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Introduction

The University of Idaho College of Forestry, Wildlife and Range Sciences operates a research nursery producing 750,000 containerized seedlings annually. The facility serves as a laboratory and offers practical experience to students in agriculture, forestry and forest nursery management. Reforestation seedlings produced at the nursery are annually planted on state lands, private forest industry lands, and on the University of Idaho Experimental Forest. Field data on outplanted seedlings, coupled with detailed crop histories maintained by the nursery, produce feedback for future crops. Microcomputers are used to monitor seedling development and guide cultural practices, yielding seedlings with high survivability and growth.

Western Larch

Western Larch (*Larix occidentalis* Nutt.) is an important timber species in the Inland Empire. Larch occurs from western Montana to eastern Oregon and Washington and northward into southern British Columbia (Rudolf 1974). In northern Idaho this species can occur in nearly pure stands or in mixtures with Douglas-fir and western white pine. Western larch grows best on deep, moist, porous soils in high valleys and on mountain slopes of northern and western exposure (Harlow et al. 1979). Tree heights average 125 to 180 feet (38 to 55 m), and stems are 3 to 4 feet (1 to 1.2 m) in diameter at breast height.

This deciduous conifer begins to bear cones at around 30 years of age, usually producing small crops annually and large crops irregularly. Seed production is hampered by the effects of frost and insects. Seeds per pound for northern Idaho western larch range from 140,000 to 175,000, with a mean of 160,000. Seed may be transferred 750 feet (229 m) in elevation and about 0.75 degrees latitude (Rehfeldt 1983).

Western larch has been cultivated since 1881 (Rudolf 1974). The following is a synopsis of the methodology used at the University of Idaho Forest Research Nursery to produce containerized western larch seedlings for research, conservation, and reforestation.

The Forest Research Nursery

Seedlings are grown in two 34- by 108-foot fiberglass greenhouses, connected by a head house. Each house is heated by two natural gas heaters and vented with two 48-inch exhaust fan and louver systems. Two 24-inch ventilating fans provide air and heat circulation through poly-tubes placed beneath the growing benches in each house. We feel poly-tubes placed in this manner, rather than overhead, aid in air circulation and drying beneath the benches and allow supplemental heat to rise through the trays. An evaporative cooling system and shutters along the north side of the facility are used for cooling. Photoperiod is extended by incandescent lamps at the intensity of 500 lux.

The pH of the well water averages 6.8. Irrigation is applied through an overhead travelling boom system. We generally sow numerous, small lots of several species, and the boom allows us to give specific irrigation, fertilization and pesticide attention to the individual lots. There are two booms per greenhouse, with nozzles every 16 inches. Fertilizers and pesticides are applied through the irrigation water by using a 1:100 injector.

Seed Quality Tests

Each lot of seed to be grown is evaluated for quality upon receipt. The evaluation includes seeds per pound, purity percentage, soundness, and germination.

Seeds Per Pound

Seeds per pound are calculated by weighing five replications of 100 seeds to the nearest 0.01 grams. The mean weight is then placed into this equation:

$$\text{Seeds per pound} = \frac{45{,}360}{\text{mean weight in grams of 100 seeds}}$$

Purity Percentage

Purity is determined by removing the "debris" from an 8-gram (2500-seed) sample of seed. Western larch seed can be cleaned during processing and should have above 95-percent purity.

$$\text{Purity \%} = \frac{\text{clean seed weight}}{\text{clean seed wt.} + \text{debris wt.}} \times 100$$

Soundness Percentage

The percentage of hollow seeds is determined by x-raying a 100- to 200-seed sample. This could also be achieved by cutting the same number of seed. If more than 5 percent of the seeds are hollow, the seed lot should be reprocessed by pneumatic or gravity means to eliminate the empty seeds.

Stratification and Germination Tests

The most important aspect of seed quality is how well the seed will germinate. Seed germination is tested, using greenhouse rather than optimum laboratory temperature conditions, so that accurate amounts of seed can be prepared for sowing.

Seed is placed into fine mesh bags and soaked 48 hours with running tap water to ensure imbibition. The mesh bags are placed into plastic bags, and a sample of seed is stratified for two stratification periods: 21 and 28 days at 33-36 °F (1-2 °C).

At the end of the stratification period, seed is removed and soaked 24 hours in running tap water. Four 100-seed replicates of each lot for each stratification period are placed into germination trays. Nonstratified seed for each lot (four 100-seed replications) is also germinated. Seed is germinated under 8 hours of light at 75 °F (18 °C). Cumulative counts are made at 7, 14, 21 and 28 days. At 28 days, any ungerminated seed are cut to determine if they are hollow or sound.

Sowing Calculations

After determining which stratification period gave the highest cumulative germination at 14 days, the total amount of seed needed for the crop can be determined. Using probability tables (see Tinus and McDonald 1979), the number of seeds needed per cell to achieve about 95-percent cell occupancy is determined. We then mathematically add 0.5 seed per cell to cover handling and sowing losses. Each lot is oversown 10 percent at the Research Nursery. With the given germination, the desired number of seedlings, purity, sound seed percentage, and seeds per pound, we can calculate the pounds of seed needed as follows:

$$\frac{\text{(Desired seedlings)} * \text{(Oversow factor)} * \text{(Seeds per cell)}}{\text{(Seeds per pound)} * \text{(Purity percent)} * \text{(Soundness percent)}}$$

Example:

With 70-percent germination, we find from the probability tables that 3 seeds per cell will give us 96 percent of the cells filled. To make sure we have enough seed to account for handling and sowing losses, we add 0.5 seed per cell for an average of 3.5 seeds per cell.

Given: 160,000 seeds per pound, 98-percent purity, 95-percent soundness, 25,000 trees desired and 10-percent oversow.

$$\frac{(25{,}000) * (1.1) * (3.5)}{(160{,}000) * (0.95) * (0.98)} = \frac{96{,}250}{148{,}960} = 0.65 \text{ lbs}$$

The required amount of seed is placed into mesh bags with no more than one-half pound per bag. The seed is stratified as discussed above, depending on which stratification period gave the best germination. Experience

Figure 1. Growing Regime for western larch.

Month	April	May	June	July
Outside Temp Max	55	65	70	74
Outside Temp Min	34	40	46	50

Week	-1	0 1	2 3 4 5 6 7 8	9 10 11 12 13
Growth Stage	Sow	Germ	Initial Growth	"Coasting"
Day Temp (F)		75-85	75-80	70-75
Night Temp (F)		65-70	65-70	60-65
Supplemental Light			500-lux Incandescent bulb	None
Irrigation	Mist during heat of day		Twice per week with nutrient solution. Medium near field capacity.	Leach with water and dry to wilting.
Fertilization		Acidify	Peters Conifer Starter and Calcium nitrate.	Micronutrients

at the nursery shows most larch lots perform best at 28 days cold stratification.

Growing Regime (Fig. 1)

Environmental Monitoring

The basic environmental factors are minimum and maximum temperature, medium temperature, humidity, and the pH and electrical conductivity of irrigation, fertigation water (irrigation water with injected liquid fertilizer in solution), and leachate from the growing medium.

Four maximum/minimum thermometers are placed throughout the greenhouse to record the daily temperature range, and a hygrothermograph charts the temperature and relative humidity patterns on a weekly basis. Medium temperatures are obtained with a soil thermometer. Irrigation and fertigation water are monitored to keep the applied solution between pH 5.5 and 6.0. Growing medium leachate is monitored also to detect increases in medium pH. Leachate conductivity will indicate any serious increases in salt accumulation within the medium that may become detrimental to the seedlings. Timus and McDonald (1979) discuss these topics and instruments in great detail, including calibration of hygrothermographs.

August	September	October	November	December	January	February
14 15 16 17 18	19 20 21 22 23	24 25 26 27	28 29 30 31	32 33 34 35 36	37 38 39 40	41 42 43
Bud Initiation and Natural Hardening						Lifting for Refrig. Storage
60-70	50-60	45-55	32-35		32-35	
50-60	45-55	40-45	30-32		30-32	
84 50	68 42	57 36	38 27	29 17	35 24	38 26
Irrigate when rootplug is barely moist.					Irrigate so rootplugs at field capacity before going into refrigerated storage.	
		Calcium nitrate and micronutrients				

Desired Seedling Characteristics

Outplanting data for western larch indicate the need for seedlings with large root collar diameters (caliper), well-formed buds, high root growth potential and a low ratio between shoot and root dry weights. This regime produces seedlings averaging 20 cm in height, 2.8 to 3.2 mm in caliper, with well-formed buds and high root growth potential (Fig. 2). Many Idaho sites may be subjected to three months of drought after the seedlings are planted. We feel the short heights rendered by this regime are a distinct advantage in preventing disease within the greenhouse and in plantation success.

Container Type, Growing Medium, and Tray Filling

Western larch is grown in 4-cubic-inch Ray Leach Pine Cells, which have 200 cells per tray, or 100 cells per square foot. Seedlings can also be produced in styrofoam containers. In general, seedlings with larger root collar diameters can be produced in containers with wider spacing between cells. Before sowing, previously used trays and cells are thoroughly washed and dipped into a 10-percent bleach solution (1 part laundry bleach to 9 parts water). After the trays and cells have dried, the bottom 1 inch of the cells is remoistened with tap water, and the tray and cells are run through the filling machine. Moistening the bottom of the cells causes dry growing medium to adhere and not fall through the drainage holes. Cells are machine-filled with a 50/50-percent peat-vermiculite growing medium. The pH of this mix averages about 4.2. Seeds are sown with a vacuum seeder and covered with about 1/5-to 3/8-inch of either Target Forestry Sand® or washed white grit.

Germination Phase

Once sowing is complete, the containers are irrigated until the medium is thoroughly moist. Phosphoric acid is injected into the irrigation water to adjust pH to around 6.0. Light mists of acidified irrigation water are applied to keep the zone around the germinating seeds slightly moist.

Some germinants may show symptoms of damping-off fungi. Common fungi associated with damping-off include *Pythium, Rhizoctonia, Phytopthora,* and *Fusarium.* Symptoms of damping-off are rotted stems at the groundline, often with an apparently healthy top lying on its side. The germinant, and preferably the entire cell, should be removed from the greenhouse to prevent disease spread. Irrigation water can cause spores to splash to other seedlings, thereby spreading the disease. Disease incidence declines as soon as the stems begin to lignify, generally in 3 to 4 weeks (Tinus and McDonald 1979). At the Research Nursery, we rely on these proper cultural practices to reduce damping-off: maintaining low medium pH with acidified irrigation water, using grit to allow air circulation around the root collar zone, keeping relative humidity low, delaying nitrogen fertilization until germination is complete, and using medium fungicide drenches. We apply one application of the fungicide Banrot® (a soil drench) at 4 ounces per 100 gallons immediately after germination is complete as a preventative method against root rots.

Seedlings with retained seed coats may show symptoms of *Fusarium* cotyledon blight, needle necrosis originating at the retained seed coat. These seedlings are promptly removed to prevent spread of *Fusarium* and to rid the growing area of dead seedlings, which may host disease organisms.

Cells are thinned to one seedling by removing the extra germinants with tweezers or fingers as soon as the majority of seedlings have shed their seed coats. Thinning is more efficient if done before lateral root development. Seed coats with high germination energy tend to shed their seed coats rapidly.

Germination is generally complete within 10 to 14 days, and seed coats are shed within 21 days, at which time the seedlings enter the "initial growth phase."

Initial Growth Phase

The objective of this phase is to develop root systems on the germinants. Large concentrations of phosphorous and potassium are applied to achieve the desired growth.

Nutrients are applied during each twice-weekly irrigation to meet targeted growth (Fig. 3). During the initial growth phase, week 2 through week 8, we inject a liquid fertilizer solution of Peters Conifer Starter® (7-40-17) at a rate of 65 ppm N and calcium nitrate (15.5-0-0-10) at a rate of 23 ppm N, supplemented with phosphoric acid to adjust fertigation water pH to below 6.0 (Table 1).

During this growth phase, day temperatures of 75-80 °F (24-27 °C) and night temperatures around 65 °F (18 °C) are maintained. Medium temperature (recorded at 8 a.m. daily) averages 68 °F (20 °C). Photoperiod is extended to 18 hours. At the end of week 8, the medium is leached with copious amounts of irrigation water to remove any salt build-up. Also during week 8, seedling foliage is tested for nutrient concentrations to detect any deficiencies.

Weather conditions, particularly the amount of sunshine, have a strong influence on initial growth of seedlings. Weekly height and caliper (root collar diameter) measurements are taken on 10 predetermined sample trees within each lot. If height growth is occuring faster than our target growth curve, rates of applied nitrogen are reduced by lowering the rate of applied calcium nitrate to about 12 ppm. Conversely, if growth is behind targeted levels, rates of applied nitrogen are increased by increasing the rate of applied calcium nitrate to 46 ppm.

During this phase, seedlings may show *Fusarium* root rot symptoms: chlorotic needles that turn necrotic, resulting in the seedling turning brown to red-brown and dying. The seedling tip may also wilt into a shepherd's crook. Infected seedlings and cells should be removed as soon as evident.

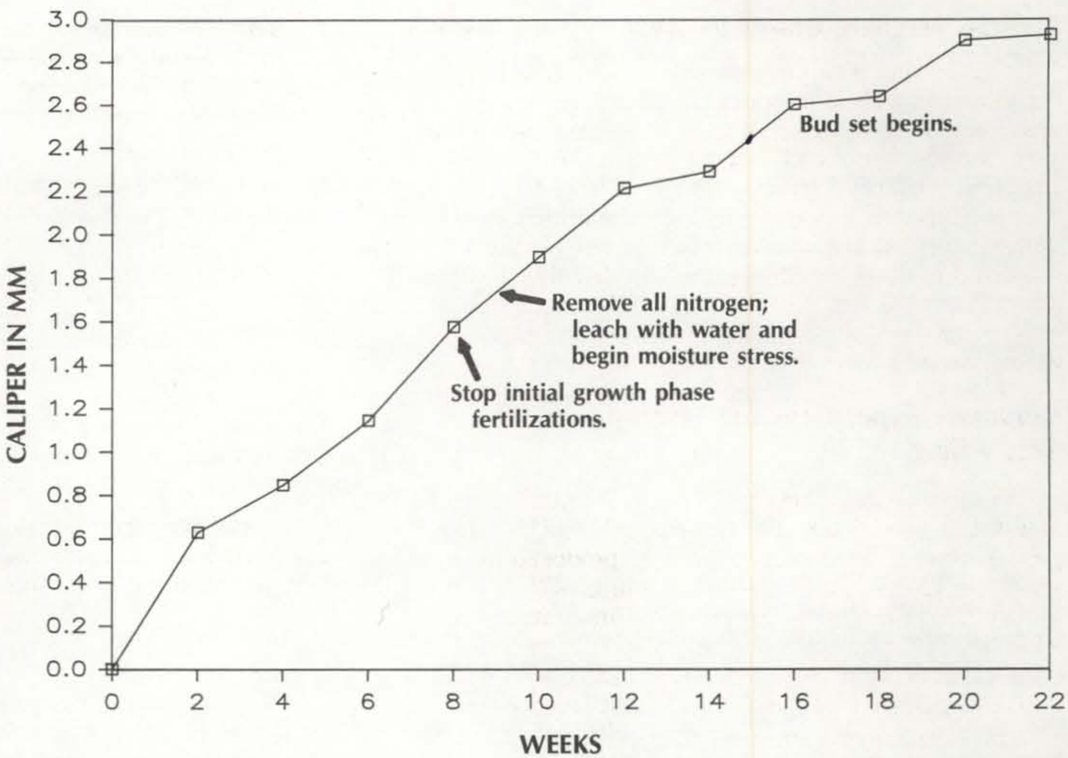

Figure 2. Western larch target caliper growth.

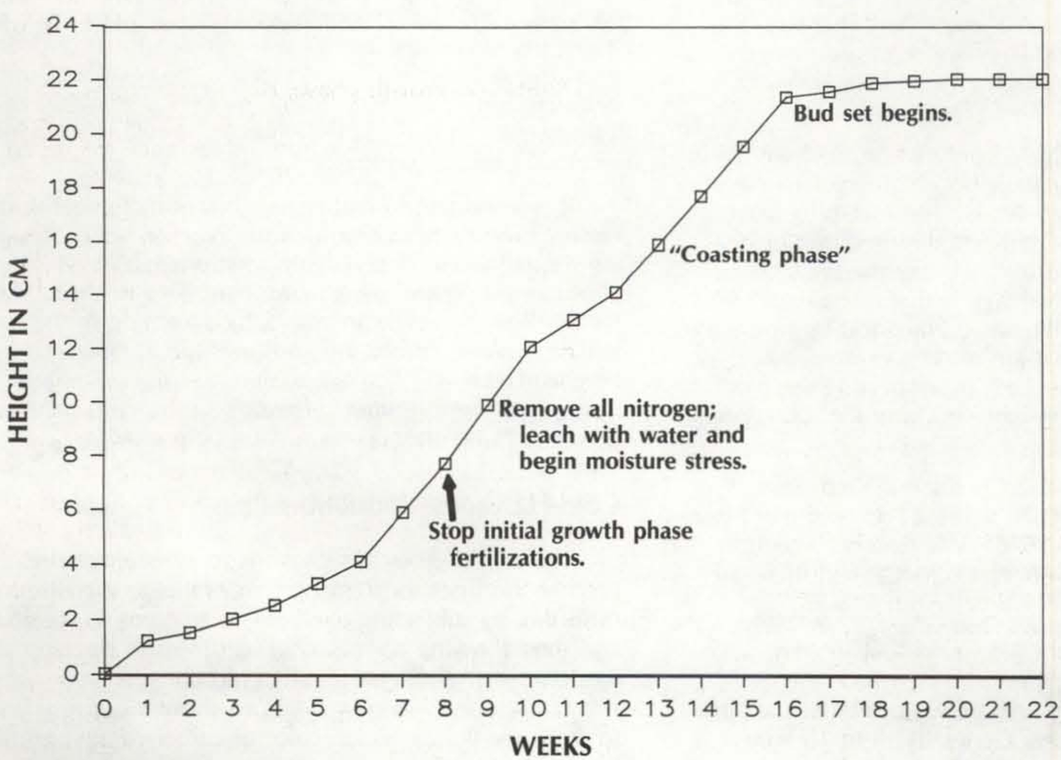

Figure 3. Western larch target height growth.

Table 1. Fertilizer levels for initial growth phase.

	Nutrients in ppm													
Mineral Nutrient Sources	NO_3	NH_4	P	K	S	Ca	Mg	Fe	Cl	B	Mn	Zn	Cu	Mo
Well water	2		2		15	28	10	0.24	2.00		0.07	0.40	0.01	
Peters Conifer Starter[1]	33	32	168	135	2			1.92		0.14	0.29	0.29	0.29	0.03
Phosphoric acid[2]			41											
Calcium nitrate[3]	21	2				28								
Total	56	34	211	135	17	56	10	2.16	2.00	0.14	0.36	0.69	0.30	0.03

[1] Applied at 8 lbs. per 1000 gal. (65 ppm N).
[2] Applied at 20 oz. per 1000 gal. (41 ppm P).
[3] Applied at 1.25 lbs. per 1000 gal. (43 ppm N).

Bud Initiation and Root Collar Diameter Growth

The objective of this phase is to withhold nutrients and moisture, creating a stressed condition in the seedlings so that height growth will cease, terminal buds will develop, and root collar diameter will increase. Beginning in week 9, the seedlings are removed from the twice weekly irrigation/fertilization schedule. Levels of applied nitrogen are eliminated (Table 2).

Seedlings are now irrigated only when medium has become barely moist. Our greenhouse technicians daily select seedlings at random, remove the root plug from the cell, and visually examine and feel the medium for dryness. Although quite subjective, we feel this method has some advantages. One advantage is that disease and insects can be surveyed at the same time, and by random selection, the seedlings that are seldom examined due to inaccessibility are also checked. By inspecting the root plug, we also gain some insight into how the root system is developing.

The extended photoperiod is discontinued. Day temperatures are set for 60-70 °F (16-21 °C) and night temperatures for 50-60 °F (10-16 °C). We maintain medium temperatures between 62-68 °F (17-20 °C) with these air temperature ranges.

Research at the nursery has found that western larch go through a "coasting" phase, during which the seedlings continue to grow, regardless of nutrient applications or moisture conditions. Generally, 8 to 10 weeks later, or week 15 through week 17, the larch begin to set terminal buds. Total height at terminal bud set is about twice that of pre-bud initiation height. Our larch generally give us a 100-percent increase in height as they "coast" through this phase.

The western larch generally do not look severely chlorotic during this growth period. Seedlings may wilt during the heat of the day. We apply cooling mist to the seedlings, and they respond by regaining turgor. We may allow the larch seedlings to wilt like this for 2 or 3 days in a row in an attempt to dry down the medium until it is barely moist. We feel this helps with lateral bud development and eventually signals the seedling to induce terminal bud formation.

It is important to realize this "coasting" effect. Our research indicates that no cultural practice short of inducing mortality will stop height growth, although photoperiod control by shading may be a method. Plan for the "coast" height increases by switching to the bud initiation phase before the seedlings are at desired heights. Larch will "coast" to desired heights without giving you the frustration of watching the crop increase in height with no alternatives for stopping growth.

Cold-Hardiness Induction Phase

The objective of this phase is to physiologically prepare the trees for freezing temperatures. We accomplish this by subjecting the trees to ambient temperatures and thus allowing normal cold hardiness to develop. The western larch will look slightly chlorotic. As early as the first of October, lots may begin to show a purplish color to their needles as an indicator of carbohydrate accumulation and the beginning of physiological changes preparing the seedling for winter.

Table 2. Fertilizer target levels for bud initiation phase.

	Nutrients in ppm													
Mineral Nutrient Sources	NO_3	NH_4	P	K	S	Ca	Mg	Fe	Cl	B	Mn	Zn	Cu	Mo
Well water	2		2		15	28	10	0.24	2.00		0.07	0.40	0.01	
Phosphoric acid[1]			41											
Magnesium sulfate[2]					24		31							
Manganous sulfate[3]					11						18.00			
Solubor (Boron)[4]										0.46				
Sequestrene 330 (Chelated iron)[5]								2.25						
Calcium nitrate[6]	42	4				56								
Total	44	4	43		50	84	41	2.49	2.00	0.46	18.07	0.40	0.01	

[1] Applied at 20 oz. per 1000 gal. (41 ppm P).
[2] Applied at 2 lbs. per 1000 gal. (24 ppm S and 31 ppm Mg).
[3] Applied at 10 oz. per 1000 gal. (11 ppm S and 18 ppm Mn).
[4] Applied at 0.3 oz. per 1000 gal. (0.46 ppm B).
[5] Applied at 3 oz. per 1000 gal. (2.25 ppm Fe).
[6] Applied at 2.50 lbs. per 1000 gal. (46 ppm N), but only applied after early October.

Beginning around mid-October, we allow air temperatures within the greenhouse to go to ambient (Figure 1). Temperatures remain about ambient until the seedlings are packed for cold storage in January. However, the minimum temperature allowed in the greenhouses is 28 °F (- 2 °C), and the root plug is not allowed to remain frozen. From late October until the trees are put into cold storage, irrigation is necessary only about once every 3 to 4 weeks. During these irrigations, calcium nitrate is applied at a rate of 46 ppm N. These act as a nutrient reserve within the medium for use by the tree once it is outplanted.

From mid-October until the seedlings are shipped for planting, infection by *Botrytis* is inevitable. The symptoms are webs of gray to gray-brown mycelium growing on and around dead and dying needles that have either fallen from the seedlings or are still attached. Tan or brown-watery stem lesions may also be present. Levels of *Botrytis* will increase as needles begin to drop. Careful crop sanitation is the greatest asset in fighting the fungus. Seedlings killed by *Fusarium* root disease should be removed immediately, especially taller seedlings that may have died during the stress period.

These seedlings provide a superb microsite for *Botrytis* development. We find that careful sanitation keeps infection under control. Spot outbreaks of the disease can often be eliminated by removing the infected dead needles and the surrounding dead needles from the trays in a one-tray radius. If part of the crop is shipped for fall planting, spreading the remaining trays apart to increase air circulation also reduces fungal incidence.

Fungicides can be used if the outbreak is severe or sanitation was not observed. Applications of Captan® or Benlate® may bring control. Unfortunately, chemical control without proper sanitation may just postpone disease occurrence until the seedlings are placed into cold storage.

Extraction and Cold Storage

Seedlings are well watered before being removed from their containers and wrapped with a Saran-like plastic in bundles of 25. The stickiness of the plastic keeps the bundle firmly packed, which maintains plug integrity and prevents moisture loss. Bundles of trees for public conservation sales are placed four to a poly-bag (100 seedlings total), which is sealed before going to refrigerated storage. Bundles of trees for large reforestation working agreements are placed into poly-lined wax boxes that also are sealed airtight before placing in cold storage. The refrigerated storage is kept at 33-34 °F (.05-1 °C) with relative humidity near 100 percent. Seedlings have been stored successfully in this manner for 5 months without the need for irrigation.

Seedlings in cold storage are routinely inspected for disease problems. *Botrytis* is the most serious disease. Preventative methods are the best way to control this problem and include the following: (1) pull, wrap and store only vigorous, disease-free seedlings; (2) store seedlings for the shortest duration possible; (3) routinely inspect a sample of each lot, especially lots containing significant quantities of dead needles, as these can be an initial food base for the pathogen; (4) immediately ship seedlings showing mold problems if possible (Sutherland and Van Eerden 1980). Mold growth can also be reduced by dropping the storage temperature for fully hardened seedlings to below freezing.

Conclusion

This regime has been very successful. Requested quantities of seedlings meeting strict physiological and morphological requirements are achieved or exceeded with a minimum oversow. Seedlings grown under this regime average 20 cm in height and 2.8 to 3.2 mm in caliper. First year outplanting survival on the University of Idaho Experimental Forest has exceeded 94 percent each of the past 6 years, and seedlings are 35 to 45 cm tall after one growing season. Some 4-year-old larch have been over 3 meters tall. We feel the most important aspect of any growing regime is continually monitoring the seedling growth as the regime progresses. Height and caliper measurements can then be used to modify or change the regime as the growth of the seedlings dictates during one growing season and between growing seasons. This regime has been developed from 6 years of records on fertilizer application rates and the resulting seedling growth, and will certainly be modified in the pursuit of high-quality western larch seedlings

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