesis, caliper increment and root growth. Root growth will continue until the medium temperature drops below 8°C (Hawkins 1991). It is imperative not to discourage root growth since a well-developed root system is important for seedling survival after outplanting (Hermann 1964). Frost hardiness to -18°C is usually achieved from early October to November under this regime without exposing the seedlings to freezing temperatures.

Maintaining greenhouse temperatures below the vent setpoint during the day and below the heat setpoint during the night in July and August can be difficult. But as the outdoor temperature and light intensity drop in September and October, greenhouse temperature control becomes more manageable.

The low outside night temperature in the northern interior British Columbia allows the greenhouse temperature to drop to the night heat setpoint (Tables 1 and 2). However, in milder areas of the province, such as the Lower Mainland, the higher outdoor night temperature may not allow the greenhouse temperature to drop to the night heat setpoint. As a result, root growth may be encouraged and height better controlled (Heins *et al.* 1988; Erwin *et al.* 1989; Karlsson *et al.* 1989),³ but the hardening off process delayed (Lavender, 1984). Consequently, seedlings grown in these areas may need to remain in the greenhouse until the temperature drops to near freezing in November and December to ensure that a hardy seedling is produced.

2.3.2 Height control

Height control is often a problem in the production of container spruce. Any economical method of controlling height without adversely affecting seedling quality would be of value to the conifer grower. Manipulation of the greenhouse temperature may be such a tool.

Most greenhouse-cultivated crops are currently subjected to low night temperatures relative to day temperatures to reduce respiration (Toki *et al.* 1978). Although Heins *et al.* (1988), Koning (1988), Erwin *et al.* (1989), and Karlsson *et al.* (1989) have found that high night temperatures and low day temperatures are an effective means of controlling plant height in ornamentals, the response of conifer seedlings to these temperature regimes still needs to be investigated.

3 FERTILIZATION

3.1 Slow Release Fertilizers

Many of the growers in British Columbia incorporate slow release fertilizers (either Osmocote[®] or Nutri-cote[®])⁴ in the growing medium to ensure that seedlings receive adequate nutrients. Seedlings grown in an exposed area where frequent rainfall constantly leaches nutrients from the growing medium may benefit from the incorporation of slow release fertilizers. Furthermore, any residual fertilizer in the plug after outplanting may promote plant growth. Improvements in growth have also been noted with liquid fertilization programs that are supplemented with slow release fertilizers (Kofranek and Lunt 1966).

However, slow release fertilizers do have several disadvantages. They do not allow the grower to modify fertilizer rates or formulations rapidly, and slow release fertilizer pellets are difficult to distribute evenly in such small volumes of medium, possibly resulting in uneven conifer growth (Tinus and McDonald 1979).

Seedlings at Red Rock are commonly grown in a 2:1 (v/v) peat-vermiculite mixture containing no slow release fertilizers. When lower rates of fertilization are needed, such as in the spring before exponential growth and in the summer and fall to achieve budset and dormancy, the concentration or frequency of liquid feed can be easily reduced.

3.2 Water Soluble Fertilizers

3.2.1 Frequency

As is done by most growers in British Columbia, fertilization is applied with every irrigation at Red Rock. Constant liquid feed was chosen because of the simplicity of the technique and ready availability of nutrients according to plant need. When nutrients are needed in greater demand (such as when environmental conditions are favourable and plant growth is rapid), evapotranspiration is increased and soil moisture drops. Thus, the need for water would be a good indicator of nutrient need. If nutrients are provided with every irrigation, they will always be readily available when required.

³ Height control was observed with ornamental plants; the response of conifer seedlings to high night temperatures still remains to be determined.

⁴ Use of a product name does not constitute an endorsement by the B.C. Forest Service.

A few growers in British Columbia occasionally fertilize biweekly. When seedlings are irrigated several times between applications of fertilizer solutions, fertility level can fluctuate widely (Landis *et al.* 1989). Immediately after fertilization, nutrient levels are high. The low nutrient levels just before fertilization may limit plant growth. This fluctuation in growing medium nutrient content may retard plant growth, although ornamental crops have been grown successfully using this method of fertilization (Yeager *et al.* 1980). Plants that have undergone periods of starvation have the ability to absorb nutrients at a faster rate than plants receiving a continuous level of nutrient (Drew *et al.* 1984).

3.2.2 Formulation

Plants can be fertilized with individual customized fertilizer mixes or with commercially formulated fertilizer packages. Some growers in British Columbia have chosen the former. Although this method offers the grower more precise nutritional control over the crop, it requires more time and effort to determine the appropriate ingredients and concentration suitable for conifer seedling production.

Many conifer growers in British Columbia are using commercially prepared fertilizer packages, of which there are several developed specifically for conifer seedling production. Some of these fertilizers include:

- 10-51-16,⁵ 7-40-17⁶ or 11-41-8⁷ as a starter during the early growing season. The high phosphorus content is chosen to encourage root development.
- 20-8-20,⁷ 20-20-20^{5,7} or 20-7-19⁶ as a grower during exponential growth. The high nitrogen content is used to encourage the development of sturdy, hardy tissue (Landis *et al.* 1989).
- 10-51-16,⁵ 4-25-35⁶ or 8-20-30⁷ as a finisher. The low nitrogen content and high phosphorus and potassium content are used to promote budset and dormancy (Tinus and McDonald 1979).

However, Draper and Hawkins (1989) showed that fertilization with the single formulation 20-8-20 produced shorter, sturdier seedlings with larger root mass than those grown with the combination of formulations of 20-20-20 and 10-52-17. Unfortunately, preliminary results indicate that these benefits observed in the greenhouse may be lost in the first year after being outplanted in the field.⁸ However, because of the simplicity of applying only one fertilizer formulation and the benefits obtained while the seedlings were grown in the greenhouse, 20-8-20 is applied for the entire growing season at Red Rock. A few growers in British Columbia use only one formulation, commonly 20-8-20, 20-7-19 or 12-17-29.

Conifer seedlings may also need to be fertilized with trace elements. The necessary trace element supplements for proper conifer seedling growth depend primarily on the water source. Many of the growers in British Columbia are supplementing their application of macroelements with either a standard trace element mix⁶ or chelated trace element mix.⁷ At Red Rock, the chelated trace element package has been used successfully to produce seedlings that meet B.C. Ministry stock specifications, although no other trace element package has ever been tried. In addition to the chelated trace element package used at Red Rock, boron and copper are often added, unless tissue analysis indicate that the nutrient levels are above the recommended range. At Red Rock, boron and copper concentrations found in the water and fertilizers are usually low.

3.2.3 Concentration

No fertilizer is applied at Red Rock during germination, since the carbohydrate reserves in the cotyledons are in sufficient quantities to meet the demands of the germinant (Tinus and McDonald 1979). In addition, the chance of damping off is reduced if fertilizer is not applied until the seed coat has been

⁵ Green Valley Fertilizer Ltd., Surrey, B.C.

⁶ Peters Fertilizer Products, W.R. Grace & Co., Fogelsville, Penn.

⁷ Plant Products Co., Ltd., Brampton, Ont.

⁸ The field study is still in progress and the results have not been analyzed statistically.

shed. After germination has been completed, the seedlings are fertilized with 20-8-20 at 60 ppm N (Table 3). This concentration is gradually raised to 85 ppm N to meet the increasing nutrient demand of the rapidly growing seedling.

Once budset induction is encouraged in July by artificially shortening the photoperiod, fertilizer concentration is lowered to promote budset and hardening off (Tinus and McDonald 1979). Fertilizer concentration is gradually reduced until 30 ppm N of 20-8-20 is reached in late October. Although the concentrations used are lower than those stated by Brix and van den Driessche (1974), Morrison (1974), van Eerden (1974) and Landis *et al.* (1989), seedlings produced at Red Rock meet the specifications of the B.C. Ministry of Forests (Table 4). Foliar analyses reveal that seedlings grown with these fertilizer concentrations are not nutritionally stressed according to the acceptable levels suggested by van den Driessche (1984), Landis *et al.* (1989) and Norwest Laboratories (Table 5).

Unlike at some of the nurseries in British Columbia, seedlings grown at Red Rock are not nutritionally stressed to control height. Although a reduction in fertilizer rates is known to be effective in controlling plant height, it may reduce stem diameter and root mass (Al-Naqib 1986).

TABLE 3. Concentration of fertilizers applied to spruce seedlings at Red Rock Research Station

Date	Growth stage	20-8-20 ^a (N ppm)	Chelated trace elements ^a (ppm)	Boron (ppm)	Copper (ppm)
March 16 ^b	germination	0 ^c	0	0	0
March 22	germination	0 ^c	0	0	0
April 19	juvenile	60	30	0.4	2
May 12	exponential	75	30	0.4	2
May 29	exponential	85	30	0.4	2
July 19	budset	60	30	0.4	2
August 16	budset	50	30	0.4	2
Sept. 13	budset	40	30	0 ^d	2
October 4	hardening off	30	30	0	2
November 1	lift	-	-	-	-

^a Plant Products Co., Ltd., Brampton, Ont.

^b Sowing date.

^c Misting.

^d Addition of boron often terminates in early September.

TABLE 4. An example of the morphology of spruce seedlings grown in B.C. Forest Service/Canada Forestry Service PSB-313b styroblocks at Red Rock Research Station

Species	Seedlot	Height (cm)	Caliper (mm)	Root dry weight (g)
Se	5261	15.4	3.1	0.58
Se	4311	17.2	2.4	0.49
Se	8482	16.0	3.0	0.53
Sw	ITIP559	17.1	2.9	0.54
Sw	8779	14.0	2.9	0.58
Sxs	3958	32.1	3.7	0.71

TABLE 5. Typical foliar nutrient content of spruce seedlings at the exponential stage

Element	Concentration	Rating	Recommended range ^a
Nitrogen	2.80%	Normal	1.49 - 3.49%
Phosphorus	0.42%	Normal	0.19 - 0.60%
Potassium	0.90%	Normal	0.79 - 2.00%
Calcium	0.88%	Normal	0.29 - 1.00%
Magnesium	0.22%	Normal	0.14 - 0.39%
Iron	165 ppm	Normal	99 - 600 ppm
Copper	5 ppm	Normal	4 - 20 ppm
Zinc	64 ppm	Normal	24 - 80 ppm
Manganese	380 ppm	Normal	99 - 600 ppm
Boron	22 ppm	Normal	20 - 50 ppm
Sulphur	0.20%	—	—

^a Recommended range suggested by Norwest Soil Research Inc., Langley, B.C.

3.3 Acidification

The initial pH of the growing medium used at Red Rock is often between 4.0 and 5.0. However, the continual addition of high pH water (usually between 7.0 and 8.0) to the growing medium can lead to an undesirable medium pH greater than 6.0 by the middle of the growing season. Once the medium pH reaches 6.0, sulphuric acid is added to the fertilizer solution to bring the solution pH to 4.0-6.0. The continual addition of sulphuric acid has been successful in bringing the medium pH to the recommended pH range of 4.5-5.5(Eng 1990).

4 LIGHT

4.1 Intensity

Some growers in British Columbia commonly increase light intensity by removing the greenhouse polyethylene covering during the warmer months of the growing season. The higher light intensity increases photosynthesis and dry matter production (Brix 1967), especially during cloudy weather, at the expense of loss of greenhouse environmental control. In contrast, the greenhouses at Red Rock usually remain covered with either one or two layers of polyethylene for the entire growing season, to allow for greenhouse environmental control and protection of the greenhouse equipment.

4.2 Duration

An obvious seasonal change occurs in the daylength in the temperate zone (Figure 1). As June 21 approaches, the days get longer and the difference in daylength between different latitudes increases. Except at the end of the growing season, the daylength in the northern Interior is longer than the daylength in southern British Columbia (Figure 1). Thus, seedlings grown in the northern latitudes are exposed to longer durations of radiation and tend to have a higher rate of dry matter production per day than those seedlings grown in the southern latitudes.

Conifers also have a photoperiodic response respond to light duration. Long days are needed during the early part of the growing season to prevent budset. After the desired height has been reached, short days are required.

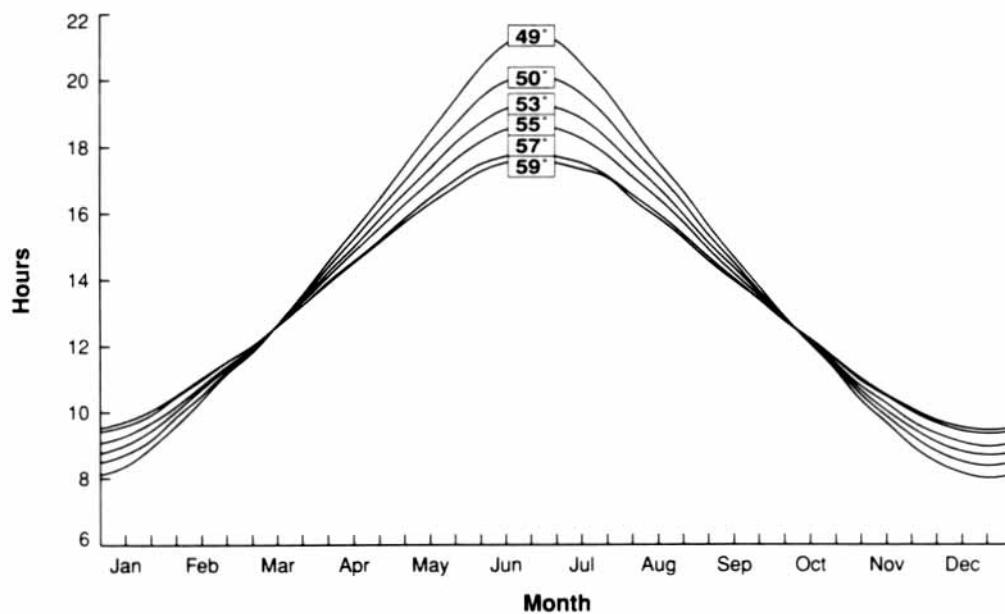


FIGURE 1. The influence of latitude and time of year on daylength at six latitudes in British Columbia.

4.2.1 Extending photoperiod

Spruce is a short day (long night) plant which initiates budset when the daylength is shorter than a critical daylength (Dormling *et al.* 1968; Arnott 1989; Draper and Hawkins 1989) or, more precisely, when the length of the dark period is longer than a critical night period. To prevent budset during the germination and juvenile stages when the days are naturally short, long day conditions are necessary. To achieve these conditions, the natural daylength is extended by the use of lamps.

Some lamps are more effective in activating the phytochrome system than others. Of the three main types used for irradiating plants in the greenhouse, incandescent lamps are the most effective in extending the daylength, followed by high intensity discharge lamps (Cathey and Campbell 1975). Low pressure tubular fluorescent lamps are the least effective.

High pressure sodium (HPS) lamps are commonly used by the conifer growers in British Columbia because these lamps are more energy efficient (Falk 1985; Bartok 1988) and cover a much larger area.

Arnott (1989) found that light intensity as low as 13 ft-c ($1.7 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) was effective in ensuring long day conditions. However, Tinus and McDonald (1979) recommended a minimum of 40 ft-c ($5 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) for phytochrome excitation to extend photoperiod. At Red Rock, HPS lamps are activated to provide a minimum of $5 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at block surface from the date of sowing until budset is desired.⁹ At such low light levels below the compensation point of approximately $100 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (Draper *et al.* 1985), the seedlings will not be photosynthesizing. However, they do grow phototropically towards the light source at such low light intensities, as observed at Red Rock.

⁹ The use of HPS lamps is discontinued when the seedlings reach 70-85% of the minimum height, which commonly occurs by late June to early July.

There are three methods of using artificial lighting to provide long days. **Cyclic lighting** (also called “intermittent lighting” and “flashlighting”) involves alternating a series of light and dark periods. Some growers in the province mount HPS lamps to a boom system which travels the length of the greenhouse to provide cyclic lighting. Although this method uses little electrical energy (Mastalerz 1977), it is not practised at Red Rock for two reasons. First, regular monitoring of boom travel is necessary to ensure complete crop coverage. Failure of the boom to travel may result in unwanted budset. Second, it is less reliable than night break lighting (see below), requiring a higher light intensity to ensure long day conditions (Laurie *et al.* 1979).

Another method is **night break lighting**, in which the middle of the night is interrupted with artificial lighting to create long day conditions. This method is not only more economical, but also more efficient for producing long day conditions than is the use of artificial lighting at the end or beginning of the natural day. It is the nightlength, not the daylength, that is crucial in controlling photoperiodic response (Mastalerz 1977). Night break lighting, commonly from 10 p.m. to 2 a.m., is the recommended method of providing long day conditions for growing photoperiodic responsive ornamental plants such as poinsettias and chrysanthemums (Ball 1975; Laurie *et al.* 1979). It can also be used in the container production of conifer crops. Arnott (1989) found that both a 1-hour night break and 2-hour night break were effective in preventing budset in conifer seedlings. However, he also found that seedlings grown under night break lighting formed terminal buds later and were taller than those grown under daylength extension. For this reason, seedlings grown at Red Rock are not subjected to night break lighting even though electrical consumption and lamp depreciation could be reduced.

The third method of artificial lighting to create long day conditions involves **extending the daylength**. Tinus and McDonald (1979) suggested activating artificial lights 4-8 hours after sunset or before sunrise. Growers in British Columbia commonly extend daylength by continuously lighting after sunset to provide a total daylength of 19 hours. In contrast, the HPS lamps at Red Rock are activated for 23 hours from 3 a.m. to 2 a.m. (lights are off between 2 and 3 a.m.) to provide a minimum intensity of $5 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at block surface. Post (1942) suggested that the radiant flux density in the greenhouse during periods of cloudy weather might not be sufficient to be registered as a long day by the plant. Thus, the 23-hour photoperiod provided at Red Rock ensures long day conditions regardless of weather conditions. Continuous lighting is not provided since some plants, such as the tomato, respond unfavourably to continuous lighting (Salisbury and Ross 1978).

The lighting regime at Red Rock may be modified from 23-hour lighting to daylength extension, with lighting provided after 4:00 p.m.¹⁰ to create a total daylength of 19 hours. There are several reasons for doing this:

- Post’s conclusion may be invalid since 4 hours and 2 hours of night break lighting are effective means of providing long day conditions for ornamental plants (Mastalerz 1977) and conifers (Arnott 1989), respectively. If the light intensity during periods of cloudy weather is not sufficient to ensure long day conditions, as suggested by Post, the practice of night break lighting would likely be inadequate in promoting long day conditions. However, night break lighting is effective in the production of photoperiodic responsive plants such as chrysanthemums and poinsettias, regardless of weather conditions.
- No additional photosynthetic benefits are obtained by lighting at levels below the light compensation point.
- A shorter lighting period will reduce electrical consumption and increase lamp longevity.
- The phototropic response of plants to the artificial lighting may be reduced.

Before this lighting regime is adopted at Red Rock, it will be tested to ensure that budset does not occur.

¹⁰ The working hours at Red Rock are from 8:00 a.m. - 4:00 p.m. The lamps are turned on at the end of the working day to ensure they are functioning properly.

4.2.2 Reducing photoperiod

For best results, spruce seedlings should put on a vigorous flush of top growth after being outplanted in spring. Growth in the spring is directly related to bud development the previous season. It is therefore important to provide proper conditions in the nursery to promote bud development as the spruce seedling approaches the minimum height of 12 cm. One condition favouring budset is short photoperiod.

The natural photoperiod varies greatly within the province. The northern regions experience longer photoperiods than regions in the south during most of the growing season. As a result, spruce seedlings grown in the north may have more difficulty in setting bud due to the longer photoperiod. However, it is possible to shorten the natural photoperiod by artificially shortening the daylength with blackout curtains.

At Red Rock, the curtains are closed before sunset to exclude natural radiation, and opened shortly after sunset to dissipate any humidity or heat buildup that might occur. They are once again drawn just before sunrise and reopened after sunrise, thus achieving a 14-hour photoperiod. Blackout is provided for 4 weeks, beginning when 70-85% of minimum height (depending on species and seedlot) has been reached.

5 MOISTURE

As soon as the newly sown blocks are placed in the greenhouses at Red Rock, they are thoroughly saturated with water. During the germination period, the blocks are misted 4-5 times daily to provide favourable conditions for germination. Once germination is completed, misting is no longer practised. The medium is allowed to dry out¹¹ before water, in a fertilizer solution, is applied. The fertilizer solution is applied until the blocks are thoroughly saturated. This practice is maintained for the remainder of the growing season until the crop is lifted in November. During the early juvenile stage, this usually means that the solution is applied once a week. As the seedling enters mid-juvenile stage in May, however, fertilizer solution is usually applied twice a week to prevent wilting. By the late juvenile, exponential and budset stages, the seedling is commonly fertilized 3-4 times weekly. Towards the end of September until the lift of the crop in October or November, fertilizer application is often practised once every 7-14 days. At the time of the lift, the moisture content of the blocks is approximately 80% of their saturated weight.

If grown under the fertilizer practices described above, the seedlings will not be subjected to intentional moisture stress. In contrast, many conifer growers in British Columbia commonly use moisture stress as a means of height control and promoting budset. Although moisture stress is known to be an effective means of height control and promoting budset (Tinus and McDonald 1979; Landis *et al.* 1989), this practice does have several adverse effects: reduced root growth (Larson 1974; Squire *et al.* 1987) and caliper (O'Reilly *et al.* 1989). In addition, the use of moisture stress probably leads to more variable results in height control and induction of budset since there are large variations in medium moisture content. Because seedlings are not subjected to moisture stress, the root and caliper growth of seedlings grown at Red Rock are not hindered and uniform budset is obtained.

¹¹ Fertilizer solution is applied when the peat mixture no longer forms a ball when squeezed, but before wilting.

6 SUMMARY

The greenhouse environmental conditions at Red Rock described here (Figure 2) are derived from the staff's experience with conifers and horticultural crops, evaluations of the results of research in forestry and horticulture, recommendations from forestry and horticultural textbooks, and discussions with other conifer growers. Using these sources of information, we have derived a suitable cultural environment for growing container spruce seedlings at Red Rock. The seedlings are germinated at 20°C. After that, the temperature is gradually reduced to 9°C/1°C in October and November, at which time the seedlings are lifted for cold storage. Fertilization starts after the germination period, with concentrations being increased to 85 ppm N in June and gradually reduced to 30 ppm N by October. Artificial lighting provided by HPS lamps is given 23 hours daily. Lighting is terminated in late June to early July to induce budset. When lighting is ended, blackout is provided for 4 weeks to provide 10-hour nights. After 4 weeks of blackout, the seedlings receive natural radiation.

Although some of the environmental conditions provided at Red Rock Research Station are unique, conifer seedlings grown under these conditions do not suffer in quality as indicated by the morphological characteristics. These conditions will be modified accordingly as we become more knowledgeable in container conifer culture. The described environmental conditions might not always be appropriate for other conifer greenhouse operations, since all operations are not identical.

	Month												
	March	April	May	June	July	August	September	October	November				
Growth stage	sow	germination	juvenile	exponential		budset		hardening		lift			
Temp (°C) heat	20/20	20/11	19/13		17/11	17/9	15/8	14/7	13/6	12/5	11/4	10/2	9/1
Vent	23/23				19.5/19.5				14/14				
Light supplemental	23 hour					none							
Blackout	none				10 hour blackout		none						
Fertilizer (ppm) 20-8-20	0	60	75	85	60	50	40	30					

FIGURE 2. Summary of the environmental conditions used to grow spruce seedlings at Red Rock Research Station.

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