TWO-CROP PRODUCTION OF WESTERN CONIFERS 1/

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Abstract.--Cultural practices to produce two crops annually in a greenhouse-shadehouse facility in western Oregon are described. Douglas-fir, true firs, pines, and larch are sown in early spring and grown for either fall or spring planting on inland and high elevation sites. Hemlock, spruce, and redcedar are sown in late spring for winter planting on low-elevation coastal sites.

INTRODUCTION

Production of containerized nursery stock is greenhouses provides major opportunities to manipulate growth environment and thus closely regulate seedling development. The level of environmental control chosen must be balanced between: (1) biological requirements of the species being grown, (2) climate at the nursery location, (3) type and size of stock required at different planting sites, and (4) operating considerations such as costs, energy availability, and planting schedules. Based on these factors, the U.S. Forest Service has chosen to test a medium level of environmental control for production of containerized seedlings in the Pacific Northwest. A research and development program covering both production and field performance was begun cooperatively between the Pacific Northwest Region and the Pacific Northwest Forest and Range Experiment Station in the spring of 1973.

Our program objective is to determine on which sites in Oregon and Washington, in which situations, and for what species containerized seedlings equal or better the performance of bare-root nursery stock. Specific purposes that we believe containerized seedlings might be well suited for include: (1) to provide Lock at optimum times for high elevation sites, (2) to make possible efficient production of hemlock and other species difficult to grow in conventional nurseries, (3) to permit planting in extremely rocky soils or where slash or brush prevent conventional bare-root planting, (4) to rapidly grow stock for areas that are unexpectedly denuded, and (5) to produce uniform, high quality seedlings for genetic and reforestation tests. We do not foresee the complete replacement of bare-root stock with containerized seedlings.

We produce two crops per year using a combination of greenhouse and shadehouse facilities. Environmental factors which are controlled in varying degree include temperature, light intensity, photoperiod, moisture, mineral nutrition, and, through choice of container, seedling density and soil volume. We aim for the level of environmental control necessary to produce vigorous, plantable stock in a single growing season and have it available for the usual fall through spring planting periods. Throughout the operation we strive to properly condition seed lings for the sites on which they will be planted.

FACILITIES

The greenhouse we use is at the Beaver Creek Seed Orchard, southwest of Corvallis, Oregon, and is operated by the Siuslaw National Forest. The site is located at 44.5°N latitude in the eastern foothills of the Coast Ranges. Summers are usually warm and dry. Winters are wet, cloudy, and generally mild. Freezing temperatures may occur from September through early May, and temperatures in the teens or lower usually occur in one or two periods during midwinter.

Present facilities consist of a quonset-type, fiberglass-covered greenhouse 32 feet wide

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and 112 feet long (9.8 x 34.1 m) and a shadehouse of identical structure and dimensions. Each house can accommodate 205,000 seedlings in the BC/CFS Styroblock 2,3/ which is our primary container. Supporting structures include two offices, heated work area for filling and sowing containers, and an unheated building for storage of supplies and equipment. A large cooler for storage of seedlings was installed this year.

The key feature of the greenhouse is a traveling-boom irrigation system, which provides even distribution of water and fertilizer (fig. 1). The greenhouse is heated with liquid propane gas, and warm air is distributed through a vented-polyethylene tube system. Cooling is accomplished with two 48-inch (122-cm) fans which draw in outside air, misting provided by the irrigation system, and shading of the fiberglass roof. A network of incandescent lights is available for extending photoperiod.

The shadehouse is covered with saran cloth providing 47 percent shade and is equipped with a traveling irrigation boom identical to the one in the greenhouse. An electric truck with trailer is used to transfer materials and seedlings between preparation and growth areas.

Figure 1.--Interior of Beaver Creek greenhouse with traveling irrigation boom across foreground.

3/ A BC/CFS Styroblock is a rectangular block, molded from expanded polystyrene beads, with round, tapered cavities varying in number and dimensions in which tree seedlings are grown. The blocks are 20 x 14 inches (50.8 x 35.6 cm) with a depth of 5-1/2 inches (14.0 cm). A Styroblock 2 has 192 cavities, each with a volume of approximately 2.4 cubic inches (39 cm^3). Cavities are 1 inch (2.5 cm) in diameter at the top and 4-1/2 inches (11.4 cm) deep (Vyse at al. 1971).

PRODUCTION TECHNIQUES

Growing Schedules

From the outset, we planned to grow two crops per year. In 1973, the first crop, which included nine species, was started in the greenhouse in late April. The second crop, mostly western hemlock (Tsuga heterophylla [Raf.] Sarg.), was sown in mid-July. Small trial sowings of hemlock were also made in June and August. A small number of western larch (Larix occidentalis Nutt.) were sown in September for spring 1974 planting on an area burned last August.

In 1974, the first crop was sown between mid-March and mid-April. We included species that require moderate to high light intensities and were destined for fall or spring planting on inland or high elevation sites. The relatively slow-growing noble fir (Abies procera Rehd.), Pacific silver fir (A. amabilis [Dougl.] Forbes), and Shasta red fir (A. magnifica var. shastensis Lemm.) were sown first. Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco), ponderosa pine (Pinus ponderosa Laws.), lodgepole pine (P. contorta Dougl.), sugar pine (P. Zambertiana Dougl.), western white pine (P. monticola Dougl.), and western larch were then sown. The entire crop was moved to the shadehouse in mid-June for continued growth and later hardening-off (fig. 2). These seedlings will be ready for outplanting by mid-October, but many will be held for spring use. Those not planted by early March will be put into cold storage to prevent budbreak.

Figure 2.--Four-month-old Douglas-fir seedlings under saran cloth providing 47 percent shade.

The second crop for 1974 was sown immediately after the first crop was moved from the greenhouse. Included were western hemlock, Sitka spruce (Picea sitchensis [Bong.] Carr.), and western redcedar (Thuja plicata Donn)--species that can continue to grow under cooler fall temperatures and reduced sunlight and are destined for winter outplanting on low elevation coastal sites. These seedlings will be kept in the greenhouse under good growing conditions until adequate height is attained--late October to mid-November. Then moisture and nutrition levels will be changed to induce dormancy and harden the seedlings for outplanting in January and February. Also included in the second crop was one lot of Douglas-fir intended for spring planting on a site burned by wildfire last May.

Under the current schedule, the greenhouse is completely full and utilized for growing or conditioning seedlings 9 months of the year. The other 3 months it is partly full: from mid-January to early March for holding stock awaiting shipment; from mid-March to mid-April for starting the slow-growing species of the next crop. The greenhouse is cleaned thoroughly during the week in March when it is completely empty.

Potting Mix, Seeding, and Germination

We decided to use primarily one size of container to produce seedlings for field testing. The BC/CFS Styroblock 2 was selected For several reasons: (1) seedlings produced in prior tests appeared well-balanced in terms of height, stem caliper, and root mass; (2) roots air-prune readily; (3) Styroblocks are easily handled in the nursery; and (4) extracted plugs have no restrictions around them to impede root growth. We are also testing Styroblock 4's and 8's4/ and small numbers of other types of containers.

Early work indicated that 1:1 or 3:2 potting mixtures of sphagnum peat moss and vermiculite were best for our purposes (Owston 1973). In addition to low weight, high water-holding capacity, and good cation exchange capacity, the mixtures produced trees superior in size and weight to those grown in other potting mixes. We are now using a commercially available 1:1 "peat-lite" mixture containing fertilizer combinations based on the "Cornell formula" (Boodley and Sheldrake 1967).

All seeds are stratified at 35 degrees - 41 degrees F (1.7° - 5° C) prior to sowing. Duration is varied by species following published recommendations (Association of Official Seed Analysts 1970, Edwards 1973) with some modification based on local experience. Most species are sown with a commercial vacuum seeder, but large-seeded pines and true firs are sown by hand. Two seeds are usually sown per cavity, but three or four seeds are used when low germination is expected. Thinning is necessary about a month after sowing, Though time consuming, it is much preferred to numerous empty cavities.

The seeds are fully covered, about 2/16-3/16 inch deep (3.2 - 4.8 mm), with No. 2 silica grit. Containers are then watered well, placed on greenhouse benches, and covered with clear polyethylene sheeting until seedlings begin to emerge. During germination, we try to hold daytime temperatures between 70° and 80° F (21.1° and 26.7° C) and nighttime temperatures no lower than 60° F (15.6° C).

Watering and Fertilizing

During germination, seeds and young germinants are usually watered once a day when the sky is overcast and twice a day when it is sunny and greenhouse temperatures are less than 80° F (26.7° C) for the first crop or 70° F (21.1° C) for the second crop. Seeds and seedlings are misted frequently for cooling purposes when those temperatures are exceeded. The ventilation that accompanies misting prevents the buildup of excessive humidity which encourages pathogen development. We are careful to maintain adequate moisture so that the potting mixture does not dry out deep within the cavities and thus retard seedling growth.

After germination is complete, we water to field capacity, allow the mixture to dry to about -1 bar soil water potential and then water again. This cycle is repeated as necessary through the season. Last year, watering time was determined by weighing sample Styroblocks. This year, we simply squeeze samples of potting mixture and observe them--in the laboratory we have determined the appearance and "squeeze" characteristics of our mixture at -1 bar water potential.

A liquid fertilizer program is begun 2-3 weeks after germination peaks. A concentrate is metered into the irrigation system; the quantity applied weekly is calculated in ounces of fertilizer per thousand square feet of gross area watered. The pH of the irrigation water, with or without fertilizer, is maintained between 5.0 and 5.5 with phosphoric acid (Matkin and Petersen 1971). Control of pH is vital for ready availability of nutrients (Lucas and Davis 1961).

Specific types and amounts of fertilizer are being modified as we gain experience. Currently, a commercial formula of 20-19-18 plus trace elements is used for the first 3-4

4/ Styroblocks with cavity volumes of 4 and 8 cubic inches (66 and 131 cm^3) each, respectively.

months of each crop cycle--with calcium nitrate (15-0-0) substituted every third week. Rate of nitrogen application ranges from 6 ounces per thousand square feet (183 g/100 m^2) per week early in the season to 16 ounces per thousand square feet (488 g/100 m^2) per week during time of most rapid height growth.

When seedlings have reached sufficient height and it is time to induce bud set, watering is reduced. At present, the greenhouse manager allows the potting mixture to dry below the -1 bar level but not to the point where the mixture becomes bone-dry. He then irrigates until the entire cavity contents are remoistened. Nitrogen additions are also stopped abruptly and 0-10-10 fertilizer is used. Once bud set is well underway, the normal cycle of watering to field capacity and drying to -1 bar is resumed; nitrogen feeding is also resumed at 3 ounces per thousand square feet (92 g/100 m^2) per week. This schedule is maintained until seedlings are shipped or placed in storage.

Laboratory analyses of foliage are made every month to determine nutrient trends and guide future fertilizer schedules. In 1973, following use of a somewhat different regime than described above, nutrient levels in composite foliage samples from 6-month-old seedlings were, in percentage of ovendry weight:

Element	Douglas-fir	Ponderosa pine	Western hemlock
Nitrogen	2.44	3.69	2.74
Phosphorus	.90	.75	.48
Potassium	1.70	1.67	1.42
Calcium	.17	.14	.39
Magnesium	.19	.21	.16

The low calcium level found in the first two species prompted use of calcium nitrate on last year's second crop and both crops this year. Our present target for calcium content in foliage is 0.5 percent (Benzian and Smith 1973, Epstein 1972).

Control of Temperature, Humidity, and Light

During the growing season we try to maintain daytime temperatures in the seventies or low eighties. But higher midday temperatures must often be accepted. In 1973, maximum temperature in the greenhouse exceeded 90° F (32.2° C) on 32 days between late April and late September. This year, we are using mist to cool the greenhouse when temperatures reach the nineties. Night temperatures generally drop to acceptable minimums in the midfifties to midsixties.

During late fall and early winter, we will condition the second crop for planting by keeping greenhouse temperatures between 35° and 40° F (1.7° - 4.4° C). This should be possible most days, since the weather is usually overcast and cool or clear and cold.

Temperatures in the shadehouse are, of course, close to ambient. During the summer daytime temperatures are often cooler than in the greenhouse and therefore better for seedling growth. Light frosts in fall and early winter cause no damage, because by that time the stock has become frost hardy.

Shadehouse temperatures in the low twenties or colder do cause us concern. In our experience, such temperatures damage roots--especially Douglas-fir--and, if prolonged, also cause desiccation of tops. This coming winter, we plan to test two methods of solving this problem: (1) place seedlings in refrigerated storage over winter and (2) cover them with polyethylene placed close above the tops and supply low heat from incandescent lights under the plastic. The second method may be sufficient in our relatively mild climate.

The greenhouse has crude humidity control--humidity can be raised by misting or lowered by ventilating. Humidity is of most concern during the winter when high levels promote the growth of gray mold blight (Botrytis cinerea) in the foliage. We ventilate the greenhouse as much as possible during the winter and especially after each watering.

Light intensities during clear weather range from 6,000 foot-candles in the unshaded greenhouse to 4,000 - 5,000 foot-candles after shading compound is applied. Light intensity in the shadehouse is about half that in the open. These levels are sufficient for optimum photosynthesis of Douglas-fir, western hemlock, and Sitka spruce (Krueger and Ruth 1969) and probably for the true firs and larch. Although the pines can utilize full sunlight (Tinus 1971), their growth at Beaver Creek indicates light intensity is adequate. When the common heavy overcast occurs in midwinter, light is reduced to as low as 900 foot-candles in the open and 500 foot-candles in the greenhouse.

Photoperiod is another important aspect of the light regime. Short photoperiods have proved effective for inducing dormancy and frost hardiness in Douglas-fir seedlings (Driessche 1970, Lavender et al. 1968, Tanaka 1974). We are testing use of artifically shortened photoperiods late in the growing season to speed induction of dormancy and hardiness in first-crop seedlings of several. species. We also used extended photoperiods in 1973 to stimulate growth of the second crop during fall and early winter.

Sanitation and Pest Control

Greenhouse pests--fungi, weeds, insects, and rodents--are controlled as necessary. We give careful attention to cleanliness and sanitation to minimize the need for chemical controls. Seeds and seedlings are not treated routinely with fungicides, and we have had only scattered instances of damping-off. Insect damage has been insignificant. Our two biggest problems occurred last year in the second crop. First, a heavy infestation of weeds and liver worts appeared in July- and August-sown containers and had to be removed manually. This annoyance was followed by an attack of ray mold blight in the lush hemlock foliage which significantly reduced the number of plantable seedlings produced.

Packing and Storing

Most of the stock is extracted from Styro-blocks at the nursery, packed into plastic bags in groups of 15 seedlings, and then placed into waxed cartons holding about 20 packed bags. If packing must he done before the day of shipment, filled cartons are placed in storage at 33 degrees -35 degrees F (0.6 degrees- 1.7 degrees C). A strong effort is made to pack and ship just before planting.

CROP PERFORMANCE AND DISCUSSION

Seedling Production

Nursery performance of individual species and lots grown in 1973, the first year of operation, varied from good to bad (table 1). Although less than half the lots had 75 percent or more cavities filled with plantable trees, many of the low yield lots represented small sowings. From a potential first crop of 127,000 seedlings, trees from approximately 76 percent of the cavities were packed and shipped for planting. In the second potential crop of 191,000 western hemlock seedlings, only 56 percent of the cavities produced plantable trees.

Failure to produce seedlings in some cavities was the result of cultural technique errors that can and are being corrected: (1) lack of seed due to machine failure and human oversight; (2) covering seed too heavily with grit--particularly on western hemlock; (3) overstratification, which resulted in damage during sowing of one lot in particular; and (4) inadequate initial watering. Other causes of failure relate to biological problems: (1) damping-off; (2) unfilled seed; and (3) failure of filled seed to germinate, especially that of true firs. The first problem could be minimized by proper fungicide application and the second by more careful cleaning of seed lots, but the third requires basic research in seed physiology.

Table 1.--Species and lot performance in the Beaver Creek greenhouse, 1973

Species	Lots sown	Lots exceeding 75 percent plantable trees	Range among lots	
			Cavities filled after germination	Cavities with plantable seedlings
	- - - *Numbers* - - -		- - - *Percent* - - -	
Douglas-fir	15	7	59 - 96	38 - 93
Lodgepole pine	2	2	92 - 97	89 - 99
Noble fir	3	0	73 - 85	62 - 75
Pacific silver fir	2	0	68 - 79	53 - 56
Ponderosa pine	6	5	88 - 99	54 - 92
Shasta red fir	1	0	81	59
Sitka spruce	1	1	92	83
Western larch	1	1	82	81
Western redcedar	1	1	89	[1]90
Western hemlock	16	2	56 - 91	6 - 83
Total	48	19		

[1] Estimated.

Seedling Growth

Sizes and weights of plantable seedlings were quite variable (table 2). Although most seedlings developed satisfactorily (fig. 3), we recognize the need for stouter seedlings with heavier root systems. A minimum stem caliper of 2.5 mm and root weight of 0.5 g is our present

Table 2.--Range in size and weight of plantable seedlings grown at Beaver Creek greenhouse in Styroblock 2's, 1973

Species	Number of lots	Range in average values among lots			
		Height of top	Stem diameter at root collar	Dry weight of top	Dry weight of roots
		cm	*mm*	- - - - - g - - - - -	
Douglas-fir:					
Coast Ranges	3	18 - 23	2.4 - 2.6	1/ 0.94 - 1.05	1/ 0.37 - 0.79
Cascade Range	5	16 - 20	.9 - 2.2	2/ .99	2/ .51
Eastern Ore. and Wash.	7	9 - 17	2.1 - 2.6	.55 - 1.18	.55 - .70
Noble fir, Pacific silver fir, Shasta red fir	6	5 - 11	1.2 - 2.1	1/ .33 - .49	1/ .20 - .28
Ponderosa pine, lodgepole pine	8	7 - 15	2.1 - 2.7	.57 - .93	.44 - .77
Sitka spruce	1	24	2.5	1.34	.45
Western hemlock:					
June sowing	3	19 - 20	2.1 - 2.3	2/ 1.05	2/ .38
July sowing	10	15 - 19	1.5 - 2.1	3/ .34 - .59	3/ .14 - .20
August sowing	3	11 - 13	1.3 - 1.4	(4/)	(4/)
Western redcedar	1	21	2.2	.65	.19

1/ Two lots sampled.

2/ One lot sampled.

3/ Five lots sampled.

4/ Data not available.

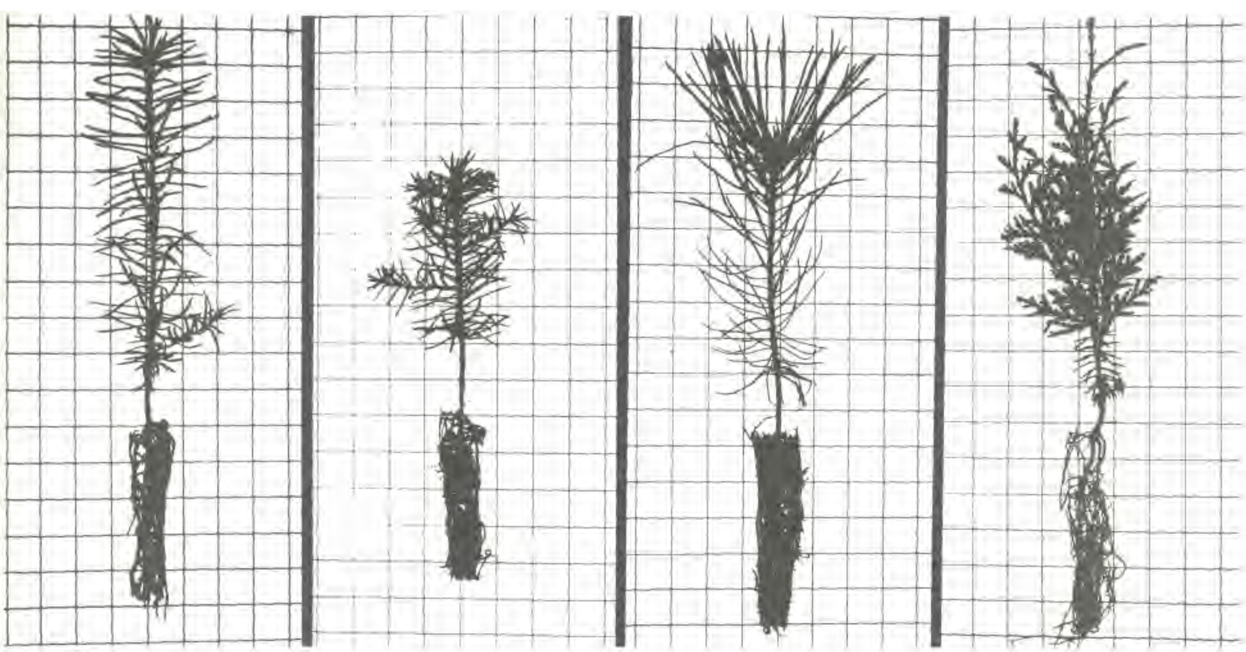

Figure 3.--Typical seedlings at 5 months of age, left to right: Douglas-fir, noble fir, ponderosa pine, western redcedar. Each scale division equals 2 cm.

goal for seedlings grown in Styroblock 2's. These are judgment values to be replaced by more specific sizes for each species as field performance is analyzed.

We are seeking to improve stem stoutness and root mass in the first crop this year by starting bud-inducing practices in mid-July rather than waiting until mid-August. Timing for the second crop will depend on its growth rate.

We now aim to have seedling tops at least as long and no more than twice as long as the cavities are deep. This goal also needs refine-cent based on field performance. Starting slow-growing species earlier than fast-growing ones, as done this year, combined with earlier induc-tion of bud set, should result in more balanced top growth for all lots and species.

Reasons for getting inadequate seedling growth last year can be attributed primarily to Lack of experience with the facility and to lack of basic knowledge about growth require-ments for individual species and ecotypes. For example, easternmost sources of Douglas-fir set buds very prematurely--this can be corrected by ace of extended photoperiods. Many true firs simply grew too slowly--earlier sowing plus knowledge of optimum nutrition levels should solve the problem. Inadequate development of lateral roots, particularly in the upper half of the cavity, occurred too frequently. Lateral root development might be related to growing temperatures, watering, nutrition, physical nature of the potting mixture, or combinations of several factors. Research is required to solve this type of problem.

The low percentage of plantable hemlock can also be tied to lack of experience. June-sown seedlings were well developed by February, but many tops of those sown in July and August were too small and root systems were not developed enough to form tight plugs. Extending the photoperiod only stimulated top growth, and resulting lush foliage was badly damaged by Botrytis.

Growing Winter Crops

We originally intended to start the second crop, i.e., the shade-tolerant western hemlock, in August and utilize the early winter months for growing as well as condition-ing the seedlings. But this soon proved infeasible in our cloudy, wet winter climate. Low light intensities, weed and mold infesta-tions, failure of extended photoperiods to stimulate root growth, and high fuel costs convinced us to sow the second crop in June and condition the stock for outplanting during late fall and early winter. Also, customers prefer planting hemlock in mid-January rather than waiting until February or March.

Winter production may be more feasible in locations where sunshine is common and heat energy reasonably priced. Such a schedule has been devised for ponderosa pine in Montana (Huseby 1973). Care must be taken, however, to induce hardiness and meet seedling chilling requirements prior to outplanting. For example, 6 to 12 weeks of chilling at 40 degrees F (4.4 degrees C) are required for Douglas-fir (Wommack 1964), 14 weeks for maximum growth of western white pine (Steinhoff and Hoff 1972), and 6 to 8 weeks for seven species of spruce (Nienstaedt 1967). Neglecting to meet these biological needs could seriously affect survival and development of plantations.

Research Needs

Much can be gained by thoroughly searching the literature. Many past studies conducted in greenhouses and growth chambers that were thought to be mostly of academic value now have practical significance for production of containerized seedlings. But there is still a need for more basic research on growth and development of seedlings in controlled environments--especially on such neglected species as true firs and hemlock. Fully realizing the potential of greenhouse production is not possible until we know precisely the optimum conditions for grow-ing and conditioning seedlings to withstand the rigors of their planting sites.

Field performance of stock is, of course, the most important measure of success. The seedlings from Beaver Creek are being planted on most of the National Forests in Oregon and Washington. Participating field units are asked to install standardized test plots to compare containerized seedlings with stock from bare-root nurseries (Owston and Stein 1974). The first-year examinations of plots containing stock produced at Beaver Creek will be made in the fall of 1974. Within 5 years we hope to develop regionwide guidelines for use of containerized, greenhouse-grown seedlings on particular sites and in specific reforestation situations.

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Question: Have you considered using artificial light in the greenhouse to start earlier in the spring and run later into the fall?

Owston: We use incandescent light to extend photoperiod in the spring for western hemlock, high elevation true firs, and Douglas-fir from east of the Cascades, otherwise they tend to set bud prematurely. In the fall we shorten photoperiod to induce more rapid bud set and hardiness.

Question: How was root development 1 or 2 years after planting stock from the Beaver Creek greenhouse?

Owston: First year examinations of field plantings will be made this fall. Seedlings from the Beaver Creek greenhouse planted under excellent growing conditions in outdoor beds have shown good root egress and vigorous development.