A New Greenhouse Photoperiod Lighting System for Prevention of Seedling Dormancy

Richard W. Tinus

Principal plant physiologist, USDA Forest Service
Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona

An oscillating light fixture consisting of a 400-watt highpressure sodium arc lamp and an oscillating parabolic mirror was designed and tested on blue spruce (Picea pungens *Engelm.). It successfully prevented apical bud dormancy at distances up to 13 m (43 ft) and light intensities as low as 0.5 µE/m^2/sec (4 foot-candles) in a greenhouse.* Tree Planters' Notes 46(1):11-14; 1995.

Many woody plants— especially those native to high latitude, high elevation, or continental climates-are sensitive to photoperiod (Tinus 1976, D'Aoust 1978, Arnott 1979, Tinus 1981, Arnott and Macey 1985, Arnott and Simmons 1985). They tend to have long critical day-lengths (or required light periods) and set bud and become dormant under short days. However, they may be kept growing in height by long days. In greenhouses, provision of light at night (or dark period) is an important tool for maintaining height growth for as long as necessary for the seedlings to reach the desired height (Struve and Blazich 1980, Arnott and Simmons 1985, Landis and others 1992, Lascoux and others 1993).

In the United States, more forest tree nurseries use incandescent lights operated intermittently than use any other lighting system (Eriksson 1978, Terbun 1980, Landis and others 1992), although a variety of other systems have been tried and used successfully (Cathey and Campbell 1975, Johnstone and Brown 1976, Young and Hanover 1977, Wheeler 1979, Cathey and Campbell 1980, Klueter and others 1980, Kraus 1980, Falk 1985, Bartok 1988, Arnott 1989). In spite of their effectiveness and widespread use, incandescent lights are not very efficient for maintaining shoot growth because their spectrum contains substantial farred light (735 nm), which partially reverses the dormancy– preventing effect of red light (660 nm). However, they can be operated intermittently, which saves power, cost, and labor of changing lamps, and have been proven effective (Hassig and Clausen 1977, Tinus and McDonald 1979).

Other lamps in use include high-pressure sodium arc lights. These are highly efficient lamps for lengthening the photoperiod, because their conversion of electricity into light is efficient, the spectrum is concentrated close to the band of maximum effectiveness for dormancy prevention, and they produce little far-red light (Thimjian and Heins 1983, Bartok 1988). They have been found effective at light intensities much lower than those recommended for incandescent lights (Arnott and Macey 1985). However, arc lights cannot be operated intermittently on short cycles because they contain ballasts that require several minutes to warm up when lighted and must cool after being turned off before they can be relighted. Furthermore, turning them on and off repeatedly greatly shortens their lifetime. Intermittent lighting can be achieved by mounting lamps on a moving boom, usually the same one that provides irrigation. This considerably reduces the number of fixtures needed, but there are questions of reliability, because the unit would normally be operating at night unattended.

The objective of this study was to design, construct, and test a device that would make best use of the capabilities of high-pressure sodium arc lamps and provide reliable intermittent lighting.

Materials and Methods

A 400-watt high-pressure sodium arc lamp (General Electric Lucolux) was rigidly mounted on a yoke so that the ceramic cylinder in the center of the bulb, where the arc is produced, was located at the focal plane of a parabolic mirror. A gear motor and drive train oscillated the mirror in a sinusoidal fashion to flick a collimated (that is, with light rays in parallel) beam from one end of the greenhouse to the other and back repeatedly with a cycle time of 1 minute (figure 1). In a large commercial greenhouse, the lamp and mirror assembly would be mounted as high as practical in the middle of the house. In this experiment, only a small 6- x 15-m (20- x 48-ft) research greenhouse was available, so the lamp was mounted at one end of the greenhouse to permit measurement of its effect as far away from the lamp as possible. The lamp operated throughout the dark period each night. Light intensity at various locations in the greenhouse was measured

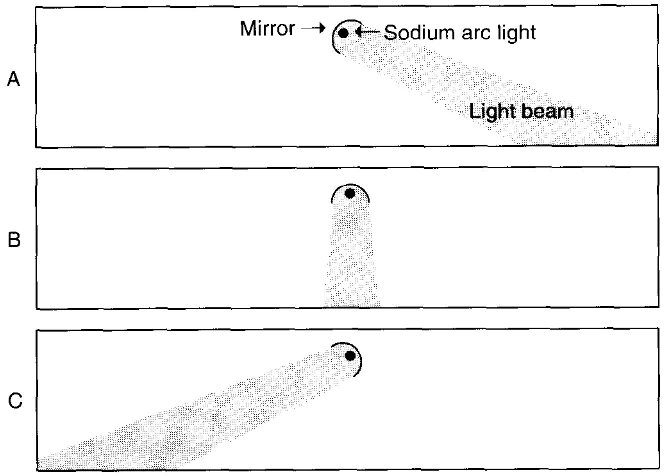

Figure 1—*Longitudinal cross section of a greenhouse. Sodium arc lamp is rigidly mounted high in the center, and the mirror oscillates in orientation from A to B to C to B to A in a 1-minute cycle, flicking the light beam from one end of the greenhouse to the other.*

with a hand-held lux meter and the readings converted to microEinsteins per square meter per second (µE/ m^2/sec) according to Thimjian and Heins (1983).

Blue spruce *(Picea pungens* Englm.) was chosen as a test species because it is highly sensitive to photoperiod and easily goes dormant unless it receives adequate light at night to maintain height growth (Tinus and McDonald 1979). If growth of blue spruce can be maintained by this lighting system, then maintaining growth of other species should not be difficult. McCreary and others (1978) have shown that 22-hour day-lengths were actually optimal for growth of seedlings. Their study, however, used continuous light periods. In this experiment, 24-hour daylengths were used, but plants received intermittent light at 1min cycles throughout the dark period (figure 1).

A crop was seeded May 15, 1990 in 400-ml (25-in^3) Spencer-LeMaire Rootrainers filled with a peatvermiculite mix. There were 20 cavities to a tray. Twenty-one trays were arranged in rows of 3 trays each at regular intervals from one end of the greenhouse, directly under the sodium arc lamp, to the other end as far from the lamp as they could be placed. Within rows the 3 trays were placed on the floor at the center of the greenhouse, the outer side wall, and halfway in between. Each night the trays were covered with polyethylene bags that were removed in the morning. Within each row, two of the bags were clear (transparent) and the third was black (opaque), and their location was randomized. This provided the seedlings with a nighttime environment that was uniform in temperature and humidity but either exposed the seedlings to the light or completely shielded them from it.

The trees were grown under day (light period) temperatures of 20 to 22 °C (68 to 72 °F) and night (dark period) temperatures of 11 to 13 °C (52 to 56 °F). Suboptimal night temperatures (Tinus and McDonald 1979) were chosen to further increase the sensitivity of the trees to inadequate light at night. Greenhouse humidity and irrigation and fertilization of the seedlings were appropriate for maintenance of the rapid growth phase of blue spruce (Tinus and McDonald 1979). Total height was measured and terminal budset noted in mid-September, October, and November 1990, and January 1991.

Results and Discussion

Light intensity was greatest directly under the lamp and least at the far end of the greenhouse (figure 2). However, the duration of illumination was shortest directly under the lamp and longest at the far end of the greenhouse. (This was observed but not measured.) The reciprocal relation of light intensity and illumination time was expected to help produce a more uniform plant response throughout the house.

Trees shielded from the light had stopped growing in height by the time of the first measurements in September (figure 3) and were setting buds (figure 4). At this time the proportion of trees setting bud gener-

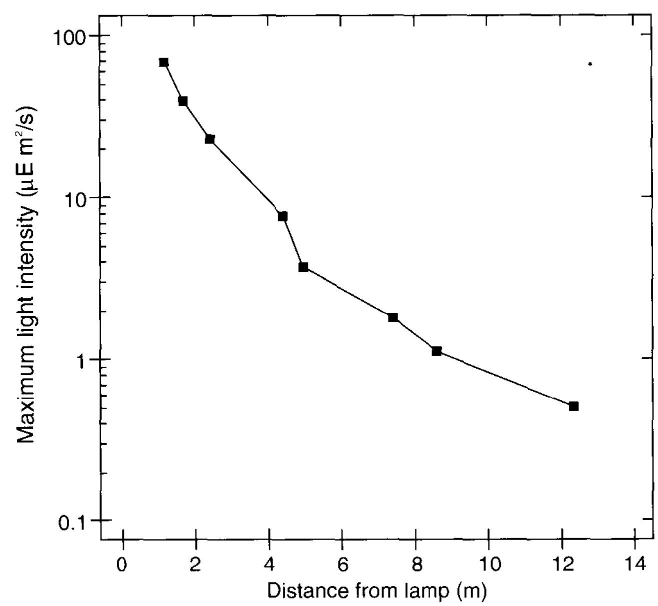

Figure 2—*Maximum light intensity versus distance from the lamp. First data point at the left is directly beneath the lamp, and the last is at the far end of the greenhouse.*

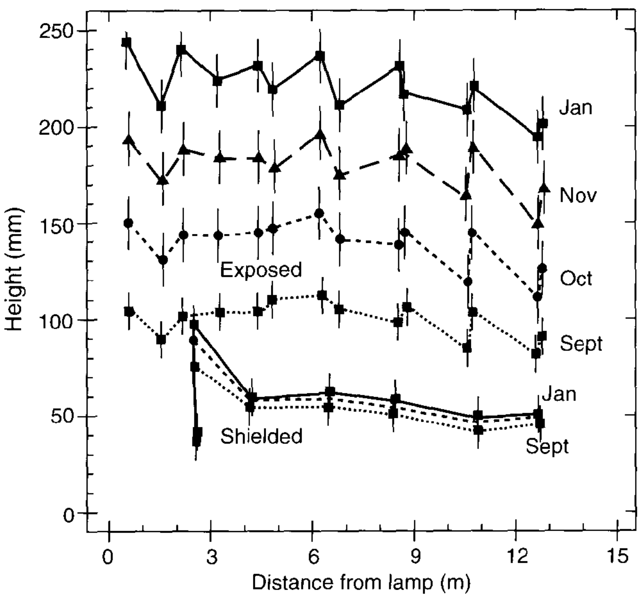

Figure 3—*Blue spruce height as a function of age and distance from the sodium arc lamp. Data points in the same vertical column are the same seedlings measured on successive dates. For each date, points are connected to show the effect of distance from the lamp on height. Seedlings exposed to the light continued height growth, while those shielded from it had stopped height growth by September. Error bars are the 95% interval, and where they do not overlap, the data points are deemed significantly different.*

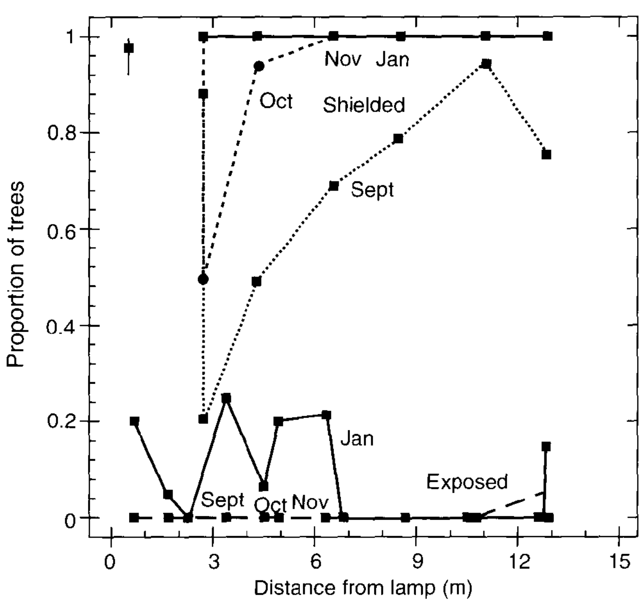

Figure 4—*Proportion of blue spruce that had set a dormant bud at successive dates, either exposed to or shielded from the light.*

ally increased with distance from the lamp, suggesting that the black bags were not entirely opaque. Budset was complete by November.

In contrast, the trees exposed to the light continued to grow in height through January (figure 3). At the far end of the greenhouse, seedlings may have been slightly shorter compared to seedlings close to the lamp, but one-way ANOVA's at each measurement date failed to show enough pairwise differences to consider the shortening significant. Budset was just beginning in January and was not significantly related to distance from the light (figure 4). The beginning of budset in spite of adequate light at night may have been caused by the seedlings becoming too large for the container volume and spacing, thus restricting growth.

Omi and Eggelston (1993) compared the effects of a 400-watt sodium arc lamp with oscillating mirror with conventional intermittent incandescent lighting on seven conifer species (with both determinate and indeterminate growth patterns) in 9- x 30-m (30- x 100-ft) greenhouses at the USDA Forest Service Coeur d'Alene Nursery. Although there were species differences, growth and morphology were generally adequate to meet regional standards under both types of light and at sodium arc light intensities as low as 1 µE/ m^2/sec (8 foot-candles).

Conclusions

A single 400-watt high-pressure sodium arc lamp with an oscillating parabolic mirror providing intermittent light proved effective in preventing bud dormancy in blue spruce. Light intensities up to 13 m (43 ft) from the lamp, measuring 0.5 µE/m^2/ sec (4 foot-candles) were able to prevent budset. This light level is considerably lower than currently recommended for intermittent incandescent lights (Arnott and Macey 1985, Landis and others 1992). Not only can the sodium arc lamps replace large banks of incandescent lights, but they are easy to install— you can "hang them up and plug them in"— and inexpensive to operate.

Address correspondence to Richard W. Tinus, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 2500 South Pine Knoll, Flagstaff, AZ 86001.

Acknowledgments

I thank Harvey Hiatt for diligent twice-daily maintenance of the study and Laura DeWald, Richard Jeffers, Clark Fleege, and Rudy King for their helpful reviews of the manuscript.

References

Arnett JT. 1979. Effect of light intensity during extended photoperiod on growth on amabilis fir, mountain hemlock, and white and Englemann spruce seedlings. Canadian Journal of Forest Research 9(1):82-89.

Arnott IT. 1989. Regulation of white spruce, Engelmann spruce and mountain hemlock seedling growth by controlling photoperiod. Forestry (Suppl) 62:157168.

Arnott JT, Macey DE. 1985. Effect of supplemental light intensity on white spruce, Engelmann spruce, and mountain hemlock seedlings grown under an extended photoperiod. Canadian Journal of Forest Research 15(2):295-300.

Arnott JT, Simmons CS. 1985. The effect of failure in extended and intermittent photoperiodic lighting on the growth of white spruce container seedlings. Canadian Journal of Forest Research 15(4):734-737.

Bartok JW Jr. 1988. High intensity discharge lighting. Efficiency, availability make this system feasible for greenhouses. Greenhouse Manager 6(9):171172, 174, 176-177.

Cathey HM, Campbell LE. 1975. Effectiveness of five vision-lighting sources on photoregulation of 22 species of ornamental plants. Journal of the American Society of Horticultural Science 100(1):65-71.

Cathey HM, Campbell LE. 1980. Light and lighting systems for horticultural plants. Horticultural Reviews 2:491-537 (abstr).

D'Aoust AL. 1978. Influence de I'irradiation sur la croissance de plants d'epinette noire en contenants places dans deux enceintes de culture. Canadian Journal of Forest Research 8(3):316-321.

Eriksson A. 1978. Intermittent Ijus for reglering av skogsplantors tillvaxt vid odling i vaxthus, examensarbete. Int Rapporter 1978-13. Umea, Sweden: Sveriges Lantbruksuniversitet, Institutionen for Skogsforyngring. 33 p.

Falk NK. 1985. Lighten up: selecting artificial lighting for the greenhouse can be confusing so here are some facts that might help. Greenhouse Manager 4(6):89-90, 92-94,96-97.

Hassig BE, Clausen KE. 1977. Assembling safe, suitable incandescent lamp fixtures. American Nurseryman(Jan): 10, 69.

Johnstone RCB, Brown W. 1976. Low-pressure sodium (SOX) tube lights as a source of supplementary lighting for the improved growth of Sitka spruce seedlings. Res Dev Pap 111. United Kingdom Forestry Commission. 10 p (abstr).

Klueter HH, Bailey WA, Zachariah GL, Peart RM. 1980. Photosynthesis in cucumbers with pulsed or continuous light. Transactions of the American Society of Agricultural Engineers 23(2):437-442 (abstr).

Kraus R. 1980. Gas light for plant illumination and C02 supply. Deutscher Gartenbau 34(2):62-66 (abstr).

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1992. Atmospheric environment, Vol 3, The Container Tree Nursery Manual. Agric. Handbk 674. Washington DC: USDA Forest Service, 145 p.

Lascoux DM, Kremer A, Dormling I. 1993. Growth and phenology of 1-year-old maritime pine *(Pinus pinaster)* seedlings under continuous light: implications for early selection. Canadian Journal of Forest Research 23(7): 1325-1336.

McCreary DD, Tanaka Y, Lavender DP. 1978. Regulation of Douglas-fir seedling growth and hardiness by controlling photoperiod. Forest Science 24(2):142-152.

Omi SK, Eggelston KL. 1993. Photoperiod extension with two types of light sources: effects on growth and development of conifer species. Tree Planters Notes 44(3): 105-112.

Struve DK, Blazich FA. 1980. Effects of selected photoperiods and fertilizer rates on growth of *Pints strobus* and *Pinus thunbergii* seedlings. Journal of the American Society of Horticultural Science 105(1):85-88.

Terabun M. 1980. Effect of cyclic lighting on photoperiodic responses in onion plant. Journal of the Japanese Society of Horticultural Science 49(3):375-382.

Thimjian RW, Heins RD. 1983. Photometric, radiometric, and quantum light units of measure: a review of procedures for interconversion. Hortscience 18:818-822.

Tinus RW. 1976. Photoperiod and atmospheric C02 level interact to control black walnut *(Juglans nigra* L.) seedling growth. Plant Physiology (Suppl) 57(5):106 (abstr 554).

Tinus RW. 1981. Effects of extended photoperiod on southern Rocky Mountain Engelmann spruce and Douglas-fir. Tree Planter's Notes 3200-12.

Tinus RW, McDonald SE. 1979. How to grow tree seedlings in containers in greenhouses. Gen Tech Rep RM-60. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 256 p.

Wheeler N. 1979. Effect of continuous photoperiod on growth and development of lodgepole pine seedlings and grafts. Canadian Journal of Forest Research 9(2):276-283.

Young E, Hanover JW. 1977. Effects of quality, intensity, and duration of light breaks during a long night on dormancy in blue spruce *(Picea pungens* Engelm.) seedlings. Plant Physiology 60(2): 271-273.