The Container Tree Nursery Manual

Volume Six
Seedling Propagation

Chapter 1
Crop Planning

Contents

6.1.1 Introduction

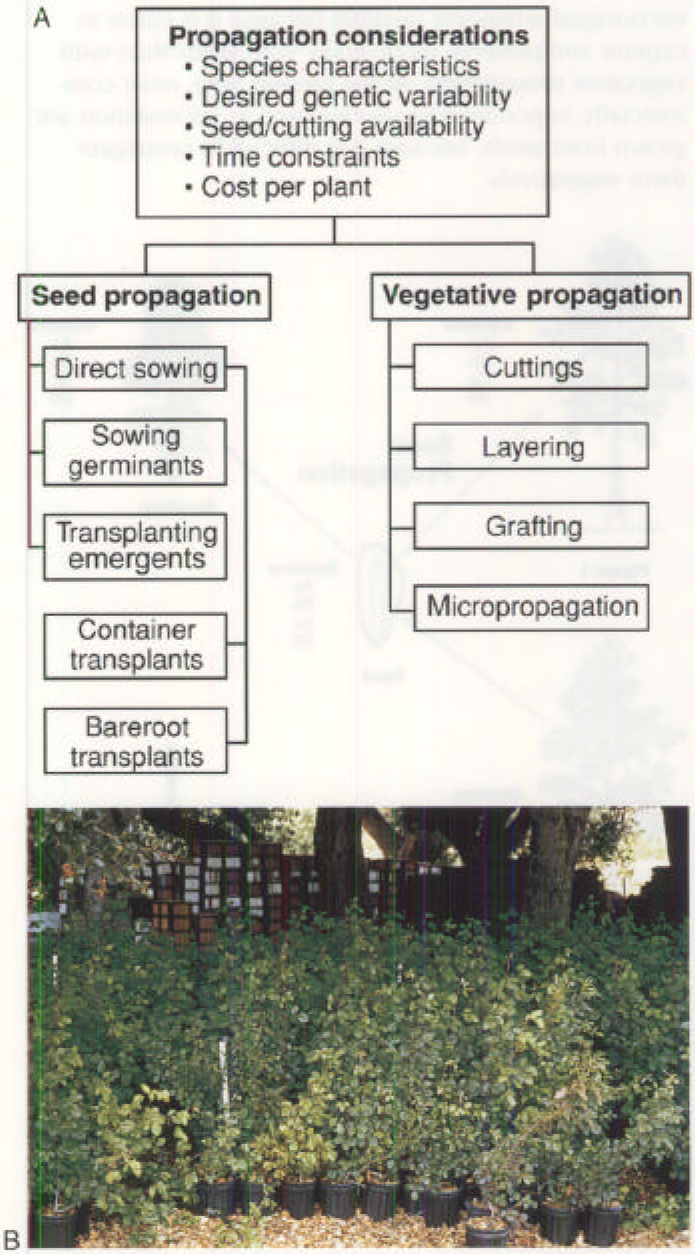
Plant propagation is both science and art. In this chapter, we will discuss the science of plant propagation, which requires a knowledge of plant physiology, nursery cultural practices, and characteristics of the particular plant that we want to grow. The art of plant propagation cannot be taught in a book or classroom, however, because it consists of specific technical skills that must be acquired through innate ability or experience and often requires a certain "feel." Good plant propagators are said to have a "green thumb." Successful propagators must be able to reproduce the desired crop species both consistently and economically. Although nursery managers can always hire growers or propagators with these skills, they themselves must also be familiar with the basic terminology and techniques of plant propagation.

The previous five volumes of this series showed how to construct the propagation facility and gather supplies for growing that first crop. In this volume, we review the sequence of processes and operations used to propagate container seedlings. Successful nursery management begins with planning. Crop planning is one of the most important, yet often neglected, aspects of seedling culture. This chapter discusses factors that must be considered during crop planning and introduces concepts of propagation protocols and planning calendars called growing schedules.

6.1.1.1 Propagation methods

The first phase of the planning process is to determine which type of propagation method should be most effective and economical for the crop species. Both the biology of the species and the objectives of the outplanting project must be considered (figure 6.1 .1 A). Most commercially important tree species used in reforestation can be grown from seeds, but some ecologically important species must be produced vegetatively. A few trees used for timber or fiber are vegetatively propagated on a large-scale to multiply "clones" that have selected for specific traits such as fast growth. In the past decade, there has been increasing interest in the propagation of non-commercial native plants. One of the fascinating aspects about working in forest and conservation nurseries is that some native plants provide unusual propagation challenges (figure 6.1 .1 B)

If it is possible to propagate a plant either by seed or vegetatively, then the amount of genetic variability that is desired in the crop must be considered (figure 6.1 .1 A). Sexual reproduction results in a mixture of genetic characteristics in the offspring, so each plant will appear slightly different from its parents and each other (figure 6.1 .2). Because maintenance of genetic diversity is so important in ecosystem management, seed propagation is



B

Figure 6.1.1—*Many factors must be considered before deciding on a propagation system* (**A**). *For plants like this poison-oak, the propagation option is obvious—seed would be much safer than cuttings* (**B**).

encouraged whenever possible because it is easier to capture and preserve biodiversity with seeds than with vegetative propagation. At the present time, most commercially important tree species used in reforestation are grown from seeds, because it is difficult to propagate them vegetatively.

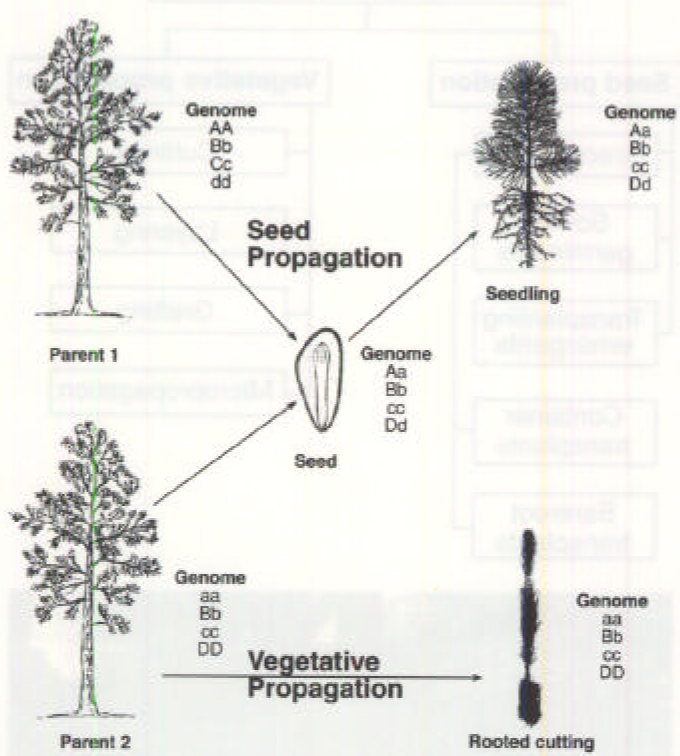


Figure 6.1.2—*Plants propagated from seed look different from their parents and each other because they contain a mixture of the genetic characteristics of their parents. Vegetative propagation, on the other hand, produces exact duplicates of the parent plant.*

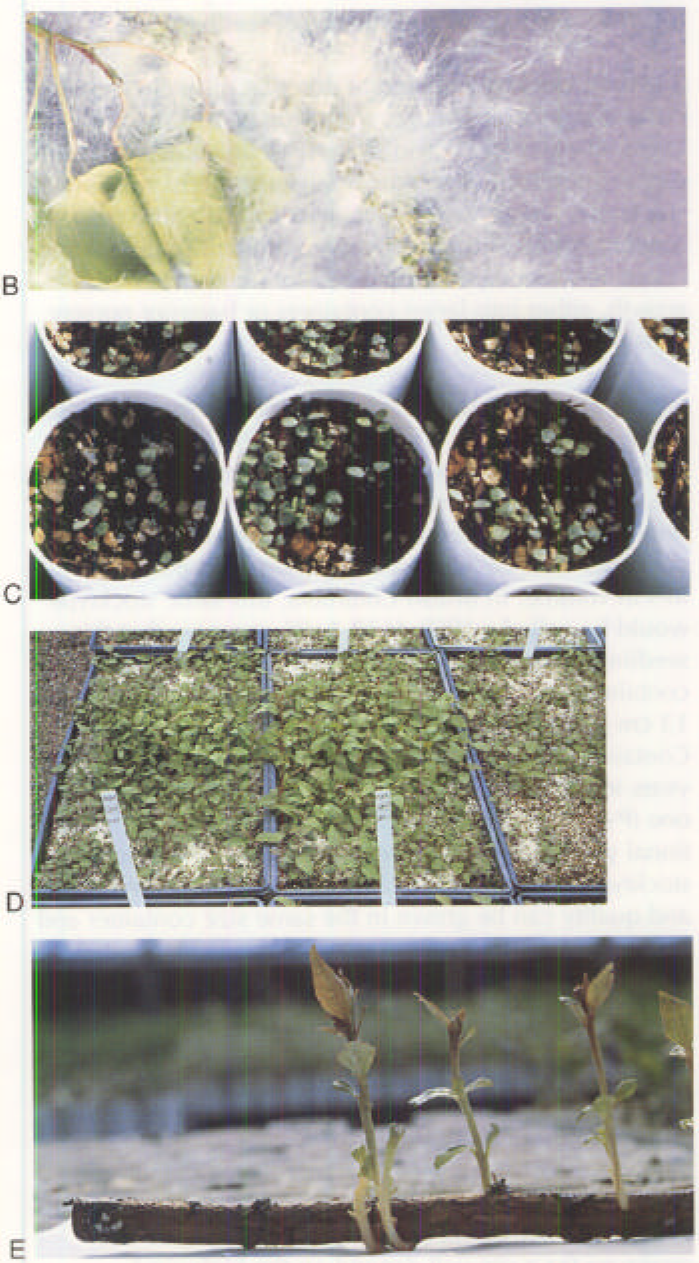
Availability of propagation material, time constraints, and economics must be considered (figure 6.1 .1 A). Some species--such as western larch- produce ample seed crops very irregularly, so it may be impossible to obtain enough seed in time for an outplanting project. This is especially true for emergency projects, such as fire rehabilitation, when crops must be grown in a very short time. Seed propagation is almost always less expensive than vegetative propagation, because all vegetative propagation techniques involve more hand labor compared to seed propagation and many require special equipment and structures.

Seed propagation. There are several options when choosing seed propagation (figure 6.1 .1 A). **Direct sowing** is the traditional method and consists of placing seeds directly into the growth container and allowing them to germinate in place (Hartmann and others 1997). Seedlings either can be allowed to grow to shippable size or transplanted into larger containers **(container transplants)** or soil beds in a bareroot nursery (**plug transplants**). Sowing seeds into shallow trays, keeping them moist, and then **planting germinants** (germinating seeds) into growth containers is a second option. **Transplanting emergents** consists of sowing seeds into shallow trays and allowing them to germinate and the seedlings to emerge. The young "emergents" are then transplanted into the growth container to finish their development.

Each of these seed propagation techniques will be needed to propagate certain forest and conservation species. More information on seed propagation, including a detailed discussion of advantages and disadvantages of the various techniques, is given in chapter 2 of this volume.

Vegetative propagation. Although they vary considerably in technique, all vegetative propagation options (figure 6.1.1 A) are a form of **asexual reproduction.** The objective is to make multiple "copies" of an individual plant or select group of plants with similar genetic composition (Hartmann and others 1997). Species that root easily can be propagated with **cuttings.** This process involves collecting stem sections, treating the lower part with rooting hormones, and then either sticking them in trays filled with growing medium until they form roots or "direct sticking" them into the growth container. **Layering** consists of inserting a section of stem or root still attached to the plant into a favorable rooting environment until roots develop. The rooted section is then cut from the parent plant and transplanted into the growth container. **Grafting** is a very specialized propagation technique in which shoots or buds from one plant are surgically implanted into another. The newest and most rapidly developing vegetative propagation technique is **micropropagation.** This involves a series of sterile laboratory techniques in which small sections of plant tissue are chemically stimulated to form multiple shoots and are then rooted. The resultant "explants" are transplanted to growth containers and raised under normal culture. Vegetative propagation techniques vary considerably in effort and cost and a detailed discussion of their advantages and disadvantages is provided in chapter 3 of this volume.

Some species can be propagated either by seeds or vegetatively, and the decision depends on the objective of the outplanting project. Fraser fir, a native conifer that has a restricted natural range in the Southern Smoky Mountains, has become a highly prized Christmas tree (Blazich and Hinesley 1994). So, if the propagation objective is revegetation, then seed propagation would be the logical choice using seeds collected from the local seed zone. On the other hand, if the objective is Christmas trees, then propagation by stem cuttings from a cultivar selected for its desirable foliage color and crown form would be necessary. Quaking aspen (figure 6.1 .3A) is another good example of how the choice of propagation method depends on the objective. Aspen seeds are very small and difficult to handle because they are enclosed in a ball of cottony material (figure 6.1 .3B). Seeds can be cleaned relatively easily, but usually are sown manually into growth containers because of their small size (figure 6.1 .3C). Some nurseries sow seeds into germination flats and then transplant the young seedlings after they emerge (figure 6.1 .3D). If the objective is to retain the physical characteristics of a specific ecotype or clone, however, then aspen can be propagated vegetatively from root sprouts (figure 6.1 .3E), which are rooted and then transplanted to growth containers.



B

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A

Figure 6.1.3— *Quaking aspen* (**A**) *can be propagated either by seed or vegetatively, depending of the objectives of the outplanting project. If the objective to maximize genetic diversity, seed propagation is best. Aspen seed is very small* (**B**), *so it is hard to control the sowing density* (**C**). *However, seeds can be grown as "emergents"* (**D**), *which are then transplanted to the growth container. If the propagation objective is to maintain the properties of a certain clone, then root cuttings* (**E**) *can be cut, rooted, and transplanted to the growth container.*

6.1.1.2 Stocktypes and the target seedling

The term **stocktype** is used to describe distinct categories of seedlings based on age, size, propagation method, and even delivery date. A wide variety of different stocktypes can be produced in container nurseries. Most seedling stocktypes are grown in containers for the entire crop rotation, whereas transplants are started in small-volume containers and then transplanted for another period of growth, either into larger containers or bareroot nursery beds (figure 6.1AA).

Stocktypes are typically described with numerical codes that refer to the type of container in which they were grown, but the system varies between regions. For example, in the western United States, a "Styro 4" refers to a seedling that has been produced in a Styrofoam® block container with cells that are approximately 65 cm3 (4 ins) in volume. In British Columbia, this same stocktype would be called a "PSB 313B 1+0", meaning that this seedling was grown for 1 year in a Styrofoam® block container that has cells that are 3 cm (1 .2 in.) wide and 13 cm (5.1 in.) deep (BC Ministry of Forests 1998). Container transplants are described by the number of years in the bareroot nursery-for example a plug-plus-one (P+1) transplant would have been grown for 1 additional year. A major problem with any of the current stocktype naming systems is that seedlings of varying size and quality can be grown in the same size container and so a Styro 4 from nursery A may be significantly different than a Styro 4 from nursery B.

The stocktype name may also include the season of outplanting--spring, summer, or fall. Because they can control seedling morphology and physiology, container nurseries can produce stocktypes for a wide variety of outplanting seasons and sites. The morphological, physiological, and genetic characteristics of seedlings should be targeted for individual outplanting sites, and the best stocktype for a site will depend on the biological demands of the site (McGilvray and Barnett 1982). **There is no one ideal type of seedling that can be used for all purposes. The ultimate measure of seedling quality is performance on the outplanting site--both initial survival and early growth.** (See section 1.1.1 and figure 1.1.3 in volume one of this series for more discussion on stocktypes.)

Recently, growth after outplanting has been receiving more attention because some existing stock standards result in seedlings that survive satisfactorily but fail to thrive, resulting in plantations that are not satisfactorily stocked or exhibit poor growth. This has led to the establishment of new "free-to-grow" standards that specify larger seedlings that are better able to successfully compete and grow after outplanting (Bowden and Scagel 1994; Wood 1994).

Both the seedling user and nursery manager are jointly responsible for successful plantations, and so must work together to define the best type of seedling for a particular planting project (Rose and others 1990). The seedling user must specify the proper genetic origin for the seedlings (for example, seed source), the type of outplanting tool, and which environmental factors on the outplanting site will be most limiting to survival and growth. By jointly agreeing on which morphological characteristics (for example, height, stem caliper, root volume) and physiological characteristics (for example, dormancy status, cold hardiness) will be needed to maximize outplanting performance for that particular site, the proper stocktype can be selected--the **target seedling** (figure 6.1.4).

The seedling buyer and the nursery manager should discuss the desirable morphological and physiological characteristics of the target seedling during the planning process and define specifications for that particular crop. The nursery manager can then design growing schedules to produce that crop in the shortest time and at the lowest cost. For example, target seedling specifications for reforestation sites in Alberta, Canada consist of four size-classes for white spruce and three for lodgepole pine (table 6.1.1). Each size class is defined by a target height and stem diameter and can be produced in various sizes of containers or as container transplants (Wood 1994). Another excellent discussion of how to select the proper target seedling in Ontario is given in the book *Artificial Regenerations of Ontario's Forests: Species and Stock Selection Manual* (Johnson and others 1996).

The effect of nursery culture on target seedling specifications is illustrated by the relationship between seedling size and container type-seedling size increases with container volume and spacing (figure 6.1.5). For example, to produce a specific size-class of white spruce, a nursery manager would select a container and design a growing schedule that would best meet the biological requirements of the species (see volumes 1 and 7 for further discussion on stocktypes).

To develop effective growing schedules, growers must consider how cultural practices affect various phases of seedling growth and development.

Figure 6.1.4—*This ponderosa pine target seedling exhibits the ideal characteristics for outplanting on sites in the Intermountain West: a relatively short top height with stout caliper, and a vigorous root system.*

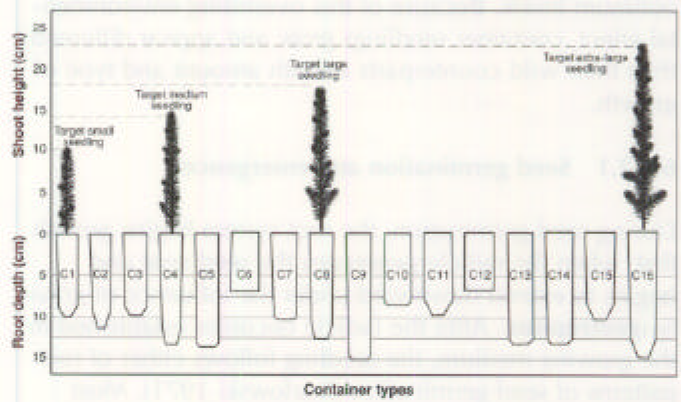


Figure 6.1.5—*The volume of a container is one of the most important factors controlling seedling size—larger containers produce larger seedlings (modified from Wood 1994).*

Table 6.1.1—*Target seedling specifications for reforestation sites in Alberta, Canada, compared to container types used to produce them*

Species & seedling size class*	Stock type	Shoot height: Target cm	Target in	Range cm	Range in	Stem diameter (mm) Target	Minimum	Container size codes*
White spruce								
Small	Container	10	3.9	8–14	3.1–5.5	2.0	> 1.8	C1–C2
Medium	Container	14	5.5	10–20	3.9–7.8	2.5	> 2.2	C3–C4
Large	Container	17	6.7	12–25	4.7–9.8	3.0	> 2.4	C5–C13
Extra large	Container	22	8.7	15–28	5.9–11.0	3.5	> 2.6	C14–C16
Extra large	Plug transplant	24	9.4	> 14	>5.5	4.5	> 3.5	N/A
Lodgepole pine								
Small	Container	7	2.8	4–10	1.6–3.9	1.5	> 1.2	C1–C9
Medium	Container	12	4.7	8–16	3.1–6.3	2.8†	3.0‡	C10–C16
Large	Plug transplant	16	6.3	> 10	> 3.9	4.5	> 3.0	N/A

Source: Wood (1994).
* See figure 6.1.5. † Spring. ‡ Fall.

6.1.2 Seedling Growth and Development

Before nursery managers can raise a crop of seedlings, they must have a basic understanding of how seedlings grow and develop because propagation environments and cultural techniques affect the morphology and some times the saleability of the stock. Seedling growth and development is controlled by genetics and environment, whether in nurseries or in the wild. Environment has a proportionally greater effect in nurseries, however, where many or all potentially growth-limiting factors are kept at optimum levels. Because of this overriding environmental effect, container seedlings grow and appear differently than their wild counterparts in both amount and type of growth.

6.1.2.1 Seed germination and emergence

During seed germination, the root system begins growth first, when the radicle penetrates the seed coat and begins to extend downward under the influence of gravity **(geotropism).** After the radicle becomes established in the growing medium, the seedling follows either of two patterns of seed germination (Kozlowski 1971). Most conifers and some broadleafed species exhibit **epigeous germination,** in which the cotyledons ("seed leaves") are pushed above the surface of the growing medium by the expanding hypocotyl (figure 6.1.6A). Conifer cotyledons carry the seedcoat on their tips to form a "birdcage." Other broadleaved species, such as oaks, exhibit **hypogeous germination,** in which the cotyledons remain underground while the **epicotyl ("shoot')** elongates upward and produces primary leaves above the surface of the growing medium (figure 6.1.6B). Some genera, such as *Prunus* spp., contain some species that have epigeous germination and others with hypogeous germination (Schopmeyer 1974).

6.1.2.2 Patterns of shoot growth

The way in which a seedling shoot grows is complicated and can be confusing because different terms have been used in the literature. We prefer the practical terminology used by Powell (1982), which recognizes two types of shoot growth. **Preformed** ("predetermined") **growth** is a result of the expansion of preexisting structures: either those preformed in the embryo for first year shoots or those in terminal and lateral buds in subsequent years. **Neoformed ("free") growth,** on the other hand, does not depend on any preformed structures but is instead determined by genetics and environment (figure 6.1.7). Some species exhibit both preformed and neoformed shoot growth in a given year, whereas others only have one or the other. This tendency is genetically determined and cannot be changed by cultural means (MacDonald 1998).

The presence or absence of buds also affects shoot terminology (Kozlowski 1971). The shoots of many temperate zone species, including spruces, form buds at the end of

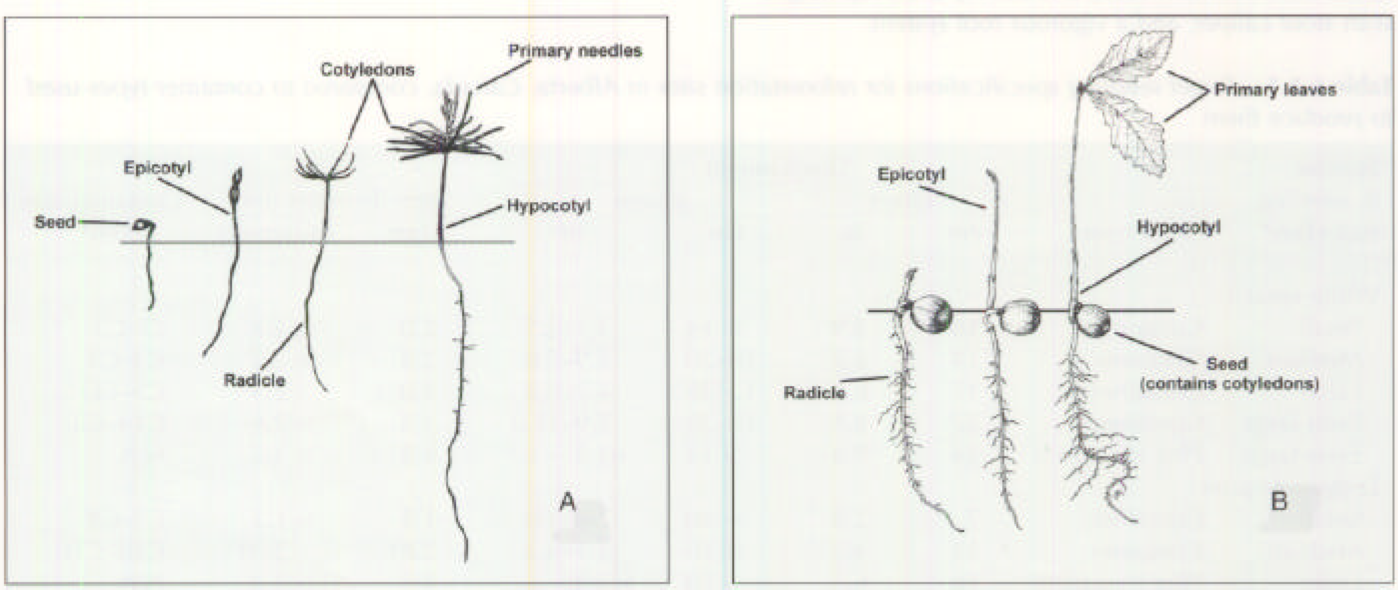


Figure 6.1.6— *In epigeous germination* (**A**), *the cotyledons carry the seed coat above the ground whereas, in hypogeous germination* (**B**), *both the cotyledon and seed coat remain in the growing medium (modifed from Schopmeyer 1974)*

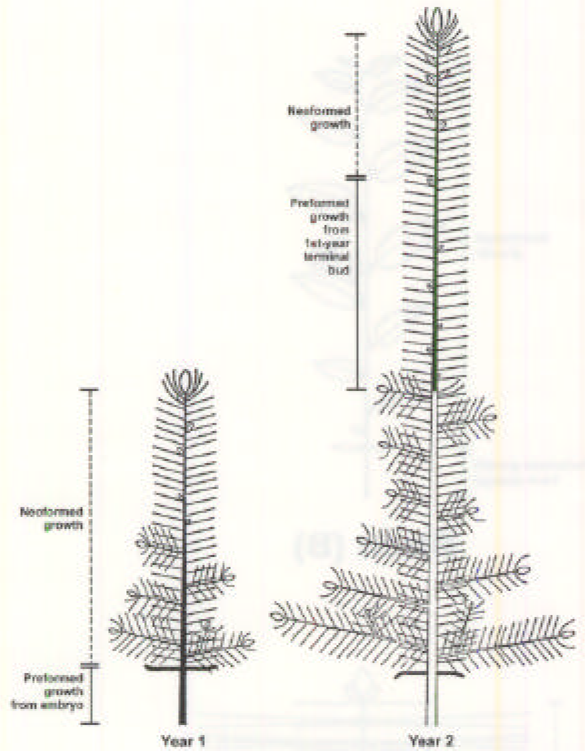


Figure 6.1.7—*Seedling shoot growth can be divided into two categories: one that expands from preexisting structures ("preformed") and one that develops freely during the growing season ("neoformed") (modified from Powell 1982).*

the growing season (**determinate shoots**), whereas other species, such as junipers, do not (**indeterminate shoots**).

First-season shoot development. Seedling growth and development is different during the first growing season than in subsequent years because all species exhibit both preformed and neoformed growth (figure 6.1.8). In the first season, the amount of preformed growth is determined by the size of the embryo (which is preformed in the seed), the stored energy in the seed, and the germination environment.

Seedlings may or may not develop typical buds at the end of the first growing season. The shoots of determi nate species cease growth and form ("set") **terminal buds** (figure 6.1.8A/D). Other indeterminate species, however, never do form true dormant buds (figure 6.1 .813/C). The shoots of pine seedlings, in particular, can look remarkably different during the first growing season, depending on species and growth environment. There are at least 4 variations in shoot development in pines (Powell, 1982; Thompson 1989). Some pines produce only awl-shaped primary foliage and, instead of a true bud, form a rosette of needles at the end of the first growing season (figure 6.1 .8C). Other pines produce fascicled secondary needles in the axils of the primary needles and form a typical resting bud (figure 6.1 .8D). In some temperate zone pines, the time of budset is under strong genetic control and the shoot will not continue to extend even under the ideal growing conditions in a fully controlled greenhouse (Thompson 1989). For example, ponderosa pine seedlings typically set a firm terminal bud in early July even though they are growing in a greenhouse under long-day photoperiod and high fertilization. In other species, such as blue spruce, shoot growth will continue for over a year under ideal growing conditions before forming a bud (Young and Hanover 1978). Growers must induce budset in these species by radically changing the propagation environment. Ecotypes from northern latitudes are particularly prone to free growth during the long days of summer, and growers need to use extraordinary cultural measures such as blackout curtains to promote budset and dormancy. Bud development is particularly important because the presence and size of buds are considered by many customers to be a sign of seedling quality (more discussion on bud development and its effect on quality can be found in section 6.4.4 of this volume).

The shoot growth of broadleaved species is also variable under nursery conditions. In oaks, a temporary resting bud with scales may form between several growth spurts and a firm dormant bud is only formed at the end of the season. Leaf size and shape will also change between these growth spurts, with those formed later being larger and more deeply lobed (Powell 1982). In other indeterminate species such as birch and elm, however, a true terminal bud never forms (figure 6.1.813). Instead, the shoot tip aborts at the end of the season and a lateral bud functions as the new terminal bud (Kozlowski 1991).

The "take-home message" here is that the type of propagation environment has a profound effect on seedling growth patterns and that some cultural practices, especially photoperiodic lighting, will affect both the amount and type of shoot growth in the nursery. (This will be discussed in detail in section 6.4.4 of this volume.)

Second-season shoot development. If seedlings are held for a second growing season (a 2+0 stocktype), some species will produce only preformed or neoformed shoot

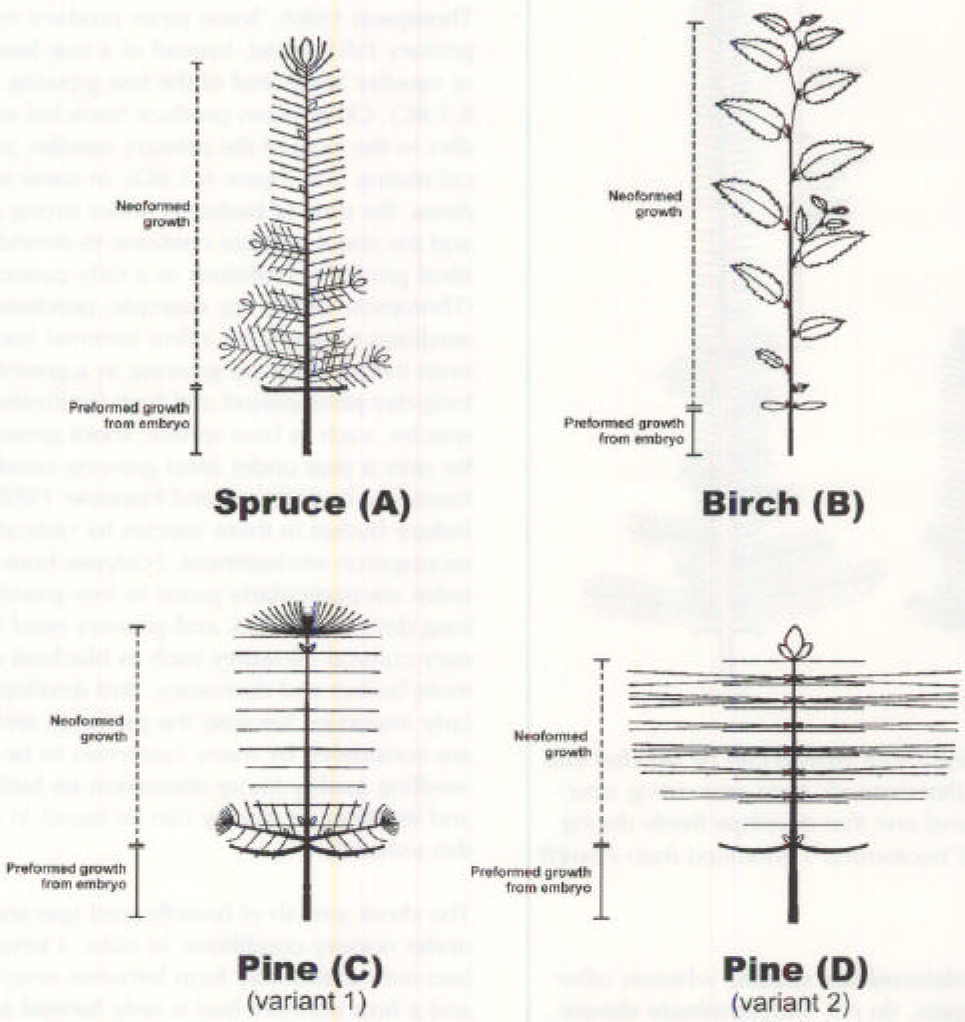


Figure 6.1.8—*First-year seedlings exhibit several different shoot growth patterns in nurseries, depending on species, propagation environment, and daylength (modified from Powell 1982).*

growth, whereas others will produce both types in sequence (figure 6.1.7). Determinate species, such as pines, exhibit the former growth pattern as their entire second-season shoot extension comes from either preformed stem units in the dormant bud, resting rosettes, or long-shoot buds (Powell 1982). Shoot growth in other indeterminate species including junipers and birches does not depend on preformed structures from the first growing season but consists of only neoformed growth. Spruces and basswood seedlings exhibit both preformed and neoformed growth, with the amount of neoformed growth strongly controlled by ecotype (Von Wuehlisch and Muhs 1991).

6.1.2.3 Annual growth cycles

In the wild, seedlings of forest and conservation species follow a typical annual growth cycle. This cycle begins when seeds germinate or seedlings break dormancy in early spring and continues until the seedlings go dormant again in the fall. These same growth cycles occur in nurseries, but the timing of the various phenological events depends on sowing date and the type of propagation environment. Usually, only shoot height and stem caliper are monitored, because these measurements are easy to record and are non-destructive. Some nurseries also sample seedlings during the growing season to obtain ovendry weight, which allows the plotting of seedling biomass and root growth over time.

These seedling growth cycles can be graphed in 2 ways: **total growth** and **incremental growth.** The total growth curve is the most commonly used graphing method and shows seedling dimensions plotted against time throughout the growing season (figure 6.1.9). Total growth curves are useful for showing seedling growth progression relative to the target specifications of shoot height and stem diameter. The relative growth rate is illustrated by the slope of the line- the steeper the slope of the curve, the faster the seedling is growing. The other, less- common type of growth curve is the incremental growth curve, which plots growth rate, rather than total growth (figure 6.1.10). Incremental growth curves are useful because they reveal growth periodicity patterns (seedling growth monitoring is also discussed in section 1 .5.4 of volume one of this series).

Roots start to grow first after seed germination as well as for older seedlings. For new sowing, shoot growth begins with emergence or with bud break for older stock (figure 6.1 .10). Stem diameter (**caliper**) growth in newly germinated seedlings begins after the vascular cambium develops and starts producing wood cells at about 4 to 6 weeks of age (MacDonald 1998). In older seedlings, stem diameter growth begins early in the spring, slowly increases until it peaks after terminal bud set, and then gradually tapers off until cold weather induces dormancy.

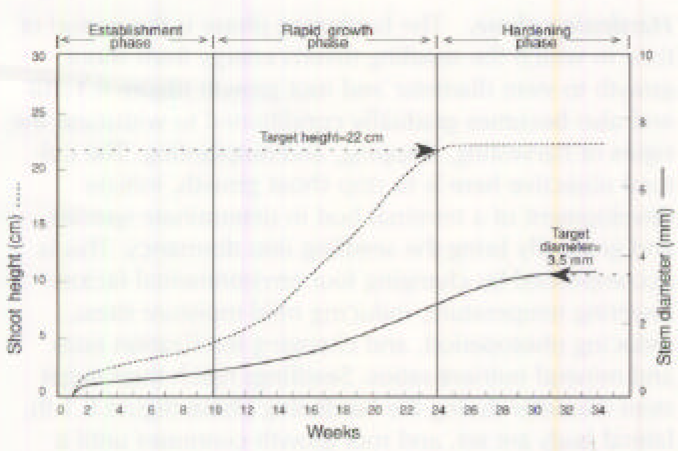


Figure 6.1.9—*The total seedling growth curve: shoot height approaches the target height specification by the end of the rapid growth phase, whereas the majority of stem diameter growth occurs during the hardening phase (modified from Wood 1994).*

Note that there is competition between the shoot and root for photosynthate, and so an increase in shoot growth causes a relative decrease in root and cambial growth (figure 6.1.10). All seedlings follow this same general pattern, although the growth rate varies between different species.

6.1.2.4 Nursery growth phases

For planning purposes, seedling growth and development under nursery culture can be divided into consecutive growth phases. Although up to seven different phases have been used, we prefer only three: the **establishment, rapid growth, and hardening phases.** The relative duration of these phases is illustrated in figures 6.1.9 and 6.1.10. Nursery managers must have a detailed cultural plan for each phase that will achieve their objectives (van Steenis 1993; Wood 1994). Because cultural objectives are different for each phase, the growing environment and perhaps even the type of propagation structure also will be different. The amount of time required for each of these growth phases will vary depending on species, seed source, type of propagation environment, and cultural practices. Nursery managers use growth data from previous crops to estimate the duration of each phase and total length of the crop cycle.

***Establishment phase**.* In the case of seed propagation, the establishment phase begins when seeds are sown, continues through seed germination and emergence, and ends when the young seedlings develop true leaves. For vegetative propagation, the phase begins when the cuttings are stuck into the container and ends when cuttings have rooted and the shoots begin to grow. For planning purposes, the establishment phase can be divided into the following 2 stages.

Germination stage. The germination stage begins when seeds are sown and lasts until the young seedlings form cotyledons. Germination and emergence should be completed in about 14 to 21 days; if not, either the seeds have not been properly prepared or are of poor quality. Temperature and moisture stress are critical during this stage, and growers must also be particularly vigilant for disease and abiotic injury.

Early growth stage. This stage begins when seedlings have emerged and continues until shoots begin rapid growth; it can last for 4 to 8 weeks. Often, seedlings exhibit a short growth pause while rosettes of primary needles form above their cotyledons, and then shoot

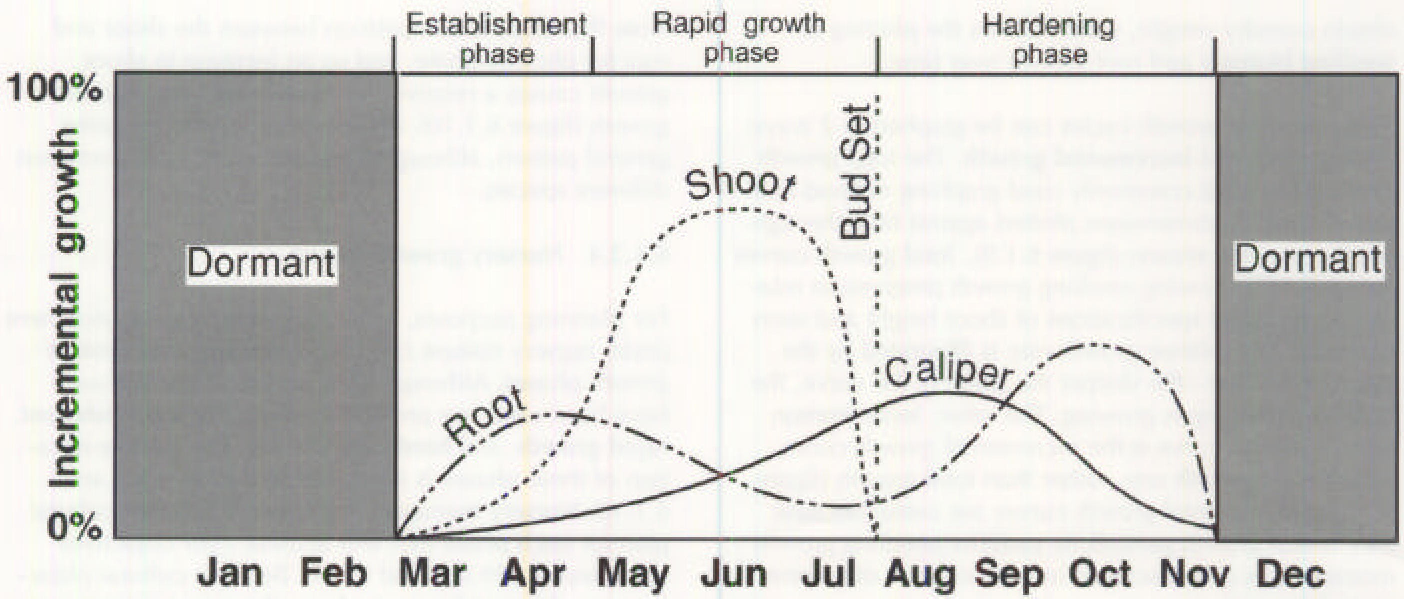


Figure 6.1.10—*Incremental seedling growth curve: root growth occurs early and late in the crop schedule; the majority of shoot growth occurs before the end of the rapid growth phase, with most stem caliper growth during the hardening phase.*

growth continues. The primary foliage of some species, including pines and eucalyptus, is different in shape, size, and color compared to mature leaves. The seedling exhibits rapid root growth during the early growth stage, with lateral roots forming after the tap root reaches the bottom of the container and stops growing ("air pruning"). (Further discussion of the cultural procedures and propagation environment for the establishment phase is provided in chapter 4 of this volume.)

Rapid growth phase. The rapid growth phase is so-named because it is during this period that young seedlings increase rapidly in size; the bulk of this biomass increase is in shoot tissue with stem diameter and root growth relatively less (figure 6.1.10). This phase begins after the cotyledon stage when the new shoot begins to grow at an accelerated or exponential rate, and ends when the seedling has reached its target height (figure 6.1.9). In determinate species, this occurs when the terminal bud is formed ("set"); in indeterminate species, no bud is formed and the achievement of the target height is the only visible indication. The duration of the rapid growth phase can vary considerably, but it typically takes from 10 to 20 weeks. This time, however, is a function of sowing date, desired target height, species characteristics, and especially propagation environment.

Therefore, it is critical to maintain all environmental factors near optimum levels. For example, shoot growth of many temperate zone species is particularly sensitive to photoperiod ("daylength") and will abruptly cease and form a terminal bud if photoperiod lights cease functioning for even a single night. (The rapid growth phase is discussed in detail in chapter 4 of this volume.)

Hardening phase. The hardening phase is the period of time in which the seedling diverts energy from shoot growth to stem diameter and root growth (figure 6.1 .10) and also becomes gradually conditioned to withstand the rigors of harvesting, shipping, and outplanting. The cultural objective here is to stop shoot growth, initiate development of a terminal bud in determinate species, and gradually bring the seedling into dormancy. This is accomplished by changing four environmental factors: lowering temperature, inducing mild moisture stress, reducing photoperiod, and changing fertilization rates and mineral nutrient ratios. Seedlings reach their target stem diameter during the hardening phase (figure 6.1.9), lateral buds are set, and root growth continues until a firm plug is formed. The hardening phase has two different but physiologically related cultural objectives that must be achieved in two sequential stages: dormancy induction and stress conditioning.

Dormancy induction. Because seedling growth cannot be stopped abruptly, the hardening phase must be initiated when seedlings are approximately 80 to 90% of the actual target to account for this "growth coast." While shoot growth begins to slow down, stem diameter continues to increase toward its target (figure 6.1.9). In most species that exhibit determinate growth, bud development starts during this stage. With indeterminate species such as southern pines and junipers, a true bud does not form and the shoot simply stops growing.

Stress conditioning. Container seedlings are extremely succulent after the rapid growth phase and have little stress tolerance. Therefore, they must be gradually hardened to tolerate the many stresses of harvesting, handling, storage, and outplanting. Timing and duration of the hardening phase will depend on when seedlings will be outplanted, and the types of stresses that will be encountered on the outplanting site:

- **Summer outplanting-Seedlings** that will be outplanted during summer on relatively low-stress sites are still actively growing and have little cold hardiness. Because these "hot planted" seedlings are shipped while still relatively succulent, they cannot be cold-stored and must be outplanted within a few days.

Fall outplanting--This stock receives a moderate amount of hardening, but seedlings are not fully dormant when shipped. Although stem tissue has lignified, seedlings are not fully cold hardy. Buds will have formed in determinant species. This degree of hardening takes 3 to 5 weeks to achieve, but root systems are still active.

Winter or spring outplanting--These outplantings require fully hardened seedlings with well-developed, dormant shoots and stock is typically cold stored for at least a few weeks. Because of their high level of cold hardiness, these seedlings have maximum resistance to all types of stresses. Full hardiness typically requires 6 to 10 weeks to complete. (The hardening phase is discussed in detail in chapter 4 of this volume.)

6.1.3 Constructing a Propagation Protocol

A propagation protocol is a comprehensive and systematic documentation of all the steps necessary to propagate a plant, starting with collection of seeds or cuttings and ending with harvest, storage and shipping. A typical propagation protocol for bur oak is shown in table 6.1.2.

6.1.3.1 Sources of propagation information

Compared to ornamental crops, forest and conservation species pose a difficult problem because of the sheer number of species and ecotypes, some of which are not widely propagated, if at all. In addition, specific growing schedules are not normally published because they vary so much with individual species response and nursery climate. There are, however, sources of information for constructing a propagation protocol (Munson and Nicholson 1994):

Systematically search the published literature. It is possible that someone has propagated the species before, so the first step is to conduct a literature search. General horticultural texts may contain some specific information but you will have more luck with technical journals and nursery trade magazines. For example, the article "Propagation of Fraser Fir" in the *Journal of Environmental Horticulture* provides a comprehensive picture of how to propagate this species by seed or vegetatively (Blazich and Hinesley 1994). In particular, the *Combined Proceedings of the International Plant Propagators' Society* is a wealth of information. Regional and special publications from botanic gardens and native plant societies can also be helpful. A list of general propagation references is provided in section 6.1.5.2 of this volume.

Compare propagation methods for related species. If specific information for the species is unavailable, information on how close relatives within the genus or even family are propagated may be useful. These relatives must grow in the general climatic zone. However, it should be remembered that there can be considerable variation even within a genus. For example, seed stratification requirements for maple species can vary considerably (Schopmeyer 1974).

Study the native environment **and *natural growth habit of the plant.*** Environmental factors such as total precipitation, its season of distribution, and maximum/minimum temperatures may affect seed germination. Most forest and conservation species from the Temperature Zone require some exposure to cold temperatures and moist conditions that naturally occur during winter. Species from this climate, therefore, would logically require a cold-moist stratification treatment before seeds will germinate. Species adapted to fire-dominated ecosystems, such as many of the chaparral species, have seeds that require treatment with hot water or even smoke. Species that grow in low thickets, such as rose and wild berries, root quite easily and so can be vegetatively propagated by cuttings or layering.

Many other clues can be gained by studying how plants grow in nature. When constructing a seed propagation protocol, ecological information such as its growth habit and type of fruit may provide helpful clues (Finnerty *1994).* In particular, information on how seeds are disseminated in nature and which relative habitat a species occupies in nature can be helpful (table *6.1.3).* However, growers must be alert for misinformation. For example, it is commonly believed that Indian paintbrush cannot be propagated because it is often found living as a semiparasite on sagebrush and other plants. Inspection of the seedcoat reveals one of the problems-it contains a network of fine hairs that inhibit water absorption. This impediment can be easily removed by hand rubbing (Borland *1996).*

Consult with other nurseries growing the same or similar species. New nursery managers, in particular, are going to need some basic cultural information before starting to plan for a potential crop. The indirect experience gained by talking to other growers, although time-consuming, is valuable. Many private nurseries do not want to share their propagation secrets for obvious reasons, but government nurseries are excellent sources of technical information, as most consider technology transfer to be part of their mandate. There are native plant societies in almost every state or often the horticulturist at regional botanical gardens would be happy to share information. The Denver Botanical Garden has propagated 1,000 to 2,000 species of native plants (Borland 1996*).*

There are a few technical publications, such as the USDA Forest Service's classic Seeds *of* Woody *Plants in* the *United States* (Schopmeyer 1974), that provide general information on seed collection, processing, storage, and nursery culture. [A newer version of this valuable book has been republished by Young and Young (1992), who included additional species. The Forest Service is working at this time to revise Seeds *of Woody Plants...,* and plans to publish it again as the *Woody Plant* Seed

Table 6.1.2—*Example of a typical propagation protocol*

SPECIES INFORMATION:
Species: Bur oak (*Quercus macrophylla*)
Ecotype: North Dakota
Outplanting site: Northern Great Plains
Outplanting date: April to May

TARGET SEEDLING INFORMATION
Height: 10 to 18 inches
Caliper: 4 to 6 mm
Root system: Firm root plug

PROPAGATION AND CROP SCHEDULING:
Propagation environment: Fully controlled greenhouse
Seed propagation method: Sow germinants
Seed source: Hand-collected from Turtle Mountains, ND
Collector & date: Roy/September 16, 1996
Seeds/kg (lb): 165 (75)
Percent germination: 45%
Percent purity: 100%
Seed processing: Float test acorns in water and use only sinkers
Seed treatments: Dip acorns in a fungicide solution (captan) to reduce mold during stratification. Place wet acorns in a plastic bag in a refrigerator for 180 days of cold-moist stratification at 0 to 2 °C (3 to 36 °F). Remove acorns from refrigerator 4 to 5 days before sowing and rinse to remove fungicide. Place acorns in tubs and cover with plastic sheeting to retain humidity. Fill tubs 1/4 to 1/3 full and place in a warm environment—60 to 66 °F (16 to 19 °C)—to stimulate rapid germination.

Vegetative propagation method: N/A
Type of cutting: N/A
Collector & date: N/A
Cutting treatments: N/A
Rooting %: N/A
Time to transplant: N/A
Container type & volume: Plant bur oak in big containers with large cavities to accommodate the large acorns; space widely to permit good caliper development. The Spencer-Lemaire Tinus Rootrainer® has a top opening of 3.8 × 5.1 cm (1.5 × 2.0 in.) and is 18.5 cm (7.2 in) deep; the cavities are 350 cm^3 (21.5 in^3) in volume with a cell density of 516 cells/m^2 (48/ft^2).

Another good container for this species is the Colorado Styroblock, which has a top opening of 5 × 5 cm (2 × 2 in.) and is 20 cm (8 in.) deep. These cavities are 492 cm^3 (30 in^3) in volume with a cell density of 270/m^2 (25/ft^2).

Growing medium: Fill cavities with 50% *Sphagnum* peat moss and 50% #2 grade vermiculite and tamp lightly to remove air pockets. Use a large pointed dibble board to make room for the germinants.

Total time to harvest: 12 months, including freezer storage

Sowing date: March 1

Sowing/planting technique: Sow germinating seeds ("germinants")

Percent emergence & date: Should have 85% by April 1

Sowing/planting technique: Irrigate filled containers to saturate growing medium. Remove germinating acorns and place 1 germinant in the pre-dibbled hole in the top of each container. Be sure to sow at least 1 cm (1/2 in.) deep and orient the radicle downwards to prevent abnormal stem crooking. Cover germinants with a shallow layer of perlite.

Establishment phase: Keep the greenhouse warm and humid both day and night (see following schedule). Mist frequently to keep the medium "moist but not wet" until the primary leaves have developed. Fertigate with a low-nitrogen (100 ppm) but well-balanced fertilizer solution twice per week. Keep leaves dry to avoid fungal pathogens. Bur oak seedlings can tolerate full sunlight, so shading is not necessary but photoperiodic lighting is required to keep the seedlings actively growing. Turn on the carbon dioxide generators as soon as the primary leaves develop and set them to come on about 4 hours before sunrise.

Rapid growth phase: After the seedlings are well established in the container, increase the range of day temperature to 24 °C (75 °F) to 32 °C (90 °F) to promote multiple flushing. Bur oak grows in a series of

Table 6.1.2—*Continued*

up to 4 flushes of similar height. Keep the relative humidity high to minimize moisture stress. As the leaves increase in size, irrigation will become more difficult because a high percentage of the applied water is intercepted and never makes it into the growing medium. Therefore, increase the duration of each irrigation and the number of irrigations per week accordingly. Although it is simplest to wait to irrigate until the foliage begins to wilt, monitor the weight of the containers to keep the growing medium in the ideal moisture range. Fertigate with a high-nitrogen (200 ppm) but well-balanced fertilizer solution twice per week to keep all essential mineral nutrients at optimum levels.

Hardening phase: As the individual containers of seedlings reach their target height, move them to the shadehouse in late summer. Removing these larger plants opens up the canopy and makes irrigation easier. Move all seedlings by mid-August to begin hardening under ambient conditions. Place seedlings on raised benches to encourage air pruning of the roots. The change to lower humidity and natural photoperiod helps trigger the hardening process. Switch seedlings to a hardening fertilizer formula with a reduced nitrogen level of around 50 ppm, and apply as long as day temperatures are above freezing and the root plugs remain unfrozen.

Harvest date: Late October

Storage conditions: Extract seedlings from their containers and group them with their rootballs wrapped in cellophane. Place bunches of seedlings in a cardboard box with a polyethylene bag liner, and move the boxes to freezer storage at − 4 to −6 °C (20 to 25 °F).

Storage duration: Keep oak seedlings in freezer storage until shipment the following spring. One week before shipping, raise the temperature in the freezer to 2 to 5 °C (35 to 40 °F). Remove individual boxes from the freezer and thaw at ambient temperatures for shipping.

Propagator: Roy Laframboise, Towner State Nursery, HC 2, Box 13, Towner, ND 58788

Table 6.1.3—*Clues on how to propagate a species can be gained by studying how a plant grows in nature*

Seed dispersal method	Natural habitat	Genera with seeds easy to germinate (%)	Genera with seeds difficult to germinate (%)
Wind	Understory	93	7
	Canopy	88	12
Birds	Understory	40	60
	Canopy	50	50
Mammals	Understory	30	70
	Canopy	47	53

Source: *Munson and Nicholson (1994).*

Manual (its popular name) and make it available on the World Wide Web.] The Forest Research Nursery at the University of Idaho has published a series of technical bulletins that describe cultural techniques and growing regimes that they have developed for most commercial conifers in their region (Wenny and Dumroese 1987a,b,c; 1988; 1990a,b; 1991; 1992). Many government nurseries have operating manuals that are also an excellent source of cultural information. Most of these have never been formally published, but they may be willing to make copies. For example, information on propagating diverse species is particularly difficult to find but the *Greenhouse and Shadehouse Production Manual* from the Mason State Nursery in Illinois covers grasses, forbs, wildflowers, riparian and wetland plants, woody shrubs, and trees for the Great Plains (Mountz 1993). (A list of other publications containing specific propagation information can be found in section 6.1.6.1.)

6.1.3.2 Growing schedules

Growing schedules are an essential part of a propagation protocol because they provide a good way to visually illustrate the steps in the protocol and how they relate in time. They serve as visual time charts of the type of propagation environment that must be maintained and cultural operations and processes that are needed from seed preparation to seedling shipment. If detailed economic data are also recorded, growing schedules can be used to illustrate costs and benefits of different growing regimes (Clements and Dominy 1990).

We recommend three different types of growing schedules: crop production, facilities, and cultural. Within each, the format is basically the same-time is plotted along the top of the chart with cultural and management factors along the right side. Time intervals will vary from weeks to months to years, depending on which factors are being tracked and the amount of detail that is needed. All growing schedules are filled-out in the same way. Start with the date that the crop must be shipped and work backwards, blocking out sections of time for the various operations until you reach the date at which the crop must be started. Although schedules will vary from nursery to nursery, the important point is not the format itself but rather that nursery managers have a detailed plan of action before starting the crop.

Although they can be drafted by hand, growing schedules are easy to construct with modern word processing or spreadsheet computer software programs. The sample schedules shown in tables 6.1.4, 6.1.5, and 6.1.6 were all developed in WordPerfect 8.0© in a couple of hours using the "Table QuickCreate" feature. Once the overall framework of the growing schedule is complete, then various features can be easily typed into cells. Features like background shading and special fill designs make the information even easier to understand. Blank forms of the growing schedules used in this section are provided in the appendix of this chapter; contact the senior author for copies of the computer files.

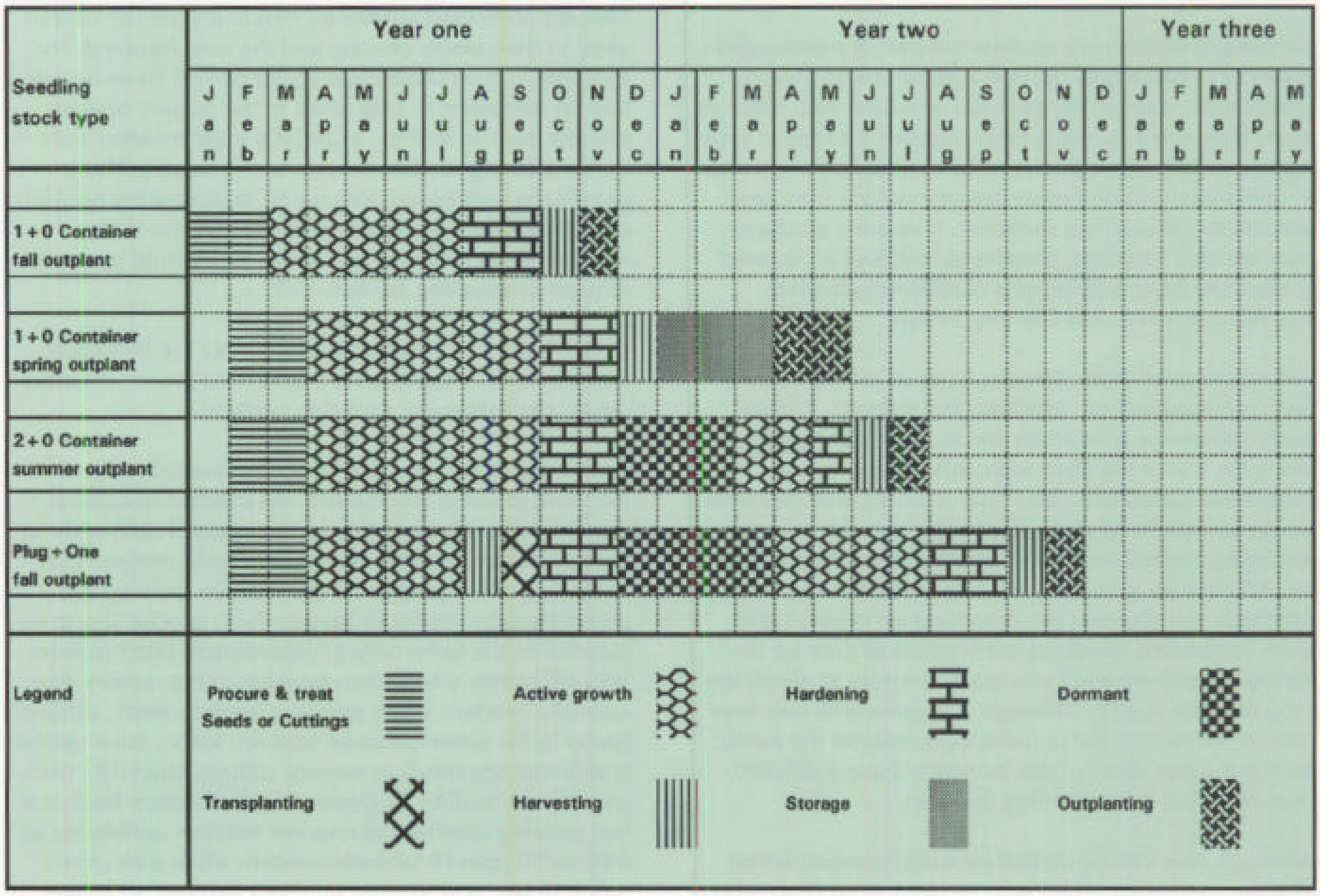
Crop production schedules. The first and most long-term type of growing schedule is the crop production schedule, which is designed to help the manager visualize "the big picture". These schedules typically are designed on a month-by-month time scale, cover at least 1 year, and include all phases of nursery production from crop planning to outplanting (table 6.1 .4). Many nursery customers fail to appreciate how long it really takes to produce a seedling crop, and so crop production schedules are particularly useful for explaining all the various steps in the nursery process and the time involved. For example, a crop production schedule will illustrate that it will be necessary to ship seeds to the nursery several months prior to sowing, especially if germination tests and presowing seed treatments are necessary. These growing schedules are also useful in illustrating how different seedling stocktypes are produced, the time required to grow them, and when they would be available for outplanting (table 6.1.4).

Crop production schedules must reflect the biological requirements of the species that will be grown, and take greatest advantage of available sunlight.

Cultural groups. Another important consideration when planning growing schedules is the concept of cultural groups. Although all plant species respond differently to nursery culture, nursery managers should analyze characteristics of the plants that they will be growing and group them by similar responses. Even species that grow together in the same natural environment often perform very differently when sown together in the nursery. For example, western white pine and western larch, although found in the same forests of northern Idaho, have radically different responses to nursery culture, especially nitrogen (N) fertilization (Eggleston 1994). Western larch is a fast-growing species that requires fertilizer containing as little as 50 ppm N, whereas western white pine grows much slower and so must be given fertilizer with over 200 ppm of N. Therefore, western larch should be placed in one cultural group with other nitrogen-sensitive trees (such as quaking aspen) and western white pine should be placed in another, slower-growing cultural group.

Solar timing. Because of seasonal changes in the Temperate Zone, forest and conservation nursery crops are scheduled around the solar cycle (figure 6.1 .11). Both light intensity and daylength vary considerably during the year, so nursery managers must plan their crops around the summer solstice to take full advantage of available sunlight. For crops grown in propagation structures, summer crops are cheaper to produce because less heat is required (Clements and Dominy 1990). This is particularly critical when multiple cropping because the first crop must be grown before the solstice so that the second crop can be sown early enough to grow to full size during the remainder of the growing season. For example, the spring crop would be sown in early February in a propagation structure and then removed to

Table 6.1.4—*Comparison of crop production schedules for four typical container seedling stock types*



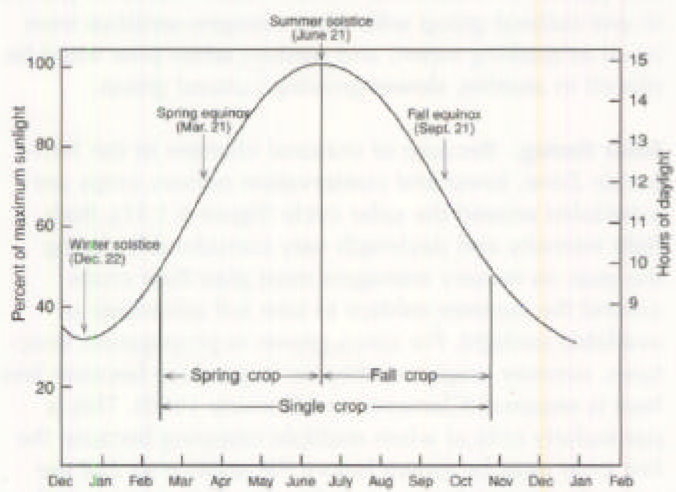


Figure 6.1.11—*Container crops should be scheduled around the solar calendar to take advantage of maximum sunlight intensity.*

a shadehouse or open growing area in early June to finish the hardening phase. The fall crop would be sown at this time and then left to harden in the propagation structure (figure 6.1 .11). Because air and soil temperatures lag considerably behind the solar cycle, multiple crops must be carefully scheduled so that they take advantage of solar light but are not damaged by late spring frosts. (More details on solar light cycles can be found in volume three of this series.)

Facilities schedules. The second type of growing schedule is the facilities schedule, which illustrates the space requirement that each crop will require in the various propagation environments, processing and storage facilities. This schedule also lists labor, equipment, and supplies needed to produce the crop. Nursery facilities schedules are organized by months and often cover 2 years (table 6.1 .5).

Table 6.1.5A—*This facilities schedule shows crop planning requirements on a month-to-month basis for western white pine for fall outplanting in northern Idaho*

	Year one											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seedling Growth Stage											Seed stratification	
Facility Space											Refrigerator	
Labor Needs											Clean containers and greenhouse	
Equipment and Supplies									Seed		Growing media & fertilizer	

	Year Two											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seedling growth stage		Establishment phase		Rapid growth phase			Hardening phase		Outplanting			
Facility space				Greenhouse				Shadehouse				
Labor needs	Sowing		Thinning				Harvest		Loading Trucks			
Equipment and supplies	Sowing Line						Packing Line		Conveyor			

Source: Eggleston (1994).

As an example, consider the facilities schedule for two different conifer seedling crops at a container nursery in northern Idaho. The first crop is western white pine, to be grown in a double-poly greenhouse for fall outplanting (table 6.1.5A). Note that seeds must be received at the nursery by September of the year before sowing because this species requires a relatively long (120-day) cold-moist stratification treatment. The crop will be sown in mid-January to allow enough time for the seedlings to meet target specifications by the shipping date. Experience with past crops has shown that this earlier sowing is necessary for this relatively slow-growing species (Eggleston 1994). This schedule shows that workers will be needed during late fall to clean used containers in the headhouse and to sterilize the greenhouse before sowing. The sowing line must be assembled during early January and then crews will be needed again in late February for thinning. The final labor requirement for this crop will be in mid-June, when the packing line will need to be assembled so that seedlings can be graded, packed, and shipped during the outplanting window (table 6.1 .5A).

Continuing with this example, the second crop is high-elevation Douglas-fir (table 6.1 .513). This species must be outplanted during the fall because the sites do not become clear of snow until too late in the spring. Douglas-fir seeds require only 6 weeks of cold-moist stratifi cation before sowing in mid-February, and high elevation ecotypes of this species are particularly slow-growing. Therefore, this second crop will be grown for 5 months in a double-poly greenhouse and then moved to a shelterhouse for hardening.

This two-crop example shows how facilities schedules help to coordinate work crews and equipment (see

Table 6.1.5B—*This facilities schedule shows crop planning requirements on a month-to-month basis for high-elevation Douglas-fir for fall outplanting in northern Idaho*

Year one												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seedling growth stage												
Facility space										Headhouse		
Labor needs										Clean containers & greenhouse		
Equipment and supplies										Seed	Growing media & fertilizer	

Year two												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seedling growth stage	*Seed stratification*	*Establishment phase*		*Rapid growth phase*			*Hardening phase*		*Outplanting*			
Facility space	*Refrigerator*	*Greenhouse*					*Shelterhouse*					
Labor needs		*Sowing*		*Thinning*			*Move seedlings*		*Harvest*			
Equipment and supplies		*Sowing line*					*Conveyor*		*Packing line*			

Source: Eggleston (1994).

"Labor needs" in tables 6.1.5A/B). One work crew can be used to clean containers and prepare the propagation structures for both crops. Because of staggered sowing dates, the sowing line has to be assembled only once and the same work crew can be used to sow both crops. This crew can then stay on to do the thinning as the seedlings emerge. The crew that returns in mid-June to harvest the white pine crop will stay over to move the Douglas-fir seedlings to the shelterhouse.

Cultural schedules. Cultural schedules are the most detailed of the growing schedules used in forest and conservation nurseries (tables 6.1 .6A/B). They are valuable not only for reference while the crop is growing but also can be filed to document the actual time and environmental conditions that were used to produce the crop. These "planned" and "actual" records can then be consulted to modify cultural schedules for subsequent crops. This is particularly easy when the schedules are constructed as computer documents that can be easily modified and stored.

Even though cultural schedules may differ slightly in format, there are common factors that should be included: the month and week, the number of weeks from sowing, the propagation environment, target seedling specifications, and the growth stage at that particular time in the crop cycle (tables 6.1.6A/B). The schedules also should contain room to list specific cultural processes and operations, such as thinning or seedling inventory. The size of work crew for that particular process also could be recorded. Each of the potential growth-limiting environmental factors should be listed along the left margin of the schedule form along with any pertinent information about how they will be controlled and monitored. Some environmental factors will be listed as discrete numbers whereas others should be listed as ranges. In fully controlled or semi-controlled propagation structures, temper-

Table 6.1.6A—*Cultural schedule for a white spruce crop during the seedling establishment phase*

Customer: T. Planter	Species: White spruce	Seed source: Zone 864 - 300m.
Target specifications:	Height: 17 cm (12 to 25)	Stem diameter: 3.0 mm (> 2.4)

Month and week	*3/13 - 3/19*	*3/20 - 3/26*		*3/27 - 4/2*	*4/3 - 4/9*
Weeks from sowing	*1*	*2*		*3*	*4*
Propagation environment	*Shelterhouse*				
Seedling growth stage	*Establishment phase - germination*		Change environment	*Establishment phase - early growth*	
Cultural processes and operations					
Labor: crew size (person hours)					
Temperature: day setpoint (range)	*27°C (25 to 29°C)*			*22°C (20 to 24°C)*	
Temperature: night setpoint (range)	*27°C (25 to 29°C)*			*19°C (17 to 21 oC)*	
Relative humidity: setpoint (range)	*80% (70 to 90%)*			*70% (60 to 80%)*	
Light: ambient	*Full sunlight*			*Full sunlight*	
Light: photoperiod: intensity & duration	*None*			*20 hour photoperiod HPS @ 250 to 400 lux*	
Carbon dioxide: rate & timing	*None*			*Yes — 800 to 1,000 ppm when sides are down*	
Irrigation: amount & frequency	*Frequent misting — keep surface of medium "moist but not wet"*			*Light irrigation — Keep growing medium at 80% wet block weight*	
Fertilization: nitrogen (N) rate & frequency	*None*			*Fertigation at 100 ppm N With each irrigation*	
Pest management: monitoring pesticide and rate	*Walk through **every day** Preventative fungicide for damping-off*			*Walk through **every day***	

Table 6.1.6B—*Cultural schedule for a white spruce crop illustrating the change from the rapid growth phase to the hardening phase*

Customer: T. Planter | **Species:** White spruce | **Seed Source:** Zone 864 - 300m

Target specifications: | **Height:** 17 cm (12 to 25) | **Stem Diameter:** 3.0 mm (> 2.4)

Month and week	6/27 - 7/3	7/4 - 7/10		7/11 - 7/17	7/18 - 7/24
Weeks from sowing	19	20		21	22
Propagation environment	Shelterhouse				
Seedling growth stage	Rapid growth phase		Change environment	Hardening phase - dormancy induction	
Cultural processes and operations	Raise sides in good weather			Raise sides permanently	
Labor: crew size (person hours)					
Temperature: day setpoint (range)	22 °C (20 to 24 °C)			12 °C (10 to 14 °C)	
Temperature: night setpoint (range)	18 °C (16 to 20 °C)			10 °C (8 to 12 °C)	
Relative humidity: setpoint (range)	60% (50 to 70%)			50% (40 to 60%)	
Light: ambient	Full sunlight			Full sunlight	
Light: photoperiod intensity & duration	20 hour photoperiod HPS @ 250 to 400 lux			None — shut-off lights	
Carbon dioxide: rate & timing	Yes — 800 to 1,000 ppm when sides are down			None — shut-off generators	
Irrigation: amount & frequency	Wet-dry cycle — irrigate at 80% wet block wight			Mild water stress — irrigate at 75% wet block weight	
Fertilization: nitrogen (N) rate & frequency	Fertigation at 150 ppm N With each irrigation			Fertigation at 50 ppm N With each irrigation	
Pest management: monitoring pesticide and rate	Walk through every week			Walk through twice every week — **Be alert for Botrytis**	

atures for both day and night could be specified as discrete **set points** that correspond to the setting on the thermostat or environmental control computer. In open growing compounds, growers would list the ideal temperature for that growth stage and then record the actual ambient temperature. Because it is more difficult to control precisely and is not as critical to seedling growth, relative humidity could either be listed as a set point or an **allowable range,** for example, "60-80% during the establishment phase" (tables 6.1 .6A/B). Other cultural information is recorded according to the nature of the environmental factor and the ability to control it. For example, if carbon dioxide generators are used in fully controlled propagation structures, a target of 1,000 parts per million (ppm) might be listed. In semi-controlled structures or open growing compounds, **ambient** would be recorded in the cultural schedule. The same procedure is done for irrigation, fertilization, and other cultural factors. Nursery pests, which can sometimes be limiting to seedling growth, should also be recorded in the cultural schedule along with plans for monitoring and control.

The accumulated information recorded in cultural schedules is valuable for monitoring seedling growth patterns as well as identifying the need for different environmental control equipment or different types of propagation structures.

6.1.3.3 Collection and preparation of propagules

One of the most common mistakes made by novice nursery managers during crop planning is not allowing enough time to collect and prepare the seeds, cuttings, or other propagation material. Sometimes these are provided by the customer, but other times seeds must be purchased from a commercial source or the cuttings collected by the grower. Although seeds of most commercial forest species are sold by seed dealers, it may be difficult to find the proper seed source for a planting project on short notice. (See section 6.2.2 in this volume for more information on purchasing seed.)

The processing of seeds or cuttings also takes time. Seeds of many forest and conservation species do not germinate readily when freshly collected or taken directly out of storage, and require a period of water soaking, cold-moist stratification, or other time-consuming presowing treatment (tables 6.1.5A/B). Some types of cuttings can be collected and used immediately, but others, especially hardwood cuttings, need a period of cold-moist stratification. (See chapters 2 and 3 in this volume for further discussion on these treatments.)

6.1.3.4 Scheduling seedling growth phases

The establishment, rapid growth, and hardening phases are easily incorporated into growing schedules. Facilities schedules provide an overview of how growth phases fit into the total crop cycle (tables 6.1.5A/B) and are useful for general planning purposes. The more short-term cultural schedules are useful in showing the really critical times in the crop cycle when environmental conditions must be changed radically. When posted in the headhouse, cultural schedules provide an easy way to alert the grower and the rest of the nursery crew. For example, the change from the germination stage to the early growth stage requires a reduction in temperature and relative humidity (table 6.1 .6A). At the same time, the photoperiod lights and the carbon dioxide generators are turned on. The crew must also be alerted to change from a frequent mist to a periodic irrigation that is controlled by block weight, and start **"fertigation"** (injecting liquid fertilizer into irrigation water, that is, fertilization + irrigation). Proper implementation and coordination of these various changes is made easier with a comprehensive cultural schedule that can be frequently consulted in case of confusion about specific instructions.

Likewise, when the propagation environment must be changed to start the hardening phase at week 20, a well-designed cultural schedule fully illustrates the entire process (table 6.1.6B). For species such as white spruce that exhibit free shoot growth, bud development must be induced by a radical change in the propagation environment to subject the seedlings to a physiological "shock." Four environmental factors are key in triggering hardening: temperature, daylength, water, and mineral nutrients, especially nitrogen. In this example, both day and night temperatures are reduced substantially, photoperiod lights are turned off, and seedlings are brought into a mild water and nutrient stress. The growing medium is allowed to dry and the nitrogen level also is reduced (table 6.1.6B). Again, the crop schedule serves to alert the nursery crew to the change in propagation environment and provides the specific details for easy reference. (Much more detailed information on the hardening phase is provided in chapter 4 of this volume.)

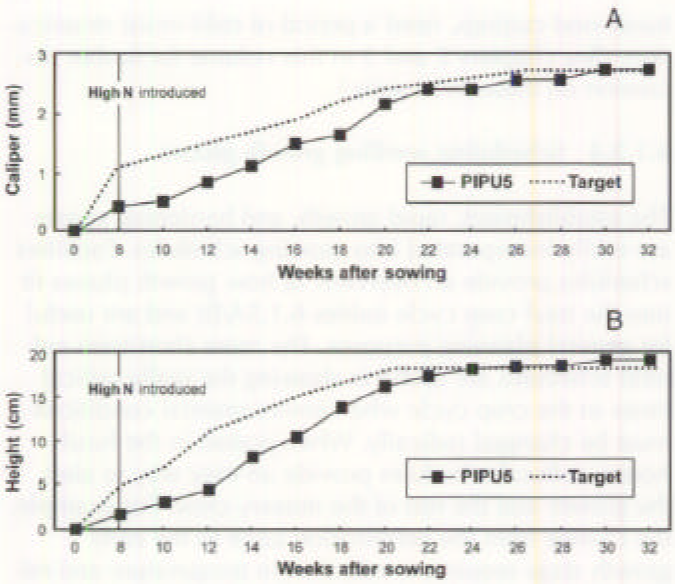


Figure 6.1.12— *Propagation protocols need to be adjusted when seedlings are not growing up to target specifications. In this example, when the nitrogen (N) fertilization rate was increased at week 8, both the caliper (**A**) and height growth (**B**) of these Colorado blue spruce seedlings increased so that it met the target by the end of the season. (Courtesy of D. Wenny, University of Idaho).*

6.1.3.5 Testing and adjusting protocols

It must be emphasized that propagation protocols are only a guide and that the crop will rarely perform exactly as projected. Because of year-to-year variations in weather conditions and unforeseen cultural or operational problems, it will be necessary to continually fine-tune protocols. Therefore, growers must monitor seedling growth and environmental conditions in the propagation environment, and record any discrepancies between expected and observed performance. As soon as seedling growth rate or development begins to deviate significantly from projected growth schedules, then specific changes will have to be made in the level of one or more of the environmental factors. For example, if the seedling growth rate of a species begins to lag behind the projected shoot height curve, then the nitrogen fertilizer level could be increased to try to accelerate shoot growth (figure 6.1.12).

Any changes must be carefully noted in crop records and growing schedules adjusted accordingly. If possible, the nursery manager should try to analyze the exact cause for the needed adjustment so that growing schedules for future crops will be even more accurate.

6.1.4 Summary

Crop planning is a critical but often overlooked part of plant propagation. The planning process must consider the biology of the species, desired genetic variation, availability of propagules, and the objectives of the outplanting project. Using this information, the grower decides whether seed or vegetative propagation would be most appropriate.

Crop scheduling can be divided into three seedling growth phases: establishment, rapid growth, and hardening with the cultural specifics outlined in a propagation protocol. Growing schedules provide a good way to visually illustrate the steps in the protocol and how they relate in time. Cultural information can either be gained directly through experience, from published articles, or from tips from other growers. Regardless of the source, propagation protocols must be tested in the specific nursery environment and need to be continually updated as more cultural knowledge is acquired.

6.1.5 References

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Appendix A—Propagation Protocol Form

Species:

Ecotype:____________________

Outplanting site:____________________

Outplanting date:____________________

Target seedling information:

Height:____________________

Caliper:____________________

Root system:____________________

Propagation and crop scheduling:

Propagation environment:

☐ Seed propagation method

- Seed source:____________________
- Collector & date:____________________
- Seeds/kg (lb):____________________
- % Germination:____________________
- % Purity____________________
- Seed processing:____________________
- Seed treatments:____________________

☐ Vegetative propagation method

- Type of cutting:____________________
- Collector & date:____________________
- Cutting treatments:____________________
- Rooting %:____________________
- Time to transplanting:____________________

Container type and volume:

*Growing medium:*____________________

*Total time to harvest:*____________________

*Sowing date:*____________________

*% Emergence & date:*____________________

*Sowing/planting technique:*____________________

*Establishment phase:*____________________

*Rapid growth phase:*____________________

*Hardening phase:*____________________

*Harvest date:*____________________

*Storage conditions:*____________________

*Storage duration:*____________________

*Propagator:*____________________

Appendix B—Crop Production Schedule Form

Seedling stock type	Year one												Year two												Year Three				
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May

Legend							
Procure /treat seeds or cuttings	Active growth	Hardening	Dormant	Transplanting	Harvesting	Storage	Outplanting

Appendix C—Facilities Schedule Form

	Year one											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seedling growth stage												
Facility space												
Labor needs												
Equipment and supplies												

	Year two											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seedling growth stage												
Facility space												
Labor needs												
Equipment and supplies												

Appendix D—Cultural Schedule Form

Customer:	**Species:**	**Seed source:**
Target specifications:	**Height:**	**Stem diameter:**

Month and week					
Weeks from sowing					
Propagation environment					
Seedling growth stage					
Cultural processes and operations					
Labor: crew size (Person hours)					
Temperature: day setpoint (range)					
Temperature: night setpoint (range)					
Relative humidity: setpoint (range)					
Light: ambient					
Light: photoperiod intensity & duration					
Carbon dioxide: rate & timing					
Irrigation: amount & frequency					
Fertilization: Nitrogen (N) rate & frequency					
Pest management: monitoring pesticide and rate					