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Photoperiod Extension With Two Types of Light Sources: Effects on Growth and Development of Conifer Species

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Growth and development of seven conifer species were evaluated using two light sources and five light environments. One source was incandescent light, which was the standard system used at the nursery. The other source was a high-pressure sodium lamp mounted inside an oscillating parabolic mirror, a system that has not been tested on an operational basis. Morphological response to the different light treatments was species dependent; however, generally all treatments produced seedlings that met our regional morphological standards for planting. With only a few exceptions, crop uniformity was not significantly altered by the new oscillating light system, relative to the standard treatment. Tree Planters' Notes 44(3): 105-112; 1993.

Extension of photoperiod for producing container seedlings is a common tool in North American nurseries. Photoperiod extension is especially important for growing northern-latitude and high-elevation ecotypes and species at southern latitudes. Height growth can cease early in the growing season if supplemental lighting is not provided (Arnott 1974). A pigment, phytochrome, is responsible for controlling the physiological responses to photoperiod. When exposed to red light (660 nm), phytochrome is converted to an active form that inhibits the initiation of dormancy. Far red light (735 nm), or absence of light, converts the active to the inactive form. The active form of phytochrome not only prevents dormancy but, in the right ratio with the inactive form, can also inhibit stem elongation. Therefore, it becomes important for nursery managers to manipulate light environments such that dormancy is prevented while height growth is promoted.

Photoperiod can be extended by continuously providing light (for example, before sunrise or after sunset) or by interrupting the dark period with intermittent lighting. Intermittent lighting is generally preferred because of growth inhibition caused by continuous red light (Landis et al. 1992). The light intensity required for promoting photoperiod effects is much less than that required to promote photosynthesis. As a general rule, Landis et al. (1992) recommended that the critical minimum light intensity should be at least 8 µmol m^{-2} s^{-1}. However, for mountain hemlock *(Tsuga mertensiana* (Bong.) Carr.), Pacific silver fir *(Abies amabilis* Dougl. ex Forbes), Engelmann spruce *(Picea engelmannii* Parry ex Engelm.), and white spruce *(Picea glauca* (Moench) *Voss),* the critical minimum light intensity was found to be as low as 0.4 to 1.6 Rmol m^{-2} s^{-1} under a continuous 24-hr photoperiod (Arnott 1979).

The duration of light during the dark period is another factor that must be controlled. As long as a dark period is less than 30 minutes, the lights can be on as little as 3% of the time (Tinus and McDonald 1979). Two minutes of light every 30 minutes was the most effective cycle for promoting height growth and plant weight for 4 provenances of white and Engelmann spruce (Arnott 1979).

The Forest Service's Coeur d'Alene Nursery has traditionally used incandescent bulbs to provide intermittent lighting during the dark period. This light source is the most widely used source for photoperiodic lighting in U.S. and Canadian nurseries (Landis et al. 1992). Incandescent bulbs have simple circuitry, have high light output relative to the size of the bulb, are cheap to install, and can be used intermittently with out loss of bulb life (Bickford and Dunn 1972, Landis et al. 1992). However, incandescent lamps have low light output per input watt of energy, generate a lot of heat, are critically affected by voltage variations, and require frequent bulb replacement (Bickford and Dunn 1972).

Another source for light that has increased in popularity is the high-pressure sodium light, now used for about 27% of the photoperiodic lighting in North American container tree nurseries (Landis et al. 1992). High-pressure sodium lamps have a relatively long life, are energy efficient, and have a spectral distribution that is close to optimum for both photosynthesis and photoperiod lighting. Recently, an attempt has been made to mount a centrally located lamp within an oscillating parabolic mirror (Landis et al. 1992). The lamp is kept on continuously during the dark period, but because the mirror oscillates back and forth, its light beam is intermittently cast throughout the greenhouse (Landis et al. 1992). Research suggests that one 400-W lamp used in this technology can provide photoperiodic lighting for an entire 15.2-m (50-foot) x 6.1-m (20-foot) greenhouse (R.W. Tinus, personal communication). However, there are no published data regarding the effects of the oscillating light system on conifer growth.

The objective of this study was to compare the growth and development of 7 conifer species under the standard system used at the Coeur d'Alene Nursery (intermittent lighting from incandescent bulbs) and under the oscillating light system (high-pressure sodium lamp).

Materials and Methods

Seven species were selected:

- Douglas-fir-*Pseudotsuga menziesii var. glauca* (Beissn.) Franco-seedlot elevation 1,950 m (6,400 feet)
- lodgepole pine- *Pinus contorta* var. *latifolia* Engelm. ex Loud.-1,981 m (6,500 feet)
- western redcedar- *Thuja plicata* Donn ex D.Don-1,219 m (4,000 feet)
- western larch- *Larix occidentalis* Nutt.-1,707 m (5,600 feet)
- ponderosa pine-*Pinus ponderosa Dougl. ex Laws. var. ponderosa*- 1,219 m (4,000 feet)
- western white pine- *Pinus monticola* Dougl. ex. D.Don-1,003 m (3,300 feet)
- Engelmann spruce- *Picea engelmannii* Parry ex Engelm..-2,154 m (7,000 feet)

These seedlots represented seeds collected from 4 national forests (Helena, Idaho Panhandle, Nez Perce, and Beaverhead National Forests) throughout Idaho and Montana. Seeds were sown in Styroblock (#315b) polystyrene containers----cell depth = 15 cm (6.0 inches), cell volume = 15.6 cm^3 (5.5 cubic inches), density = 764 cell s/m^2 (71 cells per square feet and 160 cells per tray)-on February 10, 1992, using a 1:1 (v/v) peat-vermiculite mixture as the growing medium. Seedlings were grown at Coeur d'Alene Nursery, Idaho (47° 37' N, 116° 49' W) using operational fertilizer and irrigation regimes.

Samples from each seedlot were grown in two greenhouses that were similar in temperature (based on readings from thermographs) and similar in the rates and timing of irrigation and fertilization but distinctly different in light source, intensity of light, and duration of light during the dark period (table 1). Lighting for photoperiod extension began on February 21, after about 85% of the seeds had germinated. Dark period lighting was activated by a photocell timer. Supplemental lighting was provided through May 18.

In one greenhouse-dimensions of 30.4 m (100 feet) x 9.1 m (30 feet)-the standard incandescent light system (hereafter referred to as the *standard treatment)* was used. The 300-W incandescent bulbs were mounted approximately 1.7 m (5.5 feet) above seed ling trays and were spaced every 1.2 m (4 feet).

A single 400-W high-pressure sodium light with oscillating mirror was used in the other greenhouse, which has the same dimensions as the previously mentioned greenhouse. The light was mounted in the center of the greenhouse, about 2.5 m (8 feet) above seedling trays. Four different light environments (referred to as the *high, mid, low,* and *minimum treat ments*) were created by placing seedling trays-4 trays per species for the high, mid, and low treatments; 1

Table *1-Description of light environments for the different treatments*

Treatment	Light source*	Approximate distance from source m	ft	Light intensity (µmol m^{-2} s^{-1})	Approximate duration
Standard	Incandescent	1.7	5.5	10-23	50 s, every 5 min
High	HPS-OM	2.5	8	12-30	12 s, every 18 s
Mid	HPS-OM	8.3	27	4-5	24 s, every 26 s
Low	HPS-OM	16	51	1-1.5	23 s, every 28 s
Minimum	HPS-OM	16	51	0.15	23 s, every 28 s

*300-W incandescent light bulbs were used in the standard treatment; 400-W high-pressure sodium lamp with oscillating mirror (HPS-OM) was used for the others.

tray per species for the minimum treatment---at different locations from the light (table 1). The areas of the greenhouse without experimental trees were filled with an operational greenhouse crop (total number of seedlings in the greenhouse approximately 137,000).

The minimum treatment (with oscillating light) was created by placing 1 tray of each species behind boards (35 cm (14 inches) x 66 cm (26 inches)) at the end of the greenhouse. The boards extended 20.5 cm (8.2 inches) above the trays and almost eliminated light from the high-pressure sodium lamp (table 1) but still allowed seedlings to experience the natural photoperiod. The boards were removed on May 26. Light intensity at the different locations was measured with a Li-Cor (Lincoln, NE) quantum sensor.

Following normal operational practices, all of the larch seedlings were moved on May 27 to a shelter-house under natural photoperiod, where they remained until extraction. Similarly, the other species were moved outdoors from the greenhouse on June 17. Starting at 5 weeks from sowing and continuing every 3 weeks thereafter, height was determined for 3 of the species (Douglas-fir, lodgepole pine, and Engelmann spruce) by measuring 25 seedlings per light treatment. Budset was also monitored (n = 25 seedlings per light treatment) for these species (Douglas-fir, lodgepole pine, and Engelmann spruce) 4 times during a 2-month period starting in May. The seedlings measured for height were not the same as those measured for budset, and a random selection of seedlings was made on each measurement date.

All species were extracted on July 23-24, for morphological assessment. A total of 1,036 seedlings-4 light treatments (standard, high, mid, low) x 8 seedlings per tray x 4 trays x 7 species plus the 1 minimum treatment x 20 seedlings per tray x 1 tray x 7 species--were randomly selected. Each seedling was measured for height, stem diameter, fresh weight, root volume (by displacement of water, Burdett 1979), shoot dry weight, and root dry weight (ovendrying at 70 /C for 48 hours). Shoot to root ratios were calculated using the dry weights. Seedling water balance ratio (Grossnickle et al. 1991) was calculated as shoot dry weight/(root weight x stem diameter). The water balance ratio is an estimate of the potential for water loss (transpiring surface area) in relation to the potential for water uptake and water conductance.

Using the same trays as those used for the morphological assessment, the occurrence of primary (first-formed juvenile needles) and secondary (needles grouped in fascicles) needles was estimated in the 3 pine species by counting the number of seedlings with secondary needles on May 28 (before seedlings were moved outdoors) and July 24 (at extraction). No distinction was made between seedlings having a few or many secondary needles.

Root growth potential (RGP), the ability of a seed ling to initiate or elongate new roots in an environment favorable for root growth, was determined for lodgepole pine and Engelmann spruce. The lodgepole pine seedlings were extracted on July 24, stored at 2° C for 7 days, and then tested for RGP Engelmann spruce seedlings were handled similarly as the lodge pole pine seedlings, with the exception that they were extracted on August 4. These were different seedlings from those used for the morphological assessment, but grown in the same trays.

To perform the RGP test, the medium was gently washed from the seedling roots, any active root tips were removed, and then the seedlings were grown under greenhouse conditions (19 °C air temperature (range 10 to 28 °C)) with the seedling root systems misted (18 to 22 °C root zone temperature) aeroponically (Rietveld and Tinus 1990). The number of new roots greater than 1 cm was determined after 21 days. A total of 232 seedlings was measured-4 light treatments (standard, high, mid, low) x 6 seedlings per tray x 4 trays x 2 species plus the 1 minimum treatment x 20 seedlings per tray x 1 tray x 2 species.

A preliminary analysis of variance was conducted using treatment means in a completely randomized design having 4 replications and 4 treatments (standard, high, mid, and low). This analysis was performed assuming that the two greenhouses were similar in all respects except the light environment. Because of the possible confounding effects of greenhouse environment and the lack of true replication, we present only the means and standard deviations for each treatment.

To determine if crop uniformity differed between seedlings from the 2 greenhouses, sample variances (from the morphology data) were calculated for the standard treatment (n = 32) and for the combined data of the high, mid, and low treatments (n = 96). The variances were then compared using the Dixon and Massey (1951) F-test of population variances.

Results

On May 18 and June 8, 40 to 68% of the minimum seedlings of Douglas-fir and Engelmann spruce had set bud, with little or no budset observed in the other light treatments (data not shown). As a result, the minimum seedlings lagged behind in height growth, relative to the other treatments (figure 1). On the other hand, for lodgepole pine, there was no consis-

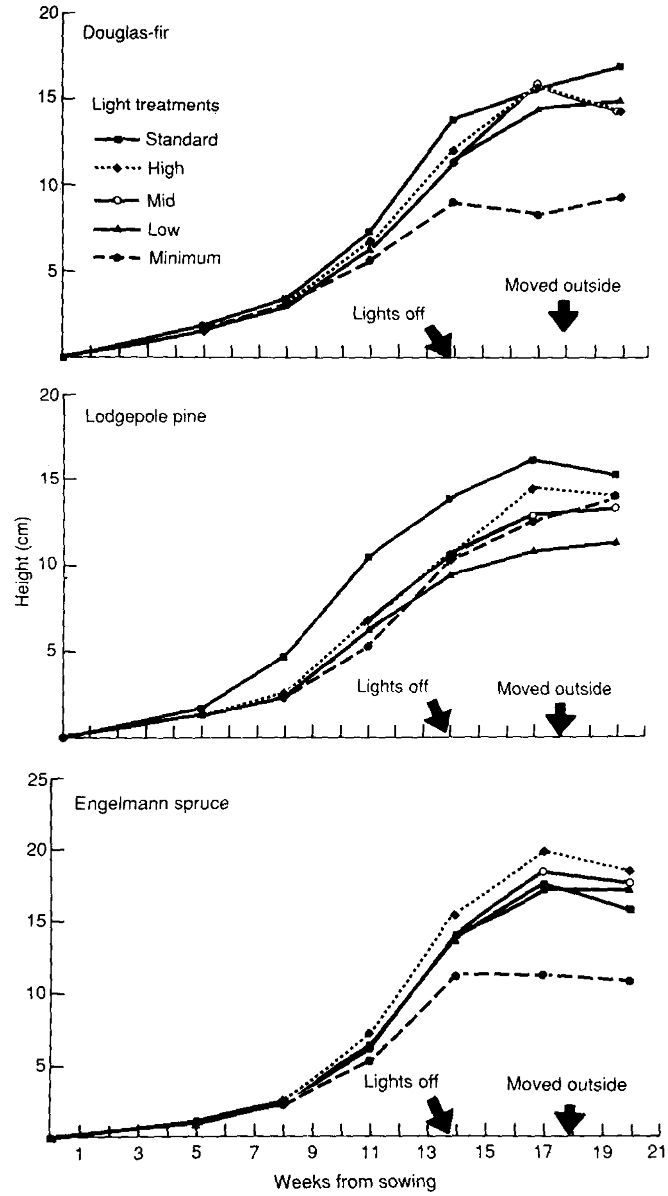

Figure 1– *Height growth of 3 species exposed to 5 different light environments (n = 25 for each mean).*

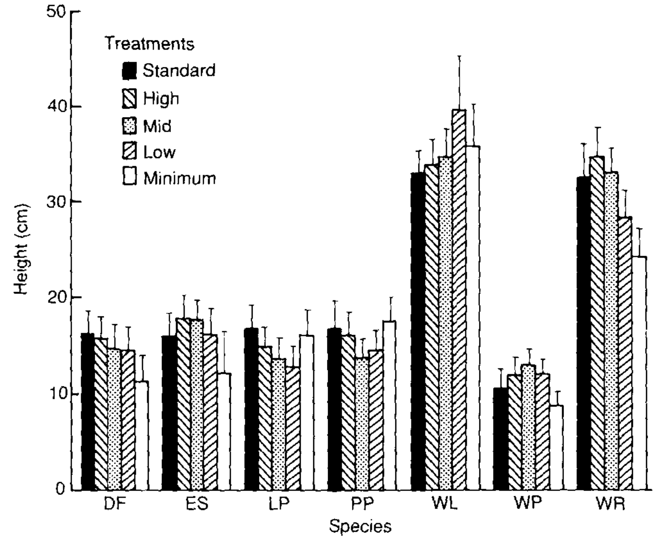

Figure 2 -*Height at the time of extraction for 5 light environments and 7 species (DF = Douglas-fir, ES = Engelmann spruce, LF = lodgepole pine, PP = ponderosa pine, WL = western larch, WP = western white pine, WR = western redcedar). Error bars represent 1 standard deviation (n = 20 for minimum; n = 32 for other treatments).*

tent budset pattern among all the light treatments, and minimum seedlings did not lag behind in growth (figure 1). In lodgepole pine, final height followed the treatment order (From tallest to shortest) of standard > minimum > high > mid > low (figure 2).

In all species except lodgepole pine, final height of seedlings grown under high light intensity (high-pressure sodium lamp) tended to be greater or very similar to the standard treatment. For Douglas-fir, lodgepole pine, ponderosa pine, and western redcedar, final height of the seedlings grown under the lowest light intensity (low treatment, high-pressure sodium lamp) tended to be less than that for seedlings under the standard treatment. For all species, there were no consistent trends for fresh weight (table 2), root volume (table 2), stem diameter (figure 3), and shoot and root weight (data not shown). Preliminary analyses of variance indicated few or no significant differences among light treatments for these five responses. On the average, the light treatments produced seedlings that met the minimum morphological standards set by the USDA Forest Service Northern Region.

Shoot to root weight ratio (table 2) was generally the smallest in the low treatment. The most notable exception was in western larch, for which the average shoot to root ratio of the low treatment was 27 to 50% greater than the other treatments. The relative rankings among treatments for water balance ratio were similar to those for shoot to root ratio (data not shown). For Engelmann spruce and lodgepole pine, the minimum light treatment resulted in the fewest

Table 2-Fresh weight, root volume, shoot to root (dry weight) ratio, and root growth potential (no. of new roots > 1 cm after 21 days) of seedli rown in different liaht environments (standard deviation in parentheses)

Species	Standard	High	Mid	Low	Minimum
Fresh weight (g)					
Douglas-fir	5.8 (1.1)	6.1 (1.2)	6.4 (1.4)	6.2 (1.1)	4.7 (1.6)
Engelmann spruce	6.5 (1.4)	7.5 (1.6)	7.0 (1.5)	7.3 (1.7)	6.0 (1.8)
lodgepole pine	10.3 (2.7)	9.6 (2.5)	10.1 (2.8)	9.6 (1.9)	7.5 (1.4)
ponderosa pine	11.7 (2.6)	12.3 (1.7)	10.7 (3.0)	11.6 (2.0)	11.2 (2.8)
western larch	10.4 (2.2)	10.9 (1-8)	10.7 (2.1)	10.0 (2.2)	10.7 (1.9)
white pine	8.2 (1.9)	7.9 (2.1)	9.2 (1.9)	8.2 (1.8)	5.8 (1.5)
western redcedar	9.6 (2.0)	9.9 (1.8)	9.0 (1.5)	8.7 (1.7)	7.7 (1.4)
Root volume (cm^3)					
Douglas-fir	4.2 (0.8)	4.7 (1.0)	5.0 (1.1)	5.1 (0.8)	3.9 (1.1)
Engelmann spruce	3.7 (1.0)	4.7 (1.0)	4.4 (0.8)	4.8 (1.0)	5.0 (1.3)
lodgepole pine	5.8 (1.7)	4.5 (1.3)	5.2 (1.4)	6.0 (1.3)	5.1 (1.0)
ponderosa pine	6.2 (1.5)	6.2 (0.9)	5.2 (1.4)	6.0 (1.1)	6.4 (1.6)
western larch	5.8 (1.4)	5.8 (1.1)	5.1 (1.5)	3.3 (1.2)	5.4 (1.4)
white pine	5.6 (1.5)	5.5 (1.5)	6.0 (1.5)	5.4 (1.5)	3.9 (1.2)
western redcedar	5.1 (1.2)	4.7 (1.1)	4.6 (1.0)	4.5 (1.0)	3.6 (0.8)
Shoot to root ratio (dry weight)					
Douglas-fir	1.3 (0.2)	1.3 (0.2)	1.2 (0.2)	1.1 (0.3)	1.1 (0.2)
Engelmann spruce	1.7 (0.3)	1.7 (0.2)	1.7 (0.2)	1.4 (0.2)	0.9 (0.2)
lodgepole pine	1.8 (0.3)	2.2 (0.5)	1.8 (0.4)	1.5 (0.3)	1.2 (0.3)
ponderosa pine	2.0 (0.4)	2.2 (0.4)	2.1 (0.4)	1.9 (0.4)	1.4 (0.3)
western larch	2.2 (0.4)	2.0 (0.4)	2.4 (0.5)	3.1 (0.6)	2.4 (0.6)
white pine	1.2 (0.3)	1.1 (0.2)	1.1 (0.2)	1.1 (0.2)	1.1 (0.4)
western redcedar	3.2 (0.4)	3.1 (0.4)	2.7 (0.3)	2.6 (0.3)	2.6 (0.4)
Root growth potential (no. > 1 cm)					
Enge4mann spruce	12.9 (15.4)	15.1 (19.2)	21.6 (23.8)	8.2 (10.7)	6.7 (10.5)
lodgepole pine	5.1 (5.3)	13.5 (11.0)	12.6 (8.9)	7.7 (7.2)	0.8 (1.7)

number of new roots, but there was considerable variation in RGP among light treatments.

When data were combined for the light treatments under the high-pressure sodium lamp and compared to the variance between seedlings in the standard treatment, there was little evidence to suggest that crop uniformity differed between the two greenhouses (table 3). In 5 of the 7 species, height variation tended to be greater from seedlings grown under the high-pressure sodium lamp, but the variances differed significantly ($P < .05$) in only western larch. In this case, seedlings grown under the high-pressure sodium lamp had a sample variance that was about 4 times greater than the height variance of seedlings grown conventionally. In general, seedling variation was not significantly different between the two greenhouses for nearly all morphological responses and species.

The light treatments appeared to have the least effect on morphological response of western white pine. This response included the needle development (primary versus secondary), where light treatment had no effect on whether primary or secondary needles were produced. In contrast, for lodgepole pine and ponderosa pine, the occurrence of primary or secondary needles was related to light treatment. For example, we estimated that close to 100% of all

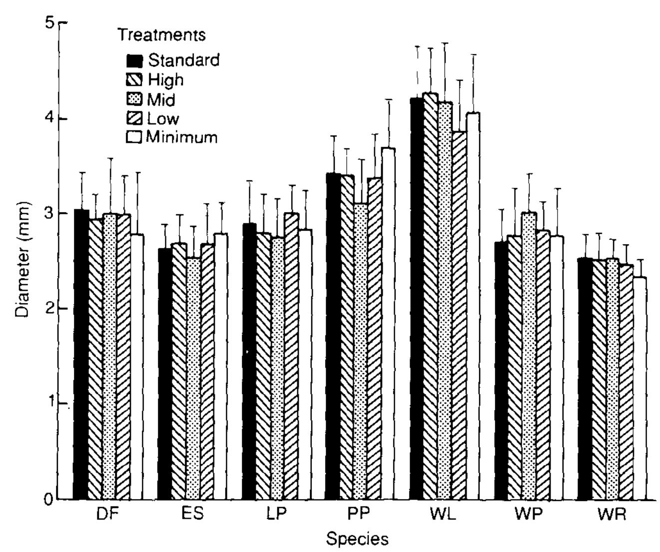

Figure 3-Diameter at the time of extraction for 5 light environments and 7 species (DF= Douglas-fir ES = Engelmann spruce, LP = lodgepole pine, PP = ponderosa pine, WL = western larch, WP = western white pine, WR = western redcedar). Error bars represent 1 standard deviation (n = 20 for minimum; n = 32 for other treatments).

Table 3-Sample variances of seedling morphology at extraction, for seedlings grown under two light sources (n = 96 for highpressure sodium lamp; n = 32 for incandescent bulbs), and F-statistic to test the hypothesis that the sample variances do not differ

Species	Sodium lamp	Incandescent bulbs	F value
Height (cm)			
Douglas-fir	6.15	5.41	1.137
Engelmann spruce	6.30	5.39	1.169
lodgepole pine	5.35	5.96	0.898
ponderosa pine	5.53	5.26	1.051
western larch	21.95	5.26	4.173*
white pine	3.04	3.46	0.879
western redcedar	15.07	10.66	1.414
Diameter (mm)			
Douglas-fir	0.21	0.16	1.312
Engelmann spruce	0.12	0.12	1.000
lodgepole pine	0.14	0.20	0.700
ponderosa pine	0.19	0.17	1.118
western larch	0.33	0.30	1.100
white pine	0.18	0.12	1.500
western redcedar	0.06	0.07	0.857
Fresh weight (g)			
Douglas-fir	1.57	1.26	1.246
Engelmann spruce	2.59	2.04	1.270
lodgepole pine	5.91	7.17	0.824
ponderosa pine	5.64	6.93	0.814
western larch	4.38	4.81	0.911
white pine	4.02	3.81	1.055
western redcedar	3.00	3.92	0.765
Root volume (cm^3)			
Douglas-fir	1.00	0.69	1.449
Engelmann spruce	0.95	1.01	0.941
lodgepole pine	2.15	2.87	0.749
ponderosa pine	1.50	2.43	0.617
western larch	2.74	1.99	1.377
white pine	2.27	2.27	1,000
western redcedar	1.07	1.55	0.690

*Variances that are significantly different (a = 0.05).

seedlings had secondary needles for all light treatments, except the minimum treatment, soon after the lights were turned off and at extraction. On the other hand, most of the minimum treatment seedlings had few secondary needles (1.3% for lodgepole, 11.2% for ponderosa) when the lights were shut down. At the time of extraction, after all seedlings had been moved outdoors, the percent of seedlings with secondary needles in the minimum treatment had risen for both species (70% for lodgepole and 28% for ponderosa pine).

Discussion

Light sources and varying light intensity for photoperiod extension affected the conifer species differently. In general, however, seedlings achieved the necessary morphological standards at the time of extraction, irrespective of treatment. That is, the seedlings met the minimum size standards as specified by Forest Service regional guidelines. In addition, with only a few exceptions (e.g., western larch), crop uniformity was not significantly altered relative to the standard lighting regime. As a result, a single highpressure sodium lamp with an oscillating mirror attachment shows much promise for providing supplemental light in a single greenhouse at Coeur d'Alene Nursery.

The height of western larch seedlings was about 4 times more variable under the oscillating mirror system than under the standard greenhouse regime. This occurred because the low treatment resulted in seedling height that was about 14 to 16% greater than the average height of seedlings in the high and mid treatments. In addition, the coefficient of variation for height in the low treatment (14%) was about 1.6 to 2 times greater than that found for the high, mid, and standard treatments. It appeared that low seedlings allocated resources toward height growth, as evidenced by relatively small root volumes and large shoot to root or water balance ratios. However, if the allocation pattern was related to a shade-induced height increase (Landis et al. 1992), we would have expected the minimum seedlings to also be relatively taller. The latter result did not occur. Dance and Running (1985) suggested that height growth, in response to light or moisture regimes, was not very predictable in young western larch seedlings. Similar to our study, they found considerable variation in height in western larch. In contrast, however, the low light treatments (27 or 37% full sunlight) used in their study tended to produce seedlings that were shorter than those grown under higher light (70% full sunlight).

Needle development (primary versus secondary) in lodgepole pine and ponderosa pine seedlings (but not western white pine) was apparently influenced by supplemental light. By providing light during the crop cycle, needle development can be influenced in some pine species. However, the relationship between needle type and subsequent field performance is largely unknown. Container nurseries in British Columbia favor the development of secondary needles for improved field performance (van Steenis 1993). In contrast, recent research at Coeur d'Alene Nursery and the University of Idaho (Omi et al. 1993) showed that lodgepole pine seedlings with primary needles were more cold-hardy, had greater water-use efficiency (ratio of photosynthesis to transpiration), and had significantly greater growth than secondary needle type seedlings in greenhouse, common garden, and outplanting experiments (unpublished data). The poor performance of the secondary needle type seedlings, however, may have been due to the application of a late-season (August) photoperiod extension. Detrimental effects of daylength extension late in the crop cycle have been noted in other species (Arnott and Mitchell 1982, Grossnickle et al. 1991, Grossnickle and Arnott 1992, Lavender and Stafford 1985, Laven der 1989, Silim et al. 1989).

We were pleased with the performance of the high-pressure sodium lamp with oscillating mirror because seedlings grew to meet our regional stock standards for morphology. Furthermore, we estimated that relative to the oscillating light, the standard incandescent technology has a 1.5-fold and 7-fold increase in initial installation costs and electricity use, respectively (table 4). Using the assumption stated in table 4, we calculated a savings of about $1,130.00 (per greenhouse) related to bulb and installation costs. Over the course of a year, assuming two crops (one sown in January and the other sown in February) requiring supplemental lighting for 90 to 120 days, the savings in electricity using the oscillating mirror is approximately $350.00 per greenhouse. These estimates exclude the savings in bulb replacement due to the extended bulb life of the high pressure sodium light (table 4).

Table 4 -*Cost comparisons of a greenhouse with incandescent bulbs and a greenhouse with a single high-pressure sodium lamp and oscillating mirror*

	Incandescent bulbs	High-pressure sodium lamp
No. of bulbs/greenhouse	90	1
Bulb life (hours)	1,000	25,000
kW hourslnight/greenhouse*	32.4	4.8
Costs		
Bulbs/greenhouse	$630‡	$50
Fixtures + installation	$1,550§	$1,000¶
ElectricitylnightJgreenhouse†	1.94	0.29

*Kilowatt hours per night = number of bulbs x kilowatts per bulb x hours light are on.
† Cost of electricity per night per greenhouse = kilowatt hours x $0.06 per kilowatt hour.
‡ 90 bulbs x $700 per bulb.
§ Light fixtures ($750.00) + materials and labor ($800.00) =$1,550.00.
¶ Light fixtures ($500.00) + materials and labor ($500.00) = $1,000.00.

Managers need to recognize, however, that a bulb failure in the oscillating light regime would create a dark period in the entire greenhouse. In our standard lighting regime, where 90 incandescent bulbs light the greenhouse, a single bulb failure probably has minimal effects. Because a single night without supplemental light can have significant height growth effects (Arnott 1985), routine maintenance and an alarm system are recommended for use of the high-pressure sodium lamp with oscillating mirror. We also recommend that the system be tested for varying combinations of nursery location, sowing date, seedlot elevation, and species.

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