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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.

Ponderosa Pine

One of the most important timber species in the western United States is ponderosa pine (*Pinus ponderosa* Dougl. ex Laws). In northern Idaho this species occurs from 2000 to 7000 feet (610 to 2135 m). Ponderosa pine is not exacting in soil requirements, but does best on moist sites (Harlow et al. 1979). Tree heights average 60 to 180 feet (18 to 55 m) and stems are 1 to 4 feet (0.3 to 1.2 m) in diameter at breast height.

This two- or three-needled pine begins to bear cones around 20 years of age, usually producing small crops annually and large crops every 5 to 7 years. Seeds per pound for northern Idaho ponderosa pine range from 8,500 to 12,000, with a mean of 10,000. Seed may be transferred 750 feet (229 m) in elevation and 0.75 degrees latitude (Rehfeldt 1980).

Ponderosa pine has been cultivated since 1826 (Krugman & Jenkinson 1974). The following is a synopsis of the methodology used at the University of Idaho Forest Research Nursery to produce containerized ponderosa pine 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 an 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 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:

$$\text{Seeds per pound} = \frac{45360}{\text{mean weight in grams of 100 seeds}}$$

Purity Percentage

Purity is determined by removing the "debris" from a 90-gram (2500-seed) sample of seed. Ponderosa pine seed is easily cleaned during processing and should have at least 99-percent purity. Thus:

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

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 seeds. If more than 3 percent of the seeds are hollow, the seed lot should be reprocessed by pneumatic or gravitational 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.

We bleach-treat ponderosa pine seed prior to stratification. Past experience with seed of unknown collection method or handling necessitated chemically treating seed coats to reduce the incidence of disease fungi. Although the treatment does not eradicate all organisms on the seed coat (James and Genz 1981), we feel it helps reduce early seedling mortality when used with proper cultural methods, while not detrimentally affecting germination. The seed sample is placed into a fine mesh bag and soaked in a 40-percent bleach solution (2 parts common laundry bleach (5.25% sodium hypochlorite) to 3 parts tap water) for 10 minutes with hand agitation (Wenny and Dumroese 1987). The agitation is important to ensure complete sterilization. Seed is then thoroughly rinsed to remove all bleach 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 each of three stratification periods: 40, 45 and 60 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. Non-stratified seed for each lot (four 100—seed replications) is also germinated. Seed is germinated under 8 hours light at 75° F (24° C) and 16 hours dark at 65° 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 seed needed per cell to achieve around 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 a given germination, the desired number of seedlings, purity, sound seed percentage, and seeds per pound, we calculate the pounds of seed needed as follows:

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

Example:

With 80-percent germination, from the probability tables we find that 2 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 2.5 seeds per cell.

Given: 10,000 seeds per pound, 99-percent purity, 97-percent soundness, 25,000 trees desired and 10-percent oversow.

$$\frac{(25{,}000) * (1.1) * (2.5)}{(10{,}000) * (0.99) * (0.97)} = \frac{68{,}750}{9{,}603} = 7.2 \text{ lbs}$$

Figure 1. Growing regime for ponderosa pine.

Month		April	May	June
Week	-1	0 1	2 3 4 5 6	7 8 9 10 11
Growth Stage	Sow	Germ	Initial Growth	Accelerated Growth
Day Temp		75-85	75-80	70-75
Night Temp		65-70	65-70	60-65
Outside Temp Max		55	65	70
Outside Temp Min		34	40	46
Supplemental Light			500 - lux Incandescent bulb	
Irrigation		Mist during heat of day	Twice per week with nutrient solutions. Medium near field capacity.	
Fertilization		Acid-ify	Peters Conifer Starter and calcium nitrate.	Peters Conifer Grower and calcium nitrate.

The required amount of seed is placed into mesh bags with no more than two pounds per bag. The seed is surface sterilized and stratified as discussed previously, depending on which stratification period gave the best germination. Experience at the nursery shows most ponderosa pine lots perform best with 40 days of 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 also monitored 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. Tinus and McDonald (1979) discuss these topics and instruments in great detail, including calibration of hygrothermographs.

July	August	September	October	November	December	January	February
12 13 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	
74 50	84 50	68 42	57 36	38 27	29 17	35 24	38 26
None							
Leach with water and dry to wilting	Irrigate when rootplug is barely moist.					Irrigate so rootplugs at field capacity before going into refrigerated storage	
Micro-nutrients	Alternate Peters Conifer Finisher but micro-nutrients each irrigation.		Add calcium nitrate to each irrigation receiving Peters Finisher formulation.				

Desired Seedling Characteristics

Outplanting data for ponderosa pine 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 15 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 plantation success.

Container Type, Growing Medium, and Tray Filling

Ponderosa pine 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 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 around 4.2. Seeds are sown with a vacuum seeder and covered with about 1/5-3/8-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. Vigorous lots of ponderosa pine show through the grit in as little as three days.

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 orginating 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. Ponderosa pine seedlings develop lateral roots rapidly, and thinning is more efficient if done before lateral root development. Seedlots 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, making them capable of incorporating large amounts of nutrients and producing rapid shoot growth during the accelerated growth phase. Large concentrations of phosphorous and potassium are applied to achieve the desired growth.

Nutrients are applied during each twice-weekly irrigation to meet target growth (Fig. 3). During the initial growth phase, week 2 through week 6, 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 six, the medium is leached with copious amounts of irrigation water to remove any salt build-up prior to beginning the accelerated growth phase. Also, during week six, seedling foliage is tested for nutrient concentrations to detect any deficiencies.

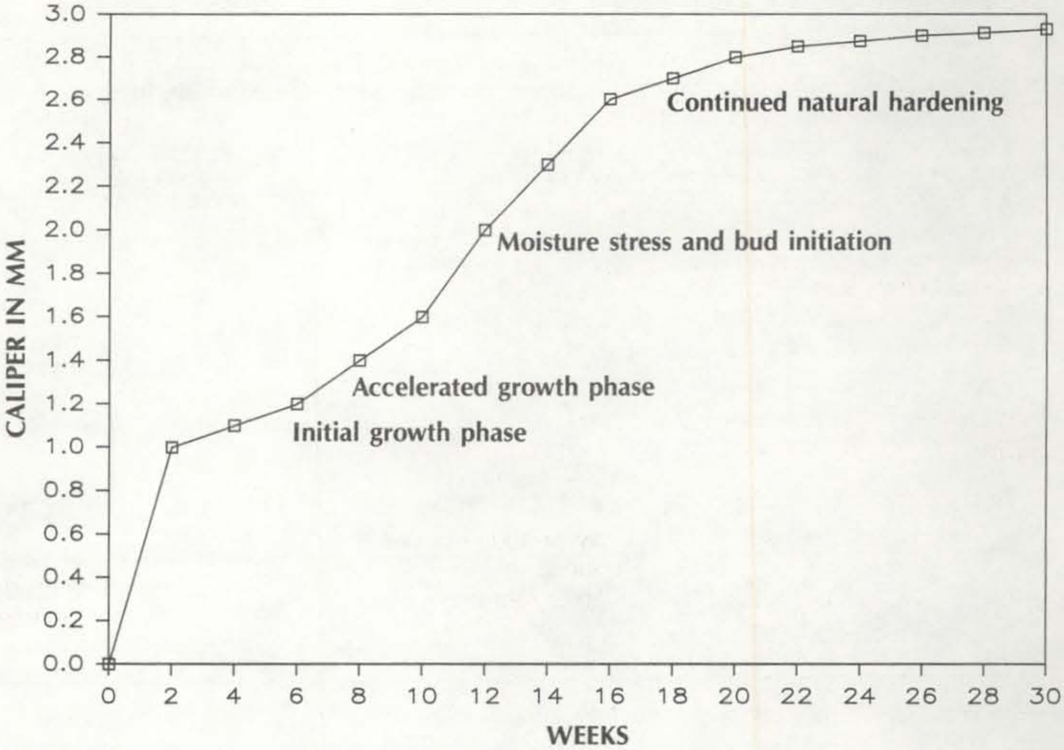

Figure 2. Ponderosa pine target caliper growth.

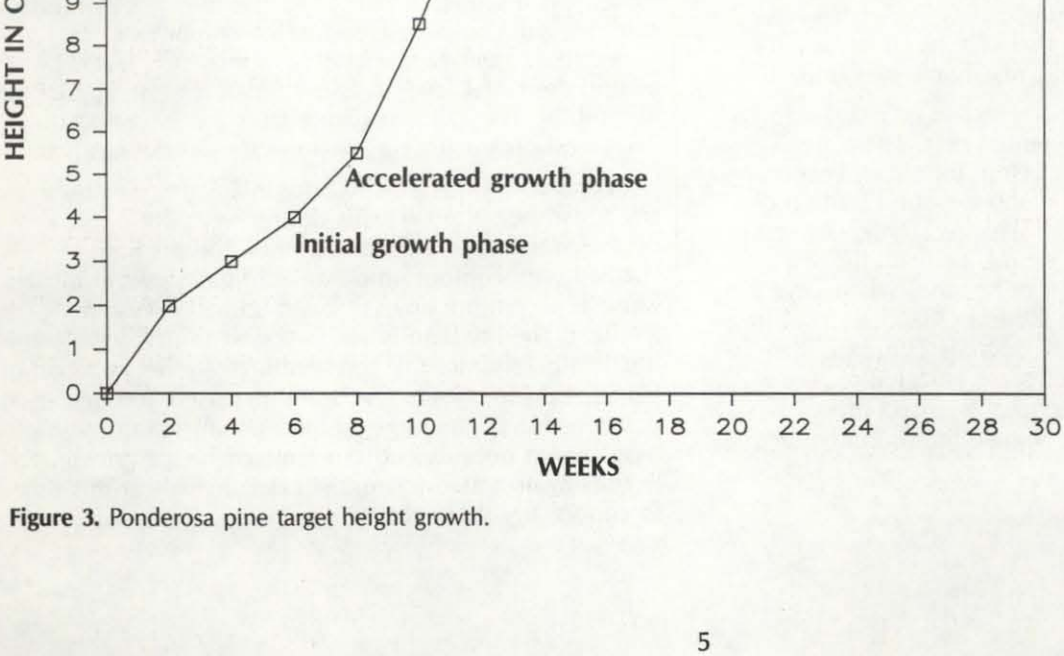

Figure 3. Ponderosa pine target height growth.

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. (23 ppm N).

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

Cutworms are another potential pest. These moth larvae attack young seedlings before the stems become woody and will eat any of the above-ground portion of the seedling, often leaving only stumps. These larvae are night feeders, hiding during the day beneath the grit when small or under the trays or benches when large. The larvae can be controlled either by hand removal or by spraying with an insecticide such as Dursban® late in the day or evening. Adult moths are attracted to the greenhouse by the photoperiod lights. Insect-proof greenhouses will exclude the female moths (Sutherland and Van Eerden 1980).

Accelerated Growth Phase

The objective of this phase is to achieve target seedling height while increasing root collar diameter. This phase begins during the seventh week. Levels of phosphorous and potassium are reduced and nitrogen concentrations increased to promote shoot growth.

Peters Conifer Grower® (20-7-19) is the main fertilizer, applied at 60 ppm N supplemented with calcium nitrate (15.5-0-0-10) at 23 ppm N, micronutrients, and phosphoric acid (Table 2). Nutrients are still applied during the twice weekly irrigations. Photoperiod and temperatures are the same as for the initial growth phase.

Seedling heights are compared to the target growth curve, and if growth is exceeding the target rate, nitrogen rates are reduced by decreasing the rate of calcium nitrate to 12 ppm N. Conversely, if growth is lagging behind the target level, calcium nitrate can be applied at 46 ppm N. The calcium nitrate rates are increased or decreased depending on what the growth curves dictate.

Ponderosa pine grown under this regime, without any stress, begin to set buds during week eleven. If height growth is at the desired level, the medium is leached with copious amounts of irrigation water during week 12 to remove any salt build-up and excessive fertilizer. The medium is then allowed to dry down until it is just barely moist. If the seedlings are below target height, calcium nitrate levels are increased and the leach postponed until the target is met. Usually, ponderosa pine growth does exceed our targeted height growth. Foliage is again tested for nutrient deficiencies at this time to correct any shortages.

Table 2. Fertilizer target levels for accelerated 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 Grower[1]	35	25	9	47	2		1	1.20		0.08	0.18	0.18	0.18	0.02
Phosphoric acid[2]			41											
Magnesium sulfate[3]					24		31							
Manganous sulfate[4]					11						18.00			
Solubor (Boron)[5]										0.46				
Sequestrene 330 (Chelated iron)[6]								2.25						
Calcium nitrate[7]	21	2				28								
Total	58	27	52	47	52	56	42	3.69	2.00	0.54	18.25	0.58	0.19	0.02

[1] Applied at 2.5 lbs. per 1000 gal. (60 ppm N).
[2] Applied at 20 oz. per 1000 gal. (41 ppm P).
[3] Applied at 2 lbs. per 1000 gal. (24 ppm S and 31 ppm Mg).
[4] Applied at 10 oz. per 1000 gal. (11 ppm S and 18 ppm Mn).
[5] Applied at 0.3 oz. per 1000 gal. (0.46 ppm B).
[6] Applied at 3 oz. per 1000 gal. (2.25 ppm Fe).
[7] Applied at 1.25 lbs. per 1000 gal. (23 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. During this growth phase, the seedlings are removed from the twice weekly irrigation/fertilization schedule. Levels of applied nitrogen are reduced and phosphorous and potassium levels increased to achieve the objective.

Seedlings are now irrigated only when medium has become barely moist. Our greenhouse technicians daily select seedlings at random, remove the rootplug 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 because of inaccessibility are also checked. By inspecting the root plug, we also gain some insight as to how the root system is developing.

When irrigation is necessary, Peters Conifer Finisher® (4-25-35) is the main fertilizer, along with micronutrients and phosphoric acid (Table 3). Micronutrients and phosphoric acid are applied during each irrigation, and the conifer finisher is applied every other irrigation.

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

Once the buds are well developed, generally by week 20 to 24, (mid- to late September), calcium nitrate can be applied at low levels (23 ppm N) during each irrigation to green the trees (allow them to recover) from their stressed status and to provide a source of necessary calcium.

Table 3. 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	
Peters Conifer Finisher[1]		24	66	174	2		2	2.40		0.15	0.36	0.36	0.36	0.03
Phosphoric acid[2]			41											
Magnesium sulfate[3]					24		31							
Manganous sulfate[4]					11						18.00			
Solubor (Boron)[5]										0.46				
Sequestrene 330 (Chelated iron)[6]								2.25						
Calcium nitrate[7]42	4				56									
Total	44	28	109	174	52	84	43	4.89	2.00	0.61	18.43	0.76	0.37	0.03

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

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, thus allowing normal cold-hardiness to develop. The ponderosa pine may appear slightly chlorotic, and some lots may begin to show a purplish color of needles and stems as an indicator of carbohydrate accumulation and the beginning of physiological changes preparing the seedling for winter.

Beginning around mid-October, we allow air temperatures within the greenhouses to go to ambient (Fig. 1). However, the minimum temperature allowed in the greenhouses is 28° F (-2° C), and the root plug is not allowed to remain frozen. Temperatures remain about ambient until the seedlings are packed for cold storage in January. From late October until the trees are put into cold storage, irrigation is necessary only about once every three to four weeks. During these irrigations, accelerated growth phase fertilizer rates are applied. These act as a nutrient reserve within the medium for use by the tree when out-planted.

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, which are also sealed airtight before placing in cold storage. The refrigerated storage is kept at 33-34° F (0.5° 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. The most serious disease is caused by fungi of the genus *Botrytis*. The symptoms are webs of gray to gray-brown mycelium growing through the tops of the seedlings, especially in the center of bundles. Tan or brown-watery stem lesions may also be present. 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 which can serve as an initial food base for the pathogen; (4) ship seedlings showing mold problems immediately, 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 15 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 93 percent each of the past six years, and seedlings are 25 to 35 cm tall after one growing season. The bottlebrush effect, or "planting shock" growth pattern, does not occur even under abnormally dry growing seasons. 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. The regime has been developed from six years of records on fertilizer applications rates and the resultant seedling growth, and will certainly be modified in the pursuit to high-quality ponderosa pine seedlings.

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