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Growth Response of White and Engelmann Spruce Seedlings to Extended Photoperiod Using Three Light Intensities

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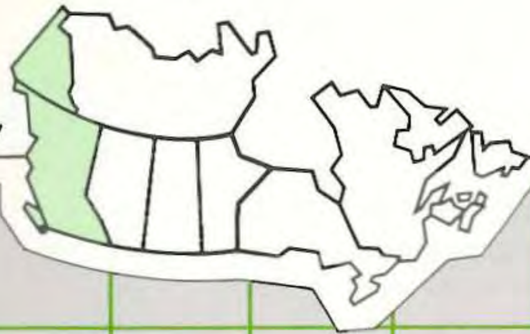

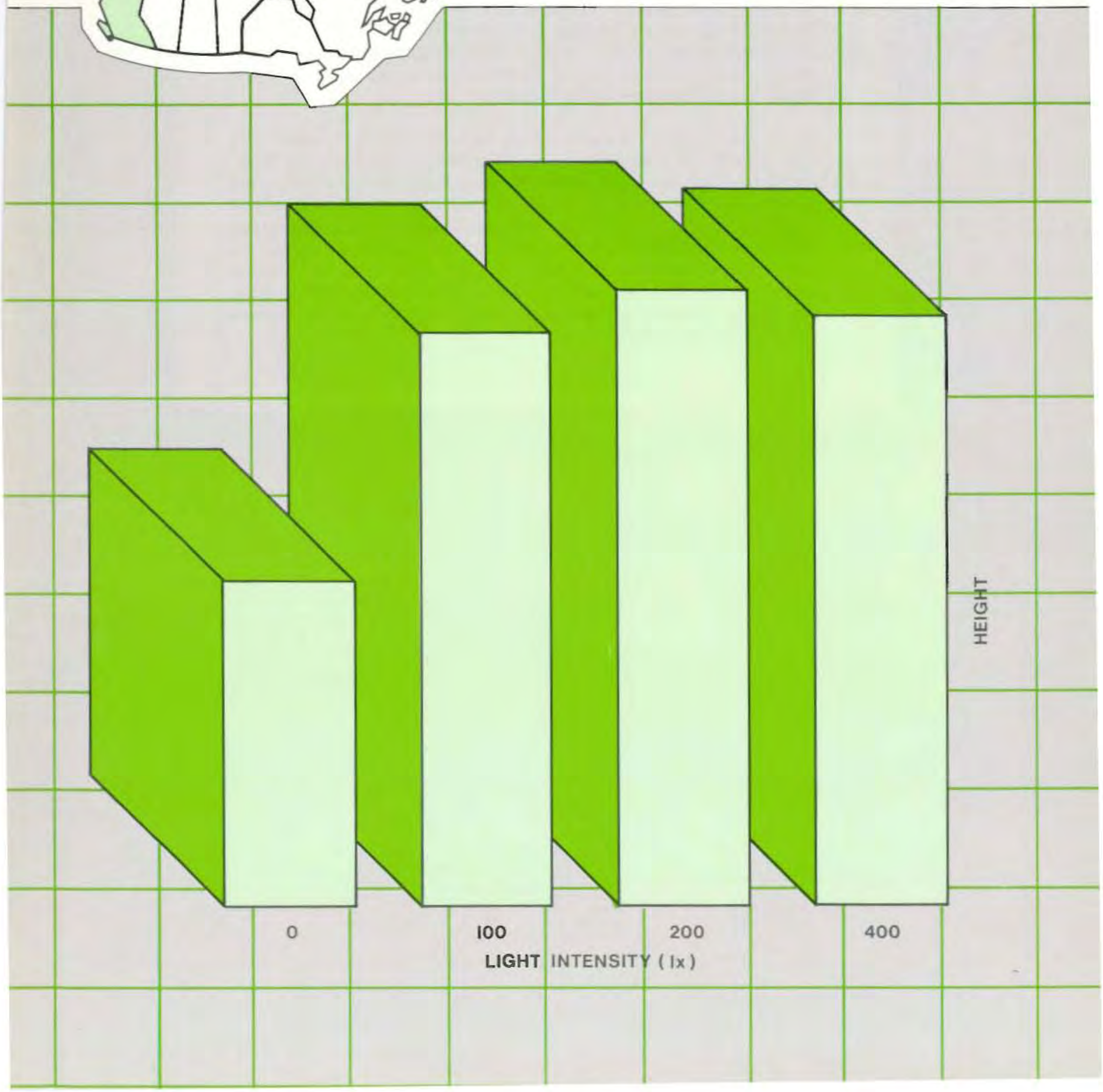

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ABSTRACT

Four seedlots of white spruce (*Picea glauca* (Moench) Voss) and three of Engelmann spruce (*Picea engelmannii* Parry), covering a range of 10 degrees of latitude and a range of altitudes, were sown in BC/CFS Styroblocks and grown in a heated greenhouse and an unheated shadehouse, using incandescent light to provide a 19-h photoperiod. Four intensities of lighting were used: 0, 100, 200, and 400 lx. A second experiment with the same seedlots was conducted in growth rooms that were programmed to evaluate the effect of low night temperature on seedling shoot growth when the photoperiod was extended to 19 h, using a light intensity of 200 lx.

Shoot length of white and Engelmann spruce seedlings grown under an extended daylength of 100 lx were significantly taller than the control (0 lx). There were no significant differences in shoot length or weight among the three intensities of light used to extend the photoperiod for all seedlots except the southern latitude-low elevation population of Engelmann spruce. The more northern populations of white spruce and the high altitude populations of Engelmann spruce did not require light intensities higher than 100 lx to maintain apical growth. Low night temperature (7^{o}C) did produce significantly smaller seedlings than the warm night (18^{o}C) regime. However, terminal resting buds of seedlings grown under the cool night regime did not form any sooner than on those seedlings grown under warm nights.

RESUME

Quatre lots de semences d'épinette blanche (*Picea glauca* (Moench) Voss) et trois d'épinette d'Engelmann (*Picea engelmannii* Parry), provenant de régions comprises dans un intervalle de 10 degrés de latitude à diverses altitudes, ont poussé dans des styroblocks BC/CFS dans une serre chauffée ainsi que dans un abri non chauffé; une photopériode de 19 heures a été assurée au moyen de lampes incandescentes. Quatre intensités d'éclairage ont été utilisées: 0, 100, 200, et 400 lx. Une deuxième expérience a été menée avec ces mêmes lots dans des chambres de croissance programmées afin d'évaluer l'effet de basses températures nocturnes sur la croissance en photopériode prolongée à 19 heures sous une intensité de 200 lx.

Les pousses exposées à un éclairage prolongé de 100 lx ont été beaucoup plus grandes que les témoins (0 lx). Aucune différence significative de hauteur ou de poids n'a été observée chez les pousses croissant sous les trois intensités d'éclairage sauf dans le cas des lots d'épinette d'Engelmann provenant des latitudes méridionales et de basse altitude. Les populations plus septentrionales d'épinette blanche et les populations d'épinette d'Engelmann de haute altitude n'ont pas eu besoin de plus de 100 lx pour conserver leur croissance apicale. Une basse température nocturne (7^{o}C) a donné des semis beaucoup plus petits qu'une température élevée (18^{o}C). Toutefois, les bourgeons dormants terminaux des semis exposés à une basse température nocturne ne se sont pas formés plus tôt que ceux des semis exposés à la chaleur.

Introduction

Both interrupted darkness and extended daylength affect tree seedling growth in container nurseries in British Columbia (Arnott 1974, 1976). The minimum light intensity required to effectively prevent apical bud formation of white spruce (*Picea glauca* (Moench) Voss) and Engelmann spruce (*Picea engelmannii* Parry) is between 20 and 80 lx (Arnott 1979). However, in the latter experiment the maximum effective light intensities were not clearly delineated. The objectives of the present work are as follows: (a) to determine the light intensity required during extended daylength for maximum shoot growth of white spruce and Engelmann spruce seedlings raised from seed in Styroblock containers during the regular growing season; (b) to determine if the more northern populations of white spruce and the higher altitude populations of Engelmann spruce require higher intensities of light during photoperiod extension to maintain apical growth; and (c) to determine what effect low night temperatures have on seedlings grown under extended photoperiods.

Methods

Light Intensity

Seven seedlots from the white/Engelmann spruce complex in British Columbia (B.C.), covering a range of 10 degrees of latitude and a range of altitudes, were selected for the experiment from operational sowings in the B.C. Ministry of Forests' nurseries (Table 1). The stratified seed was sown in late April and early May of 1980 in BC/CFS Styroblocks having a cavity volume of 40 cm^3 and containing a 3:1 mixture of peat and vermiculite containing 17-7-12 (N-P-K) Osmocote. Following seeding, the Styroblocks were shipped to the Pacific Forest Research Centre at Victoria (lat. 48^{o} 28′N), where they were placed in a heated greenhouse (min. temperature $18^{o}C$) with a 19-h photoperiod, for germination and early growth before initiation of the light intensity experiment on June 13, 1980.

The light sources used to extend the natural photoperiod were 150-watt tungsten incandescent reflector flood lamps, suspended at various heights above the seedlings to provide the following average light intensities: 0, 100 (96-118), 200 (180-230), and 400 (380-500) lx. The figures in brackets indicate the variation in light intensities over the irradiated growing space. Light intensities were measured with a Gossen 'Panlux' cosine photometric sensor having a spectral response of 380 to 770 nm. The time clocks switched the lights on 1 1/2 h before sunset and were adjusted to provide a constant 19-h photoperiod. Standard cultural practices of fertilization and irrigation for container seedlings were employed (Van Eerden 1974).

The effect of the four different light intensities on seedling growth was studied under two environmental regimes—in an unheated, outdoor shadehouse and in a greenhouse (minimum night temperature $18^{o}C$)—to determine what influence the lower night temperatures of the shadehouse would have on seedlings grown under the four light intensities (Table 2).

Within each growing regime, styroblocks, each containing 100 seedlings per seedlot, were arranged in a completely random design under each of the four light intensity treatments. Within each styroblock, six replicates of five seedlings each were randomly selected for measurement throughout the experiment. Measurements were made every two weeks, recording frequency of terminal resting buds and shoot length of seedlings. The supplemental lights were shut off on September 15, 1980, and the measurements continued until most seedlings had formed terminal resting buds. At this point, a destructive sample was taken of the seedlings measured above for seedling oven dry weight and height. These data were subjected to analyses of variance and the Student-Newman-Keuls' multiple range test (Steele and Torrie 1960).

Low Night Temperature

Simultaneously with the above, the same seven spruce seedlots were grown in two controlled environmental chambers programmed as follows:

Growth Chamber	Treatment	Day Temp ^{o}C	Night Temp ^{o}C	Light Intensity (lx)
A	Warm nights	21	18	200
B	Cold nights	21	7	200

The objective of this second experiment was to study the effect of low night temperature alone on the growth of the seven spruce seedlots. This was not possible in the shadehouse/greenhouse comparison due to higher mean maximum day temperature encountered in the greenhouse (Table 2). The growth room environments simulated a 16-h day with a temperature regime of 21°C and a light intensity at plant level of 20 000 lx provided by cool white fluorescent tubes supplemented by incandescent light bulbs. Three hours of supplemental lighting was supplied by the incandescent lights which provided an intensity of 200 lx (range 199 to 226 lx) at the seedling level. Experimental design, seedling measurement schedule and data analyses were identical to that described for the light intensity phase of the investigation.

Results

Light Intensity

Shoot length of white and Engelmann spruce seedlings grown under an extended daylength were significantly (p = .05) greater than the controls in all but seedlot 7 in the greenhouse and seedlot 6 in the shadehouse. In both instances, light intensities of 100 and 200 lx produced seedlings that were significantly (p = .05) taller than the controls, but seedlings grown under 400 lx were not. There were no significant differences (p = .05) in shoot length and weight among the three intensities of light used to extend the photoperiod for most seedlots in both environments, except seedlot 7 where seedlings in treatment 3 were significantly taller than those in treatment 4 in the greenhouse and significantly heavier than treatment 2 in the shadehouse (Figs. 1 and 2). Shoot weight of seedlot 2 grown under 400 lx in the greenhouse was also significantly less than those seedlings grown under 100 and 200 lx. Seedlings grown in the unheated shadehouse showed a nonsignificant trend to reduced shoot length and weight as the light intensity increased to the higher levels. These effects were not so apparent when seedlings were grown in the heated greenhouse.

Seedlings grown in the shadehouse formed terminal resting buds earlier than those seedlings in the greenhouse (Tables 3 and 4). There were no significant differences (p = .05) in the frequency of terminal resting bud formation in seedlings grown under all three extended daylength treatments. Therefore, the data have been combined for the 100, 200, and 400 lx treatments in Tables 3 and 4. A significantly (p = .01) higher proportion of seedlings in the shadehouse were setting terminal resting buds on August 22, before the supplemental lights were turned off. Although this was one of the factors contributing to the smaller seedling size in the shadehouse, it was not the main factor. A comparison of seedling growth curves between shadehouse and greenhouse indicated that a significant difference (p = .01) had already occurred in seedling heights

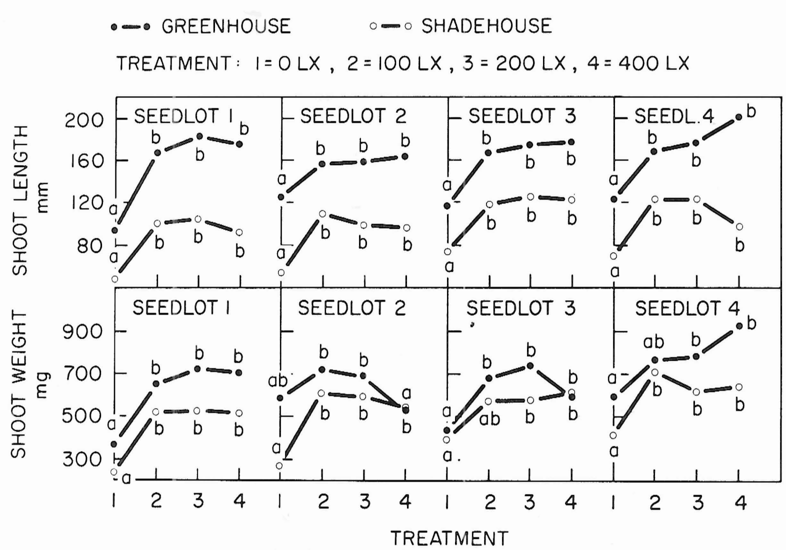

Figure 1. Light intensity effect on seedling shoot length and weight of the four white spruce seedlots. (On each curve, points with the same letter are not significantly different (p = .05).

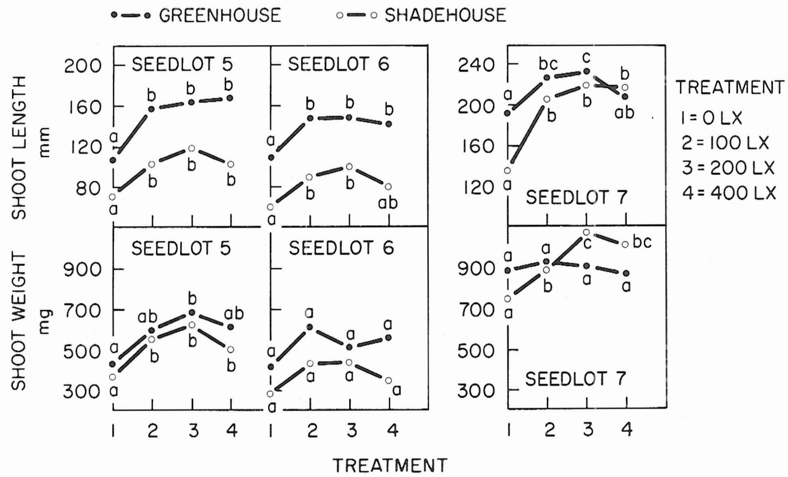

Figure 2. Light intensity effect on seedling shoot length and weight of the three Engelmann spruce seedlots. (On each curve, points with the same letter are not significantly different (p = .05).

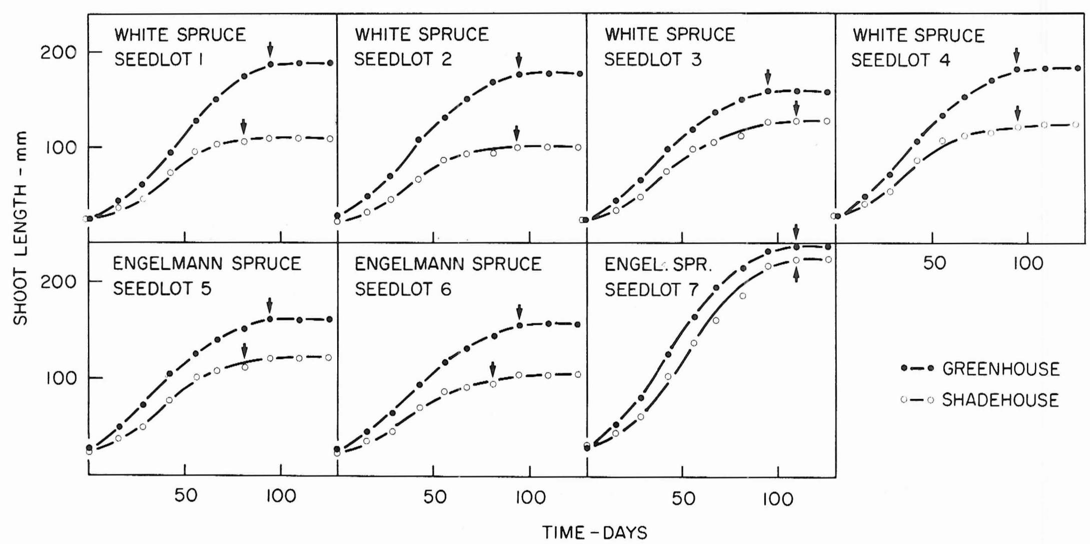

Figure 3. Height growth curves for the seven spruce seedlots under an extended light intensity of 200 lx (arrow indicates point at which more than 50% seedlings had formed terminal resting buds).

before the seedlings had achieved 50 per cent terminal bud set (Fig. 3). Such growth differences were likely the result of higher mean maximum and mean minimum temperatures in the greenhouse (Table 2).

Oven dry weight of seedling roots in the shadehouse was significantly (p = .01) greater than that in the greenhouse (Fig. 4). In the shadehouse seedlings, there were no significant differences (p = .05) in oven dry weight of roots among all light intensity treatments, including the control. Similar results occurred in most of the greenhouse seedlings. Only in one instance (white spruce, seedlot 2) were significantly (p = .01) fewer roots produced under treatment 4 (Fig. 4).

Overall, the greenhouse/shadehouse data show that the more northern populations of white spruce and the high elevation seedlots of Engelmann spruce did not require higher intensities of light than the southern, low elevation populations to produce seedlings of comparable size.

Low Night Temperature

Cooler night temperature produced significantly smaller (p = .01) seedlings than those under the warm night regime (Table 5), but this was not the result of the seedlings forming terminal resting buds earlier in the cooler nights. In fact, the cool night regime tended to delay the formation of terminal resting buds in all spruce seedlots (Table 6).

Discussion

These results confirm earlier work (Arnott 1974, 1979) which suggested that high latitude white spruce and high altitude Engelmann spruce require daylength extension to maintain shoot growth when grown in southern, low altitude nurseries in Coastal British Columbia. These experiments also define the light intensity required for maximum shoot growth of these species when using incandescent light to supplement the natural daylength at southern, coastal nurseries. Since the differences in shoot length and weight were not significant (p = .05) between the 100- and 400-lx light levels, in all but one seedlot (no. 7), the results suggest that the effective maximum intensity to use for supplemental photoperiodic lighting in southwestern Coastal British Columbia nurseries is 100 lx. Seedlot 7, the southern latitude-low elevation provenance of Engelmann spruce, grew quite adequately in both nursery environments without supplemental daylength. It is possible that 100 to 400 lx did not represent enough of the light intensity scale to conclude that these results delineate the maximum effective level for white and Engelmann spruce. Reason for this possibility can be found in the trend of one or more parameters in seedlot 4 (Fig. 1) and, to a lesser degree, in seedlots 2, 3, and 5 (Figs. 1 and 2). Although such trends were statistically nonsignificant in these experiments, research is now underway to study the response of white and Engelmann spruce seedlings to a wider range of light intensities.

Since white and Engelmann spruce cover such a wide latitudinal and altitudinal range, the different populations (seedlots) tested in this experiment were expected to have significantly different critical levels of light intensity for photoperiod extension. In contrast to work by Häbjørg (1972) on white birch (*Betula pubescens* Ehrh.), higher intensities of light during extended photoperiod were not required for the northern sources of white spruce or the high altitude populations of Engelmann spruce. The data

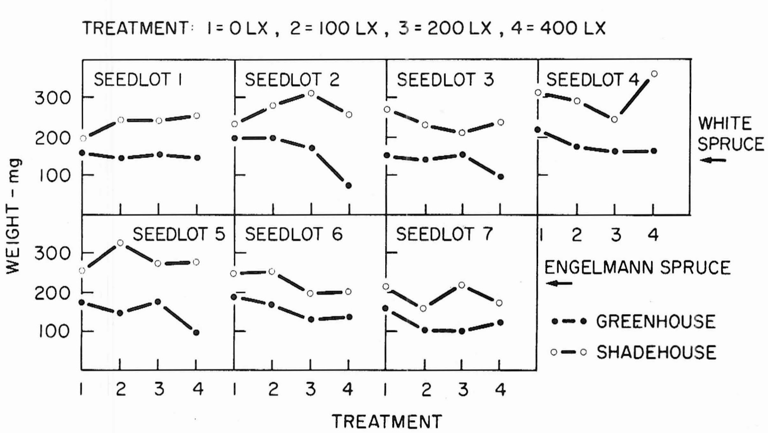

Figure 4. Light intensity effect on seedling root weight of the seven spruce seedlots.

in Figures 1 and 2 indicate that growth of most seedlots responded in a similar manner to increases in light intensity in both heated and unheated nursery environments.

The simple effect of low night temperature did not cause any of the seedlots to form terminal resting buds sooner than those seedlings grown under a warm night regime in controlled environment conditions. Slower apical bud formation in the 'cool night' regime is consistent with other growth room/ phytotron research (Malcolm and Pymar 1975; Owston and Koslowski 1981). The mean daily maximum/minimum temperatures in the greenhouse and shadehouse were 26/19.5^{o}C and 23/14^{o}C, respectively. In comparable regimes studied by Hellmers *et al.* (1970), terminal bud formation was approximately 4 weeks earlier under the cooler shadehouse regime. It therefore seems likely that the specific combination of day and night temperature influences terminal bud development in Engelmann spruce more than low night temperature alone. These experimental results are consistent with earlier work which demonstrated that white and Engelmann spruce seedlings grown in an unheated shadehouse under extended photoperiod using even higher light intensities (1600 lx) formed apical buds in the latter half of the growing season before the lights were turned off (Arnott 1974).

In conclusion, no evidence was uncovered to suggest that, at the light intensity levels tested, the more northern populations of white spruce and the high altitude populations of Engelmann spruce required higher intensities of light during photoperiod extension to maintain apical growth. Within the range of light intensity investigated, the minimum intensity of supplemental lighting required for maximum shoot growth of all seedlots, except the southern latitude-low altitude Engelmann spruce, was 100 lx in both heated and unheated environments. Furthermore, low night temperature alone did not appear to promote earlier formation of terminal resting buds at the light intensity levels tested in this experiment.

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Table 1. Geographic origin of seven spruce seedlots used in the experiment.

Seedlot	Species	B.C.M.F. Registered Seedlot No.	Latitude	Longitude	Altitude (m)	Location
1.	*P. glauca*	1823	58°50′	122°25′	518	Fort Nelson
2.	*P. glauca*	3978	56°47′	121°21′	800	Aitken Creek
3.	*P. glauca*	2240	54°05′	121°50′	640	McGregor
4.	*P. glauca*	1877	53°47′	121°30′	823	Monkman
5.	*P. engelmannii*	1379	51°47′	120°15′	1372	Moira Lake
6.	*P. engelmannii*	3141	49°43′	118°56′	1753	Kettle R.
7.	*P. engelmannii*	0946	50°18′	118°48′	762	Shuswap Falls

Table 2. Temperature differences between greenhouse and shadehouse (°C).

Month	Mean Maximum			Mean Minimum		
	G.H.[a]	S.H.[b]	Diff.	G.H.	S.H.	Diff.
June	26	20	6	19	11	8
July	27	24	3	18	14	4
August	26	25	1	18	14	4
Sept.	25	23	2	19	15	6

[a] G.H. = Greenhouse.

[b] S.H. = Shadehouse.

Table 3. Percent seedlings with terminal resting buds in shadehouse by treatment, seedlot and date.

Treatment (1x)	Seedlot	Dates					
		Aug. 11	Aug. 22	Sept. 5	Sept. 19	Oct. 3	Oct. 20
0	1	87	100	100	100	100	100
	2	80	100	100	100	100	100
	3	73	93	100	100	100	100
	4	77	97	100	100	100	100
	5	73	97	100	100	100	100
	6	73	100	100	100	100	100
	7	7	30	77	100	100	100
100-400	1	0	48	87	90	100	100
	2	0	23	66	79	100	100
	3	0	23	42	45	100	100
	4	1	35	71	77	100	100
	5	1	47	81	77	98	100
	6	6	51	80	76	99	100
	7	1	1	4	7	89	100

Table 4. Percent seedlings with terminal resting buds in greenhouse by treatment, seedlot and date.

Treatment (1x)	Seedlot	Dates					
		Aug. 11	Aug. 22	Sept. 5	Sept. 19	Oct. 3	Oct. 20
0	1	40	60	83	100	100	100
	2	0	30	73	100	100	100
	3	10	60	87	97	97	100
	4	37	77	87	90	97	97
	5	30	87	97	100	100	100
	6	13	83	97	100	100	100
	7	0	7	13	70	97	100
100-400	1	0	1	4	90	100	100
	2	1	4	8	89	100	100
	3	0	0	3	90	98	98
	4	1	2	8	83	97	100
	5	1	3	4	92	99	100
	6	0	2	7	82	98	98
	7	0	2	2	36	94	99

Table 5. Length and oven dry weight of seedling shoots grown in two controlled environment regimes.

	Species/Seedlot						
	White spruce				Engelmann spruce		
Variable	1	2	3	4	5	6	7
Shoot length (cm)							
– A[1]	26	26	21	26	29	24	31
– B[2]	22	24	19	23	19	20	24
Shoot weight (mg)							
– A	1201	1615	1011	1513	1432	926	1552
– B	994	1499	900	1345	1014	940	1284

1 A = warm nights

2 B = cold nights

Table 6. Percent seedlings with terminal resting buds in growth rooms by treatment, seedlot and date.

		Dates					
Treatment	Seedlot	Aug. 22	Sept. 5	Sept. 9	Oct. 3	Oct. 20	Oct. 31
Warm nights	1	0	0	3	10	60	100
	2	0	0	0	7	50	100
	3	0	3	10	37	60	100
	4	0	3	7	17	27	100
	5	7	10	17	33	57	100
	6	3	3	10	43	70	100
	7	13	17	30	37	63	100
Cold nights	1	0	0	7	10	20	100
	2	0	0	0	0	7	100
	3	0	0	3	3	20	100
	4	0	0	0	7	20	93
	5	0	0	0	7	40	97
	6	0	0	0	3	10	97
	7	0	0	7	7	13	90