Chapter 16
Plug + 1 Seedling Production

P. F. Hahn

Abstract

The recently developed plug+1 seedling begins life as a typical plug in a containerized nursery. At the end of its first year, it is transplanted to a bareroot nursery, where it continues to grow for another year before outplanting. This new stock type, with bushy top and moplike, fibrous root mass, has had good survival and height growth on typical Northwest transplant sites. It has also shown, on these sites, a comparable or better total cost:benefit ratio than any other seedling type currently in use.

16.1 Introduction

The plug+1 seedling, one of the newest among a variety of seedling types used for reforestation, is a hybrid derived from merging recently developed containerized-seedling production methods with age-old bareroot methods. Plug+1 production utilizes both container and bareroot types of growing facilities and technologies; but it is often difficult to coordinate both technologies because, in most cases, container and bareroot nurseries are operated separately. Furthermore, it is hard to define which phase is more important in such production; credit for a good crop or blame for a bad one is often disputed by the two different growers. In spite of the newness of plug+1 seedlings and initial difficulties in producing them, they are gaining rapid acceptance, proving themselves a good stock type for certain species in certain areas. However, plug+1s are not a cure for all reforestation problems.

In this chapter, I describe the evolution of the plug+1 and its production in both containerized and bareroot phases and assess its overall applicability for reforestation in the Northwest. Most of the discussion relates to Douglas-fir *[Pseudotsuga menziesii* (Mirb.) Franco], the major commercial species in the Northwest. However, the production methods described can be quite successfully applied to other Northwest species.

16.2 A Brief Description and History

The plug+1 seedling, or p+1, starts its life in a containerized nursery (Fig. 1a). Once the seedling has a firm root plug and sturdy top and reaches the right physiological stage, it is transplanted to a bareroot nursery (Fig. 1b). The transplanted plug grows as a bareroot seedling for another year—thus the name "plug+1." Production of p+1 seedlings always involves these two distinctly different nursery operations, although the scheduling and rearing of p+1 seedlings in each nursery differ somewhat from those of regular containerized and bareroot seedlings.

It is difficult for the bareroot nursery operator to produce good p+1 seedlings if the containerized seedlings are of poor quality or are not scheduled properly for transplanting. On the other hand, even the best produced and scheduled containerized seedlings could become poor p+1 stock if not reared properly in the bareroot nursery. The two types of nurseries greatly depend on each other and must strive to use good growing technology to achieve the desired end product.

Plug+1 seedlings were first produced in 1971 by the Ray Leach Nursery in Aurora, Oregon. Because the idea showed very little success at that time, further production attempts were abandoned until 1975. During the regular 1975 spring transplanting season, Georgia-Pacific Corporation transplanted 22,000 Douglas-fir seedlings produced in the company's container nursery at Cottage Grove, Oregon, to the Tyee Tree Nursery (bareroot) near Roseburg, Oregon. Cultural practices and production scheduling applied to the plug and bareroot phases of these seedlings did not differ from the normal rearing practices in either facility. At the end of the growing season, the following fall, the entire seedling crop was quite uniform and showed good yield. Seedling tops and roots looked distinctly different from those of regular bareroot transplant stock, however; tops were bushy, and roots resembled a mop, with a large, fibrous root mass (Fig. 2). This clearly was a

In Duryea. Mary L., and Thomas D. Landis (eds.). 1984. Forest Nursery Manual: Production of Bareroot Seedlings. Martinus Nijhoff/Dr W. Junk Publishers. The Hague/Boston/Lancaster, for Forest Research Laboratory, Oregon State University. Corvallis. 386 p.

new product, at least in appearance, although its field performance was as yet unknown.

The following winter, field trials were established on various sites to compare the new p+1 seedlings to regularly used seedling types. A year later the first evaluation showed encouraging results in survival and height growth in spite of the 1976 summer drought.

The drought continued into the fall and winter, delaying the regular winter planting season for months. There was real concern that most of the millions of seedlings produced that year would never reach their destination. It is a well-known fact that seedlings held over for an extra year in containers or bareroot nursery beds may reach a size and condition unsuitable for successful field planting; furthermore, containerized seedlin gs become "pot-bound." Because transplanting seemed to provide the best solution, some of the surplus containerized seedlings were moved to the Tyee Tree Nursery in November. This was possible because the warm, dry weather provided good conditions for seedling bed preparation and transplanting. Transplanted seedlings were not affected by the drought because proper ground moisture was maintained through watering.

After rain finally came in February 1977, full-scale field planting resumed, but there was not enough time left to move all the remaining containerized seedlings to the field. Therefore, another group of containerized seedlings was transplanted during the regular spring transplanting season.

The fall- and spring-transplanted plugs were reared with normal bareroot transplant cultural practices during the next growing season. Neither batch received special treatment. In spite of this, fall and spring transplants differed distinctly in seedling quality; fall transplants had 4 to 5 mm larger caliper, 20 to 25 cm greater top growth, and a better developed root system than spring transplants. We at Georgia-Pacific have seen similar differences due to fall and spring planting for containerized seedlings in previous field-planting operations, but none as pronounced as those at this nursery.

Thus, the disastrous 1976 drought had some side benefits: the nursery industry learned more about large- (or commercial-) scale p+1 seedling development and production. Technology and usage have continued to be refined since.

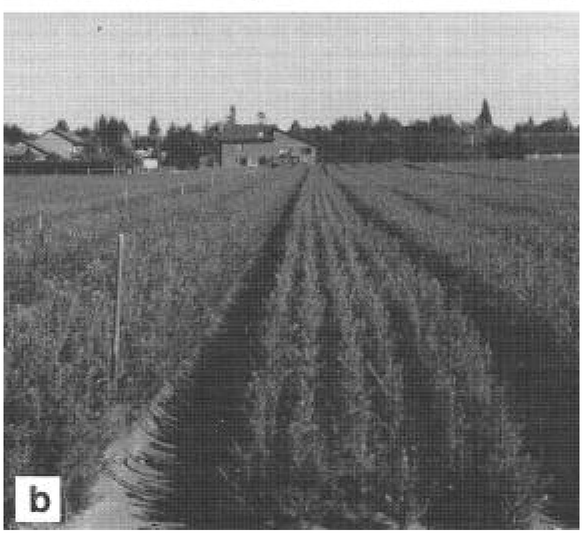

Figure 1. (a) Bird's-eye view of a container nursery, where the p+1 begins life, and (b) transplant beds in a bareroot nursery, where the p+1 grows for another year before outplanting.

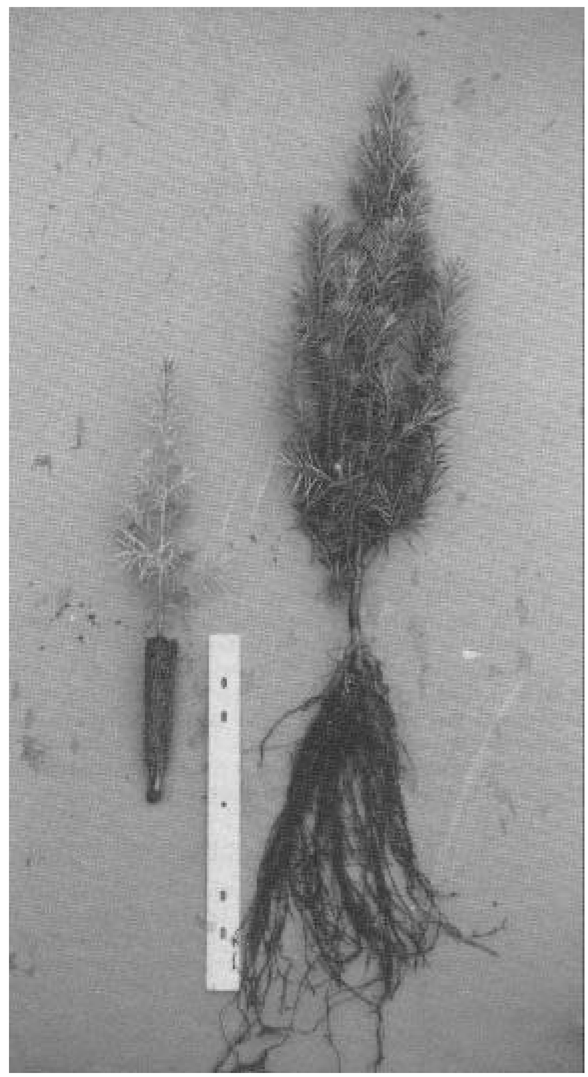

Figure 2. A 1-year-old greenhouse-grown plug (left) and a 2-year-old bareroot originated from a plug, or p+1 (right). Note the p+1's bushy top and moplike, fibrous root system.

16.3 Plug+1 Status in the Northwest

Plug+1 seedling production in the Northwest was limited to only a few containerized and bareroot nurseries during the late 1970s in spite of its initial success—mainly because of the newness of the p+1 product and the lack of popularity of containerized seedlings. Although the end product is a bareroot seedling, quality of the initial plug still has a major effect on the ultimate crop. Bareroot nursery operators were not always eager to accept container-grown seedlings for transplanting. Some nurseries had strict rules against accepting any crops, bareroot or containerized, from another nursery to avoid possible disease contamination from an outside source.

Tyee Tree Nursery was first to accept containerized seedlings for transplanting and has continued to do so on a large commercial scale ever since. Other small private bareroot nurseries have also adopted this practice. Large industrial and government-operated nurseries, however, were slow in gearing up for p+1 production. The Industrial Forestry Association's nursery at Canby, Oregon, transplanted its first p+1 crop from an outside source in August 1978; soon after, other large nurseries followed suit.

According to the OSU Nursery Survey (see chapter 1, this volume), p+1 production reached about 6.5 million seedlings in the Northwest by 1980—about 2% of total seedling production. Since the 1980 tabulation, p+1s have gained even better and wider acceptance in the Northwest and other areas.

16.4 Containerized Growing Phase

Containerized seedling production is relatively new and, in general, poorly understood. It has developed rapidly over the last 10 to 15 years, during which time many different containerized systems have been tested. Although some systems produced excellent seedlings for direct field planting or p+1 production, not all systems worked as expected; therefore, containerization recently reached a point of stagnation—and reassessment [3].

Specific growing facilities, climate control units, container types, crop scheduling, growing regimes, hardening methods, and shipping preparation for containerized seedling production can now be better defined from experience, as reflected in the following discussion.

16.4.1 Growing facilities

Containerized seedlings can be grown in three types of facilities:

- **Semicontrolled growing facilities** provide minimum protection for the seedling crop because they are seldom equipped with any environmental control units other than a shade screen or plastic-covered roof. For this reason, these seedlings are the least expensive to produce but are suitable for growing only under mild climatic conditions (Fig. 3a).
- **Shelterhouses** are not permanently enclosed and have an environmental control system that can be fully automated and regulated. They are normally equipped with a cooling system that uses thermostatically controlled, removable wall and roof covers for natural ventilation rather than cooling pads and fans (Fig. 3b).
- **Greenhouses** are similar in structure to shelterhouses but have permanent roof and wall covers. For this reason, they rely heavily on artificial environmental control to hold the temperature at a desired level. Therefore, this is the only facility type suitable for growing seedlings year-round regardless of natural climatic conditions (Fig. 3c).

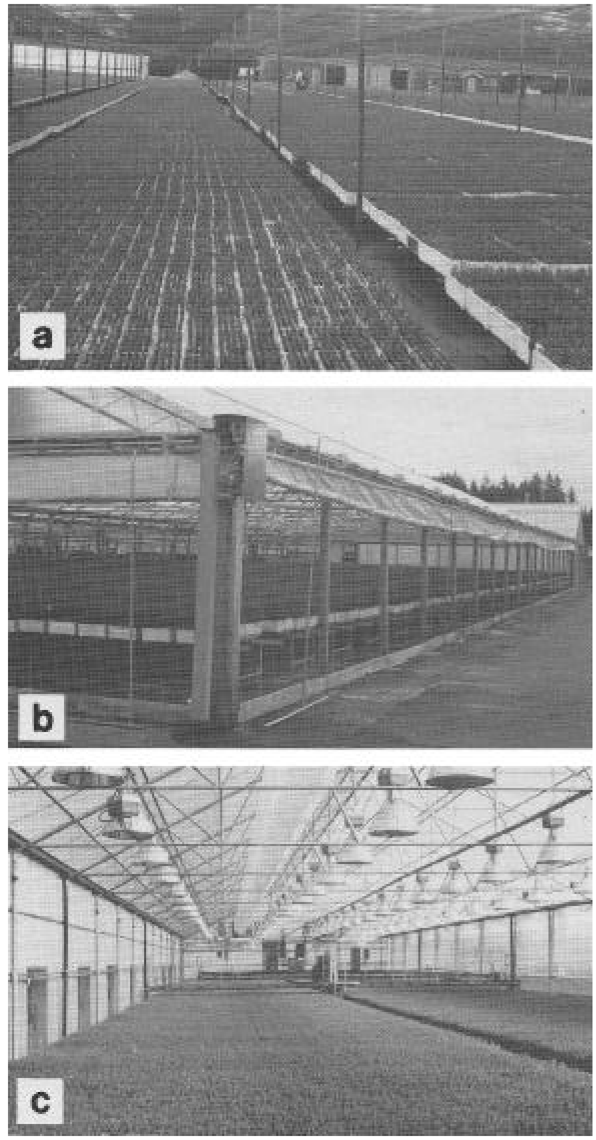

Figure 3. (a) Semlcontrolled growing facility; (b) shelterhouse, with thermostatically controlled, removable wall covers; and (c) fully controlled and permanently enclosed greenhouse.

With minor modifications to fit given local conditions, shelterhouses have proved to be the best all-around type of growing facility. They are relatively inexpensive to build and operate and can provide all the needed environmental control for producing good seedlings if a compatible container is used. Such seedlings normally have the required physical and physiological traits to meet the desired transplant quality and date and are performing well when field planted. Because most shelterhouse-grown seedlings are produced on a one-crop-per-year schedule and during the natural growing season, growing is less troublesome and quite low in cost.

16.4.2 Containers

Many different container types and sizes are in use. For successful crop production, the container type must be compatible with the growing facility (see 16.4.1). Normally, almost any type of container is suitable in a greenhouse, in which the environment can be easily regulated to maintain temperatures considered "near optimum." Seedlings raised in shelterhouses or semicontrolled facilities, however, may be exposed to greater climatic extremes. Such conditions promote hardier seedling development within certain limits and, therefore, are more desirable than detrimental, as long as the seedling's most sensitive part—its roots—are protected. For this reason, containers with good insulating capacity, such as styroblocks, are the best choice for producing hardy seedling crops not only in shelterhouses but in all types of growing facilities [3].

Because p+1 seedlings are raised for a total of nearly 2 years in two different nurseries, they generally have plenty of time to reach their desired size if reared properly. Therefore, plugs may be grown in relatively small (30- to 40-cm^3) container cavities. The use of small cavities makes the plug phase more economical because fewer resources (soil, water, fertilizer, etc.) are needed, growing space is better utilized, and handling costs during shipping and transplanting are reduced.

16.4.3 Crop growing schedule

Before a p+1 seedling crop is initiated, the plug growing phase has to be timed so that seedlings will reach their optimum size and condition on the desired target date for transplanting. Typical bareroot seedlings reach this optimum in spring, when, traditionally, they have been transplanted. Containerized seedlings, however, differ in this respect because of the way they are grown: raised in semicontrolled or fully controlled facilities, these seedlings have more scheduling flexibility. They can be successfully transplanted to bareroot nurseries almost any time as long as they are in the proper physical and physiological condition and the bareroot nursery is ready to plant them. Past experience shows three frequently used time periods—spring, fall, and late summer—for plug transplanting.

16.4.3.1 Spring transplanting

Spring transplanting is traditional and is well suited to bareroot crops because of the bareroot seedling's favorable physiological condition at that time of year. Nurseries pressed for space also can rotate their transplant beds more favorably in spring than in fall or late summer. But spring transplanting of plugs has had varied success and might be desirable only when:

- Crop rotations or specific nursery practices in a bareroot nursery restrict bedspace availability for late-summer or fall transplanting.
- Winter crops are specifically grown for spring transplanting. This is often done to better utilize expensive greenhouses through multiple-crop production. However, producing a crop during winter requires a lot of costly energy for winter heating and lighting in addition to the ongoing expenses of running a greenhouse. This high energy requirement undoubtedly affects overall p+1 costs.
- Seedling crops initiated in spring and reared during summer are not properly cultured and fail to reach the desired size and condition for late-summer or fall transplanting. Other crops may be deliberately raised during summer for spring transplanting. In either case, seedlings have to be overwintered in greenhouses, which normally results in additional root growth. Producing too many roots for small container-cavity size creates pot-bound plugs: roots of such plugs may have a hard time breaking out of their plug form and developing into a freely growing heavy root mass the following growing season (Fig. 4). Overwintering seedlings in cold storage may avoid the potential problem of pot-bound plugs, but prolonged and improper cold storage may cause deterioration in seedling quality [4].

Because of the stated problems resulting from winter growing, overwintering in greenhouses, and cold storage, spring transplants generally lack the vigor often seen in seedlings transplanted in late summer and fall. Though their height growth is generally acceptable, their roots have a harder time breaking out of the plug form—and little time to do it in—and their tops are often uneven. As a result, some seedlings do not meet minimum standards.

Figure 4. Spring-planted plugs may not have enough time to develop freely growing heavy root mass by lifting time.

16.4.3.2 Fall transplanting

Fall transplanting may work well when plugs are prepared for it and when bareroot nursery conditions are suitable for accepting transplants. Recall that the very first fall transplanting (described in 16.2), in the Douglas-fir region in 1976, was possible because the unusually dry weather conditions favored bed preparation and transplanting that late in the year. Those fall transplants showed considerably better height, diameter, and root growth than spring transplants a year after transplanting: they had maintained actively growing root systems in their polystyrene containers and were well hardened by the time they were transplanted. Trees with active root tips expand their roots in the nursery bed after transplanting, ensuring rapid development the following growing season.

Normally, however, climatic conditions in fall in the Northwest create considerable problems for transplanting plugs:

- Transplanting may be hindered by high soil moisture due to excessive rains, which limits access to transplant beds and often cuts the transplant season short.
- Early frosts may damage just-transplanted and improperly hardened seedlings.
- Late-transplanted seedlings have very little time to adjust for possibly severe winter conditions.

The stated difficulties were experienced in our operations. To overcome them, we went to late-summer transplanting. We had to readjust our greenhouse growing schedule accordingly, as did the bareroot nursery to which plugs would be transplanted.

16.4.3.3 Late-summer transplanting

Six years of experience in testing and using millions of p+1 seedlings convinced us that late-summer transplanting provides the best growing and transplant logistics and results in good-quality p+1 crops. August-planted plugs can double their caliper and triple their root mass by mid-November (Fig. 5).

For this schedule, the containerized production phase is initiated in late winter or early spring. Most container facilities have some environmental control capabilities to accommodate early sowing, and early germination can be aided by frequent misting and artificial heating. As the weather warms, most seedling growth closely coincides with the natural growing season- which is especially important when plugs are grown in shelterhouses (see 16.4.l). An early sowing date and good cultural practices during summer make it possible for seedlings to reach the desired size, root form, and physiological condition for late-summer transplanting.

Due to inappropriate scheduling or poor cultural practices, container nurseries can have problems readying their p+l crops for such a transplant date. We succeed in achieving this by following a strict growing schedule and cultural regime (Tables 1 to 4). A similar schedule is used for our regular crop production, but a fifth holding, or overwintering, phase is required during the winter planting season (Table 5). Plug+1 seedlings destined for spring transplanting may also be overwintered (see 16.4.3.1). The schedules in Tables 1 to 4 are typical for Douglas-fir in Oregon, though they may vary from year to year, depending on climatic and seedling conditions, and large portions of them also may apply to other species and different growing areas. Therefore, these schedules should be used only as general guidelines for developing growing regimes for specific local conditions.

Seedlings destined for late-summer planting should be sown in early March (Table 1). During the first portion of the early growth phase (Table 2), extra lighting may be necessary to extend the photoperiod to avoid premature budset: seedlings from high-elevation sources and those east of the Cascade Mountains definitely need the extra light. The procedures for seeding, germination, and thinning of p+1 seedlings do not differ from those used for the regular crop; but rearing practices (watering, fertilizing, disease control, etc.) are tailored to p+1 production.

Seedlings for p+1 crops are normally raised in containers with small (30- to 40-cm^3) cavity sizes not only to hold down the production cost but also to encourage rapid seedling growth. Such small containers, densely (900 to 1,000 seedlings/m^2) spaced, promote rapid seedling development during the accelerated growing period (Table 3). Seedlings closely spaced in this stage tend to become taller than those grown in larger cavities at wider spacings. The heavy fertilizer regime outlined in Table 3 also promotes rapid stem and root de-

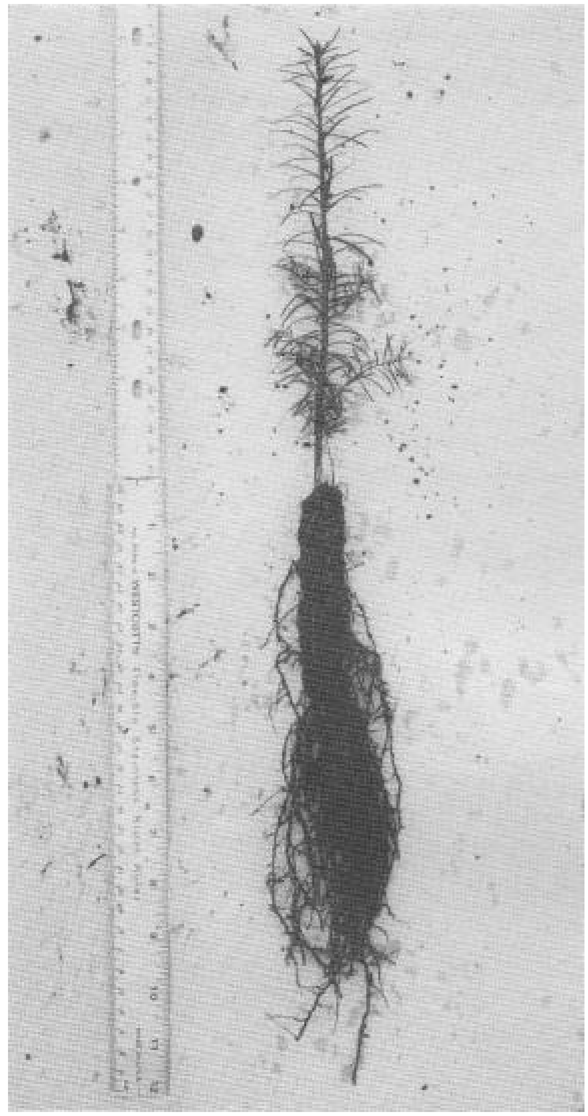

Figure 5. Plugs transplanted in late summer increased their average caliper from 2 to 4 mm and maintained vigorous root growth, tripling their root-mass by mid-November.

velopment. Roots fill the small container cavity rapidly; because of this, height growth normally starts to decline by early July, when hardening can be initiated.

During the hardening phase, seedlings are subjected to periodic moisture stress and special fertilizer treatments (Table 4), which promote good budset and stem lignification by early August. By this time, roots have formed a firm plug. Even though not yet completely dormant, seedlings have the needed size and physiological condition to be moved to a bareroot nursery and transplanted, despite the normally hot summer days. (See 16.5.2 for late-summer transplant development and post-transplant care.)

16.4.4 Packaging, handling, and shipping

The crop can be termed ready for transplanting when seedlings are in the proper physiological and morphological stage, when stems are lignified enough to allow extraction of seedlings from containers without injury, and when root plugs are firm enough to hold together during shipping and transplanting.

Seedlings can be packaged and shipped either in a pre-extracted form or in their original containers. Either approach

Table 1. Phase 1, the stratification and germination period, is geared toward proper seed preparation, efficient sowing, germination, and juvenile seedling development.

Growth components	January 3	January 4	February 1	February 2	February 3	February 4	March 1	March 2	March 3	March 4	April 1	April 2
	Weeks											
Seed preparation	Soak seed			Stratify at 2°C for 6-8 weeks			Sowing and germination				Juvenile development	
Day temperature, °C												
Optimum							25.				25	
Permissible							18-25				15-30	
Night temperature, °C												
Optimum							25				25	
Permissible							18-25				15-30	
Relative humidity, %												
Optimum							80				40-60	
Permissible							50-90				40-70	
Light, %												
Natural							60-80 sunlight				60-80 sunlight	
Supplemental artificial							None				To avoid budset, extend photoperiod with 400-lux light intensity	
Water							Frequent light irrigation				As needed; keep surface dry to avoid disease	
Fertilizer							None				Formula A (balanced)	
pH							4.0-4.5				4.0-4.5	
Fungicide											One preventive application	
Recordkeeping	Monitor temperature and humidity in cooler						Keep daily records of all activities					

Table 2. Phase 2, the early growth period, is geared toward seedling establishment, good root and side-branch initiation, and prevention of disease and insect problems.

Growth components	April 3	April 4	May 1	May 2	May 3	May 4
	Weeks					
Temperature, °C						
Optimum	20-30		20-30			
Permissible	10-33		10-33			
Relative humidity, %						
Optimum	40-60		30-60			
Permissible	30-70		20-70			
Light, %						
Natural	Only sunlight as it penetrates roof covers					
Supplemental	To avoid budset, extend photoperiod with 400-1ux light intensity		Continue with extended photoperiod in problem areas			
Water	As needed; keep surface dry to avoid disease		Mostly applied with fertilizers as needed; leach each 4-b weeks			
Fertilizer	Chelated iron (l5 g/100 liters water), calcium nitrate (60 g/100 liters water)		Apply chelated iron (15 g/100 liters water), calcium nitrate (120 g/100 liters water), and a balanced fertilizer with micronutrients (30-10-10, 30 g fertilizer in 100 liters water), alternately with each watering as needed			
pH	4.5-5.0		5.0-5. 5			
Fungicide	Apply only if needed		One Benlate-Truban preventive fungicide drench (30 g/l00 liters water)			
Operations	Daily checks on crop		Thin to l seedling/cavity			
Environmental control	Automatic heating and ventilation as needed		Heat only during cold nights; begin opening roof vents and sidewalls of shelterhouses on warm days for good air circulation and cooling			
Recordkeeping	Monitor the crop closely each day; record all activities; note potential problems and their solutions					
Soil and foliar testing	Start routine testing once every 2 weeks; adjust fertilizer regimes to comply with nutrient needs					
Seedling growth	Keep height growth low (4-8 cm); concentrate on side-branch initiation and root development					

Table 3. Phase 3, the accelerated growth period, is geared toward pushing seedling height and diameter growth, root development, and stem lignification. Natural growing conditions are generally optimum in this period.

Growth components	June — Weeks 1	2	3	4
Temperature control	Natural air temperature during the day (vents, side walls normally open); vents and walls may be closed on cool nights		Natural air temperature; cool with irrigation water if needed	
Humidity	Same as ambient conditions			
Light				
Natural	Only sunlight as it penetrates roof covers			
Supplemental	None			
Roof covers	Retain on main greenhouse units to keep rain off seedlings; alley roof covers may be removed for added ventilation			
Prewetting	Prewet 5-10 minutes before fertilization to aid water penetration for better fertilizer utilization			
Wetting agent	Use when water penetration becomes poor			
Leaching or nutrient flush	Prevents salt buildup; flush about once a month with about 20 liters water/m^2 of area			
Water	Irrigation water is mostly accompanied by fertilizer			
Fertilizer	Compounds high in nitrogen (3:1:1) and calcium nitrate: 1,000 ppm total fertilizer, 2-3 times a week, and iron chelate (300-500 ppm) once every 2-4 weeks		Compounds high in phosphorus; also those with calcium, magnesium, and potassium (1,200-1,500 ppm total fertilizer solution)	
pH	5.0-5.5			
Height and diameter measurement	Establish sample trees; measure them and plot on graph every 2 weeks			
Soil and foliar testing	Continue testing and adjust nutrient regime as needed			
Disease control	Normally, very little problem in this phase			
Recordkeeping	Same as previous phase			
Seedling growth	The natural growing conditions and fertilizer regime favor fast height growth; push height growth as much as possible to match target curves		Concentrate on rapid height, diameter, and root development: the natural growing conditions and fertilizer regimes favor this	

Table 4. Phase 4, the hardening period, is geared toward initiating and achieving budset, stopping height growth, lignifying stems, boosting diameter and root development, and initiating dormancy.

Growth components	July — Weeks 1	2	3	4	August — Weeks 1	2	3	4
Temperature control	Close to natural air temperature; cool with irrigation water if needed							
Humidity	Similar to phase 3							
Supplemental light	None							
Roof covers	Keep rain off seedlings, eliminating interference with hardening							
Prewetting	Very important after stressing							
Wetting agent	Use after heavy water stress, if needed, to rewet plugs							
Leaching or nutrient flush	Start hardening by flushing nutrients from the soil							
Seedling stress	Dry to wilting point and repeat stressing 2-3 times							
Fertilizer	After first stress, apply 0-52-34 (60 g/l00 liters water); after second stress, apply 00-62 (30 g/100 liters water); after third stress, apply hardening formulas alternately with 0-52-34 until budset							
Chilling	None						Cool nights may help chill seedling stems	
pH	5.0-5.5							
Soil and follar testing	Once every 2 weeks or more frequently if needed							
Height and diameter measurement	Similar to phase 3: the two target curves help in adjusting fertilizer regimes							
Disease control	Watch for *Fusarium* and *Botrytis* problems							
Recordkeeping	Similar to the previous phases							
Operations	Spread seedling blocks for better aeration; turn outside blocks to reduce edge effect							
Late-surnmer transplanting	Package and ship seedlings to transplant nurseries							

has its advantages and disadvantages. Preextracted seedlings are preferable for long-distance shipping and cold storage because they take up less space. Containerized seedlings are preferable for short-distance shipping and direct transplanting because they can be handled economically while remaining well protected.

Seedling extraction and packaging is a routine operation in container nurseries. Most nurseries have an assembly-line set-up (Fig. 6) which makes these processes quick and cost effective. Forty to 50 extracted seedlings generally are placed in small plastic bags to protect the roots (Fig. 7). About 12 to 14 of these bags are packed into cardboard boxes (Fig. 8a), which can then be stacked on pallets and easily moved into enclosed vans or storage areas. Seedlings still in their containers also are placed into cardboard boxes (Fig. 8b), which are stacked on pallets for transport and storage.

Shipping large crops requires large trucks to keep pace with the rapid transplant operation. One transplant machine can plant 70,000 to 80,000 seedlings daily, and some nurseries may operate several transplant machines at the same time, depending on their size and on the urgency of the job. A 40-foot-long van can haul about 380,000 packaged preextracted seedlings or about 160,000 seedlings boxed in their original containers in one trip (Fig. 9). On their return, trucks can bring the empty containers and boxes back to the nursery; well-built boxes can be reused 5 to 6 times. This recycling effects a large savings in packaging and hauling costs.

16.5 Bareroot Growing Phase

As soon as seedlings are moved to transplant nurseries, the second, or bareroot phase of p+1 production begins. Naturally, by this time, transplant beds and equipment must be prepared and crews organized to start transplanting.

16.5.1 Bed preparation

This phase of p+1 production may not differ much from regular transplant-bed preparation. Cultivating the ground with plows, disks, rototillers, and other soil-loosening devices dur-

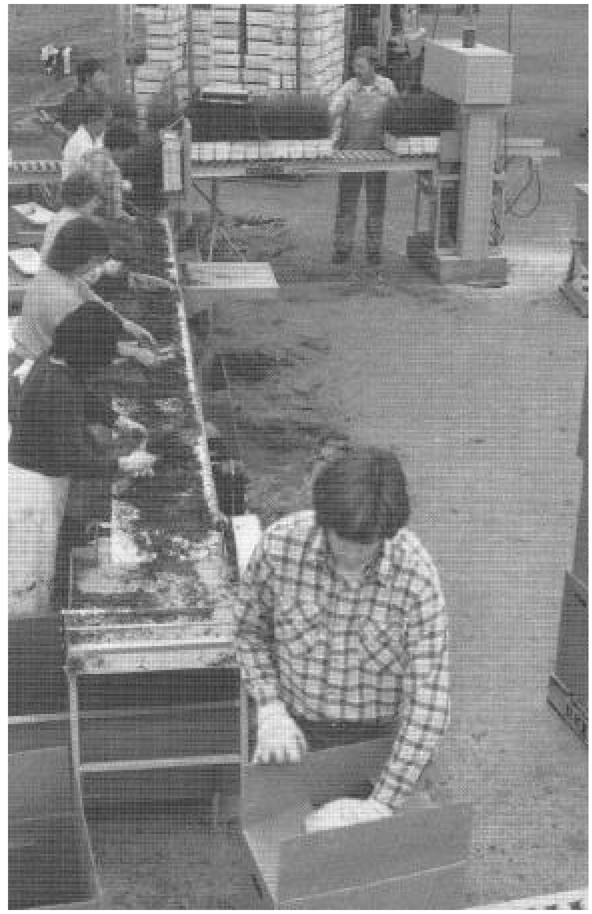

Figure 6. Assembly-line operation: plugs are loosened with an extractor, removed from their containers, and then packaged for shipping.

Table 5. Phase 5, the holding (or overwintering) period. During this phase, the crop is held while trees await field planting. Diameter growth continues on a reduced scale; root tips in styroblocks remain active, and transpiration rate is low. The primordial shoot, which will be next season's first flush of growth, is forming inside the bud.

Growth components	September (Weeks 1 2 3 4) – October (1 2 3 4) – November (1 2 3 4) – December (1 2 3 4) – January (1 2)
Temperature	Allow cooling down to -6°C, in case of frost, for short periods; this helps chill seedlings for better hardening and dormancy; avoid freezing of soil plugs
Light	
Natural	Natural daylight as permitted through roof covers
Supplemental	None
Roof covers	All roofs, including alleys, are covered
Watering	As needed: less frequent, because of low transpiration rate
Fertilizer	Resume use of higher nitrogen fertilizer for a balanced fertilizer regime; this promotes more diameter growth and frost hardiness and development of more needles in first growth flush of next season [1]; reduce fertilization frequency
pH	5.0-5.5
Soil and foliar testing	Once a month as needed
Height and diameter measurement	Continue monitoring until growth levels off
Disease control	Botrytis generally causes the most problems if not prevented or controlled
Recordkeeping	Same as in all other phases
Operations	Start packaging and shipping seedlings as soon as field planting conditions warrant it; seedlings may be shipped in styroblock containers or in a preextracted form; extracted seedlings also may be cold-stored for later planting

ing dry summer months may require some irrigation to develop the proper soil texture and moisture for transplanting. The ground occasionally has to be fumigated and cultivated before transplanting to minimize disease problems (see chapter 19, this volume).

Often, fertilizers are applied before transplanting to develop good nutritional balance in the soil (see chapter 7, this volume). Late-summer-applied fertilizer should contain a very low proportion of nitrogen because too much nitrogen may interfere with the natural hardening process (see chapter 15, this volume).

Field work should be completed before seedlings arrive for transplanting. Normally, there is very little problem accomplishing this during dry summer months, though wet weather may hamper the same operation later in the season or in early spring.

16.5.2 Transplanting

16.5.2.1 Timing

As mentioned earlier, the best time for transplanting plugs in the Northwest is late summer. Experience shows that such timing allows the properly conditioned seedlings to continue to harden under favorable climatic conditions and to enter dormancy. Late-summer transplanting also provides time for active roots to egress from plugs (see Fig. 5). It is important that roots continue their rapid development in nursery soil so that seedlings overwinter safely and begin accelerated development the following growing year.

Figure 7. Extracted seedlings are protected by plastic bags during shipping, storage, and field handling.

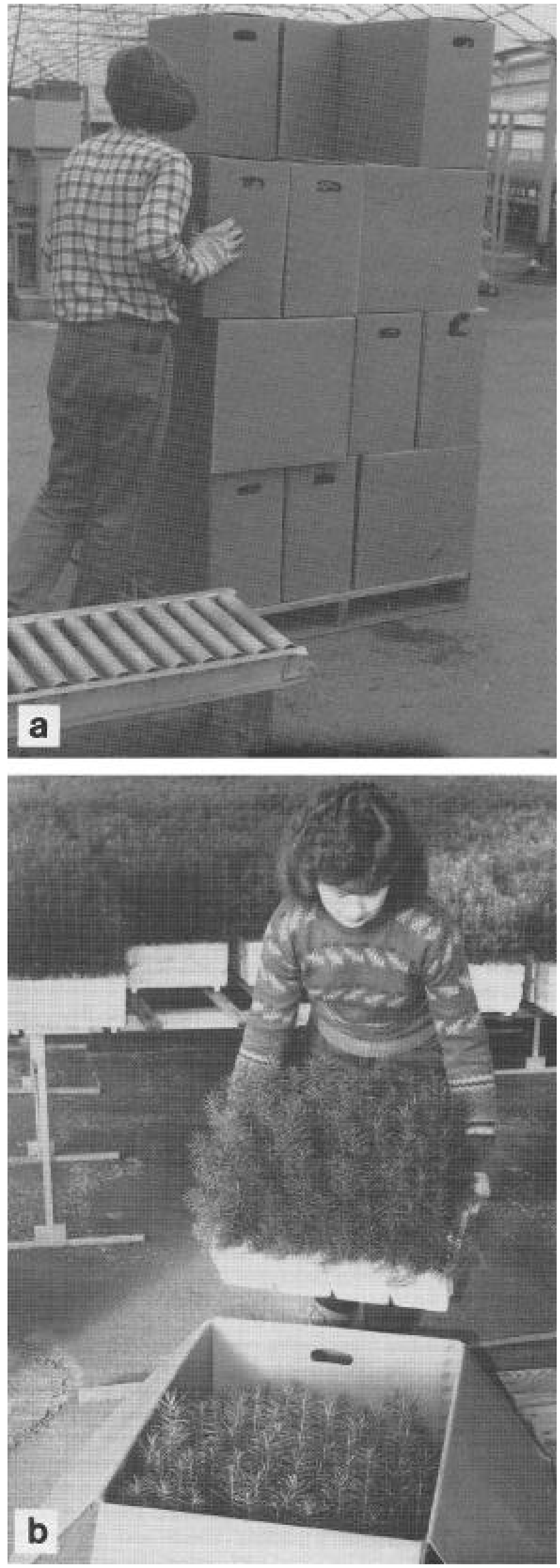

Figure 8. Seedlings can be either (a) preextracted, packaged, and boxed or (b) boxed while still in their original containers.

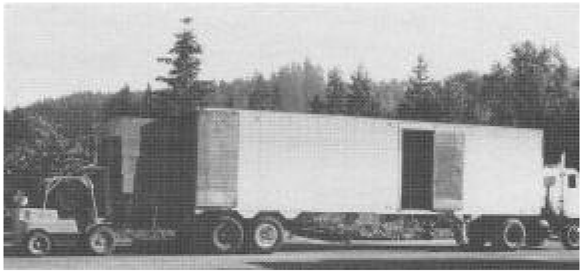

Figure 9. Large, enclosed vans are needed to transport both preextracted and containerized seedlings, to keep pace with today's rapid transplant operations.

A late-summer transplant operation produces not only the best quality p+1 crop but also the best handling logistics for both container and bareroot nurseries. There is generally good weather to prepare transplant beds at a time when both container and bareroot nursery activities are at a low level. Taking advantage of such factors spreads the workload while realizing some savings. Although late-summer planting requires especially close attention to seedling care, well-prepared seedlings will not be damaged by the usually hot weather as long as irrigation systems provide the needed moisture for protection and for initiating seedling development at the new location.

16.5.2.2 Planting and handling

Mechanized transplanters identical to those used for transplanting regular crops are employed for planting p+1s.

Seedlings may be handled on the transplanter while still in their containers or in a preextracted form. Both methods have been widely and successfully used; however, conditions may dictate the method of choice. For instance, if seedlings must be stored for later planting or shipped to distant nurseries, then a preextracted form would be more desirable. For short-distance hauling, handling seedlings still in their containers is preferable, to protect seedling root systems. Either method provides approximately the same planting speed, but handling logistics, handling and shipping costs, and effects on seedling quality may differ.

For planting out of containers, transplant machines are outfitted with racks to hold containers in a convenient position to facilitate direct extraction and transplanting without sacrificing speed (Fig. 10a, b). Though a savings is realized from not preextracting, some additional costs are generated in shipping and from the additional ground support equipment and personnel needed to supply the transplanters with seedlings (Fig. 10a).

Preextracted seedlings are transplanted out of trays (Fig. 11). However, such plugs are handled several times before actually being placed in the ground by the transplanter. Each handling tends to cause root disturbance and exposure. Depending on the severity, such exposure and disturbance may adversely affect seedling performance later on.

During the actual transplanting operation, workers can place seedlings in the clips on the planting wheel rapidly and with minimal effort if the seedlings are well developed and the root plugs hold their form. Clips may have to be adjusted to handle the smaller caliper. Plug-type seedlings eliminate the usual root tangle problem so common with bareroot seedlings. With good moisture content for added weight, plugs enter the ground in a vertical or suspended position. They are firmly anchored by the planter's packing wheels and are free to develop a straight and balanced root system. Because of their widespread roots, bareroot seedlings are difficult to transplant and often develop deformed roots; two of the most common deformities are "J" and "flat" roots. "J" roots are caused by bending the root mass into a one-sided horizontal position during transplanting; "flat" roots occur when the root mass egresses in a single plane in the transplant trench during seedling development. Plug+ I seedlings very seldom develop "J" roots, and their roots are free to develop in all directions.

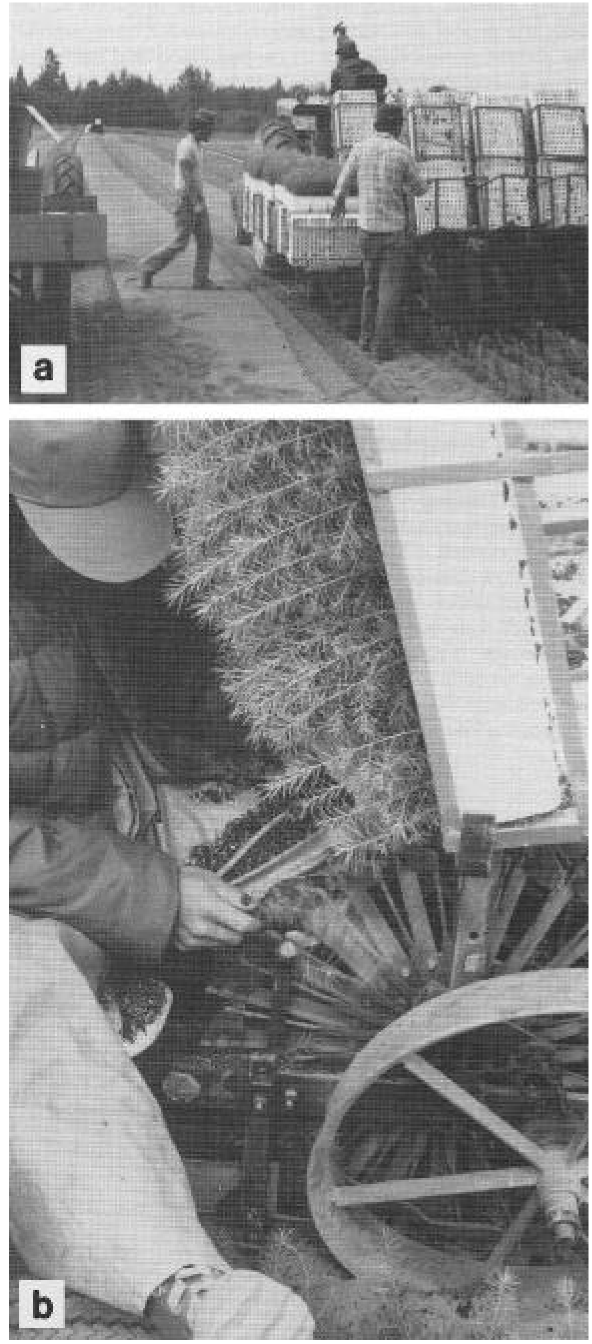

Figure 10. Transplant machines are (a) equipped with racks to hold containers so that (b) seedlings may be transplanted directly out of their containers.

16.5.2.3 Post-transplant care

Once seedlings are placed in the transplant bed, a good soaking with irrigation water firms the soil around the plugs and eliminates air pockets. Additional light watering for cooling, especially during warm late-summer days, may also be necessary. Care should be taken not to overwater; too much water, combined with a high nitrogen level, may cause budbreak this time of year if seedlings are not in an advanced stage of hardening.

Past experience shows no problems in rearing seedlings after late-summer transplanting if the seedlings were properly prepared for such an early transplant date. Nevertheless, the nursery operator must pay closer attention to the crop in late summer than after fall or spring planting because of potentially hot, dry weather.

16.5.3 Rearing

16.5.3.1 Seedling development

Containerized seedlings are in a different developmental stage and condition according to whether they are transplanted in spring, fall, or late summer. Such stages and conditions affect how p+1 transplants develop during their bareroot growing phase. Possible effects must be taken into account when cultural practices—slightly different from those used for 2+1 transplants—are designed and applied.

Rearing practices for spring-transplanted p+1s and regular 2+1s probably differ least because these seedling types are often stored the same way and planted at the same time. Their physiological condition and growth initiation closely coincide. Spring-planted p+1s may have some disadvantages in root and stem development during the bareroot growing phase because of possible after-effects of overwintering and less time for root growth from spring to fall. This is evidenced in their top and root quality (see Fig. 4). To counteract this, a more intensive fertilizer regime should be scheduled for spring p+1 transplants to promote faster root and stem development, if needed.

Seedlings successfully transplanted in fall may not differ much in their development stage and rearing practices from late-summer p+1 transplants. However, any development problems due to soil or winter weather conditions should be considered when cultural practices are designed for their rearing during the next growing season.

Late-summer p+ 1 transplants normally develop into nicely formed trees with numerous strong side branches and a unique moplike root system, compared to other commonly used planting stock (Table 6). Whereas height and caliper were generally smaller for containerized seedlings than for bareroot seedlings, total root mass was greater. The p+3-months seedlings were especially outstanding in this respect. Their root mass tripled

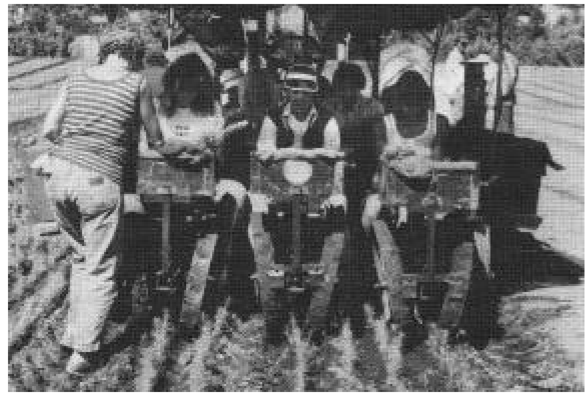

Figure 11. Preextracted seedlings are transplanted from trays.

and their calipers doubled during the 3 months after transplanting, although their height remained the same because they had already set buds in August. Such caliper and root development during fall and winter is typical for late-summer transplants, priming them for outstanding development during the following growing season. Height of p+1s at field planting time was comparable to that of the 2+1s; but their caliper, branch characteristics, and total root mass were considerably better than those of 2+1s or of any other seedling type (Table 6).

The root mass, which supplies seedling tops with water and nutrients, must be well balanced with height and caliper if outplanted seedlings are to perform well. The comparison in Table 6 indicates that 2+0 bareroot seedlings, on the average, had only 91 cm of total root length to each millimeter of caliper; this ratio was 98% higher for 2+1s, 189% higher for styro 2s, 264% higher for styro 5s, 281% higher for styro 8s, 349% higher for p+3-months, and 403% higher for p+1s. Comparing total root mass length to seedling height revealed a similar trend (see Table 6).

One of the most common problems with late-summer p+ 1 transplants has been their excessively rapid height growth (Fig. 12), which may be due to the following conditions:

- Containerized seedlings grown in greenhouses extend their heights in stages several times without forming buds each time.
- An early sowing date, dense spacing, and small container-cavity size pushes seedling development and promotes early budset in the greenhouse.

Table 6. Top- and root-growth comparisons of nursery stock types.

	Tops				Roots		
					Total length, cm		
Stock type	Average height, cm	Average caliper, mm	Number of branches	Average branch length, cm	Per tree	Per mm of caliper	Per cm of height
Container							
Styro 2	25	2.6	7	2.6	684	263	27
Styro 5	33	3.3	13	2.4	1,024	315	31
Styro 8	39	4.2	17	3.9	1,457	347	37
Bareroot							
2+0	32	5.0	15	4.7	456	91	14
2+1	55	8.0	22	7.8	1,442	180	26
P+3-months[1]	21	4.2	7	3.2	1,717	409	82
Plug+1	51	10.6	32	10.2	4,854	458	95

[1]Plugs planted in August and lifted for evaluation 3 months later.

- Late-summer, p+1 transplants continue their diameter growth, bud development, and root growth long after transplanting.

The after-effects of the above promote early flush next spring and more needle and branch development on the rapidly growing new stems. Although vigorous stem, root, and branch development is most desirable, too much height growth could become a handling problem during lifting, packaging, storing, shipping, and field planting. Rapid seedling height development can be controlled through fertilization and other cultural treatments or by early top mowing or root wrenching.

Figure 12. Vigorous height growth of p+1s must be considered when designing fertilizer regimes, to avoid excessive seedling growth.

16.5.3.2 Treatment procedures

Watering.—Routine watering during the growing season will depend greatly on soil composition, local climate, and seedling need. Representative sampling points established throughout the nursery for monitoring soil and seedling moisture will provide guidelines for watering. The "pressure bomb," developed by blaring and Cleary [5], gives good indication of seedling moisture stress (see chapter 12, this volume).

Fertilization.—Transplanted seedlings should be fertilized during the growing season according to soil fertility level (see chapters 7 and 8, this volume) and seedling need. However, seedlings require different combinations of fertilizers during the various seasons and stages of growth [2]. One or two large fertilizer applications during the growing season normally do not satisfy this need and may cause problems in achieving the desired seedling size and quality.

Bareroot nurseries are slowly adopting the fertilizer techniques developed in container nurseries in recent years—and a similar technology is strongly suggested for p+1s. Seedling height and diameter development are plotted on charts and compared to target curves. Foliar and soil nutrition levels are regularly analyzed in the laboratory to ensure that seedlings are being fertilized in the proper amounts and types. Fertilizer should be applied in frequent small doses, rather than in one or two large doses, so that the nursery manager can better control seedling growth to match target curves. It is always possible to add more fertilizer if needed—but impossible to remove it.

As a general rule, seedlings require a fertilizer with higher nitrogen content at the beginning of the growing season. Midseason, more phosphorus is needed for better root and stem development. At the end of the season, a fertilizer low in nitrogen and high in potassium will aid hardening, stem lignification, and bud development [2].

Weed control.—Chemical weed control is becoming a standard practice in bareroot nurseries (see chapter 18, this volume). New chemicals are constantly being developed to provide a large variety of selective treatment methods. Most of these chemicals can be used with p+1s if the directions outlined in the literature and on labels are properly followed.

The nursery operator must remember, however, that transplanted p+1s are younger than the 2+0 seedlings planted for 2+1 stock and may exhibit a slightly different physiological condition. Therefore, some of the standard transplant chemical treatments for weed control should be applied with caution or not applied at all to p+1 transplants.

Manual weed control might still be necessary on a limited scale but could become very expensive because of the high labor costs.

Disease control.—Containerized seedlings generally have few disease problems because of the way they are raised. However, these seedlings still need to be carefully examined before they are shipped to a transplant nursery to avoid transfer of contaminated material. If a disease problem develops, p+1s should be handled like regular bareroot crops (see chapter 19, this volume).

Top mowing.—Many nurseries have had trouble controlling the top growth of p+1 transplants because of their aggressive development. Top mowing is frequently used to hold seedling height at a desired level and to keep the crop more even (Fig. 13); however, the effect of this treatment is still not well understood (see chapter 15, this volume).

A lone mowing catches the various Northwest species in their succulent-leader growth stage. These leaders snap off easily if the proper equipment is used without causing much damage to the remaining portion of the leader. Experience has shown that the lateral bud nearest the cut becomes dominant and generally develops into the new leader.

August or September mowing should be avoided because it substantially damages lignified seedling stems. Wounds made at this time do not heal easily and may provide an entry point for diseases. August mowing also often causes a flushing problem; newly flushed tender shoots seldom harden in time to develop cold resistance against early frosts. Late mowing

Figure 13. Plug+1 transplants top-mowed in lone achieved a desired height of 19 to 21 inches by lifting time.

also predisposes top buds to excessive forking during the following year.

Root wrenching.—Root wrenching is a new cultural technique in which seedling roots in nursery beds are severed at a given depth by a device equipped with a sharp blade (see chapter 15, this volume). This technique helps control height growth and promotes root development. Properly grown p+1 transplants may not require root wrenching if their heights are controlled with a nutrition regime or top mowing and if seedlings develop their typically strong, fibrous roots and stems.

Hardening.—The treatment for achieving proper cold hardiness-very important in seedling development—is probably no different for p+1s than for other seedling types.

16.6 General Evaluation of the Plug+1

16.6.1 Advantages and disadvantages

No single stock type available can fit all reforestation needs. What may be an advantage in a given condition for one user might be a disadvantage in a different condition for another.

Some general advantages of the p+ 1 are:

Container growing phase

- Good utilization of genetically improved seed
- Good, even seedling yield
- 1-year lead time before transplanting
- Easy timing and conditioning of seedlings for transplanting in spring, fall, or late summer
- More mechanized handling of seedlings during shipping and transplanting without the need for refrigeration

Bareroot growing phase

- Rapid, good-quality transplanting
- Little problem with root deformities
- Good height, diameter, and root development after transplanting
- Uniform, high seedling yields
- Easy root pruning, packaging, shipping, and field planting because of narrow, fibrous root systems

Field application

- Good survival and growth rate
- Seedling quality and cost:benefit ratio comparable to or better than those of any other seedling type when used on a typical transplant site

Some of the above advantages may become disadvantages if seedlings are not raised, handled, or used properly. Potential problems include:

Container growing phase

- Improper facility and container selection
- Poor crop scheduling and growing practices
- Improper crop conditioning for transplanting
- Seedling-quality deterioration during greenhouse overwintering or prolonged cold storage
- Mishandling during packaging, shipping, or transplanting

Bareroot growing phase

- Improper transplant scheduling
- Heat and frost injury due to poorly prepared and timed transplants
- Rearing problems due to limited experience with p+1 production

Field application

- Improper timing of field planting
- Inappropriate planting-site selection

The above-listed problems do occur—though most are the exception, not the rule-largely because the p+1 growing and application concept is new and very often poorly understood. Though some of these problems are classified as disadvantages, most should disappear with time and experience.

16.6.2 Suggested applications

Plug+1s have been used in routine reforestation under many different conditions and in many locations in the Northwest. As is true for all other stock types, the p+1 will not solve all reforestation problems, and its survival rate and growth performance will vary with conditions.

Comparable survival data for p+1s and other seedling types have been collected by Georgia-Pacific on typical Douglas-fir reforestation sites in western Oregon during routine plantation survival surveys over 7 years. Sites represented a total of 110,000 acres of reforested land and more than 50 million seedlings. Though the data gathered were not from designed and replicated research installations, they nevertheless provide good information for managers and show trends.

Trees planted on coastal, or moist, sites (Fig. 14)—often classified as typical Northwest transplant sites—face strong vegetation competition. This is perhaps why the larger transplants (2+1s and, especially, p+1s) performed so much better than the smaller 2+0 bareroots and container stock types on these moist sites. Trees planted on inland, or drier, sites—for example, the Willamette Valley and southern Oregon—often face a long, dry period during summer. Containerized planting stock performed better than bareroot stock, including p+1s, on these drier sites (Fig. 14).

The containerized seedlings used on the drier sites were raised in styroblocks in shelterhouses, were well hardened, and had a good root mass with active root tips when field planted during routine late-fall and winter planting. Because root tips were active, root growth continued during dormancy; this helped seedlings become established and primed them for good survival and growth the following summer.

Tops of husky bareroots, especially transplant stock, generally are large compared to their root mass. Such large tops often do not get the needed support from their roots for good survival and growth on dry sites after planting. Of all the bareroot stock types, p+1 transplants survived best and came closest to matching the survival of containerized stock—probably due to their root development (see Table 6).

To better quantify and corroborate the above results, well-designed research installations have been established. Of many regeneration experiments, the following replicated test is especially worth mentioning.

In 1979, 2,200 seedlings—p+1s, three containerized stock types (styro 2, 5, and 8), and two bareroot stock types (3+0 and 2+1)—were planted on a north and south slope on typical reforestation-site land near Eugene, Oregon. Concurrently, the same stock types were planted in general reforestation on Georgia-Pacific land. The two Eugene test sites were felt to represent large acreages of Georgia-Pacific land; the north-exposure site was analogous to inland north slopes or to coastal areas (cooler "wet" sites), and the south-exposure site to inland areas (warmer "dry" sites). Each site represents a particular reforestation problem: seedlings must vie with competing vegetation on "wet" sites and suffer moisture stress on "dry" sites. Animal browsing also was monitored in this experiment.

Containerized seedlings showed a remarkable survival rate on both sites (Table 7, Fig. I S), probably due to their superior

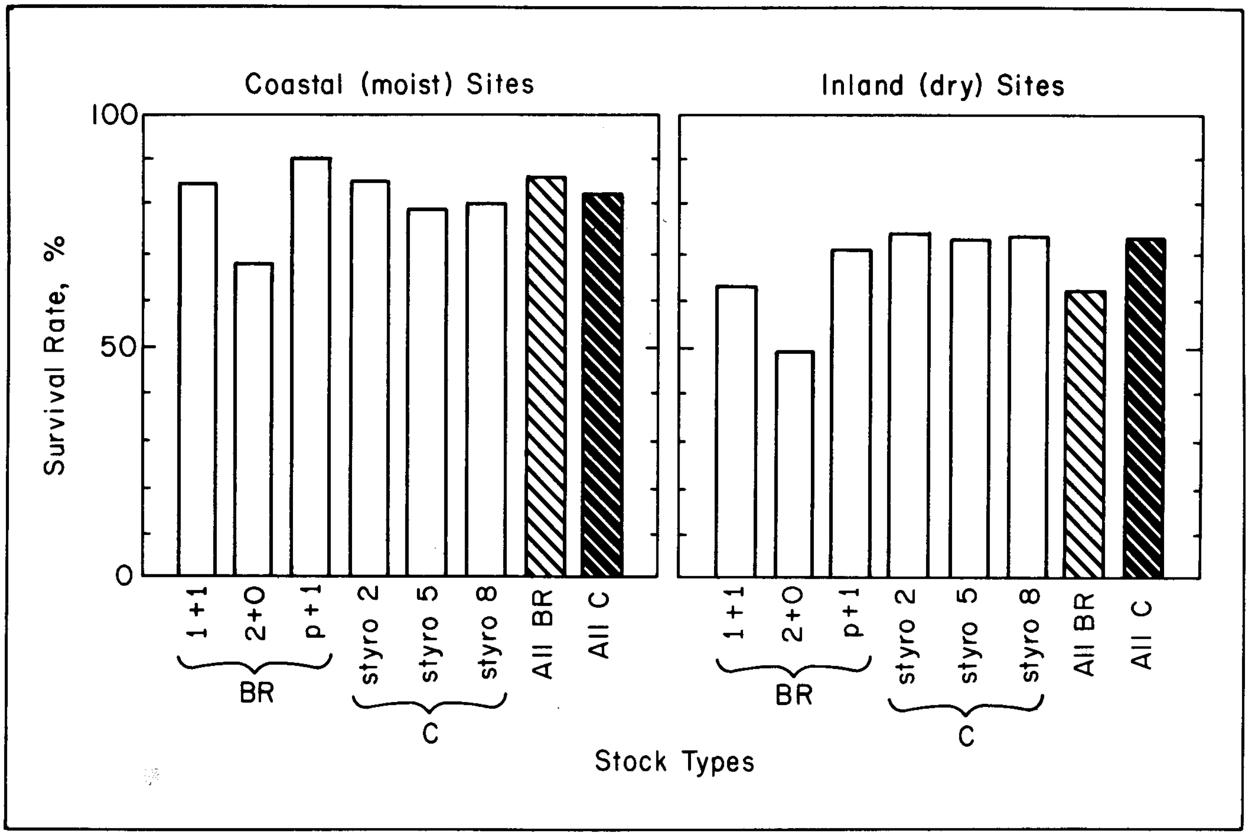

Figure 14. Survival of bareroot (BR) and container (C) stock types on typical Douglas-fir plantations in western Oregon, 1976 to 1982.

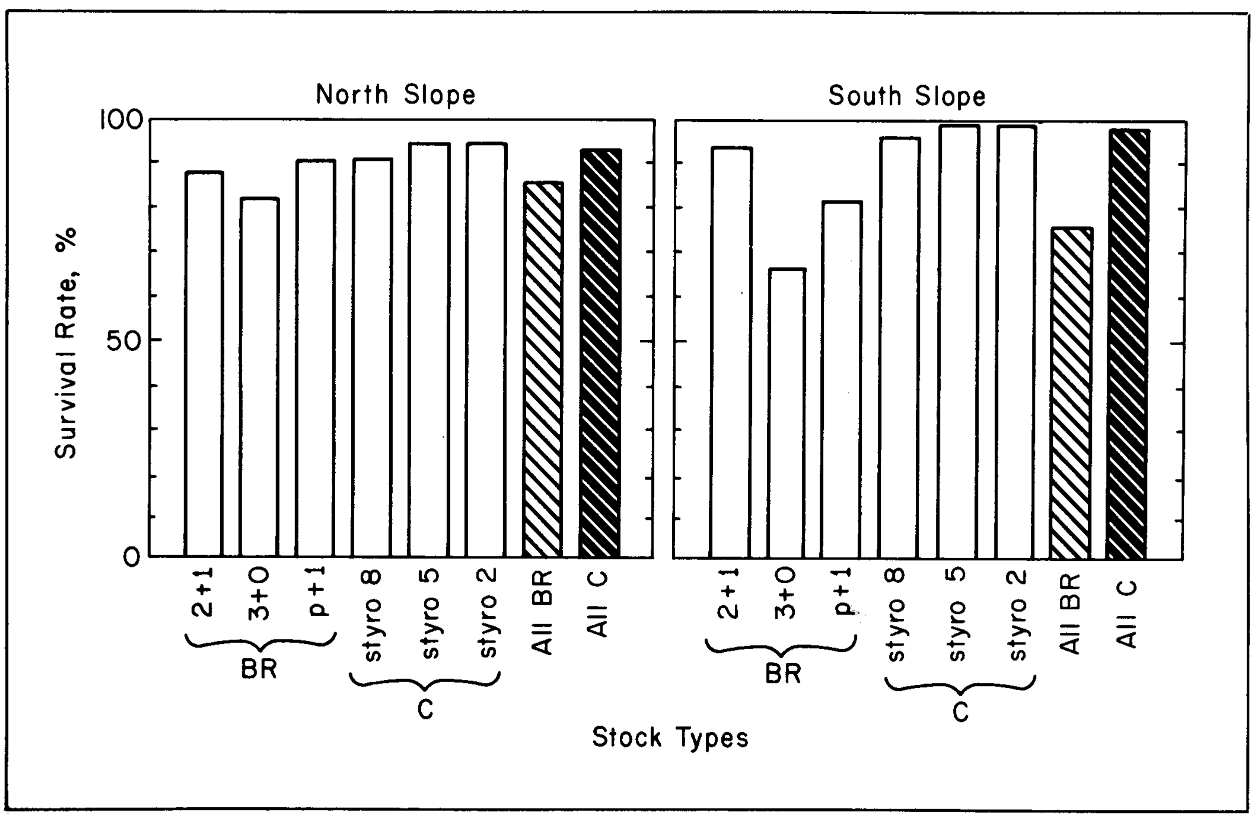

Figure 15. Survival of bareroot (BR) and container (C) stock types in the Georgia-Pacific experiment.

root quality and physiological makeup. In height growth, they had a hard time competing against the initially taller bareroot seedlings on the north slope but made up for their height disadvantage on the south slope (Fig. 16), where they performed extremely well. Containerized seedlings outscored bareroots in growth increment 3:1 on the south slope and 2:1 on the north slope.

The initially taller, "top-heavy" bareroot seedlings generally performed well on the cooler north slope, where they were not exposed to rapid drying conditions after planting and therefore not subjected to typical dry-site planting shock; those seedlings remained above the brush and maintained good height growth. In contrast, bareroot stock did poorly on the south slope (Figs. 15 and 16); their performance trend was exactly the opposite of that on the north slope.

Table 7. Survival and growth of six stock types on north- and south-facing test sites in the Georgia-Pacific experiment.

Stock type, by exposure	Average height /tree, cm		Survival rate, %	Growth increment
	Starting (2/79)	Ending (12/81)	(12/81)	per average tree, %
	North slope			
Bareroot				
2+1	46	135	86	193
3+0	59	109	80	85
P+1	36	108	89	200
Total	49	111	84	127
Container				
Styro 2	17	74	89	335
Styro 5	22	82	92	273
Styro 8	33	96	93	191
Total	24	84	91	2 50
	South slope			
Bareroot				
2+1	48	97	92	102
3+0	61	102	65	67
P+1	38	106	80	179
Total	50	103	74	106
Container				
Styro 2	17	95	94	459
Styro 5	25	100	97	300
Styro 8	33	1l2	97	239
Total	25	103	96	312

Animal damage on both sites was less than normal for freshly planted areas. Generally, the south slope suffered about twice as much damage as the north slope. Furthermore, bareroot seedlings on both sites were browsed about twice as heavily and twice as often as containerized seedlings. In spite of this, overall height growth was not significantly reduced due to browsing on either site or for any one stock type.

We concluded that the large p+1 transplants, like other large bareroot seedlings, should not be used on hot, droughty sites. Such sites are far better suited for well-developed plug seedlings. Large bareroot seedlings, including p+1s, do rather well on moist slopes and on cool, coastal lands with high site productivity. There, the tall seedlings have the needed ground moisture for good survival and excellent height growth and a better chance of competing with the fast-growing weeds normally present.

16.6.3 Species correlations

Most of the discussion in this chapter directly relates to Douglas-fir seedling production because Douglas-fir is the major species in the Northwest. However, the p+1 production method has also been used quite successfully, on a smaller scale, with other Northwest species, including western hemlock [*Tsuga heterophylla* (Raf.) Sarg.], Sitka spruce *[Picea sitchensis* (Bong.) Carr.], western redcedar *(Thuja plicata* Donn ex D. Don), white fir [*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.], grand fir [*Abies grandis* (Dougl. ex D. Don) Lindl.], noble fir (*Abies procera* Rehd.), ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.). So far, there is no real evidence that the stated species and others would not be suitable for p+1 production, though this has yet to be proven.

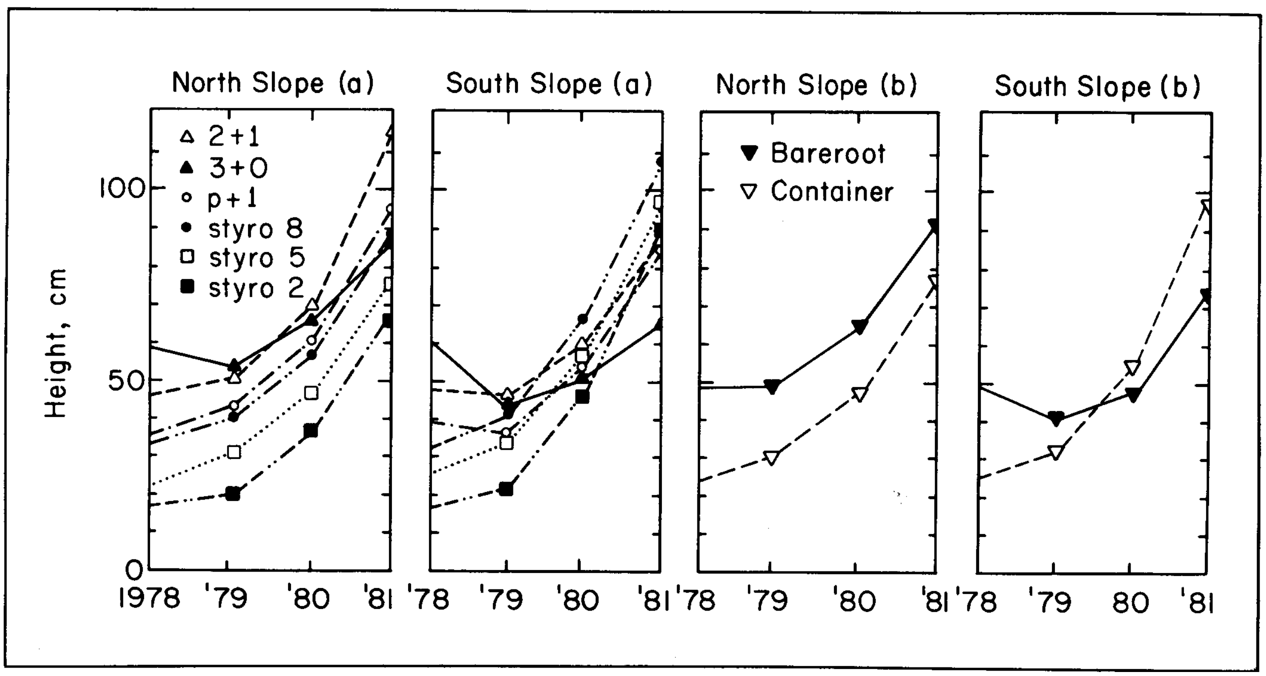

Figure 16. Total (height x survival) performance of individual (a) and combined (b) bareroot and container stock types for the Georgia-Pacific experiment.

16.6.4 Cost comparisons

Containerized seedlings destined for p+1s normally cost slightly more than 1+0 or 2+0 seedlings regularly used for transplanting, although the actual production cost of the transplant phase is normally the same for all transplanted stock. But managers must look at the **total** costs and savings for producing and using stock types—right up through establishment and field performance—to arrive at a realistic cost comparison.

Careful analysis indicates that p+1s have the following advantages:

- Uniform, high-yield stock, in both container and bareroot phases, resulting in low cull factor
- High transplant speed
- More efficient packaging, storing, and shipping
- Easier field handling, resulting in higher planting speed and quality
- Excellent root and top development, supporting good seedling establishment for high survival and growth rates.

Although some of the savings generated at bareroot nurseries are not always passed on to users, other savings resulting from a good-quality product are easily measured in a cost:benefit calculation. **All** costs, from land preparation through seedling establishment, should be included and the total cost then related to seedling performance.

Cost:benefit ratios were computed on the basis of stocking-survey survival results gathered on about 3,000 acres of typical, comparable transplant sites planted with 1.3 million p+1s and 2+1s in equal ratios. The actual total reforestation costs, including site-preparation, seedling, and outplanting costs, were available for both stock types. Total reforestation cost per 1,000 seedlings was 11% higher for the 2+1 transplants than for p+1s right after planting—and 22% higher when survival was considered 3 years later. This illustrates quite well that p+1 stock, seemingly more expensive at the nursery stage, may look quite favorable later because of its good quality and performance.

The Georgia-Pacific experiment with six stock types (see 16.6.2) also was subjected to cost:benefit analysis. Commercial, large-scale reforestation cost figures for each stock type—more useful than the installation cost of the experiment—were available. Cost:benefit ratios were calculated by dividing the establishment (seedling and outplanting) cost for each stock type by its total performance.

The result was a straight-line correlation (± 2 % variation) for the containerized seedling types. As the establishment cost

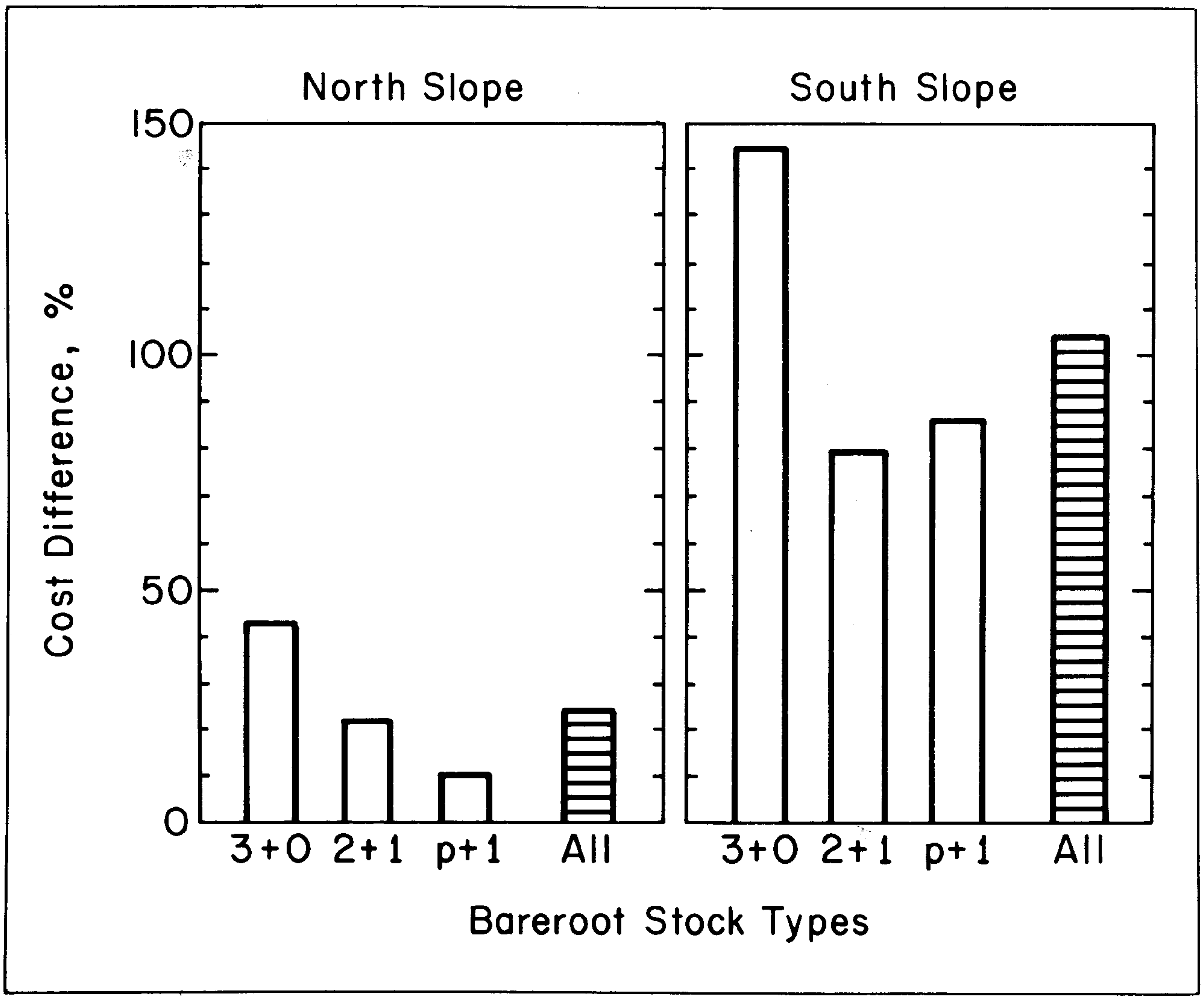

Figure 17. Relative differences in cost:benefit ratio for bareroot stock types when compared to the cost:benefit ratio of containerized seedlings for the Georgia-Pacific experiment.

increased for a given container type, so did its performance; styro 2s had the lowest cost and performance, and styro 8s the highest. However, the cost:benefit ratio varied greatly for the bareroot seedling types. The 3+0s had the lowest initial cost but performed poorly; therefore, their ratio was the least satisfactory. The 2+1s did slightly better than the p+1s on the north slope, but the opposite was true on the south slope.

Because the cost:benefit ratios for the three containerized stock types showed almost no variation, they were used as a base of comparison for the three bareroot stock types. Combined figures for the bareroots indicate that the cost of using bareroot seedlings was about twice that of containerized seedlings on the south slope, but only about 25% greater on the north slope (Fig. 17).

In summary, the experiment showed not only that bareroot transplants survive and grow well on north slopes or cooler sites but also that their cost:benefit ratio is quite low, compared to that of container-grown seedlings. A 12 to 22% higher cost for p+1 and 2+1 stock, respectively (Fig. 17), is justifiable on transplant sites to ensure successful reforestation where vegetation competition is strong.

16.7 Conclusion

Plug+1 seedlings are just one more seedling type available for reforestation-and should always be viewed as such. They have demonstrated special qualities and abilities to perform well if produced and used properly, and they are economical.

This seedling type has good application at present and should perform even better, after improvements, in the future.

References

1. Carlson, W. C., and C. L. Preising. 1981. Effects of controlled bed-release fertilizers on the shoot and root development of Douglas-fir seedlings. Can. J. Forest Res. 11(2):230-242.
2. Hahn, P. F. 1978. Nutrient requirements of containerized nursery stock. Section B. Pages 7-15 *in* Proc., Western Forest Nursery conf., Eureka, California.
3. Hahn, P. F. 1983. Containerized seedling production in a shelter-house system. Pages 110-128 *in* Proc., Western Forest Nurserymen's conf., Medford, Oregon, Aug. 10-12. 1982. Southern Oregon State Coll., Ashland.
4. Schalla, S. L. 1979. Transplanting the Douglas-fir plug. Tyee Tree Nursery, Roseburg, Oregon.
5. Waring, R. H., and B. D. Cleary. 1967. Plant moisture stress: evaluation by pressure bomb. Science 155(3767):1248-1254.