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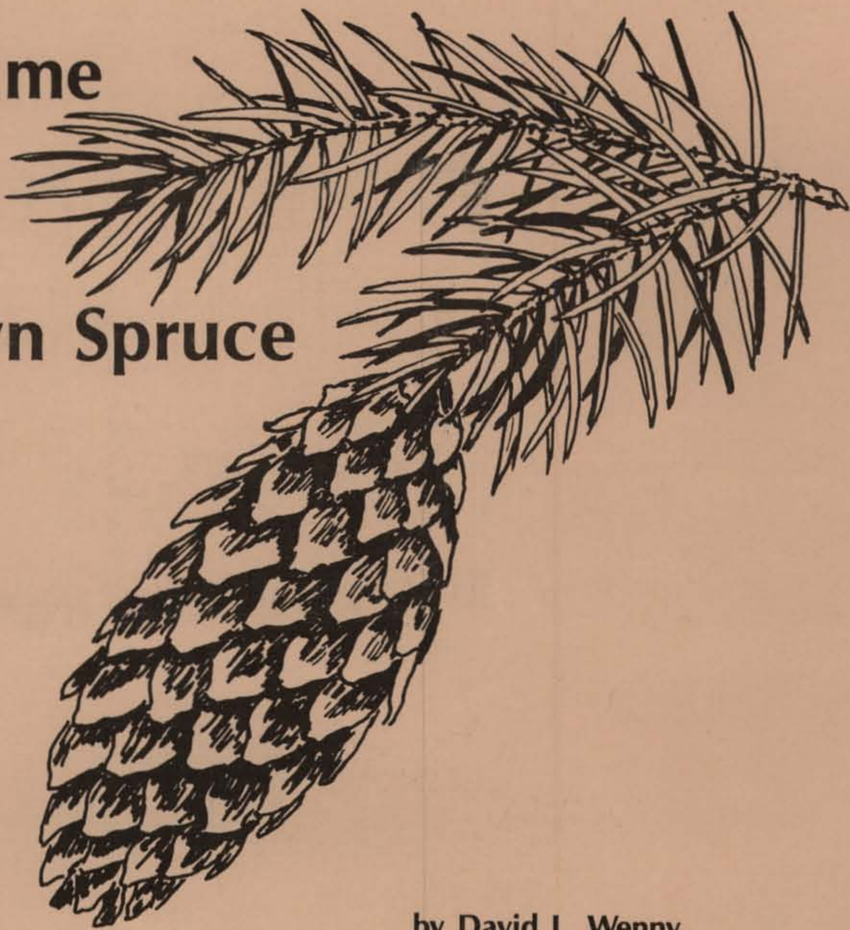

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Introduction

The University of Idaho College of Forestry, Wildlife and Range Sciences operates a research nursery producing 925,000 container-grown seedlings annually. The facility serves as a laboratory and offers practical experience to students in agriculture, forestry and forest nursery management.

Three spruce species are annually grown at the facility: Engelmann, Colorado blue, and Norway. Engelmann spruce is grown primarily for reforestation, and seedlings are annually planted on state lands, private forest industry lands, and on the University of Idaho Experimental Forest. Blue and Norway spruce seedlings are planted for conservation purposes throughout Idaho. Field data on outplanted seedlings, coupled with detailed crop histories maintained by the nursery, produce feedback for future crops. Microcomputers help monitor seedling development and guide cultural practices, yielding seedlings with high survivability and growth.

Engelmann, Colorado Blue, and Norway Spruce

Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), an Idaho native, reaches its maximum size on deep, rich, loamy soils of high moisture content. Engelmann spruce can occur in pure stands, or in mixed stands in northern Idaho with Douglas-fir, subalpine fir, western hemlock, and western white pine (Harlow et al. 1979). This tree can attain a height of 100 feet (30 m) and a diameter of 18 to 30 inches (45 to 76 cm).

Colorado blue spruce (*Picea pungens* Engelm.) ranges from northwestern and central Utah south along the mountains to south-central New Mexico and southeastern Arizona. Blue spruce is widely grown for conservation and ornamental plantings. This tree can reach heights of 70 to 90 feet (21 to 27 m) and 2 feet (61 cm) in diameter (Harlow et al. 1979).

Norway spruce (*Picea abies* (L.) Karst) is native to Europe, but has been planted extensively for conservation and timber production. This species is extremely hardy and wind resistant, with fast growth to 100 feet (30 m). As Norway spruce matures, its youthful pyramidal growth is replaced with strongly drooping branchlets.

Engelmann and blue spruce begin to bear cones around 20 years of age, but Norway spruce may take 30 to 50 years to bear cones. Seeds per pound for northern Idaho Engelmann spruce range from 150,000 to 225,800 with a mean of 175,000 (330,750 to 497,900 with a mean of 385,900 seeds per kilogram). Blue spruce averages 100,000 seeds per pound, while it takes an average of 64,000 Norway spruce seeds to weigh one pound (220,500 and 141,100 seeds per kilogram, respectively; Safford 1974).

Norway spruce has been in cultivation for over 400 years, while blue and Engelmann spruce have been grown since 1862 (Safford 1974). The following is a synopsis of the methodology used at the University of Idaho Forest Research Nursery to produce container-grown spruce seedlings for research, conservation, and reforestation.

The Forest Research Nursery

Seedlings are grown in two 34- by 108-foot (10- by 33-m) fiberglass greenhouses, and one 30- by 96-foot (9-by 29-m) double-poly greenhouse, all connected by a head house. Each greenhouse is heated by two natural gas heaters, and vented with two 48-inch (122-cm) exhaust fan and louver systems. Two 24-inch (61-cm) 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. Recent research also indicates that this reduces foliar disease incidence (Peterson and Sutherland 1990). 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 with nozzles every 8 inches (20 cm). 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. Fertilizers and pesticides are applied through the irrigation water using a 1:100 injector.

Seed Quality Tests

Each lot of seed is evaluated for quality upon receipt. The evaluation determines 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:

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

$$\text{Seeds per kilogram} = \text{mean weight in grams of 100 seeds} * 1000$$

Purity Percentage

Purity is determined by removing the "debris" from a 10-gram (blue and Engelmann) or a 20-gram (Norway) (2500-seed) sample. Spruce should be cleaned during processing and exhibit at least 95-percent purity.

$$\text{Purity \%} = \frac{\text{clean seed weight}}{\text{clean seed weight} + \text{debris weight}} * 100$$

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.

The seed sample is placed into a fine mesh bag 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 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 stratified lot are placed into germination trays. Non-stratified seed for each lot (four 100-seed replications) are also germinated. Seed are 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 treatment gives the highest cumulative germination at 21 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 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 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:

$$\frac{\text{(desired seedlings)} * \text{(oversow factor)} * \text{(seeds per cell)}}{\text{(seeds per pound)} * \text{(purity percent)} * \text{(soundness percent)}}$$

Example:

For Engelmann spruce with 88-percent germination, we find from the probability tables that 2 seeds per cell will give us 99 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.

Figure 1. Growing Regime for Engelmann, Colorado Blue, and Norway spruces.

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. Leach with water during week 6.	
Fertilization		Acidify	Peters Conifer Starter and micronutrients.	Peters Con. Grower and micros. alternated with calcium nitrate.

Given: 175,000 seeds per pound (385,875 seeds per kilogram), 95-percent purity, 98-percent soundness, 25,000 trees desired, and 10-percent oversow.

$$\frac{(25{,}000) * (1.1) * (2.5)}{(175{,}000) * (0.95) * (0.98)} = \frac{68{,}750}{162{,}925} = 0.42 \text{ lbs.}$$

$$\frac{(25{,}000) * (1.1) * (2.5)}{(385{,}875) * (0.95) * (0.98)} = 0.19 \text{ kg}$$

The required amount of seed is placed into mesh bags with no more than one-half pound per bag. The seed may or may not be stratified as discussed previously, depending on which treatment gave the best germination. Experience at the nursery shows that many blue and Norway spruce lots perform best without stratification, while Engelmann spruce seems to benefit from 28 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 water, fertigation water (irrigation water with injected liquid fertilizer in solution), and leachate from the growing medium.

Maximum/minimum thermometers are placed throughout each greenhouse to record the daily tempera-

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		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.		Irrigate when rootplug is barely moist.			Irrigate rootplugs to field capacity prior to refrigerated storage.		
Peters Conifer Finisher and micronutrients.			Alternate Peters Conifer Finisher and micronutrients with calcium nitrate.				

ture 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.

Desired Seedling Characteristics

Outplanting data for spruce indicates 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 blue and Engelmann spruce seedlings averaging 15 cm in height and 20 cm for Norway spruce; all three species have caliper between 2.5 to 2.8 mm, well-formed buds, and high root growth potential.

Container Type, Growing Medium, and Tray Filling

Spruce are 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 (one part laundry bleach to 9 parts water). After the trays and cells have dried, the bottom 1 inch of the cells is re-moistened 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 peat-vermiculite (1:1) growing medium. The pH of this mix averages about 4.2. Seeds are sown with an optical precision seeder and just barely covered with 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 about 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 three to four 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, and delaying nitrogen fertilization until germination is complete.

Once sowing is complete, the crop is monitored daily for problems. Damped-off seedlings are immediately rogued and tallied by species and seedlot. If damping-off passes our damage threshold level (at least 15% of the blocks within the seedlot have 3-5% of their cells with disease), fungicide is applied to the problem seedlot. Thinning crews also rogue diseased seedlings and help with monitoring. The process of roguing dead or dying seedlings continues until the seedlings are extracted, and is facilitated by rolling benches which allow convenient access to all trays. We feel roguing is especially important in removing potential hosts for *Botrytis* and for minimizing *Fusarium* and other pathogen inoculum build-up in our containers (Dumroese et al. 1990). If the damage threshold is passed, we apply the fungicide Banrot® (a soil drench) at 4 ounces per 100 gallons as necessary.

Germination is generally complete within 21 to 28 days. 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 seedcoats. Seedlots with high germination energy tend to shed their seedcoats rapidly. During seedcoat shed (about week 2), 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 targeted growth (Figs. 2 and 3). During the initial growth phase, week 3 through week 6, we inject a liquid fertilizer solution of Peters Conifer Starter® (7-40-17) at a rate of 42 ppm N supplemented with micronutrients and 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 6, 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 6, seedling foliage is tested for nutrient concentrations to detect any deficiencies.

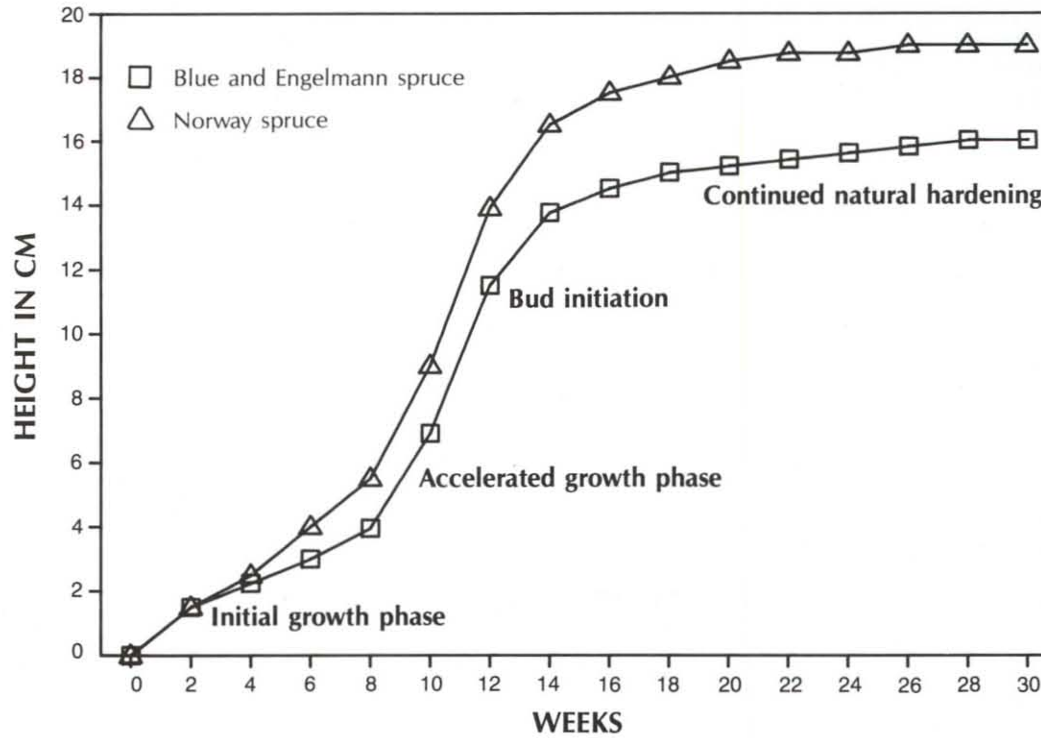

Figure 2. Spruce target height growth.

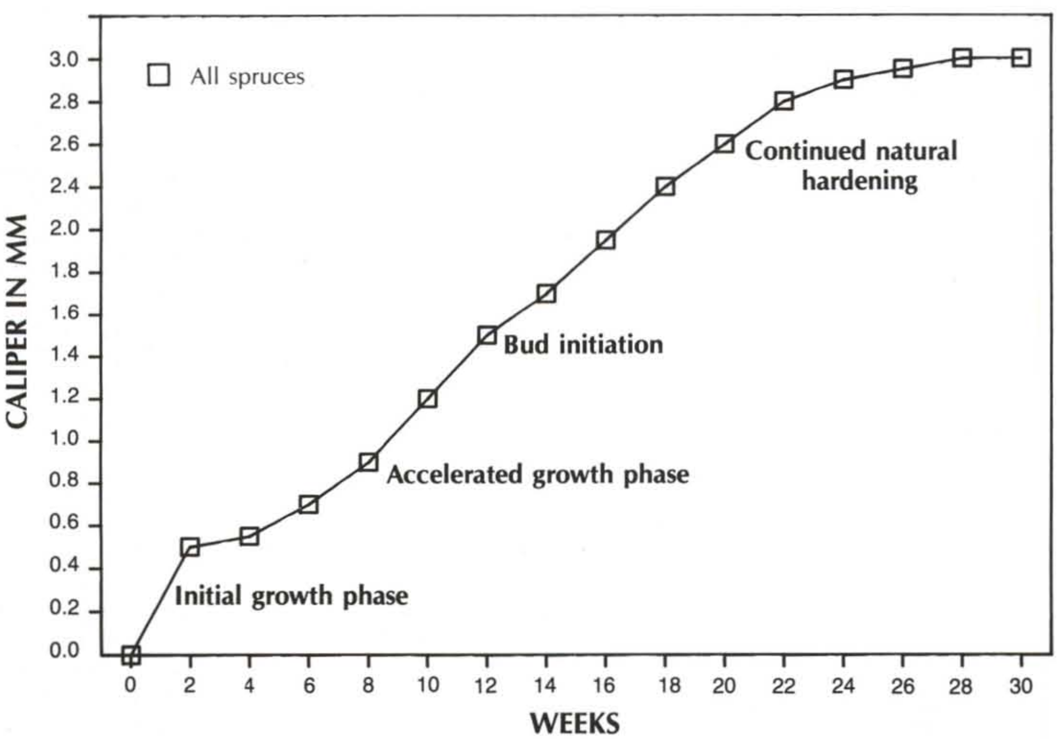

Figure 3. Spruce target caliper growth.

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		0.07	0.40	0.01	
Peters Conifer Starter[1]	22	20	105	85	2		2	1.20		0.09	0.18	0.18	0.18	0.02
Phosphoric acid[2]			41											
Magnesium sulfate[3]					24		31							
Solubor (Boron)[4]										0.46				
Sequestrene 330 (Chelated iron)[5]								3.75						
Total	24	20	148	85	41	28	43	5.19	2	0.55	0.25	0.58	0.19	0.02

[1] Applied at 5 lbs. per 1000 gal. (42 ppm N).
[2] Applied at 20 oz. per 1000 gal. (41 ppm P).
[3] Applied at 32 oz. per 1000 gal. (24 ppm S and 31 ppm Mg).
[4] Applied at 0.3 oz. per 1000 gal. (0.46 ppm B).
[5] Applied at 5 oz. per 1000 gal. (3.75 ppm Fe).

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	0.24	2		0.07	0.40	0.01	
Peters Conifer Grower[1]	70	50	18	95			1.8	2.40		0.15	0.36	0.36	0.36	0.03
Phosphoric acid[2]			41											
Magnesium sulfate[3]					24		31.0							
Manganous sulfate[4]					11						18.00			
Solubor (Boron)[5]										0.46				
Sequestrene 330 (Chelated iron)[6]								3.75						
Calcium nitrate[7]	86	6				114								
Total	158	56	61	95	50	142	42.8	6.39	2	0.61	18.43	0.76	0.37	0.03

[1] Applied at 5 lbs. per 1000 gal. (120 ppm N) alternated with calcium nitrate.
[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 5 oz. per 1000 gal. (3.75 ppm Fe).
[7] Applied at 5 lbs. per 1000 gal. (92 ppm N) alternated with grower.

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 applied at 120 ppm N along with micronutrients and phosphoric acid. Grower is alternated with calcium nitrate (15.5-0-0-10) at 92 ppm N 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.

Weather conditions, particularly the amount of sunshine, have a strong influence on initial growth of seedlings. Weekly height and caliper measurements are taken on ten pre-determined sample trees within each lot. If height growth is occurring faster than our target growth curve, nitrogen rates are reduced by decreasing the rate of calcium nitrate to 46 ppm N. Conversely, if growth is lagging behind the target level, calcium nitrate levels can be increased.

During week 12, if height growth is at the desired level, the medium is leached with copious amounts of irrigation water to remove any salt build-up and excessive fertilizer. Notice that Norway spruce grows more rapidly than the other species (Fig. 2), and may need to be leached sooner. 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. Foliage is again tested for nutrient deficiencies at this time to correct any shortages.

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 the 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.

Between weeks 12 and 15 when irrigation is necessary, Peters Conifer Finisher® (4-25-35) is the primary fertilizer, along with micronutrients and phosphoric acid (Table 3). After week 15, finisher is alternated with calcium nitrate (15.5-0-0-10) at a rate of 92 ppm.

Table 3. Fertilizer target levels for bud initiation and root collar diameter growth.

	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		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			
Solubar (Boron)[5]										0.46				
Sequestrene 330 (Chelated iron)[6]								3.75						
Calcium nitrate[7]	86	6				114								
Total	88	30	43		50	142	41	3.99	2	0.46	18.07	0.40	0.01	

[1] Applied at 5 lbs. per 1000 gal. (24 ppm N) alternated with calcium nitrate after week 15.
[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 5 lbs. per 1000 gal. (92 ppm N) alternated with finisher after week 15.

Micronutrients are applied only with finisher, but phosphoric acid is applied during each irrigation.

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

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.

Beginning around mid-October, we allow air temperatures within the greenhouses to reach ambient levels (Figure 1). However, the minimum temperature allowed in the greenhouses is 28ºF (-2ºC) 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 outplanted.

Extraction and Cold Storage

Seedlings are well watered before being removed from their containers and placed in plastic bags in groups of 20. Bundles of trees for public conservation sales are placed five 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 air-tight before being placed in cold storage. The refrigerated storage is kept at 33-34ºF (0.5-1ºC). Seedlings have been stored successfully in this manner for five months without needing 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 include 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, and (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.

Conclusions

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 to 20 cm in height and 2.5 to 2.8 mm in caliper. We feel the most important aspect of any growing regime is continually monitoring 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 eight years of records on fertilizer application rates and the resultant seedling growth, and will certainly be modified in the pursuit of high-quality spruce seedlings.

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