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Raising Native Plants in Nurseries: Basic Concepts

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Abstract

Growing native plants can be fun, challenging, and rewarding. This booklet, particularly the first chapter that introduces important concepts, is for the novice who wants to start growing native plants as a hobby; however, it can also be helpful to someone with a bit more experience who is wondering about starting a nursery. The second chapter provides basic information about collecting, processing, storing, and treating seeds. Chapter three focuses on using seeds to grow plants in the field or in containers using simple but effective techniques. For those native plants that reproduce poorly from seeds, the fourth chapter describes how to start native plants from cuttings. The final chapter provides valuable information on how to successfully move native plants from the nursery and establish them in their final planting location. Several appendices expand on what has been presented in the chapters, with more details and specific information about growing a variety of native plants.

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Trade names are used for the information and convenience of the reader and do not imply endorsement or preferential treatment by the U.S. Department of Agriculture.

Nomenclature for scientific names follows the U.S. Department of Agriculture, Natural Resources Conservation Service PLANTS (Plant List of Accepted Nomenclature, Taxonomy, and Symbols) database (2011) at http://plants.usda.gov.

Pesticide Precautionary Statement

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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Chapter 1. Basic Concepts of Growing Native Plants

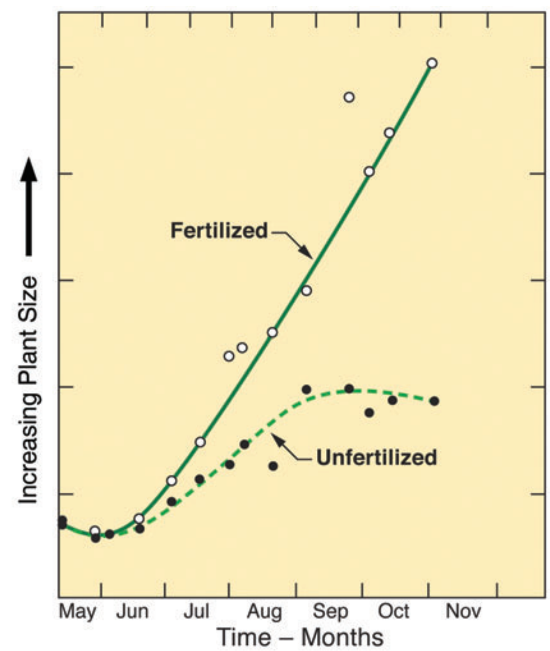
This booklet was written for the novice who wants to grow native plants and may also wonder what is involved in starting a nursery. If you think that operating your own native plant nursery as a business is your calling, then this manual, and particularly this first chapter, can help you move forward. If, however, you plan to grow native plants for fun, perhaps for use around your home or as a science fair project, this manual can still give you the basic information required for you to be successful, and all the concepts provided in this chapter are still applicable.

Much has been written about growing trees and commercial conifers in particular, and the same basic principles can be used to grow native shrubs, forbs, ferns, wildflowers, and grasses. Growing native plants involves a unique combination of science and art. Although this book explains the basic science of growing native plants, a good grower must also have skills that can be acquired only through innate ability or experience. Collectively, these special skills are what is commonly known as having a "green thumb."

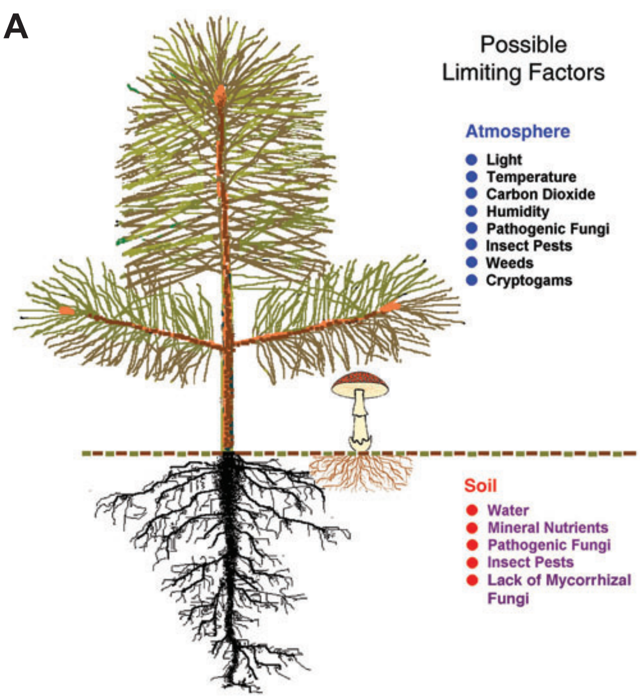
1.1 Factors That Limit Growth

To grow plants well, it is important to understand what limits growth. Ecologists refer to this as the concept of limiting factors and it can be helpful to people starting a native plant nursery. It states that, although a biological process such as growth is affected by several factors, the rate of that process is controlled by the factor that is most limiting. If we apply this concept to nursery culture, we can identify those environmental factors that would be potentially limiting to plant growth and design our nursery to overcome them (Figure 1.1A). For example, water is often limiting so we supply plenty of quality water through irrigation. The concept of limiting factors is easy to demonstrate; when fertilizer was provided to spruce seedlings, their growth increased significantly compared with those plants grown without fertilizer (Figure 1.1B), indicating that the lack of fertilizer was limiting growth.

B



A



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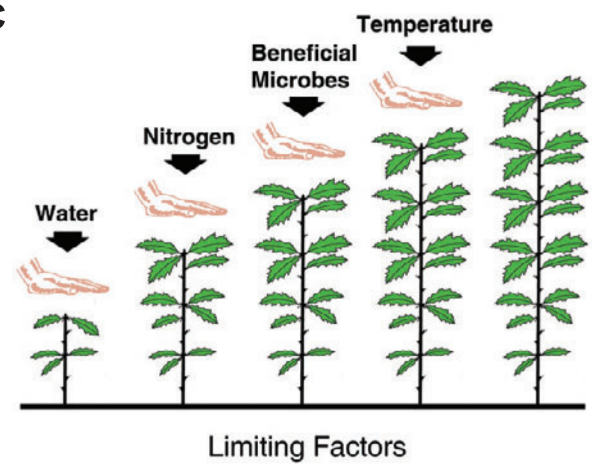


***Figure 1.1**—Many environmental factors can limit plant growth (A), and we can overcome most of those limitations in nurseries. For example, supplying fertilizers greatly increases plant growth (B). Typically, more than one factor is limiting so their effects can be sequential and cumulative. In this example (C), water is the most limiting factor but once we supply irrigation then nitrogen becomes most limiting, and so on.*

Note that plant growth is usually limited by more than one factor and that these limiting factors are sequential—as soon as you satisfy one, another one becomes limiting. Only when we overcome all the environmental factors that limit plant growth can we achieve their maximum growth (Figure 1.1C).

By managing growth-limiting factors we can develop an environment suitable for growing plants, our "propagation environment"; this is any location that has been modified for the purpose of growing plants. Propagation environments can be as simple as a garden plot where water and fertilizer are applied, or as complex as high-tech greenhouses that also modify light, temperature, humidity, and carbon dioxide levels.

1.2 Starting Your Own Nursery

If you decide to start a native plant nursery, the first question to answer is whether it should be a bareroot or container facility. Limiting factors must be considered when deciding between a bareroot or container nursery, and often, the lack of a suitable nursery soil is the critical factor. Your general climate is also critical because greenhouses used to grow seedlings in containers are best at high latitudes or elevations where extremely short growing seasons make bareroot production impractical. Under some circumstances, the most appropriate nursery includes bareroot and container capabilities.

1.2.1 Bareroot Nurseries

Bareroot nursery plants are, as their name implies, harvested and outplanted (planted at their final destination) without any soil around their roots (Figure 1.2A). They are grown in open fields in native soil (Figure 1.2B), and consequently, the quality of the soil and water is critical. The types of bareroot seedlings (stocktypes) include those grown from seeds or rooted cuttings. Sometimes these seedlings are transplanted, physically removed from their original nursery bed, and moved to a different bed for an additional 1 or 2 years' growth. In bareroot nurseries, plant growth rate is controlled by local climate because it determines the length of the growing season. Although any good garden soil can be used to produce bareroot seedlings, large, quality bareroot nursery sites are difficult to find in convenient locations, and good agricultural land is often expensive. Due to land and equipment costs, a considerable capital investment is usually required to develop a bareroot nursery of any size. However, compared to container nurseries, energy requirements and operating expenses are relatively low.

A

B

Figure 1.2*—Bareroot seedlings are stored and shipped for outplanting without soil around the root system (A). They are grown in outdoor nursery "beds" in native soil and are exposed to local weather conditions (B).*

1.2.2 Container Nurseries

Most native plants are grown in containers filled with an artificial substrate (growing medium) rather than soil (Figure 1.3A). In colder climates, plants are grown in a controlled environment, such as a greenhouse, where all growth-limiting factors can be controlled (Figure 1.3B), whereas in milder climates, container plants can be grown in outdoor growing areas. Because the volume of growing medium is relatively small, the roots bind the medium into a cohesive “plug” by the time they are harvested (Figure 1.3C). Although they are also called “containerized,” “container-grown,” or “plug” seedlings, we prefer the term “container plants” because it is simple and definitive.

Container nurseries can be located on land with low agricultural value that would be unsuitable for bareroot seedling production. Fully controlled greenhouses require expensive structures and environmental controls, but open growing compounds are much less costly. Because container seedlings are grown at high densities, considerably less land is required than would be needed to produce a similar number of bareroot seedlings. Container plants can have high growth rates, especially in fully controlled environments, and so many crops can be produced in one growing season.

Many things must be considered when deciding whether to start a bareroot or container nursery. It is helpful to list the various considerations side-by-side for ease of comparison (Table 1.1).

A

B

C

Figure 1.3*—Container plants are grown in artificial growing media (that is, not native soil) in some type of special propagation container (A), and raised in a propagation environment designed to minimize factors that potentially limit growth (B). By the end of the growing season, container plants are harvested with the root system and growing media forming a “plug” (C).*

Table 1.1—Many factors should be considered when deciding whether to start a bareroot or container nursery.

Factor	Container Nursery	Bareroot Nursery
Land Requirement	Less land needed	More land needed
Soil Quality	Not important because artificial growing media are used	Critical—sandy loams are preferred
Water Quantity	Lesser amounts required	Greater amounts required
Water Quality	Good water is desirable but some problems can be chemically corrected	Good water is critical
Propagation Structures	Depends on location, size, and complexity of the nursery	None
Equipment	Depends on size and complexity of the nursery	Tractors and specialized equipment for sowing and harvesting
Duration of Crop Cycle	4 to 12 months to several years depending on container size	1 to 3 years
Crop Storage and Transportation	Greater volume required	Lesser volume required
Plant Handling	Roots are protected in plug	Roots are exposed and are often treated for additional protection
Season Seedlings Can Be Outplanted	Year-round if soil moisture is good	Spring or sometimes Fall

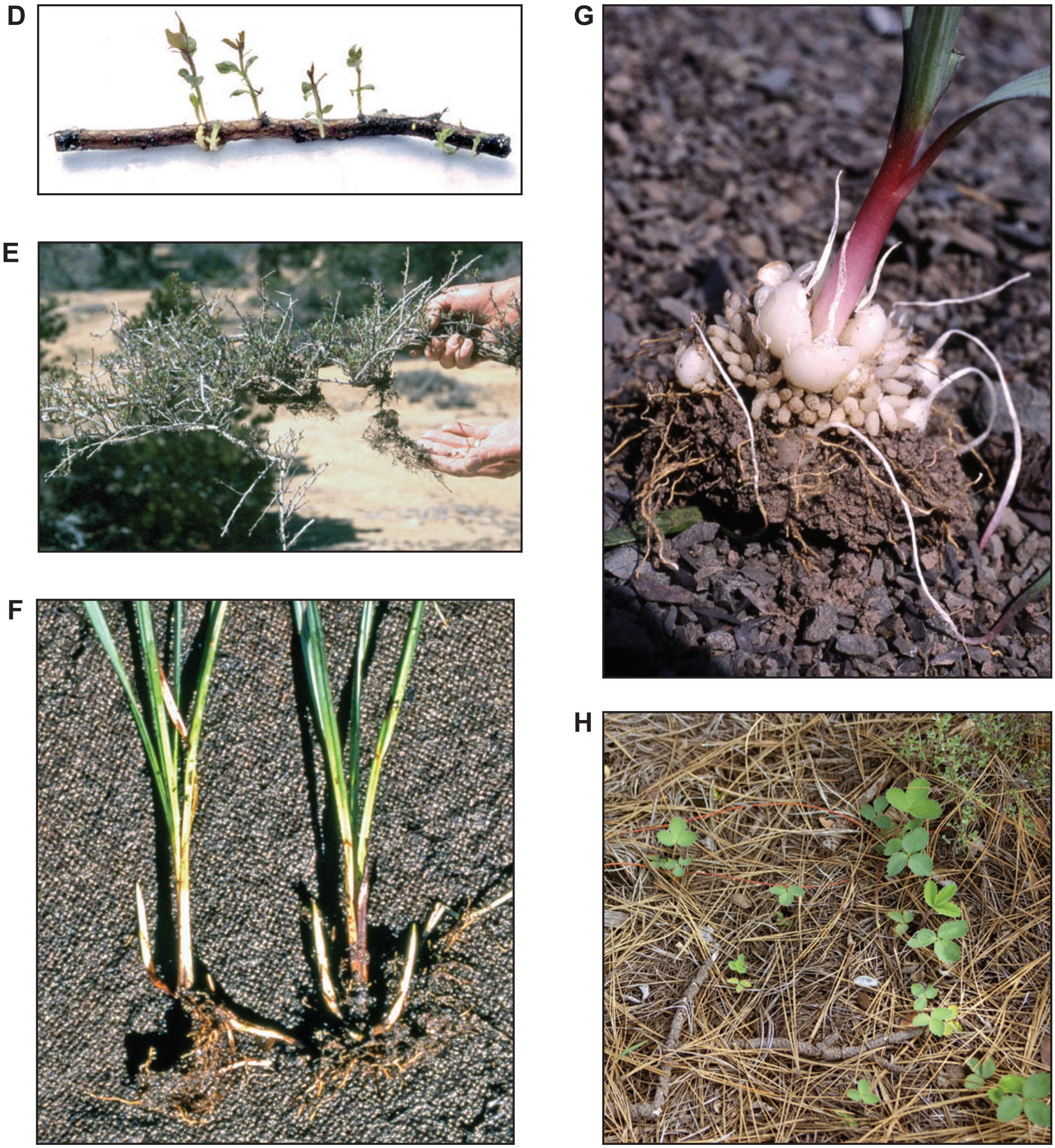
1.3 Seeds and Other Propagules

A "propagule" is any plant part that can be used to produce another plant. These are typically either seeds (sexual propagation) or cuttings (asexual or vegetative propagation). To determine which type of propagule would be most efficient, you should become familiar with the life cycle of the plants that you wish to grow and how they reproduce in nature. For example, common snowberry produces abundant white fruits (Figure 1.4A), but the small seeds (Figure 1.4B) do not germinate reliably. Therefore, native plant nurseries usually propagate this species from another type of propagule—stem cuttings, a form of vegetative propagation (Figure 1.4C). Many native plants do not produce a reliable crop of viable seeds every season, which is another reason that growers sometimes prefer to propagate from cuttings. The rooting ability of cuttings also varies with the time of the year, so growers must collect cuttings carefully at the proper season. Some species can be propagated from either seeds or cuttings. Quaking aspen seeds are very small and don't store well, but this species does produce root sprouts, which can be collected and used as propagules (Figure 1.4D). Some plants with branches that grow low along the ground naturally root into the soil, so each branch section with roots can be a propagule—a propagation method called layering (Figure 1.4E). Many grasses and other grass-like plants have extensive root masses that can be divided into propagules (Figure 1.4F). If the native plant you want to grow produces bulbs, the bulblets that form naturally around the perimeter are potential propagules (Figure 1.4G). Other natives, such as woodland strawberry, produce stolons, which are specialized horizontal stems that produce new shoots and roots that can be used as propagules (Figure 1.4H). Seed (sexual) propagation will be discussed in Chapter 3 and vegetative (asexual or cutting) propagation in Chapter 4.

When collecting or purchasing propagules, the sex and genetics of the resulting plants must be considered. It is important to consider where seedlings will be planted before you begin to grow them. Native plants are adapted to their local growing conditions so it is usually best to collect seeds or cuttings from plants growing near the eventual outplanting site. This is important because moving a plant from one environment to another induces stress. Often the result is poor growth or even death. In addition, collecting propagules from a variety of individual plants ensures that the genetic diversity of the resulting nursery plants represents the original population of plants (see Chapter 2 for more information). In addition, plants that reproduce sexually (through flowering) obtain a mixture of genetic characteristics in their offspring, so each new plant will appear slightly different from its parents and each other (Figure 1.5). About 15% of native plant species are, however, dioecious, which means that plants are either male or female. This is important for species that are often propagated by cuttings, such as willows and cottonwoods, because taking cuttings from a single plant means that all new plants will be the same sex and have exactly the same genetics as the source plant; so because sexual and genetic diversity are desired, it is even more important to collect a few propagules from a large population of source plants.

Figure 1.4—*Types of propagules used to grow native plants include fruits (A) containing seeds (B), stem cuttings (C); continued on next page.*

Figure 1.4*—(Continued) Types of propagules used to grow native plants include root sprouts (D), layers (E), divisions (F), bulblets (G), and stolons (H).*



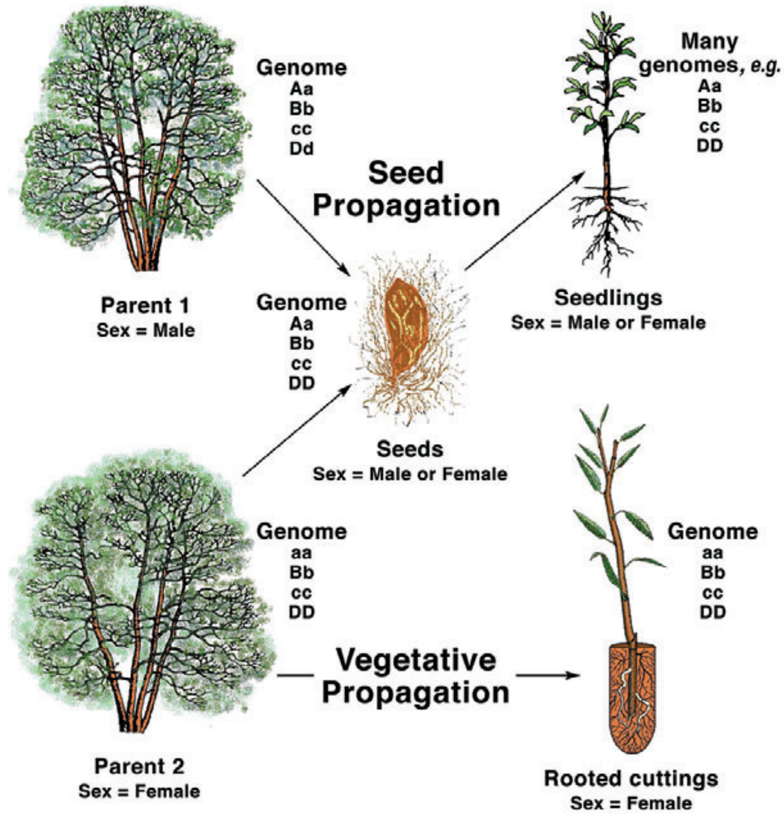


***Figure 1.5**—Plants propagated from seeds may look different from their parents and their siblings because they contain a mixture of the genetic characteristics of each parent. Conversely, vegetative cutting propagation produces exact duplicates of the parent plant ("clones").*

1.4 Crop Scheduling

Once the best propagation technique has been identified, then the grower must do some planning and consider several different factors (Figure 1.6). Species characteristics, genetic variability, and availability of propagules were discussed in the previous section, and now we'll cover crop scheduling. The final cost of producing a crop depends on all these factors but especially the choice of propagation method—plants propagated from seeds are always less expensive to produce than those from cuttings.

Native plant growth and development, whether in nurseries or in the wild, is controlled by two factors: genetics and environment. Genetics are predetermined but, as we discussed earlier, you can control the propagation environment and minimize the effects of growth-limiting factors. All native plants follow a typical annual growth cycle, which begins when seeds germinate or seedlings resume shoot growth in early spring and continues until the plants become dormant in the fall. For nursery planning purposes, plant growth and development during the year can be divided into three

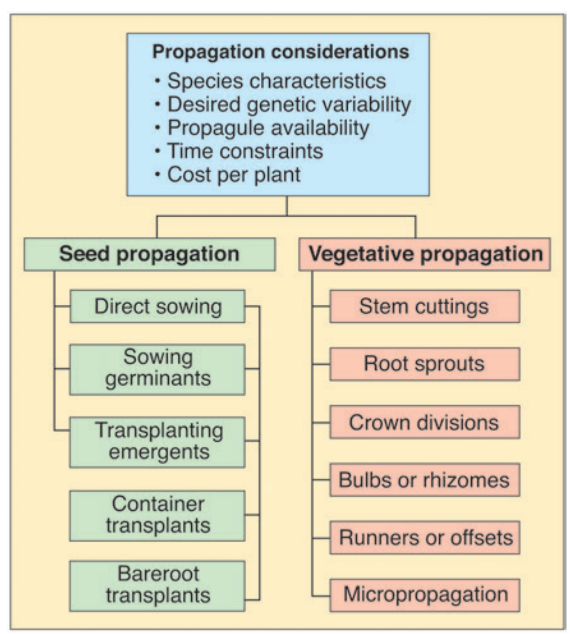


***Figure 1.6**—A successful native plant nursery is based on proper planning and many factors must be considered.*

consecutive growth phases: establishment, rapid growth, and hardening. Because cultural objectives are different for each phase, the growing environment and perhaps even the type of propagation structure may be different. The amount of time required for each of these growth phases varies depending on species, the propagule collection location (that is, the "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.

1.4.1 Seedling Growth Phases

1.4.1.1 Establishment—In the case of seed propagation, the establishment phase begins when seeds are sown, continues through seed germination and emergence, and generally ends when the young seedlings develop true leaves. For vegetative propagation, the phase begins when the cuttings are struck into the container and ends when cuttings have rooted.

1.4.1.2 Rapid Growth—The rapid growth phase is so-named because it is during this period that young nursery plants increase rapidly in size; in general, most of this increase in biomass is shoot tissue with relatively less root growth—some native plants, especially those adapted to harsh, dry sites, may do just the opposite, growing more roots than shoots . With seedlings, this phase begins after the cotyledon stage when the new shoot begins to grow at an accelerated rate and ends when plants have reached their target size.

1.4.1.3 Hardening—During the hardening phase, plants divert energy from shoot growth to stem diameter and root growth, and gradually become conditioned to withstand cold temperatures and the rigors of harvesting, shipping, and outplanting. In general, the cultural objective is to stop shoot growth, initiate development of a terminal bud in determinate species, and improve the plant's tolerance to colder temperatures.

1.4.2 Crop Production Schedules

The first and most long-term type of growing schedule is the crop production schedule, which is designed to help nursery managers 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 (Figure 1.7). Many nursery customers fail to appreciate how long it really takes to grow native plants crop, 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.

1.4.3 Solar Timing

Because of seasonal changes in the Temperate Zone, native plant crops are usually scheduled around the solar cycle (Figure 1.8). Both light intensity and daylength vary considerably during the year, so nursery managers plan their crops around the summer solstice to take full advantage of available sunlight. This is particularly critical for container nurseries that grow two crops per season. The first crop must be sown very early so that they can be large enough to move out of the greenhouse in time to allow plenty of sunlight for the second crop. Planning around the solar calendar also ensures that crops perceive the naturally shortening daylengths that queue them to prepare for winter.

1.5 The Right Plant for the Right Place

Although many people think that all plants of the same species are alike, they can be very different. We already discussed that plants can have different genes, which means they may have different morphology (how they look) and physiology (how they function).

The best nursery stock has the proper morphological characteristics (such as height, stem diameter, and root volume) and physiological characteristics (such as dormancy status and cold hardiness) to have maximum survival and growth for a particular outplanting site. Seedlings being grown for a very dry place need thicker stem diameters, shorter shoots, and more roots than those being grown for a very moist place. Seedlings being grown for a very mountainous site must survive colder temperatures than seedlings being grown for valley locations. Trees for urban landscapes or orchards can be quite large with a large ball of soil around the roots because they will have better care after planting. The type of tool used to plant the seedlings will also affect how the seedlings must look in the nursery. Remember, before starting your crop, it is always important to consider where the plants will be outplanted to ensure they are adapted to the environment, the conditions on the planting site, and the type of planting tool.

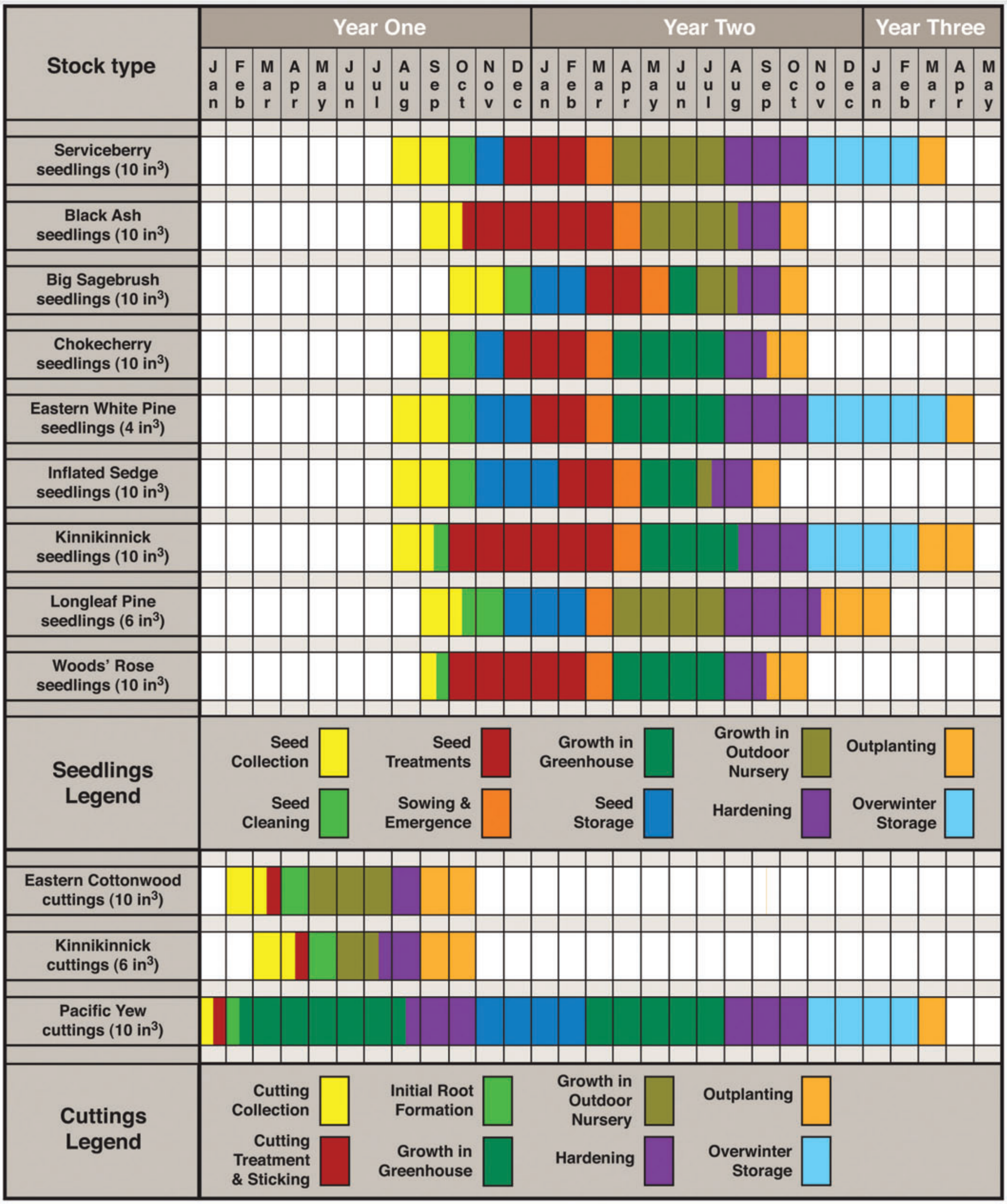


Figure 1.7—*Crop production schedules give a chronological view of the necessary steps to produce a native plant crop, and how long it takes to complete each of those steps. Schedules are useful planning aids for nursery managers as well as their customers.*

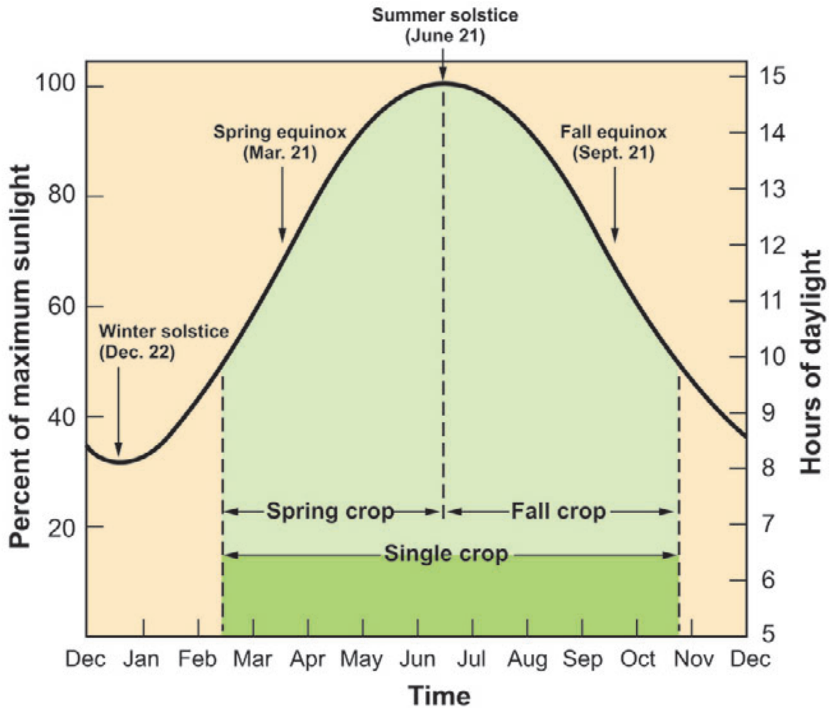


Figure 1.8*—Native plant crops should be scheduled around the annual solar cycle to take advantage of available sunlight; this is especially important for nurseries that plan to grow two crops each year.*

1.6 Additional Reading

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Chapter 2. Obtaining and Preparing Seeds

The process of growing any native plant begins with procuring a supply of high quality seeds or other propagules. In Chapter 1, we talked about the various types of native plant propagules, and now, we will discuss how to find and process seeds to get you ready for your first crop.

2.1 Important Seed Concepts

Before collecting or buying any native plant seeds, you should understand a few critical concepts.

2.1.1 Seed Dormancy

Although native plant seed can be categorized in many ways, its ability to germinate promptly is the most important from a grower's standpoint. This seed characteristic is known as dormancy, and for our purposes, we'll discuss non-dormant and dormant seeds. Non-dormant seeds are those that will sprout in a relatively short time—a few days, weeks, months but generally less than 1 year—without any special treatments. Examples include aspen, willow, and asters. Non-dormant seeds do not require any pre-sowing treatment other than soaking in water, and they are usually sown in the nursery soon after collection. Storage and handling of non-dormant seeds is critical because they must be kept moist. Temporary storage should be in a shaded, cool location. Large seeded, non-dormant seeds, such as acorns and nuts, must be kept fully moist by keeping them in trays under damp burlap bags or in plastic bags filled with moist sand or peat moss. Just prior to sowing, seeds are usually soaked in water for a few hours to a few days, depending on species.

Dormant seeds require some sort of pre-sowing treatment, but store easily for long periods and can tolerate drying. Most conifers and many other native species fall into this category. Pre-sowing treatments to overcome seed dormancy will be discussed later in Section 2.8, Seed Treatments. Dormant seeds retain viability for periods longer than a year and can be dried to low seed moisture levels and stored under lower temperatures.

2.1.2 Seed Source

Plants are genetically adapted to their environment, and this adaptation is known as "seed source" in nursery jargon. If you plan to collect seeds locally, grow plants, and outplant them in the same climatic region, then your plants will be adapted and seed source isn't critically important. If you purchase seeds, however, then you must consider where they were collected.

Collecting seeds from a wide genetic base fosters a more diverse gene pool at the outplanting site. This can protect a planting against unforeseen biological and environmental stresses, and it also protects against potential genetic problems in future generations. For restoration and conservation projects, maintaining genetic diversity is a key project objective.

2.2 Purchasing Native Plant Seeds

If you need a small quantity of seeds or don't have the time or resources to spend collecting your own, purchasing from a seed dealer may be more appropriate.

Seeds for many native plants are available from seed collectors or seed dealers. Seeds are generally listed by common or scientific name, and it only makes sense that local seed vendors will more likely have the species that you are looking for. Finding the proper seed source is often more difficult. It's a good idea to ask the seed dealer which seed sources of a particular species they have in stock, rather than specify which source you're looking for. Some unscrupulous dealers always seem to have whatever source you need if they want to make a sale badly enough. To find reputable seed dealers in your area, call some local native plant nurseries or your local native plant society.

2.3 Collecting Native Plant Seeds

Collecting seeds may be appropriate if you want seeds from a specific location or from specific plants. Just like people, plants of a particular species come in different shapes and sizes and, young plants usually resemble their parents. Therefore, only collect seeds from healthy and vigorous plants—ones that look like you want your plants to look. It may be easy to collect seeds from low growing plants or trees with limbs close to the ground, but this growth form may be genetic. So, with forest trees, especially those that are being grown for timber purposes, avoid trees that are forked, crooked, or have excessively large limbs.

Before starting any seed collection, learn as much as you can about the ecology of the plant species. Some seeds are large and easy to collect while others will require special procedures or equipment. Annual plants, and perennial grasses and forbs, produce some seeds every year but the seed crops of perennial woody plants, such as shrubs and trees, can vary considerably from year to year. For example, trees like aspen produce seeds in 1 year, but others like pines and oaks can take 2 years or more to produce seeds.

For an example of why it's important to know the biology and ecology of a native plant species, let's consider the oaks. Oaks can be divided into two groups: the "white" oaks, which produce acorns in one year and the "red" oaks, which take two years. In southern Oregon, two oak species grow on the same site. California black oaks (red oak group) have large acorns that are easy to collect (Figure 2.1A), but this species takes 2 years to produce seeds and only have abundant seed crops every 8 years or so. In contrast, Oregon white oaks (white oak group) produce acorns in a single year. By knowing the biology of this species, the location of a seed crop can be predicted by observing the abundance of the female flowers on second year twigs (Figure 2.1B).

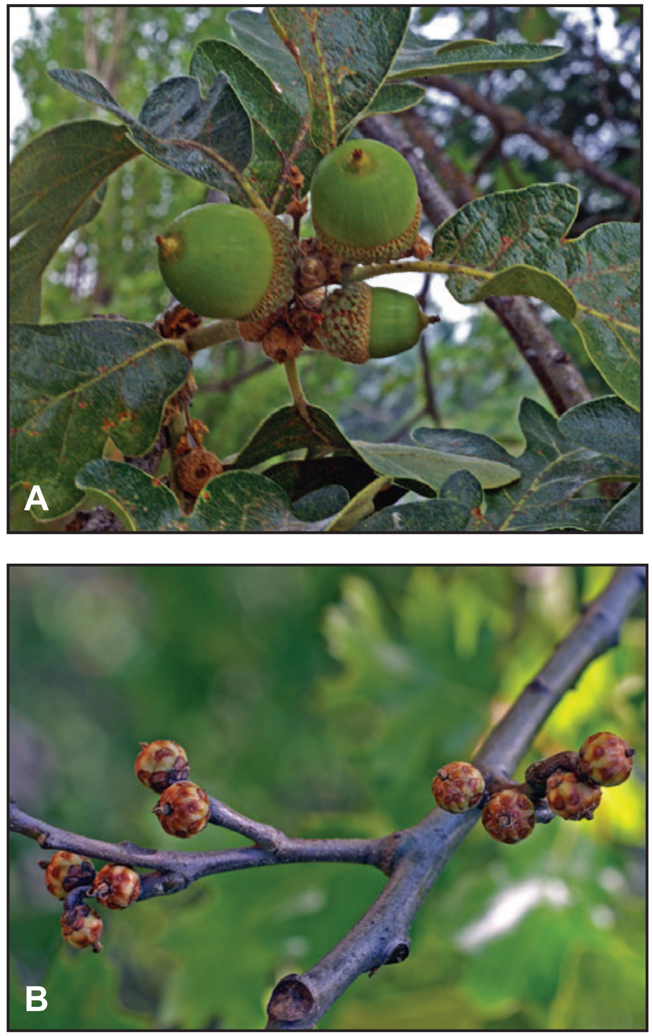

Figure 2.1*—Oak acorns vary in the time they take to mature and how long they can be stored. Acorns of California black oak (A) take 2 years to mature but can be stored for several years. Future seed crops can be predicted by observing the small female flowers on twigs (B).*

Native Plant Seed Collection Guidelines

- Always ask permission to collect seeds from private lands, and don't collect from public lands without a permit.
- Be absolutely certain of the positive identification of plant species. If in doubt, collect and press a specimen for identification.
- Collect a few seeds from as many individual plants of the species as possible. A good rule of thumb is to collect from at least 30 individuals.
- Try to collect the same amount of seeds from each plant; no one plant should be over-represented in the collection.
- If you are collecting seeds from a different location from where you will be outplanting your crop, try to select an area with similar elevation, aspect (north, south, east, west), and soil type.
- Leave enough seeds as a food source for animals and to ensure the natural reproduction of the plants.
- Avoid soil disturbance and plant damage while collecting seeds, especially in fragile habitats.
- If possible, leave an area to rest for at least two growing seasons between collections. Keep in mind that longer periods may be needed for some plant species.
- To prevent possible contamination of your seeds, avoid weed infested areas if possible.

2.3.1 Collecting Seeds and Fruits

Native plants produce a wide variety of seeds and fruits that often need to be cleaned and processed before sowing. The process for each species is very different so we won't attempt to cover all species here, but we will give some general examples.

2.3.1.1 Conifer Cones—Conifer fruits are woody cones that contain many hard-coated, winged seeds (Figure 2.2).

Most conifers do not produce abundant cone crops every year, and the frequency depends on the species (Table 2.1).

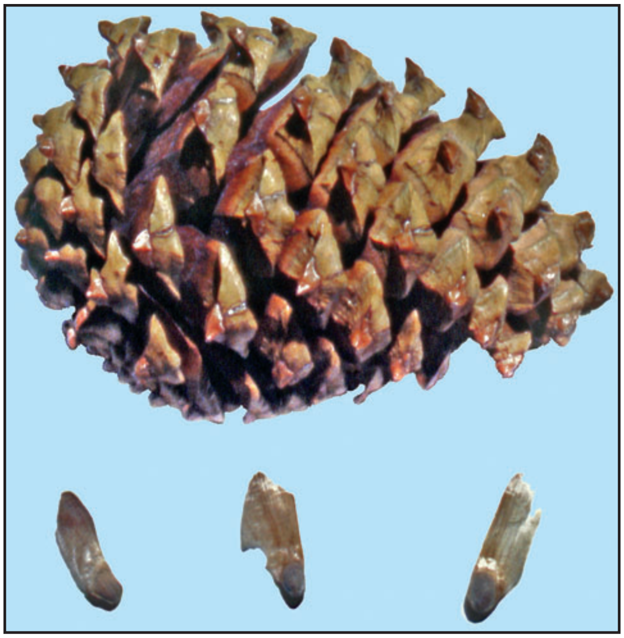

Figure 2.2—*Conifer cones are actually woody fruits that contain winged seeds.*

Generally, cones at lower elevations are ready first, ripening gradually at higher elevations. Start checking potential trees in early summer at low elevations or mid summer for higher elevations.

Because seeds develop gradually in cones, it is difficult for a beginner to determine when it's time to harvest them. In nature, most cones dry out until the seed scales open and the winged seeds blow away in the wind. So, the challenge is to harvest cones when seeds are mature, but before the cones dry too much and release the seeds. Pine cones change color from green or purple to yellowish-green to tan as the cone dries and the seeds mature. This change occurs gradually and is not a perfect guide to seed maturity, and often seeds are mature before the cone changes color.

To really tell if conifer seeds are mature, you'll need to cut the cone in half and check. Cones can be cut with a machete or hatchet. Cut cones lengthwise to expose seeds of Douglas-fir, pine, hemlock, spruce, and larch (Figure 2.3). Cones of true firs (noble, grand, balsam, and others) are cut a little different; slice the cones lengthwise about ½ inch to one side of the cone's core

Table 2.1—Four common conifers of the western U.S. and the years between good cone crops.

Common name	Scientific name	Cone cycle (years)
Grand fir	*Abies grandis*	2 to 3
Colorado (blue) spruce	*Picea pungens*	1 to 3
Ponderosa pine	*Pinus ponderosa*	2 to 5
Rocky Mt. Douglas-fir	*Pseudotsuga menziessii* var. *glauca*	2 to 11

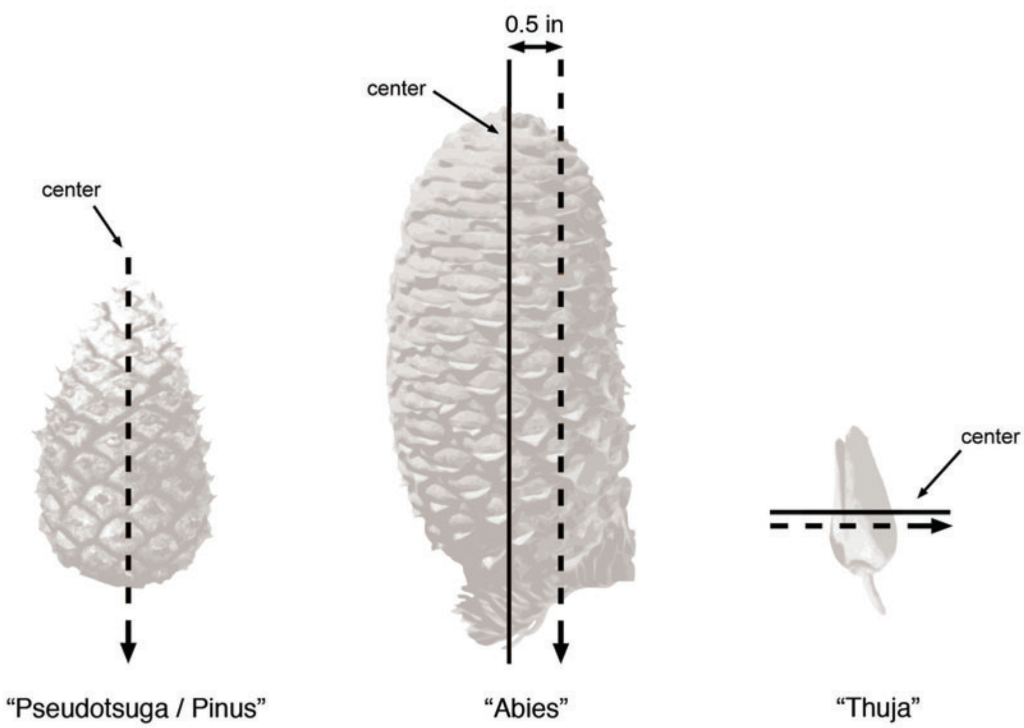

Figure 2.3—*Conifer cones can be checked for filled seeds by cutting them in half. For Douglas-fir, pine, hemlock, and spruce, cut the cones exactly through the middle (left). For true firs, cut cones lengthwise about ½ inch to one side of the cone's core (middle). For western redcedar and northern white-cedar, cut the cones widthwise just below the center of the cone (right).*

to ensure cutting through seeds. For western redcedar, incense-cedar, and arborvitae, cut the cone widthwise just below the center of the cone.

Inspect the cut seeds on the cone faces with a hand lens to evaluate seed maturity (Figure 2.4A). Mature seeds have embryos that fill 90% or more of the embryo cavity (Figure 2.4B), and the material around the embryo is whitish and firm with a texture like coconut (Figure 2.4C). Cones can be harvested earlier, when embryos fill 75 to 90% of the cavity, but then you will have to after-ripen the cones for 2 to 6 weeks (see Section 2.7.2.1, Internal Dormancy).

Based on the number of filled seeds per cone, you can determine how many cones you will need to collect. Cones can be collected with pole pruners or by climbing the trees, but climbing should generally be left to experts. Squirrels begin cutting cones and caching them around the bases of trees at about the time that seeds mature, so the easiest harvesting is to steal a few cones from a cache but make sure you leave some for the squirrel. Place cones in burlap or nylon screen sacks, and don't contaminate your cones with needles, branches, and dirt that could introduce damaging molds. Cones have a high moisture content so fill sacks only half full to allow for air circulation and cone expansion during drying. Never toss or drop a bag of cones. Label each sack immediately with species, elevation, collection location, date, and any other pertinent information. Store sacks on open racks in dry, well-ventilated shelters, such as open-sided sheds or well-ventilated barn lofts. You may also hang sacks from rafters. Either way, sacks should be separated to permit good air circulation. Stored this way, cones will dry gradually with a minimum of overheating and mold damage. Check cones often and inspect them for mold. If mold is present, rearrange sacks to improve air circulation. If you picked cones with mature seeds, cones should dry satisfactorily in a few days, depending on the weather. If you picked green cones, it may take a few weeks or months for seeds to finally mature.

Some pines, such as lodgepole, knobcone, and jack, have cones that require heating before they will open. Here's an easy way to open them. Put cones into a burlap bag and immerse the bag into very hot water (about 180 °F) for 30 seconds to one minute. Remove the bag, dump the cones onto a screen-bottomed tray, and place them in a warm location. The hot water softens the resins that keep the cones closed. As the cones dry, the scales pull open and you can extract the seeds.

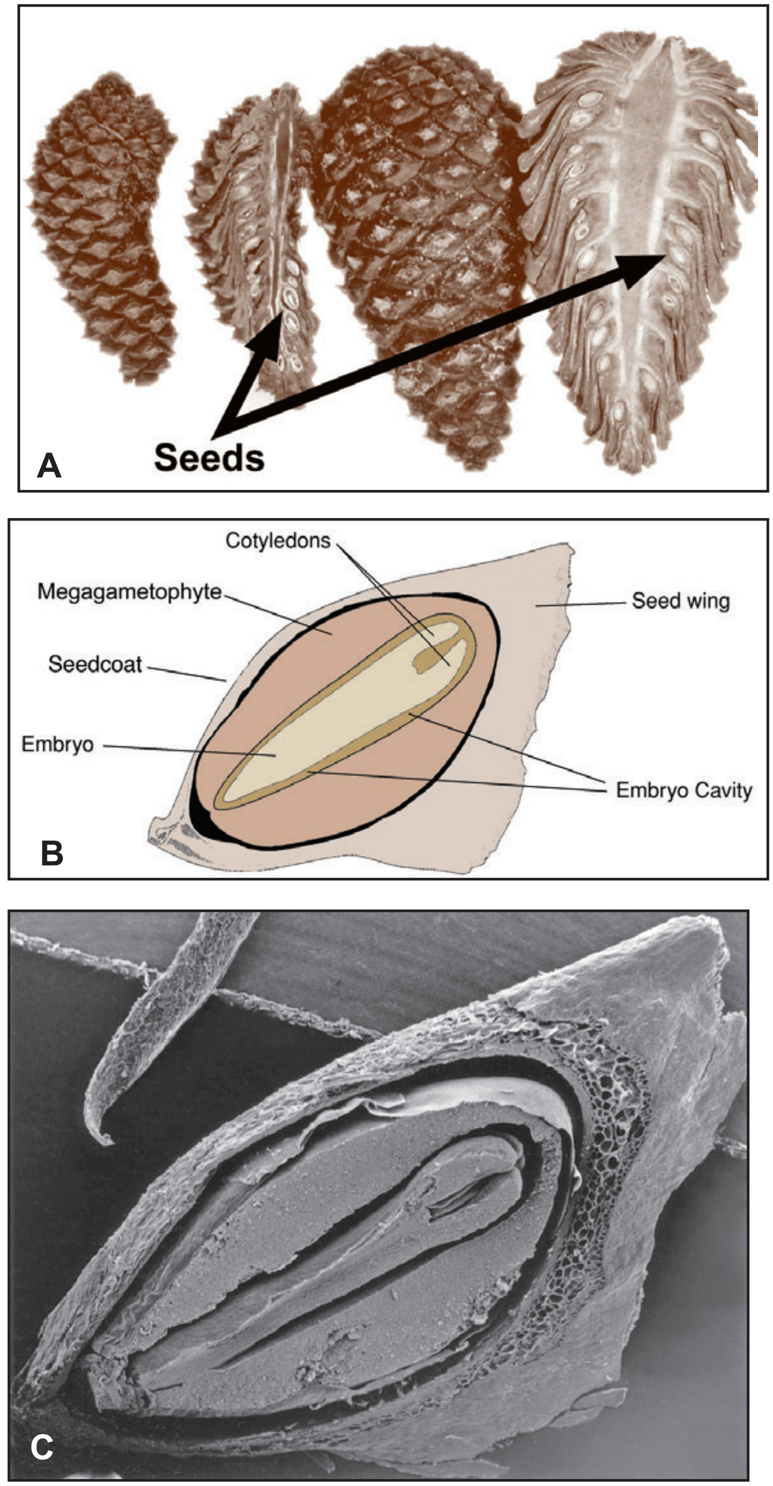

Figure 2.4*—The cut faces of conifer cones (A) can be inspected with a hand lens to evaluate seed maturity. The embryo (undeveloped seedling) in a mature conifer seed should almost fill the cavity (B). The embryo and megagometophyte (storage tissue) should be white and have a firm texture like coconut meat (C) (courtesy of L.E. Manning, Canadian Forest Service).*

2.3.1.2 Dry and Fleshy Fruits—Dry fruits are those that are woody or papery at maturity and examples are hazel nuts (Figure 2.5A) and capsules (Figure 2.5B). Some dry fruits will split open at maturity. You will need to harvest these just before the fruits begin to split open and seeds disperse. Other dry fruits have structures where both the fruit and seed are fused together and do not split open at maturity. Dry fruits can be collected like cones. Nuts and acorns can be harvested after they drop from the tree as long as they are handled and cleaned immediately after collection (described below).

Fleshy fruits are those usually comprised of three layers: the skin, the often fleshy middle, and the membranous or stony inner layer (Figure 2.6). Depending on species, fleshy fruits can contain many seeds per fruit or they can bear a tough, stony pit that encloses only one seed. Therefore, the amount of fruits you have to harvest to obtain a desired number of seeds will vary greatly from species to species. When collecting and handling fleshy fruits, it is important to keep them cool and out of direct sun. Heat buildup and subsequent fermentation can damage the seeds inside the fruits. It is also important not to let the fruits dry out, because this can make cleaning more difficult. Collect fleshy fruits in white plastic bags, and store them in a cool place or a refrigerator until they are cleaned.

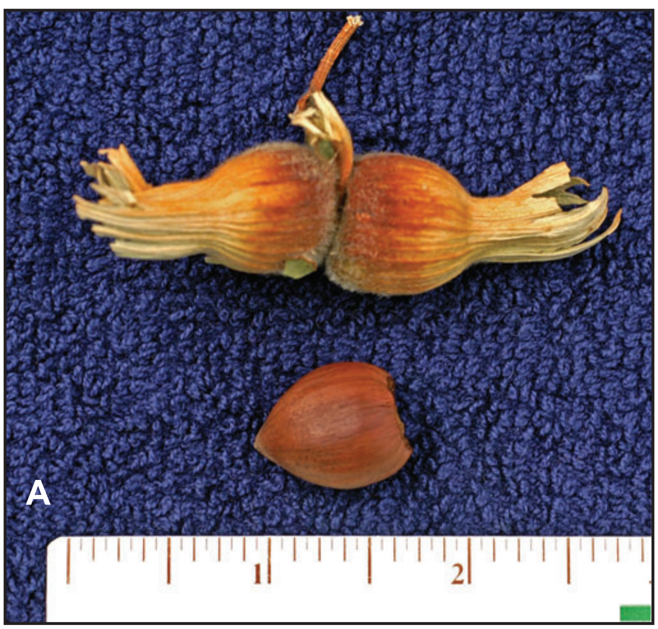

Figure 2.5*—The seeds of some dry fruits, such as hazel nuts, are enclosed in a thin papery shell (A). Penstemon fruits are capsules (B) that contain many small black seeds (C).*

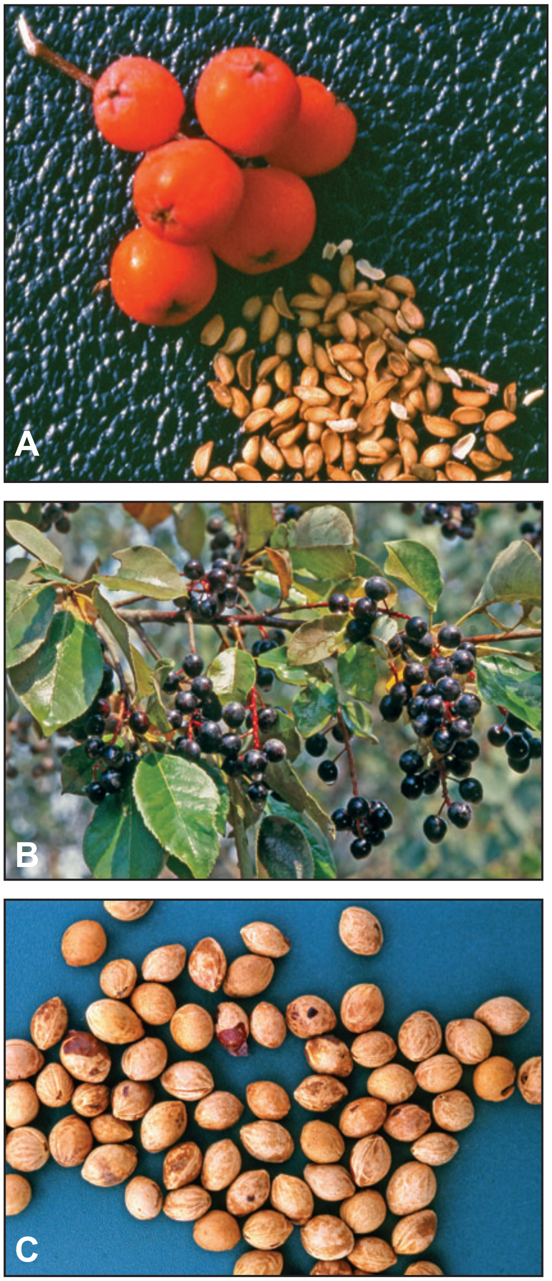

Figure 2.6—*Fleshy fruits, such as mountain-ash berries, contain small tan seeds (A). Chokecherries grow in a raceme (B), and each berry contains a large hard seed (C).*

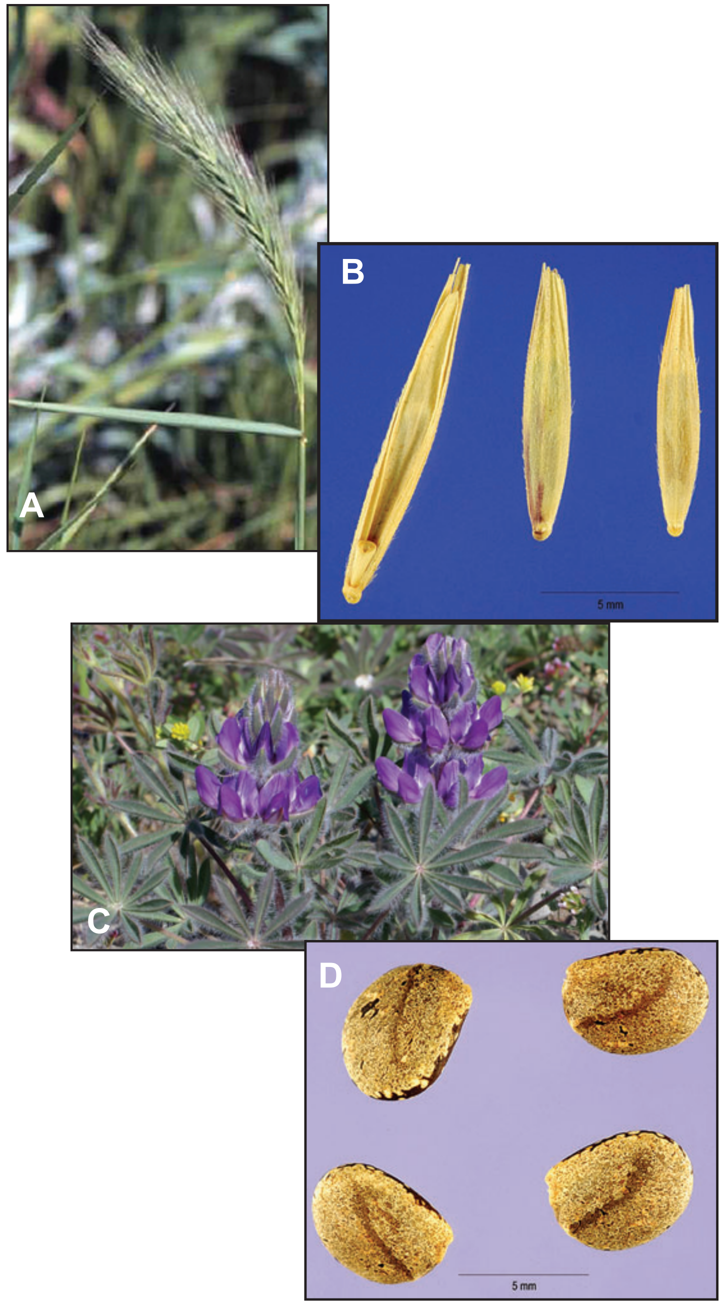

Figure 2.7—*Native grasses produce seedheads that are a papery sheath (A) containing many seeds (B). Forb seedheads develop directly from flowers (C), and seeds (D) are contained within papery or woody structures.*

2.3.1.3 Grasses and Forbs—Seeds of native grasses and forbs (herbaceous plants) are not contained in dry or fleshy fruits, and they can be collected directly from the plants. Grass seed heads form at the top of the plants (Figure 2.7A) and the seeds are contained in a papery sheath (Figure 2.7B). Forb seed heads form directly from the flowers (Figure 2.7C); seed heads are therefore variable in size and shape and the seeds can be hand-collected (Figure 2.7D). Photos and illustrations can be found on the USDA Natural Resources Conservation Service PLANTS database (http://www.plants.usda.gov).

2.4 Handling Seeds and Fruits After Collection

After harvest, begin drying cones, fruits, and seed heads as soon as possible. Freshly collected fruits, whether they are dry or fleshy, have high moisture content and will mold if stored inappropriately even for a few days. Drying reduces the moisture content of the seeds, helps open dry fruits, and prepares seeds for further cleaning. Good air circulation, low humidity, and temperatures maintained at 64 to 80 °F are ideal conditions for post-harvest drying. A ventilated storage shed works well for this purpose. Temperature control is very important; keep temperatures cool. Poor air circulation can also cause severe seed damage. Spread cones, dry fruits, and seed heads over a mesh screen with fine holes that allows air movement to promote even drying and eliminates moisture build up, but prevents seeds from falling through the screen. For dry fruits and cones that split open at maturity, cover the collection with a fine mesh cloth to prevent the loss of seeds after fruits begin to split open. Small quantities of dry fruits can be dried in paper bags or large envelopes as long as the bags are not packed too tightly with collected material.

2.5 Seed Cleaning and Extraction

Seed cleaning is necessary so that seeds can be sown or stored properly. In some cases, seeds will fail to germinate if they are not removed from their fruits. The seed cleaning area should be well ventilated because some fruits can cause allergic reactions and fine dust can irritate eyes and lungs. It is important to wear gloves and dust masks during cleaning, and wash your hands afterwards.

Seeds can be cleaned from fruits in many, easy ways. Some are described below. It is important to remember that dormant seeds need to be spread evenly and dried completely before storage, while non-dormant seeds need to be kept moist and in a high humidity environment until they are sown.

2.5.1 Cleaning Non-Dormant Seeds

Large seeded, non-dormant seeds are typically cleaned from other debris by floating them in water immediately after collection. This keeps seeds hydrated and facilitates the removal of non-viable seeds, trash, and other debris that will float. If nuts and acorns are collected under very dry conditions, good seeds may also float. Therefore, soak large seeds in water overnight to allow enough time for good seeds to hydrate and sink.

Other non-dormant seeds, such as willow or azaleas, are sown without further preparation or cleaning. With these species, the cottony material that surrounds the tiny seeds can aid in holding seeds in contact with the soil when they are planted.

2.5.2 Cleaning Dry Fruits, Capsules, and Seed Heads

The first step in cleaning seeds is to remove them from the cones, capsules, or seed heads. You can extract small quantities of seeds and clean them reasonably well at home with simple, low-cost equipment. As cones and capsules dry, they open and seeds fall out. Properly dried fruits will partially open inside the sacks and some seeds will fall out. To remove all the seeds, however, they may need further drying. They will dry best if placed in window screen-bottomed trays (Figure 2.8), which are placed in warm locations with good air circulation. Adding wooden spacers at each corner allows the boxes to be stacked, and fans will accelerate drying. If you have small batches of fruits, place them in a paper sack instead, but leave the top open. When most seeds fall out with a little gentle tapping, the cones or fruits have opened sufficiently. When true fir cones dry sufficiently, they disintegrate into scales and seeds.

Figure 2.8*—Screen-bottomed boxes are an excellent way to allow conifer cones, dry fruits, and seedheads to dry without losing the seeds.*

The next step is to separate seeds from cones, fruits, and other debris. Separation is typically accomplished with a combination of screening and air separation. Move the dry fruits and seeds to another screen box with a mesh size large enough to permit the seeds to fall through (Figure 2.9A). Gentle shaking will let seeds and smaller impurities fall through the screen, leaving cones and larger debris on the screen. Screen mesh size will vary greatly with species. For example, a 1⁄4- to 1⁄2-inch mesh works well for Douglas-fir, while a 3⁄8- to 5⁄8-inch mesh is necessary for larger true fir seeds. But with other small seeded plants like sedges, rushes, and some wildflowers, you will need very fine mesh screens or kitchen sieves to properly separate seeds from other debris. Extracted seeds may be mixed with pitch globules, dry leaves, wings, and other debris. Repeat the screening process with a mesh size that retains seeds but allows the smallest debris to pass through (Figure 2.9B). You're then left with seeds and seed-sized debris.

Many native plant seeds have wings or other appendages that need to be removed to make sowing easier. Wings can be manually removed by filling a burlap or cloth sack 1⁄4 full, tying or folding it shut, and gently kneading the seeds by squeezing and rubbing the sack between your hands (Figure 2.10). Friction between seeds and between seeds and burlap will detach wings. Remember to knead slowly and gently because too much friction might damage seeds. Another trick for dewinging conifer seeds is to alternately moisten the seeds and let them dry, and then repeat the rubbing process. A few species, such as alder, western redcedar, and angelica, have very tight wings that should be left on the seeds. Repeat the screening process again with a mesh size that retains seeds but allows the smallest debris to pass through.

The final step in the seed cleaning process is fanning or winnowing, which separates detached wings, hollow seeds, and seed-sized impurities from good seeds. Winnowing can be done outside on a breezy day or, for smaller batches, just cup the seeds in your hands and blow through them while gently bouncing the mixture. For larger batches, winnow in front of an electric fan, which separates seeds

***Figure 2.9**—Wooden frame boxes with screened bottoms (A) can be used to separate seeds from other debris. Depending on the type of dry fruits and seed size, several boxes with different sized mesh may be needed. With gentle shaking over a series of screens, pure seeds can eventually be obtained (B).*

Figure 2.10—Many native plant seeds have wings or other appendages that must be removed before sowing. An easy way to de-wing seeds is to put them in a cloth bag and gently knead the bag and seeds.

from the lighter debris (Figure 2.11). Most heavy, sound seeds will come to rest near the base of the fan, and hollow seeds, wings, and lighter impurities will tend to blow farther away. Changing the fan speed or moving farther way will improve the separation. After each winnowing, collect a small sample of seeds and cut them in half to check for soundness. This way you can determine where the hollow seeds are and discard them. All species will probably require several successive separations to obtain a desired degree of seed purity. A good target for most species is 90% or more sound seeds.

2.5.3 Cleaning Fleshy Fruits

Fleshy fruits should be processed soon after collection to avoid fermentation, mummification, heat buildup, or microbial damage. Just before cleaning, soak fleshy fruits in water to soften the pulp. Fruits can be soaked for a few hours to a few days, depending on the species. Change the water every few hours during soaking. Flesh can be hand squeezed or mashed using a wooden block, rolling pin, or other device. Fruits can be also be cleaned by wet screening, which involves hand rubbing the fruits against screens using a steady stream of water to eliminate the pulp.

A modified food blender or kitchen food processor (Figure 2.12A) can be used for small lots of fleshy fruits. Just coat the impeller blades with rubberized plastic or tape (Figure 2.12B) so that seeds are not damaged during cleaning. The final processing step is to thoroughly wash seeds with fresh water to remove any remaining pulp, and then place them on a drying rack for several days before storage.

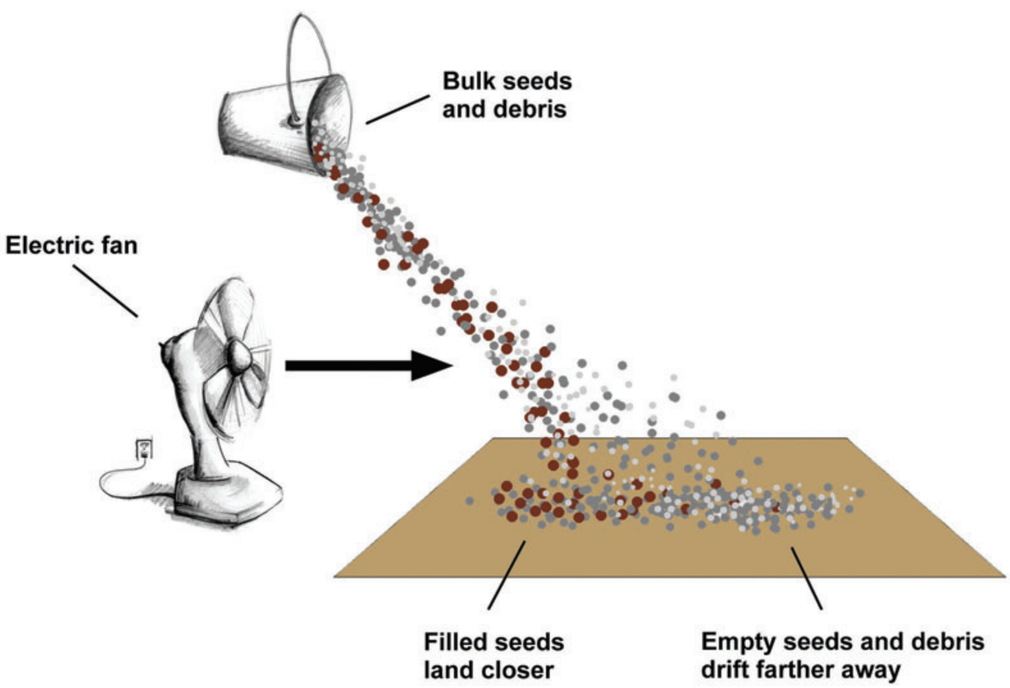

Figure 2.11—Winnowing in front of a fan separates filled seeds from empty seeds and other lighter debris.

Figure 2.12*—Small batches of berries or other fleshy fruits can be cleaned with a modified food processor (A). Coating the impeller blades with plastic or tape (B) prevents seed damage.*

Remember, how seeds and fruits are handled during collection, temporary storage, post harvest handling, and cleaning can directly affect seed quality, viability, and storage life.

2.6 Storing Seeds

Most seeds can be sown immediately after cleaning. Immediately after harvesting and cleaning, sowing seeds into bareroot beds or containers left outdoors exposes seeds to their normal cycle of climate and allows any dormancy to be overcome naturally (see Section 2.7, Seed Dormancy). In the case of spring ripening seeds, such as elm, they can be planted immediately and will germinate and grow during summer. Seeds that are sensitive to drying, such as acorns, willow, and Culver's root, perform best when sown immediately. Sowing immediately after harvest is the best option when you have as many seeds as you need, have adequate outdoor space prepared, and can protect the seeds from predation while they undergo exposure to natural conditions. Storing seeds will be necessary if you have collected more seeds than you need in a single year and expect to use those seeds in the future, if you are not ready to plant the seeds, or if the conditions simply are not favorable for planting immediately. If stored, most seeds require some treatment to alleviate dormancy (see Section 2.8, Seed Treatments; Appendix 6.1). Seeds that require scarification (see Section 2.8, Seed Treatments) need to be treated before sowing whether they are stored or not.

To properly store seeds, they must be mature and free of mechanical injury. The key to good seed storage is to control moisture content and temperature. Remember that, in general, non-dormant seeds normally remain viable only for a few days to 1 year and must be stored moist. Some nut and acorn bearing species can be stored for several months, as long as seeds have high seed moisture content (35 to 50%) and are stored under cool and moist conditions. To provide constant gas exchange, non-dormant seeds are usually stored in unsealed containers in plastic bags filled with moist peat moss in refrigerated storage.

Dormant seeds, however, can be dried, which increases the amount of time they can be stored. Once dormant seeds are clean, air-dry them in drying trays for 2 to 4 weeks to reduce their moisture content. At room temperatures, seeds can be stored for short periods of time in bottles or plastic bags in boxes. Make sure that you label the containers with species, collection date, and location (Figure 2.13).

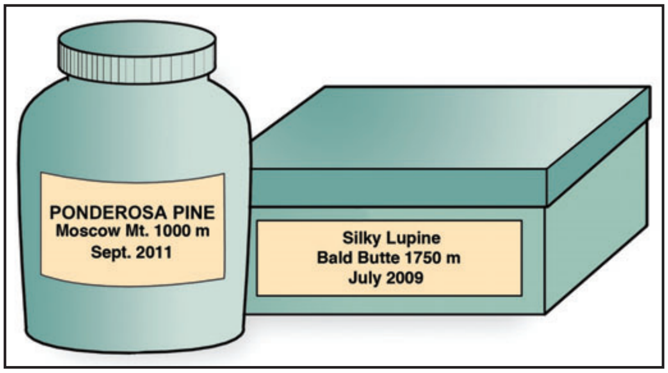

Figure 2.13—*Controlling moisture content is the most critical aspect of seed storage, so place seeds in airtight bottles or in zip-lock-type plastic bags in a protective box. Make sure all storage containers are properly labeled.*

For larger quantities of seeds, refrigerated storage is recommended. All native plant seeds can be stored under refrigeration (34 to 41 °F) in airtight containers. If possible, use a self-defrosting refrigerator that maintains the humidity at 10 to 40%. If the door is rarely opened, the humidity in a self defrosting unit will stay at lower humidity levels. Many dormant seeds can be stored for long periods at temperatures below freezing; some trees seeds will remain viable for 10 years or more. Because high seed moisture reduces viability, store seeds in airtight containers.

2.7 Seed Dormancy

Dormancy is a fascinating physiological adaptation that ensures native plant seeds germinate at appropriate times for survival and growth. It also is a mechanism by which plants increase the time their seeds remain viable. Seed dormancy is, therefore, one of the major challenges to growing native plants because it can be highly variable, not only between different species but among seed sources of the same species. In this section, we will discuss seed dormancy types and seed treatments that are used to overcome, or "break," dormancy. Good information on ways to overcome seed dormancy for individual native plant species can be found in Appendix 6.1, or on the Native Plant Network (www.nativeplantnetwork.org).

2.7.1 Non-Dormant Seeds

Non-dormant seeds germinate immediately after maturation and dispersal from the mother plant. The time it takes for the seeds to germinate, however, is variable. Some species may germinate immediately (willow and aster) while others may take up to a month to germinate after sowing (white oaks).

2.7.2 Dormant Seeds

Dormant seeds are those that do not germinate immediately after maturation and dispersal from the mother plant even when the right environmental conditions exist. Causes of dormancy are either inside the seed (internal) or outside the seed (external) and some species have a combination of these. When seeds have more than one type of dormancy, that is, internal and external, or more than one type of internal dormancy (described below), they are said to have "double dormancy."

2.7.2.1 Internal Dormancy—Internal dormancy is caused by some property of the seed that prevents germination. With some species, certain environmental conditions (usually cold and moist) are necessary to change the seeds' metabolic processes and allow germination. With other species, the embryo within the seed is under-developed at time of seed dispersal and a period of after-ripening (set of correct environmental conditions, usually warm and moist) is needed for the embryo to fully mature before germination can occur. Some species may require a combination of warm, moist conditions followed by cold, moist conditions for an extended period of time before germination is possible.

2.7.2.2 External Dormancy—External dormancy generally describes seeds with hard seed coats that are a barrier to water. Depending on species, various environmental factors cause these seeds to become permeable during a certain time of year, or after several months or years. In nurseries, these seed coats must be modified by a technique called scarification (see Section 2.8.2, Scarification). Some species may have double dormancy so the seeds must first be scarified to allow water uptake, and then given additional warm and moist and/or cold and moist conditions to alleviate any internal dormancy.

2.8 Seed Treatments

Soaking some seeds in running tap water for a few hours up to several days is often helpful because seeds must have exposure to water and oxygen before they can go through metabolic changes needed for germination. Stored seeds are usually at low moisture content and must become fully hydrated before they are capable of germination or before temperature can be effective in breaking seed dormancy. Soaking seeds in running water also helps to remove any naturally occurring chemicals present on or within the seeds that prevent germination.

Seed cleansing is used to remove bacteria and fungi from seed coats, and it is particularly important for seeds that easily mold or take a long time to germinate. Seed cleansing is a standard procedure used at most nurseries to prevent one of the most common nursery problems: damping-off disease. Running water soaks (Figure 2.14A) can effectively cleanse seeds and all native plant seeds will tolerate this procedure. Seeds can also be cleansed with solutions of household bleach (Figure 2.14B) or hydrogen peroxide (Figure 2.14C). For example, two standard procedures are to either soak seeds in 3% hydrogen peroxide for up to 4 hours, or in a 40% bleach solution (2 parts bleach [5.25% sodium hypochlorite] in 3 parts water) for 10 minutes. After soaking in either bleach or hydrogen peroxide, be sure to thoroughly rinse seeds with running tap water. Always test treatments on a small sample first to ensure it does not damage the seeds.

2.8.1 Stratification

Many dormant seeds require a cold, moist period before they germinate; this happens naturally during winter. Stratification is a nursery term that describes the combined use of moisture and temperature to overcome seed dormancy. Historically, stratification meant layering seeds between moist substrates and exposing them to cold temperatures. Although nowadays stratification is often used to describe any temperature treatment that causes metabolic changes, we will use the historic definition.

During stratification, seeds are kept moist at temperatures of 34 to 41 °F. Some species may only require a few days or weeks of stratification while other species may require several months. Different seed sources of a given species may break dormancy at different times during stratification. You can expect to see some variation when dealing with many seed sources. As a general rule, it is best to use the maximum recommended dormancy breaking treatment (see Appendix 6.1). Another valuable advantage to stratifying seeds is that it increases germination energy (how fast the seeds germinate when placed in favorable conditions) and uniformity, which is desirable. If seeds begin to mold during stratification, remove them from stratification and rinse them thoroughly in running tap water to remove the mold. Place the seeds in a clean plastic bag and return to the refrigerator. You may need to repeat this process often, so keep a watchful eye on your seeds.

A few species have double, internal dormancy that is best removed through a combination of a warm, moist treatment followed by stratification (see Appendix 6.1). The warm, moist treatment enhances the after-ripening of seeds with under-developed embryos. Juniper, Pacific yew, hawthorns, and trilliums are examples of species that often benefit from both treatments. The requirements and procedures for warm, moist treatment are basically the same as for stratification, except temperatures are increased to around room temperature. Again, seeds should be soaked in running water for 12 to 48 hours and then placed either

***Figure 2.14**—One of the major reasons for poor germination of native plant seeds is seed coat contamination, so a running-water rinse (A) is recommended for all species. Large seeds can be surface sterilized with bleach (B) or hydrogen peroxide (C).*

into a plastic bag or between moistened paper towels. Place the bag in a dark area. For some pine species, a 2 to 4 week period is probably sufficient, but juniper and yew seeds may require 15 to 20 weeks of warmth. (Because of the long warm treatment, bareroot growers should probably sow juniper and yew seeds in late summer or early fall [see Section 3.2.3.2, Sowing and Germination].) Once the warm period is over, seeds are transferred to a refrigerator to complete their stratification. Check often for mold because it can grow rapidly at the warmer temperatures. After stratification, re-soak seeds in running water for 12 to 24 hours. Soaking ensures the seeds have plenty of water to begin the germination process.

2.8.1.1 Naked Stratification—This method is best for larger quantities of seeds (more than a handful or two). Start by putting seeds into a bag made from bridal mesh, cheesecloth, or women's nylons. A square piece of mesh, with seeds placed in the center, can be tied to form a crude bag (Figure 2.15A). Don't put more than a half pound of seeds per bag. Label it. Place the bag into a bucket and allow water to run through it for 12 to 48 hours. After soaking, allow the bag to drip dry for a minute or so and suspend it within a plastic bag (Figure 2.15B). Hang the bag in your refrigerator for the required time (Table 2.2; Appendix 6.1). Check it often for mold. If mold is present, gently rinse the seeds in running water and rehang in the refrigerator.

2.8.1.2 Sandwich Stratification—This is the best technique for small amounts of seeds, for very small seeds, and for those species that only require a few weeks of stratification. Loosely stack paper towels about ⅛-inch thick and moisten them completely. Drain off the excess water by vertically holding one end of the towel (Figure 2.16A). Then, place seeds one layer deep on half the paper towel surface. Be sure to distribute the seeds evenly across the moist paper towel so that they do not contact each other. This will help prevent the spread of mold to other seeds. Fold the paper towels over the seeds (Figure 2.16B). Put your sandwich into a clear, plastic zip-lock type bag and refrigerate for the required time (Table 2.2; Appendix 6.1). Check occasionally to ensure seeds are moist and not moldy. If they're moldy, remove the sandwich. Rinse seeds under cool, running tap water. Wash out the zip-lock type bag with warm water and soap. Spread seeds onto a new stack of moistened paper towels, put the sandwich back into the bag, and refrigerate. Keep checking for mold.

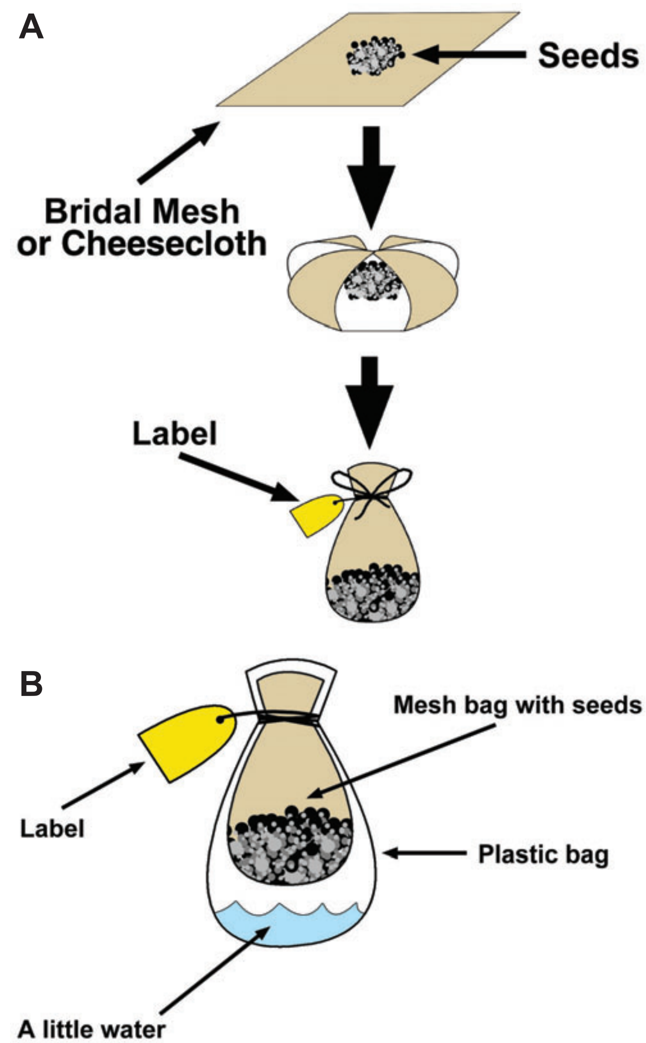

Figure 2.15—Use bridal mesh or cheesecloth to make a bag to soak and stratify seeds (A). After soaking and draining, place the mesh bag into a larger plastic bag and add a little water to maintain 100% humidity around the seeds without immersing them (B). Don't forget to label bags properly.

Table 2.2—Stratification durations for six common native plants. See Appendix 6.1 for more species.

Common name	Scientific name	Days of stratification
New England aster	*Aster novae-angliae*	60
Beaked sedge	*Carex utriculata*	30 to 60
Dogwood	*Cornus florida*	90
Indian blanketflower	*Gaillardia aristata*	0 to 60
Colorado (blue) spruce	*Picea pungens*	0 to 28
Antelope bitterbrush	*Purshia tridentata*	60 to 90

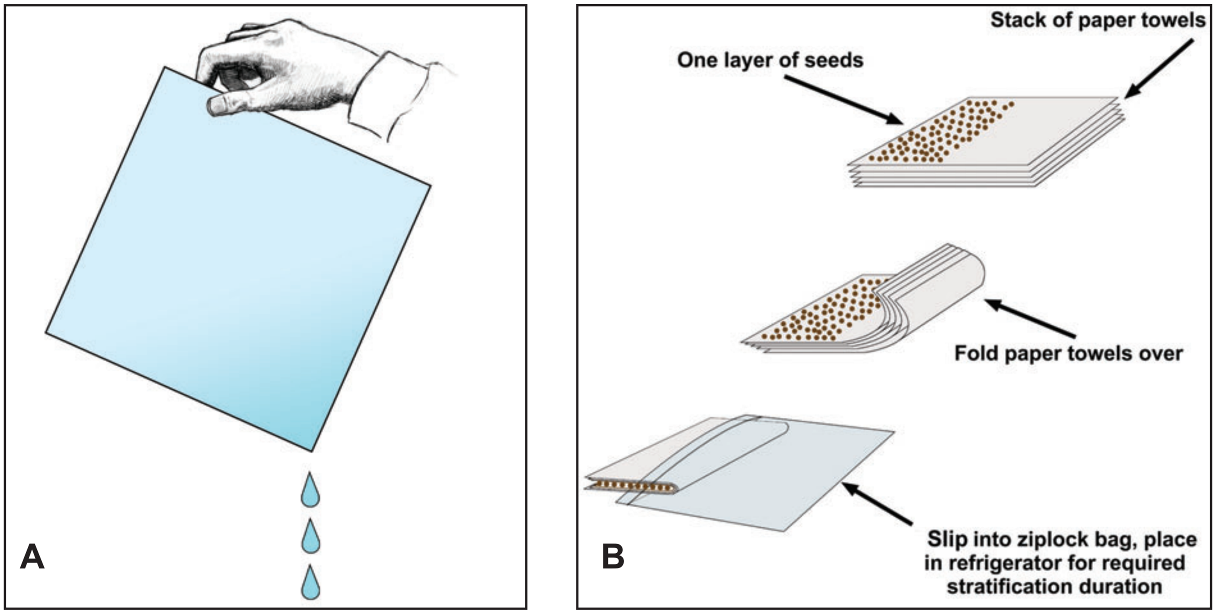

Figure 2.16*—Sandwich stratification requires paper towels that are moist but not soaking wet, so hold them by the corner until excess water drips off (A). Place one layer of seeds on the towels, fold them, place in a plastic zip-lock-type bag (B), and refrigerate.*

2.8.2 Scarification

Scarification is any method used to treat hard and impermeable seed coats so that moisture can enter the seeds, thus allowing them to germinate. In nature, hard seed coats often have a "plug" that must be softened or opened by exposure to extreme temperatures or the digestive acids in the stomachs of animals. Some species with hard seed coats that benefit from scarification include lupine, globemallow, and sumac (see Appendix 6.1). Other species that are adapted to fire or inhabit desert environments may also benefit from scarification.

Seeds can be scarified several ways, but we will discuss only three of the easiest methods. How well the scarification method works depends on the species and the thickness of the seed coats. Whichever method you choose, it is very important not to damage the interiors of the seeds. Take the time to learn the anatomy of the seeds that you are working with. Trying different methods and tracking your results will help you determine the best method for that species and your seed sources.

2.8.2.1 Mechanical Scarification—The seed coats of large seeds can be filed or nicked using a knife or metal file (Figure 2.17A). Be sure to scarify on the side of the seed away from the embryo. This method is time consuming, requires precision so that the seed coat is scarified without damaging the seed, and can be dangerous if the knife is improperly held.

Rubbing small seeds with sandpaper can be effective for some species, particularly the grasses and sedges, but it is difficult to treat all seeds uniformly. One easy and effective technique is to construct a wooden box (4 inches wide, 6 inches long, and 1 inch deep), line it with 100 grit sandpaper, and then wrap a small block of wood with the same sandpaper. Place the seeds inside the box and rub them with the wood until the desired amount of abrasion is achieved.

Hobby size rock tumblers can be used to scarify hard-coated seeds and avoid the potential damage that can occur with other scarification methods. You can use a rock tumbler two ways: dry tumbling and wet tumbling. Dry tumbling involves placing seeds, coarse carborundum grit (sold by rock tumbler dealers) and pea gravel in the tumbler. The duration of treatment is usually for several hours, but it is an effective and safe way of scarifying seeds of many hard-seeded species. After tumbling, the grit can be separated from the seeds using a fine mesh screen, and the grit can be reused. In the wet tumbling treatment, water is occasionally added to the grit and pea gravel. An additional benefit of wet tumbling is that seeds are moistened and chemical inhibitors are leached out. Wet tumbling has been effective treatment for species such as redstem dogwood and golden currant.

2.8.2.2 Hot Water Scarification—Scarifying seeds with hot water works well for many species with hard seed coats because it provides a rapid, uniform treatment and results can easily be seen within a few hours (Figure 2.17B). Thickness of the seed coat may vary somewhat between sources, so it is a good idea to dissect a few seeds and examine the thickness of seed coats from each seedlot.

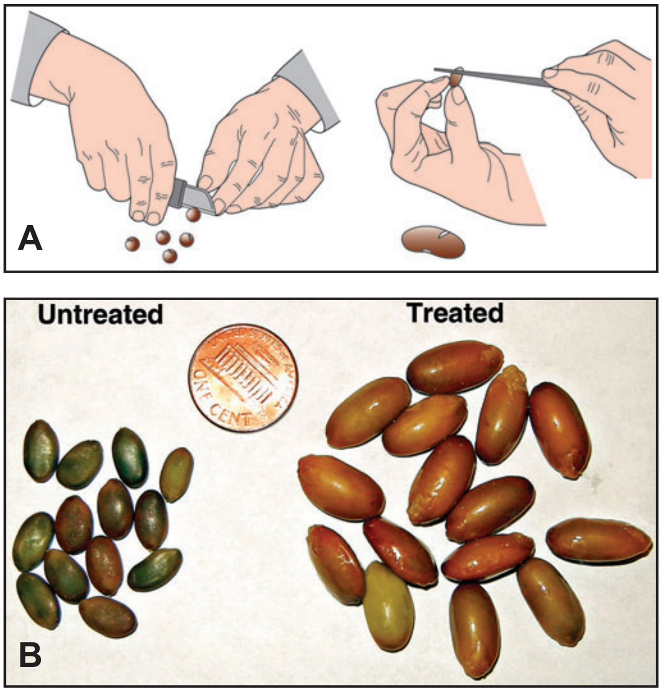

***Figure 2.17**—Large seeds with hard seedcoats can be mechanically scarified with a sharp knife or triangular file (A). Hot water scarification softens the hard seedcoat and greatly speeds germination (B) (courtesy of Greg Morgenson).*

Doing several hot water scarification tests with a small number of seeds will help determine the length of time needed for treatment.

Seeds are added to boiling water for a few seconds and then immediately transferred to a vat of cold water so that they cool quickly to prevent embryo damage. If the seeds have been scarified they will enlarge while they are soaking in the cool water for a day or so. If the seeds have not been properly scarified, they will be the same size of the dry, non-treated seeds. In this case, you will need to re-treat the seedlot. Some species cannot tolerate excessively high temperatures, so you may only want to heat the water to 158 °F or so and monitor your results.

2.9 Premature Germination

Oh no! You're not ready to sow but you just checked your seeds and a few are beginning to sprout. You will need to plant the seeds that have sprouted (see Chapter 4), but you can slow down the germination process with the remaining seeds. Remove the non-sprouted seeds from stratification and gently spread them out to surface dry. Allow the surface of the seed coat to dry until it's dull, not glossy. Put the seeds back into a plastic bag and refrigerate. The reduced moisture content will greatly reduce the germination process.

2.10 Germination Testing

A germination test will tell you how well your filled seeds will sprout (Figure 2.18A). If you have just a few seeds and plan on growing only a few seedlings for fun, a germination test is unnecessary. A germination test will, however, help you use seeds efficiently and grow higher-quality seedlings. For species that require these treatments, germination tests usually start by scarifying and/or stratifying seeds. After stratification, rinse seeds in running water for 12 to 24 hours. If you test non-stratified seeds, rinse them at the same time, but for 24 to 48 hours. Stack paper towels about ⅛-inch thick and moisten them completely. Drain off the excess water by holding towels as shown in Figure 2.16. Put the paper towels into your plastic container and spread seeds over it, maintaining each group. Close the lid and place the container in a location with room temperature and out of direct sunlight. Every 5 days thereafter, count seeds with primary roots at least as long as the seedcoat, and remove them from the test (Figure 2.18B). After 30 days, you can record percent germination. Another value you may obtain is germination energy. Germination energy (also known as germination speed) tells how rapidly

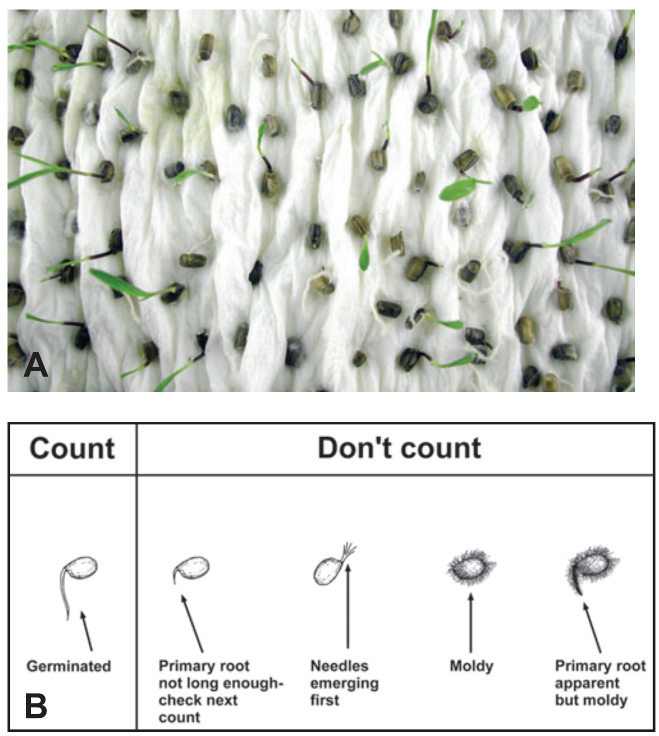

***Figure 2.18**—Germination tests will give you an idea of your seed quality (A), and help determine how many seeds to sow. When checking your germination test, only count seeds that have primary roots as long as the seed coat. Don't count seeds that have leaves emerging instead of roots, or are moldy (B).*

seeds germinate and is usually given in days. Of the total number of seeds to germinate, check to see by what day 50% had sprouted. Ideally, most will germinate in the first 10 to 21 days or sooner. If not, your seeds may need a longer stratification period.

2.11 Additional Reading

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Steinfeld, D.; Archibald, C. 1999. Propagating native grass seed and seedlings. In: Rose, R.; Haase, D.L., eds. Symposium proceedings—Native plants: propagating and planting; 9-10 Dec 1998; Corvallis, OR. Oregon State University, Nursery Technology Cooperative: 32-37.

Chapter 3. Growing Plants From Seeds

You can grow your seedlings two ways: in the ground or in containers. Naturally, both have advantages and disadvantages. In general, seedlings in the ground (called bareroot seedlings) grow slower than seedlings grown in containers, especially when containers are in a greenhouse or sheltered growing area. For the novice, the choice boils down to personal preference, space availability, whether or not you have a greenhouse, and soil quality.

3.1 The Importance of Quality Water

Water is the most important biological factor controlling plant growth, so the quantity and especially the quality of irrigation water are critical to growing native plants. For irrigation purposes, water quality is determined by two factors: 1) the concentration and composition of dissolved minerals often referred to as "soluble salts" or "dissolved salts," and 2) the presence of harmful fungi, weed seeds, algae, and possible pesticide contamination. Groundwater and surface water are the two sources of irrigation water, although surface water from streams, reservoirs, or lakes is more likely to be contaminated with fungal pathogens or weed seeds. Dissolved salts are a more serious problem because there is no inexpensive way to remove them (Figure 3.1). For our purposes, we define a salt as a chemical compound that dissolves in water into positively and negatively charged particles called ions. Using this definition, fertilizer is also a salt. Therefore, salts in the proper concentrations can be beneficial, but too much of any salt can also be harmful. We recommend you have your water tested by a laboratory; water tests are relatively inexpensive and can identify problems before you start growing plants, which can save money in the long run.

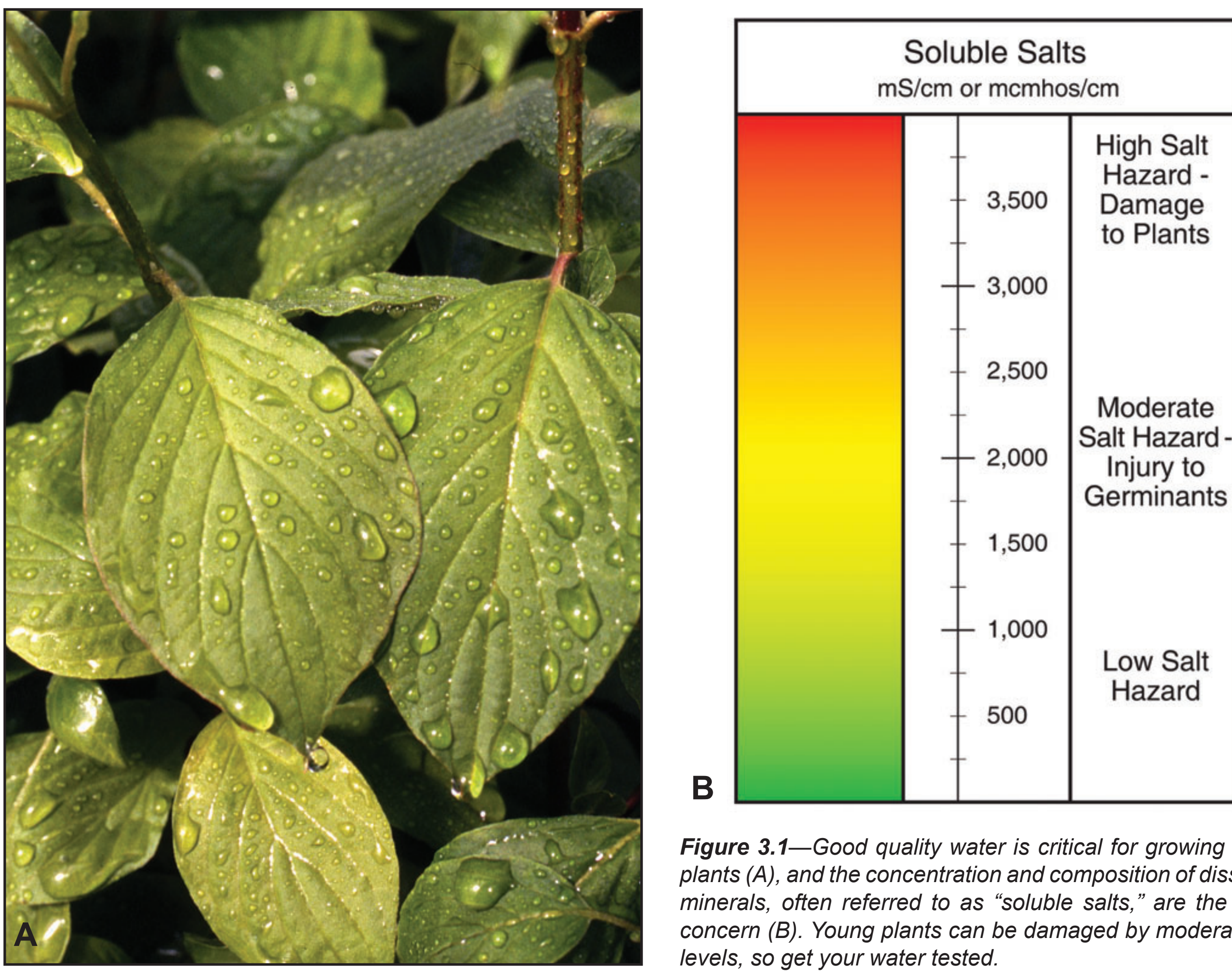


Figure 3.1*—Good quality water is critical for growing native plants (A), and the concentration and composition of dissolved minerals, often referred to as "soluble salts," are the major concern (B). Young plants can be damaged by moderate salt levels, so get your water tested.*

3.2 Growing Bareroot Seedlings

3.2.1 Nursery Site Selection

One of the most important factors in selecting a nursery site is soil texture, which refers to the fineness or coarseness of a soil (Figure 3.2). "Light" or "coarse" soils are predominately sandy, with some finer particles of silt and clay. Light soils have fast water infiltration, drain well, and are easy to work. "Heavy" or "fine" soils are predominately comprised of silts and clays, with just a few coarser sand particles. Heavy soils have slow water infiltration, drain slowly, and get very hard and crack when dry. A good

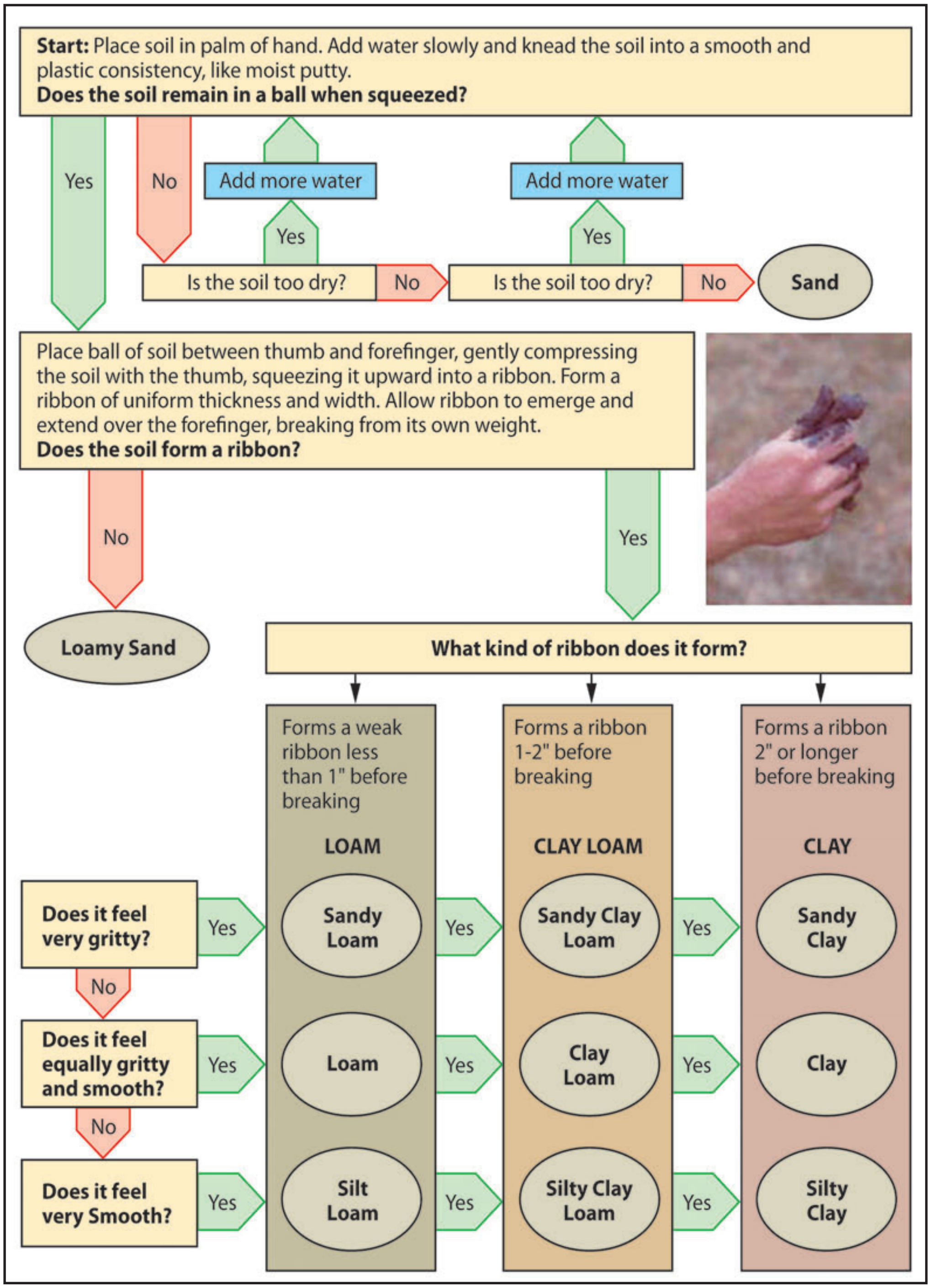


Figure 3.2—*How to determine soil texture by the feel method. Adapted from Colorado State University Extension Publication (GardenNotes #214 at http://www.ext.colostate.edu/mg/gardennotes/214.html (accessed 23 Jan 2012).*

nursery soil for bareroot seedling production has at least 40% sand particles, and no more than 40% silt particles or 25% clay particles (see Figures 3.2 and 3.3A for determining your soil texture). The best soil for growing seedlings is a deep, crumbly, loamy sand, or sandy loam that drains well and maintains a loose structure during prolonged wet weather (Figure 3.3B). Bareroot seedlings must be harvested during winter when they are dormant and soils are wet; removing seedlings from sandy soils causes less damage to fine roots than removing them

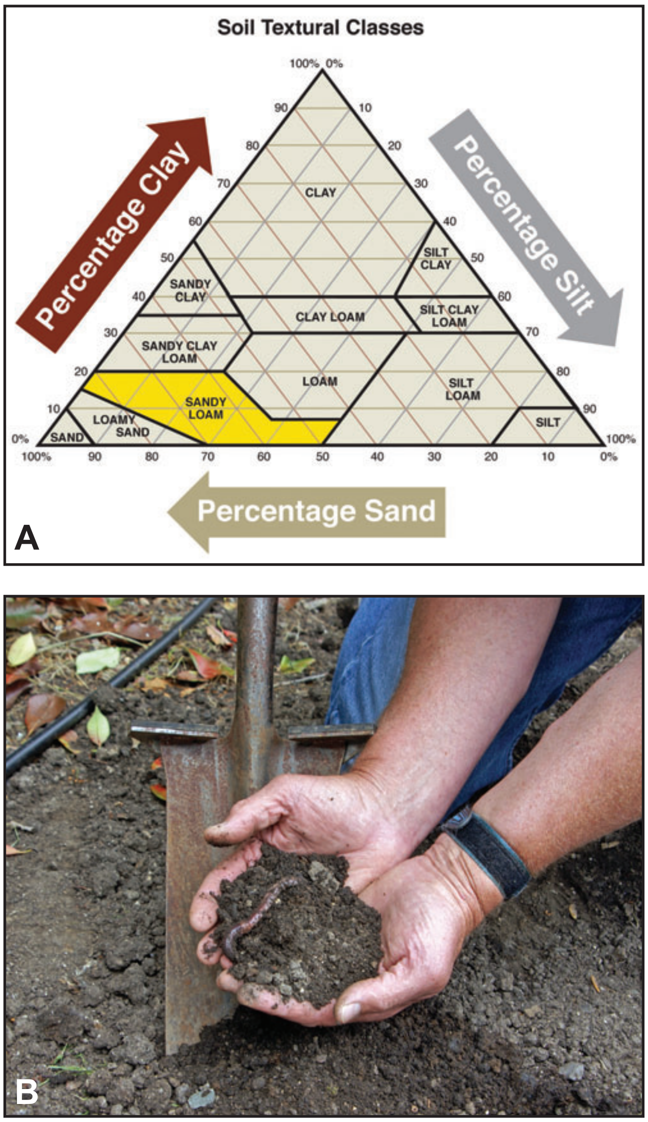


Figure 3.3—Good nursery soils are "light" in texture and sandy loam soils are ideal with high percentages of sand and lower percentages of silt and clay (A). Healthy soils contain earthworms and other beneficial organisms (B).

from heavier soils. Farmers and gardeners use the term "tilth" in describing good soils. Although tilth is hard to describe in words, you can feel it when you are working with a shovel. You should be able to spade a good nursery soil, one with good tilth, and it should break into crumbs, not clods, and be at least a foot deep. Avoid soils with a claypan, hardpan, numerous rocks or bedrock within 18 inches of the surface. The soil should have a pH between 5.0 and 6.0. We'll discuss below what to do with marginal soils on otherwise good sites.

Try to find a gently sloping (1 to 4%) bench, long slope, or ridge top where late spring or early fall frosts are unlikely. In general, a northwestern aspect is better because seedling growth begins later and is less subject to frost damage, and the soil surface dries more slowly, but at high elevations with sufficient water, a southerly aspect is better.

Unfortunately, sandy loam soils are usually associated with river bottoms or other flat areas. Freezing air flows like water from higher slopes down to flat lands at lower elevations, and such areas are known as "frost pockets." Even on sloping ground, a physical obstruction such as the edge of a timber stand or topographical barrier may form an "air dam" and cause a frost pocket effect. Seedlings growing in frost pockets can experience shoot die-back, and may frost heave during winter (the lifting action caused by repeated freezing and thawing of the surface layer of soil).

Low-lying flat areas may also accumulate standing water during prolonged rainy seasons. Waterlogged soil is damaging or fatal to seedlings because of oxygen depletion in the soil or buildup of toxic gases. Poorly drained soils are conducive to several fungi that weaken or kill seedlings. You may be able to correct drainage problems with tile or careful leveling, but the best long-term solution is choosing a well-drained site.

Good nursery sites require full sun, otherwise most seedlings grow weak and spindly. Avoid root zones of adjacent, large trees because they invade seedbeds and deplete soil moisture and nutrients. If you must sow near larger trees, root competition can be controlled by trenching 3-feet deep between the trees and your nursery.

Windbreak trees planted near your nursery should be a different species than crop seedlings because older trees may harbor insects and diseases harmful to nursery seedlings. For example, cottonwoods and aspens are alternate hosts for Douglas-fir needle rusts, and gooseberries (*Ribes* species) should not be grown near white pine because they are an alternate host of a serious disease.

3.2.2 Site Preparation

How big a nursery site will you need? Well, it depends on how many seedlings you plan to grow. Plan on growing about 25 seedlings per square foot using beds 4 feet wide (so you can reach the centers). Therefore, each lineal foot of nursery bed will yield 100 seedlings. For example, if you want to grow 1,000 seedlings, the length of bed required would be 1,000 divided by 100 = 10 feet. So a 4 x 10 foot bed would be sufficient. Plan on adding about 50% more space for walkways between beds.

Your soil should be thoroughly worked at least 12 inches deep the year before sowing. If your site was recently cultivated and is free of heavy sod and weeds, one plowing in fall is sufficient. That plowing should be followed in spring by fine disking and harrowing, rototilling, or spading and raking just before laying out your beds. Just a note about rototilling—do it sparingly and at a low RPM. Rototilling enhances the breakdown of soil organic matter and soil structure, two characteristics of soil beneficial to seedling growth.

If your site hasn't been recently cultivated, deeply plow and grade the soil a full year before establishing beds. Heavy debris like roots, rocks, wood chunks, and other foreign matter should be removed. This should be followed by summer fallowing (repeated cultivation) to break down heavy organic matter and control new growth of grass and weeds. Persistent, deep-rooted plants like blackberries, thistles, bindweed, and quack grasses should be eradicated with herbicides during the early summer growing season (please consult your university extension agent or Natural Resources Conservation Service [NRCS] representative for proper chemicals and application rates; use them only with a great deal of caution for the crop, yourself, and the environment—always read and follow label directions).

If you have an otherwise good site but only marginal soil, you'll have to modify the soil with large quantities of amendments. Either incorporate sandy loam soil or organic matter. We recommend organic material, including peat moss, garden compost, ground and composted leaves, and well-composted manure. Adding organic amendments and/or coarse sand to heavy clay loams will improve drainage, texture, tilth, and fertility. Put the amendment about 6 inches deep on top of the soil (about 2 cubic yards of amendment per 100 square feet of soil to be treated), and then work it into the soil to a depth of 12 inches. Sawdust, a readily available source of organic matter, can be used as an amendment with caution (see Section 3.2.6, Soil Management).

Test your soil for pH, soil acidity, with kits available at garden centers or through gardening catalogs. Soils with pH below 7.0 are considered "acid" while those above 7.0 are considered "basic" (Figure 3.4). A good nursery soil for native plants should have a pH between 5.5 and 6.5. If your soil pH is too high (more than 6.0), add sulfur to bring it down. Conversely, if the soil is too acidic (less than 5.0), add lime to increase pH. The actual amounts of sulfur or lime needed to achieve the desired change in pH vary with the amounts of sand, silt, and clay in your soil. You'll need a more complete soil test and some expert advice in order to apply the correct amounts. Soils can usually be tested at universities or other testing laboratories and test results often include sulfur and lime recommendations. Ask your university extension agent or NRCS representative for nearby laboratories.

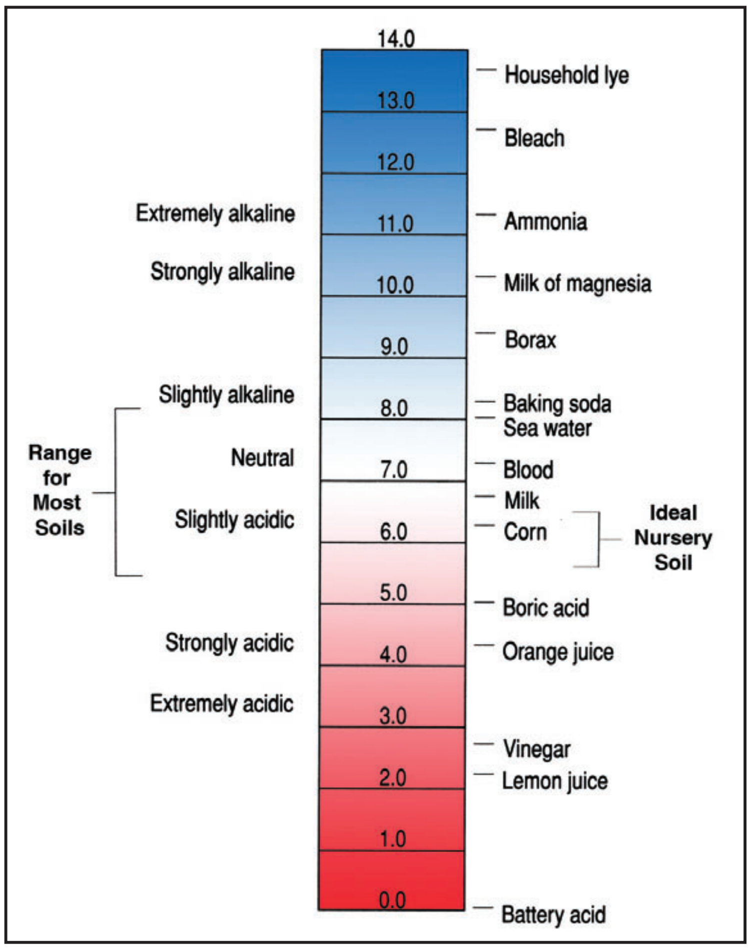


Figure 3.4*—The ideal nursery soil has a pH of from 5.5 to 6.5, so have your soil tested.*

3.2.3 How to Grow Seedlings

Generally, it takes 1 to 2 years to grow bareroot, woody, native plant seedlings large enough for planting, but some slow-growing species like bristlecone pine may take 3 or 4 years. Most conifer seedlings are grown 2 years in the same nursery bed, and professional nursery managers call them 2+0 seedlings (2 years in the same bed without any years in a transplant bed). Huskier seedlings can be grown by transplanting 2+0s into another bed for an additional year. These would be called 2+1s. Many eastern deciduous trees and shrubs and conifers of the southeastern U.S. can be grown in a single year, whereas conifer seedlings at more northerly latitudes and in the western U.S. require 2 years. For the sake of discussion, let's assume you'll be growing 2+0 seedlings.

3.2.3.1 Fertilizers: Organic vs. Synthetic—Plants require 13 nutrients to sustain healthy growth (Figure 3.5); sometimes these are referred to as minerals or elements. Six of these nutrients are called macronutrients because the plant requires them in greater amounts than the other seven, called micronutrients, which are required only in very small amounts. Of the six macronutrients, three are considered the primary, or most important, nutrients for healthy plant growth and are commonly supplied through fertilizers: nitrogen (N), phosphorus (P), and potassium (K). Nitrogen is critical for aboveground plant growth, especially new shoots, needles, and buds. Plants lacking sufficient N grow slowly or are stunted and have pale green or yellow needles. In young seedlings, P is important for root growth and bud development. Potassium is necessary for root growth, efficient water use by the plant, and improved disease resistance. The secondary macronutrients and micronutrients are normally present in fertile soil or supplied through irrigation water. Soil tests are necessary to diagnose nutrient deficiencies.

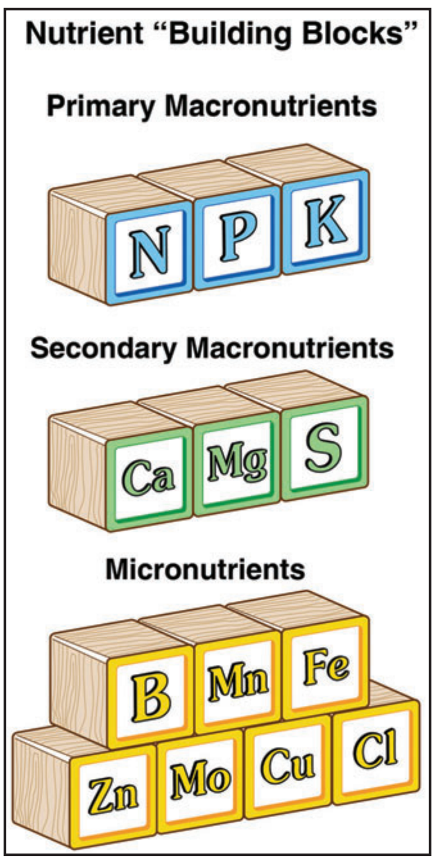


***Figure 3.5**—Plants need 13 nutrients for healthy growth, especially the three primary macronutrients found in most fertilizers: nitrogen, phosphorus, and potassium.*

Nutrients can be supplied to your plants through either organic fertilizers (for example: manure, compost, kelp) or synthetic fertilizers that are available at garden centers or farm chemical suppliers. To a native plant seedling, a molecule of nitrate nitrogen is the same whether it comes out of a cow or out of a bag purchased at a garden center. In general, organic fertilizers have low percentages of N:P:K; N ranges from 0.5 to 1.5% in manure and 2 to 4% in composts, whereas synthetic fertilizers have much higher concentrations of N, ranging up to 33% or more. Because organic fertilizers like manure and compost are associated with lots of decomposing organic matter and microorganisms (bacteria and fungi), and organic matter is important to healthy soil, one benefit of using organic fertilizers is the organic matter and microorganism additions. Because synthetic fertilizers don't supply it, organic material should be added to nursery soil.

Fertilizer can be applied to seedlings two ways: incorporated into the soil or applied over the crop (top-dressing). The application technique depends on the solubility of the fertilizer. Nitrogen and K fertilizers are soluble so they can be top dressed and your irrigation water will carry them down to the roots. However, P is not soluble so it must be incorporated into the root zone before sowing the crop.

How much fertilizer should you apply? Too much fertilizer is a common mistake. It's better to put slightly less fertilizer on a crop rather than too much. Remember that the label on any fertilizer always shows the percentages of N, P, and K, and always in this order: N:P:K. (Well, that's not completely true, and this can be made really complicated, which we show in Appendix 6.2.) Here's the easiest approach that should work for most situations. Using a whirlybird type spreader or a drop-type spreader, apply fertilizer evenly across the bed. Before sowing, incorporate 2.5 pounds of 0:20:0 (calcium superphosphate) into every 100 square feet of nursery bed. Use a spade or rototiller to work the fertilizer into the ground.

Once seedlings are growing, top dress seedlings (apply fertilizer over the tops of seedlings) at a rate of 7 ounces of 10:10:10 (N:P:K) per 100 square feet of nursery bed three times during summer (mid-June, early July, mid-July) and again in mid to late September. The mid-June application should be avoided if damping-off is a problem. Water immediately after applying the fertilizer to wash it off foliage and move it into the ground where it's available to roots.

If you care to be more intense with your fertilization program, the result being larger seedlings in less time, check the appendices for necessary formulas for determining the amounts of different fertilizers to apply. Some examples are provided for fertilizers to use on acidic soils with pH under 6.0 (Appendix 6.2.1), basic soils with pH more than 6.0 (Appendix 6.2.2), or if you want to use a strict organic fertilization program (Appendix 6.2.3).

3.2.3.2 Sowing and Germination—After incorporating fertilizer and/or adjusting soil pH, make sure your nursery bed is smooth and level. Professionals usually make beds that are 4 feet wide and raised 3 to 6 inches, but you can make raised beds of any size using redwood or cedar boards for siding. Raising the beds promotes drainage and soil-warming, which encourages faster germination and root growth; saturated soil stays cooler and promotes damping-off and root diseases.

You may sow either in rows or by broadcasting. Either way, the idea is to get enough seedlings per square foot to achieve good seedling growth without causing too much competition between seedlings. If you broadcast sow (Figure 3.6A), spread three-fourths of the seeds evenly over the nursery bed. Mixing a little baby powder (talc) on the seeds, especially when they are small, makes them easier to handle and easier to see on the ground. Use remaining seeds to fill any "holes." Gently press seeds into the soil with a board and cover with a light layer of mulch. When properly done, broadcast sowing results in even-spaced seedlings that have room to grow (Figure 3.6B).

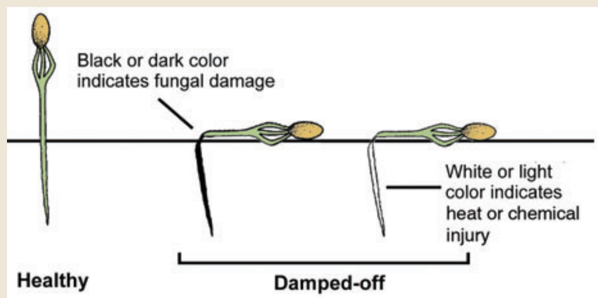
Sowing seedlings in rows or "drills" (Figure 3.6C) may take more time, especially if you manage the within-row distance between seeds, but it's worth it —you'll spend less time weeding, root pruning, and harvesting, and you'll grow more uniform, nicer-looking, healthier seedlings. Rows are typically about 6 inches apart for most species. Probably the easiest way to sow in rows is by using a marking board (Figure 3.6C). Based on your germination percentage, sow enough seeds so you'll have about 25 seedlings per square foot after germination is complete (Table 3.1). If you plan to transplant the seedlings after the first growing season, you may use densities up to 50 seedlings per square foot. A handy tool, especially for smaller seeds, is a vibrating hand seeder, available in garden centers and through mail-order nursery catalogs. If you are sowing a lot of seeds, you should consider a walk-behind precision garden seeder like the Cole Planet Junior (Figure 3.6D), which can handle many sizes of seeds.

Regardless of when or how seeds were sown, most species should be covered by a thin (1⁄8- to 1⁄4-inch-thick) mulch of pine needles, sawdust, fine-screened bark (1⁄8-inch diameter), sand, very fine gravel, or screened garden compost (only use the fines). Mulch should be no more than twice the thickness of the seed, and will keep seeds from drying out. Sowing seeds too deep is a common and serious mistake (Figure 3.7). Seeds that should not be covered include those that are very small (for example, sagebrush) or require light for germination (for example, birch).

Seeds may also be sown in fall, allowing them to stratify under natural conditions. Fall sowing can be particularly advantageous for species that required some warm, moist treatment before stratification (see Appendix 6.1). Fall-sown seeds must be protected from predators, especially mice (see below), and from drastic variations in temperature. To

Damping-off

Germinating seeds and young seedlings are very susceptible to diseases, which are collectively known as "damping-off." Several factors including fungi, chemicals, or high-temperatures can cause the stem tissue to collapse at the ground surface. When fungi cause damping-off, the roots are dark and decayed, discolored roots; however, when seedlings damp-off because of chemical damage or heat injury, the root remains white. Damping-off is most serious on seeds with low germination percentages, seeds germinating during periods of cold and wet weather, and when seedbeds are watered too much. Damping-off can be minimized by using clean seeds and well-drained soil. If damping-off is particularly bad, refrain from using any nitrogen fertilizer because this worsens the disease. Remove and discard dead and dying seedlings immediately to help prevent infection of other seedlings.



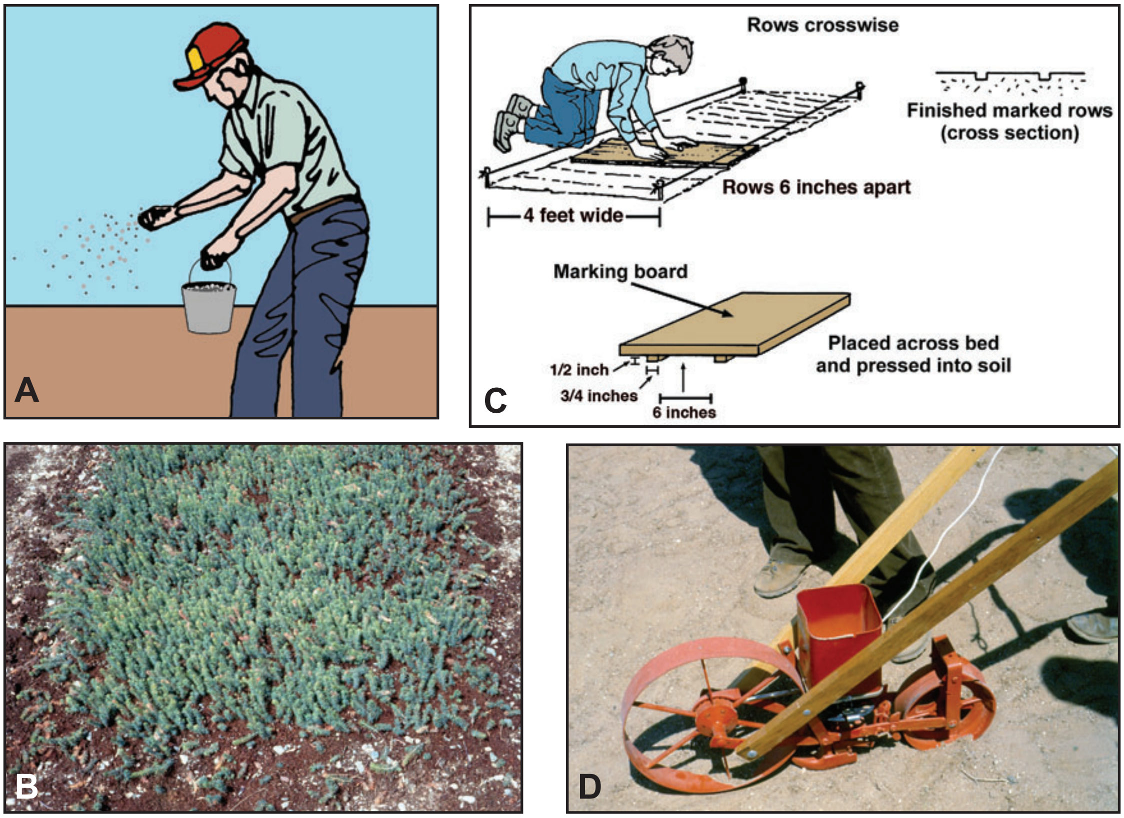


Figure 3.6*—Broadcast sowing can be done by hand (A) or with a whirly bird seeder. The biggest problem with broadcast sowing is controlling plant density – these seedlings are much too dense (B). Row or "drill" sowing can be done by hand using a marking board (C) or a walk-behind seeder like the Cole Planet Junior (D) adapted from Raising Forest Tree Seedlings at Home, Pacific Northwest Cooperative Extension Publication PNW 96, 1981. 11 p..*

Table 3.1—For the germination percentage of your seedlot, and assuming you'll sow 10% extra for losses and that your rows are 6 inches apart, this table provides an estimate of how many seeds to sow per square foot and how far apart those seeds should be in each row.

Germination percentage	Seeds to sow per square foot	Seeds to sow assuming a 10% loss during the first year	Inches between seeds in rows
80 to 100	32 to 25	35 to 27	1 to 1¼
60 to 80	42 to 32	46 to 35	¾ to 1
40 to 60	62 to 42	68 to 46	½ to ¾
20 to 40	125 to 62	138 to 68	¼ to ½

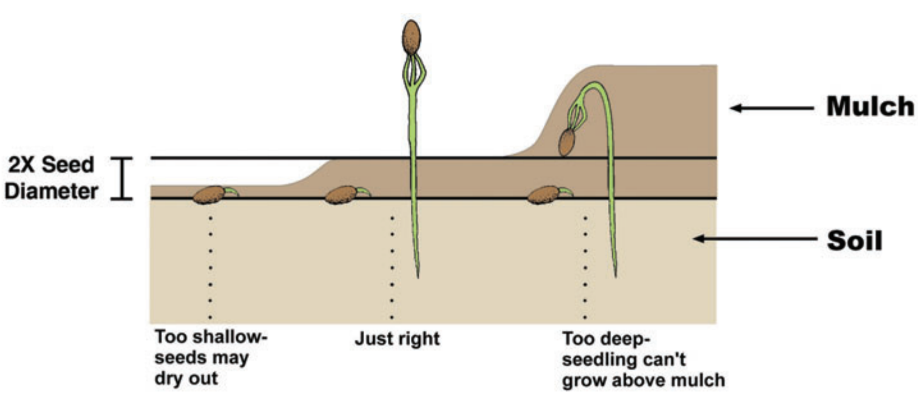


Figure 3.7*—Sowing at the proper depth is critical and varies with seed size. Seeds that are sown too shallow will dry out or be eaten by birds or rodents, but seeds sown too deep will not have the energy to push to the surface.*

protect seeds from drying and frost heaving, fall sowings will need to be covered with a thick mulch. A 2-inch-thick layer of straw works well, but it must be removed in early spring to allow germination.

Newly sown seeds should be protected from pests, especially mice and birds. Covering seedbeds with mesh, elevated 6 to 12 inches above the soil but extending to the soil around the edges, will minimize losses to birds. If the mesh is small enough, this will also exclude mice and help prevent wind and water erosion. Keep the area near your seedbeds free of weeds and debris to eliminate hiding places for mice and other pests.

Water sparingly during germination and emergence—"moist, but not wet" is a good rule of thumb. A few light mistings on sunny days are better than one thorough watering. Remember, sprouting seeds are very susceptible to damping-off, which is a serious problem when seedbeds are overwatered.

3.2.3.3 Young Seedlings: Establishing Your Crop—About a month after germination, check your seedling densities. If you have more than 40 seedlings per square foot and don't want to transplant after the first growing season, consider thinning seedlings to 25 to 30 per square foot to ensure healthy growth. Discard thinned seedlings the same way you discard diseased seedlings—burn or bury them.

Remove weeds diligently by pulling or apply herbicides before they grow large and interfere with growth of your seedlings (Figure 3.8A). Use herbicides with a great deal of caution for the crop, yourself, and the environment—always read the label. Make sure you control weeds in and around your nursery beds, too. Good weed control efforts on the rest of your property will diminish the number of weed seeds sprouting in your nursery.

As seedlings grow, maintain a good mulch layer (¼- to ½-inch thick). Mulch reduces watering needs, keeps soil cool, prevents soil from splashing onto your seedlings, and helps retard weed growth (Figures 3.8B). Young seedlings can be damaged by high soil surface temperatures so, on very warm days, you may need to water to cool the seedbeds. As the stems of your plants grow thicker, they can tolerate higher temperature so this type of watering won't be needed.

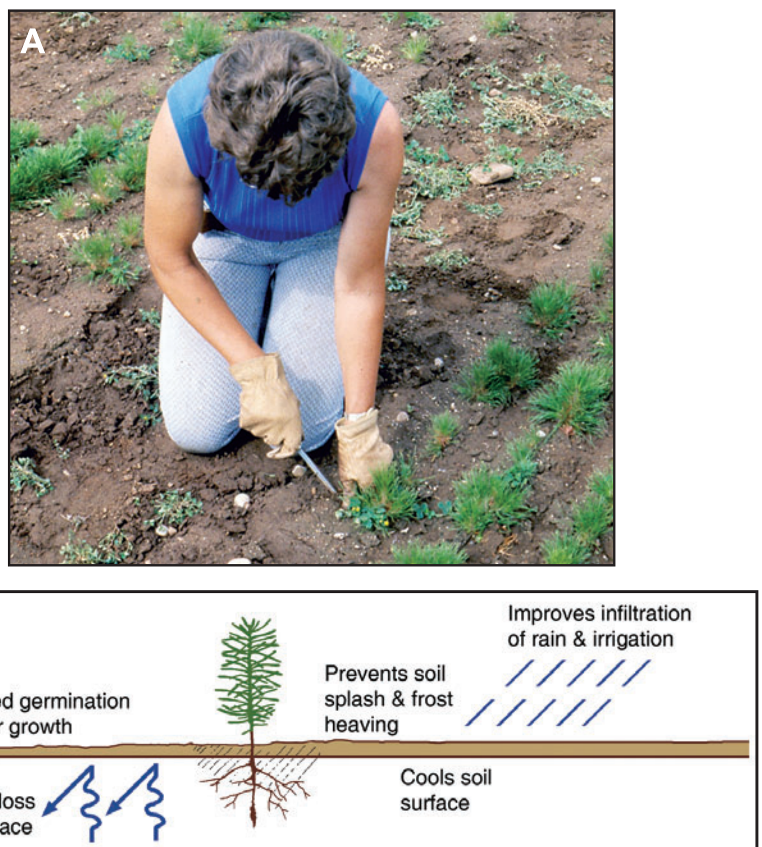


Figure 3.8—Weeds should be controlled by hand (A) or with herbicides, and it's much easier when they are small. Maintaining a good seedbed mulch has many benefits (B).

Some native plants will grow much better if inoculated with beneficial microorganisms, such as mycorrhizal fungi (Figure 3.9A) or *Rhizobium* bacteria (Figure 3.9B). You can inoculate with soil or duff that you collect from beneath the same plant species in the field, or buy commercial inoculum. Many beneficial microorganisms are specific to one type of plant so do some research online before purchasing any product.

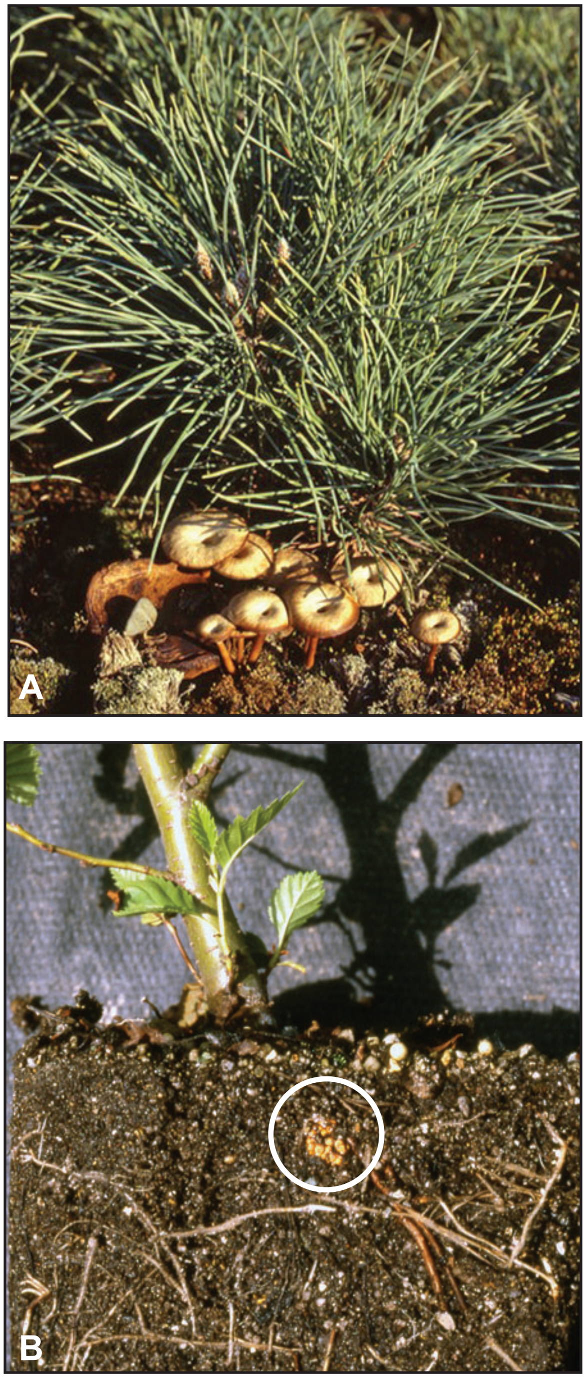


Figure 3.9*—Beneficial microorganisms such as mycorrhizal fungi (A) and* Rhizobium *bacteria (B) can improve the growth of some native plants.*

3.2.3.4 Watering—Once seeds germinate, the basic philosophy for watering seedlings is to water deeply but infrequently (Figure 3.10A). Be sure to wet the entire root zone during each watering. How long you need to water will depend on how much water is going through your irrigation system, your soil, outside temperature and wind, and whether or not you are using a mulch. Keep your nursery soil evenly moist—use a small hand trowel to see if the soil is dry or moist. Irrigate early in the day to allow seedling foliage to dry.

You have a variety of options for watering seedlings, from low-tech to high-tech. The easiest technique is using a watering can or a garden hose with a soft-spray nozzle. This option is fine if you have a small area. Larger areas will probably require a less labor-intensive watering system. An oscillating yard sprinkler hooked up to a garden hose works well, provided you check its output over the entire nursery bed, making sure all portions receive adequate amounts of water. For larger nursery areas, the next level of sophistication would be a fixed irrigation line with systematically spaced nozzles. Such a system will provide a more even irrigation, resulting in more uniform seedlings and probably less wasted water. Fixed-line systems can be placed in exact locations and put on timers to use water most efficiently.

Check the output from any sprinkler system by systematically placing small jars, plastic cups, or cans throughout your bed (Figure 3.10B). Run the sprinkler system for a known time, and then measure how much water is in each collection vessel. Once you know how long the sprinkler must run to achieve adequate watering, you can put the system on a timer. Some variability across the nursery bed is inevitable, but make sure the minimum amount of water delivered entirely wets the root zone. Unfortunately, sprinklers "waste" a lot of water due to evaporation from plants and runoff so water early in the morning before it gets too hot and windy.

Drip irrigation lines can be laid along rows of seedlings in small seedbeds (Figure 3.10C), or individual emitters or drip rings around large transplants. Drip systems are very efficient as little water is lost to evaporation (especially if covered with mulch), but you'll have to water for a longer period of time due to the slower water application rates.

3.2.3.5 Root Pruning—Root pruning promotes a fibrous root system and makes harvesting seedlings easier on you and the seedlings. Remember, you can only root prune efficiently if you sowed in rows—it's nearly impossible to root prune broadcast sown seedlings. If you're growing 2+0 seedlings, they need to be undercut at a depth of 5 to 6 inches during fall of the first growing season. The easiest way to do this is to use a sharp tile spade or shovel

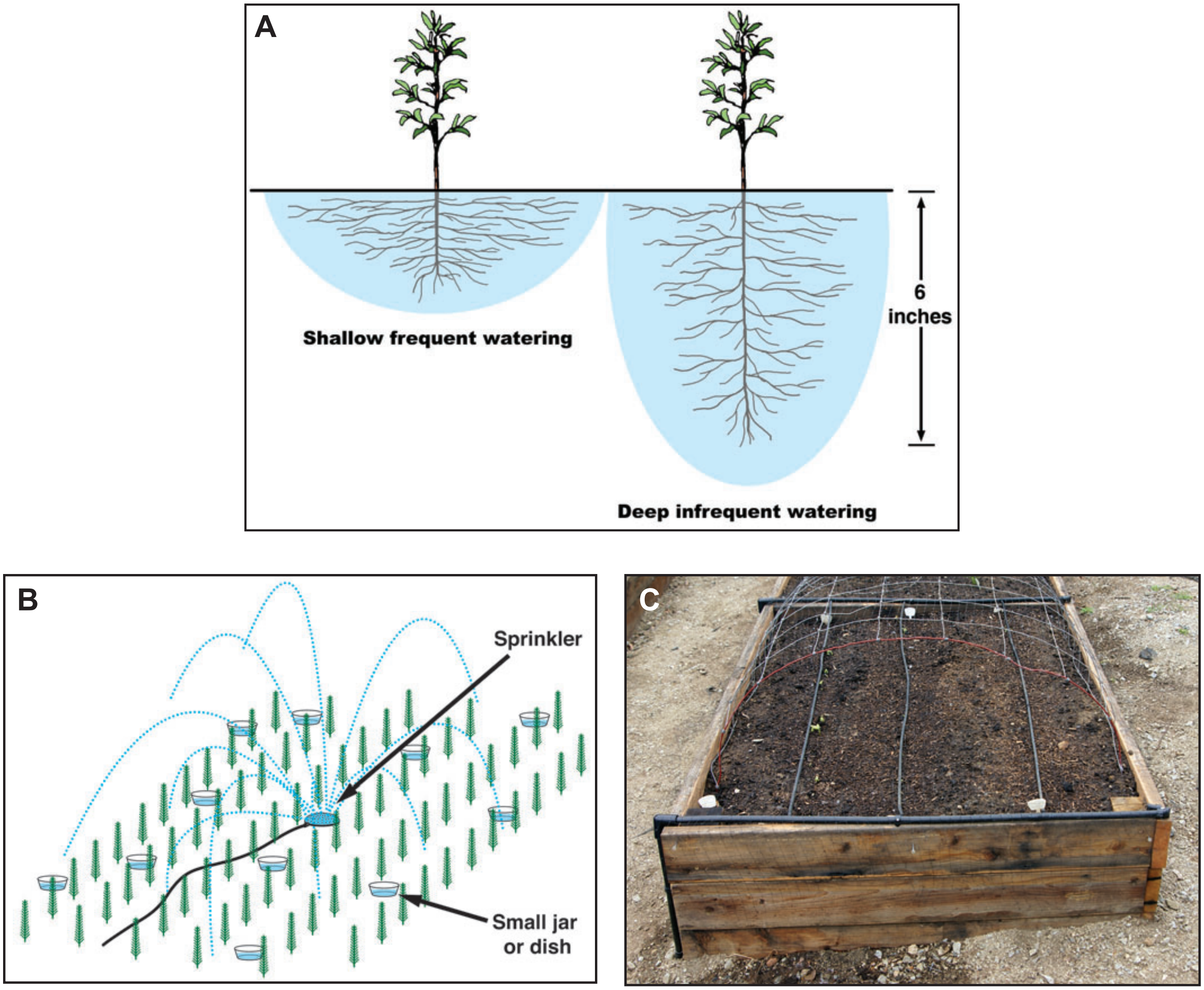


***Figure 3.10**—Water is the most important chemical for growing native plants. Deep, infrequent irrigations promotes a strong, well-developed root system (A). Check your soil to determine when irrigation is necessary and, if using a sprinkler system, check water distribution with a grid of small cans or jars (B). Drip irrigation lines are an efficient way to irrigate bareroot seedbeds (C).*

and slice in on an angle under the rows of seedlings (Figure 3.11A). You may have to make angle cuts from both directions to ensure seedlings are fully undercut. During the second growing season, you'll want to prune the lateral roots 2 or 3 times, first in late spring and the last time in late summer (Figure 3.11B). This cutting procedure keeps roots of seedlings in one row from intertwining with roots of seedlings in another row—a real nightmare to untangle when you dig seedlings for planting. Use your sharp tile spade or shovel and slice vertically halfway between rows, and an equal distance outside the outer row. Schedule root pruning so seedlings are watered and fertilized after the treatment. Transplants should be root-pruned with the same timing and frequency of 2+0s.

3.2.4 Lifting, Handling, and Storage

Nursery managers call the process of digging seedlings out of nursery beds "lifting" or "harvesting." Harvesting should be done when seedlings are dormant, either late fall, winter, or very early spring before new growth starts. Dormant seedlings handle stresses of lifting, storage, and planting better than non-dormant stock—the result being

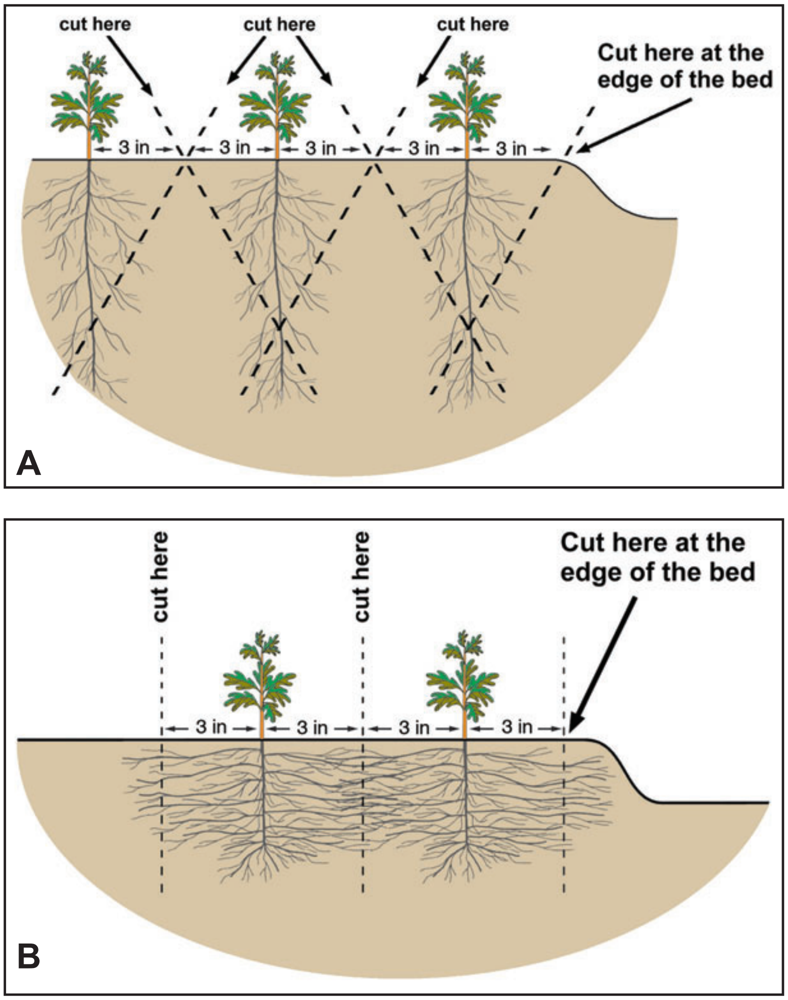


Figure 3.11*—Root pruning with a sharp spade or tile shovel during the first growing season helps develop a more fibrous root system (A). Vertical pruning of larger plants (B) creates moisture stress, which slows height growth.*

better outplanting survival and growth. Using a garden fork, seedlings should be gently dug from the ground, the soil gently removed from their roots while preserving the fine roots (Figure 3.12A), and seedlings gently put into boxes, plastic tubs, or buckets (Figure 3.12B). Gentle handling is the key. Always keep the root system moist by wrapping roots in wet burlap or covering them with moistened wood shavings or chips. Keep harvested seedlings out of the sun and wind. If you harvest in the fall for spring planting, wrap seedling roots to keep them moist, enclose seedlings in plastic bags to prevent desiccation, and keep them cool (32 to 36 °F). Check often for mold. Storage molds usually begin developing on dead foliage. Therefore, be diligent when you put seedlings into storage and remove as much dead foliage as possible. Storing seedlings in an upright position also seems to help reduce mold problems. Remove moldy seedlings as soon as they are evident.

3.2.5 Transplanting

Typically, plant density in a transplant bed is much less than in a seedbed, about 10 seedlings per square foot (spaced 6 inches by 6 inches apart). Because they are planted at wider spacing (Figure 3.13A), transplants grow faster and develop better stem diameter (Figure 3.13B) and roots. When transplanting seedlings, be sure to place the roots in a vertical plane without any twisting or kinking (Figure 3.13C). The roots of improperly transplanted seedlings become deformed, which seriously decreases plant quality. Although plants can be transplanted almost any time except when they are actively growing, transplanting during the fall or early spring is recommended. This reduces transplant shock because plants are more hardy and weather conditions more favorable. Transplants are cultured much the same way as seedlings but increased growth rates will require more irrigation and fertilizer.

3.2.6 Soil Management

Between crops, add amendments to maintain healthy soil and good tilth. Additions of organic matter improve tilth, reduce puddling, increase water infiltration, insulate soil, improve soil structure, promote better root growth, improve soil aeration, make working the soil easier, and help suppress root diseases. Adding organic matter is necessary because soil microorganisms are constantly decomposing it as a food source. Good green cover crops include canola, kale, ryegrass, and buckwheat. Avoid clovers or be prepared to do a lot of weeding of these overzealous seed producers. Clovers also tend to promote root disease. Cover crops should be cut and worked in while green. Other good organic amendments include compost (Figure 3.14), manure, straw, fine-screened bark, shredded leaves, and peat. Use 1 to 1.5 cubic yards of amendment per 100 square feet of nursery bed (a layer about 3 to 4 inches deep), and work it in to a depth of 6 to 8 inches. With amendments like fresh sawdust, straw, leaves, bark, and fresh manure, you should add extra N at a rate of 5 to 10 pounds per ton of amendment. Otherwise, soil microorganisms that decompose the amendments will use all available nitrogen in the soil, leaving little available for your seedlings. Soil amendments and cover cropping are just good farming practices, and a wealth of good information can be found online.

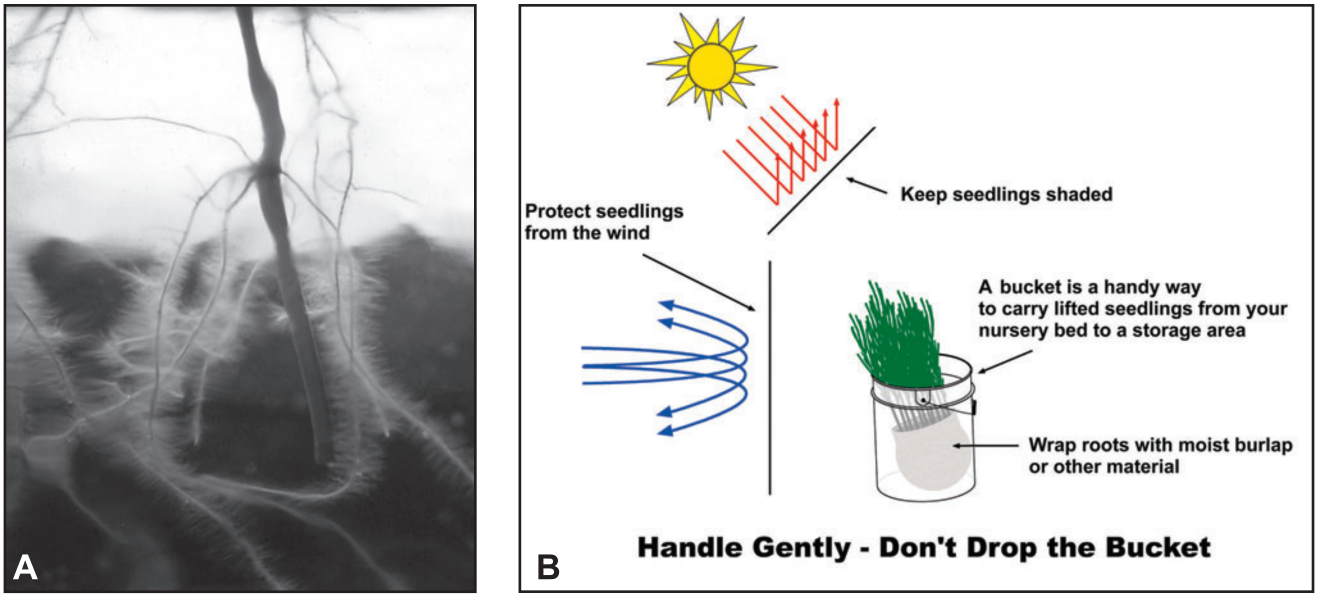


Figure 3.12—*Harvesting, or "lifting" nursery stock, must be done carefully to minimize injury to fine roots (A). After removing them from the seedbed, wrap roots in wet burlap and place bundles of plants in a bucket out of the sun and protected from wind (B).*

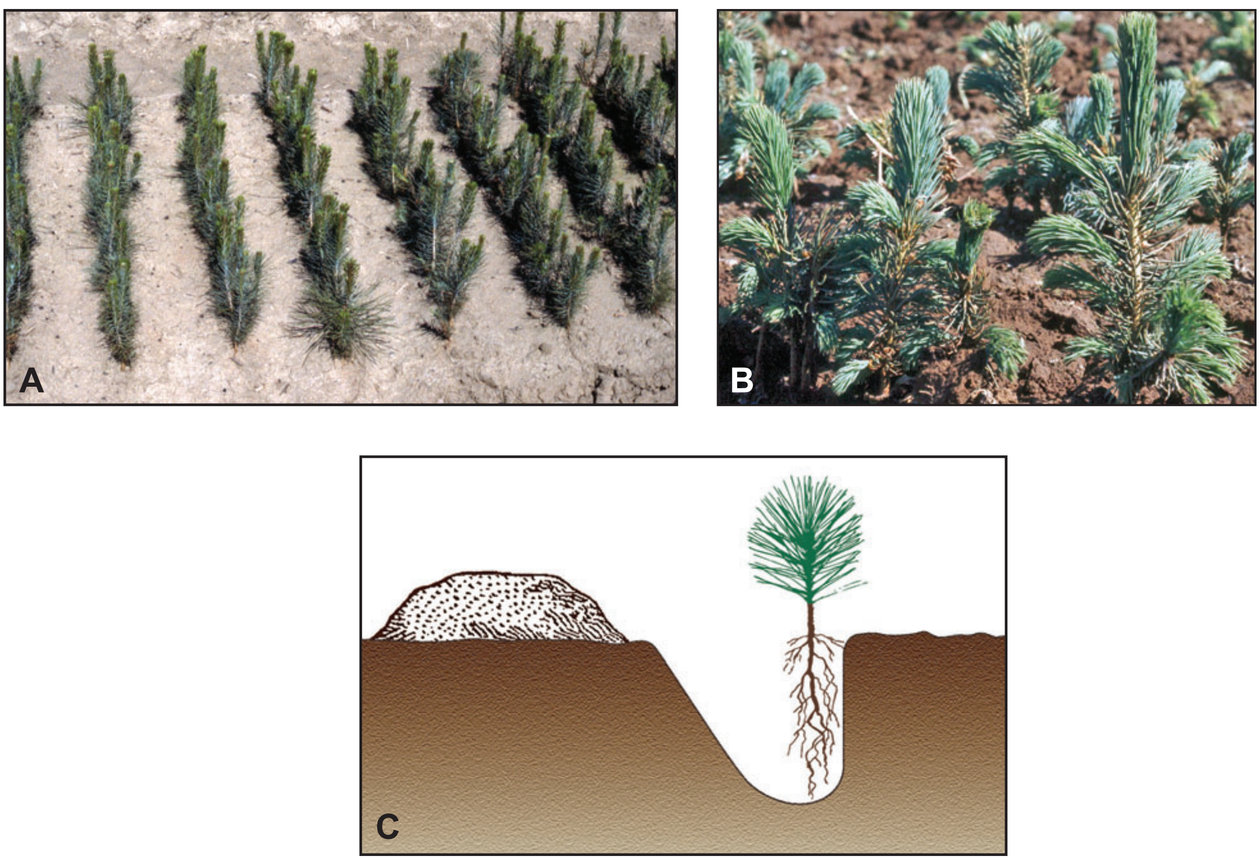


Figure 3.13—*Transplanting seedlings increases their growing space (A), which produces plants with larger stem diameter and more fibrous roots (B). When transplanting, it is critically important to orient the roots vertically (C) to prevent deformation.*

__Figure 3.14__—Organic matter, like this mushroom compost, is the ideal amendment to improve the productivity of nursery soils.

3.3 Growing Container Seedlings

Seedlings can be grown in containers in a variety of propagation environments where growth limiting factors, such as temperature, water, and fertilizer, are controlled. One big advantage of container plants is that you can grow them larger in less time than bareroot stock. However, because container plants have much less moisture reserves, you can kill them a lot faster too!

3.3.1 The Propagation Environment

The basic concept is to create an environment where as many of the environmental factors that control plant growth can be modified (see Section 1.1, Factors That Limit Growth). Professional growers constantly adjust temperature, moisture, fertilizer, humidity, and sometimes even sunlight to keep their crops growing in particular ways to produce seedlings of the highest quality. Environmental conditions and cultural procedures in your set-up will probably be less sophisticated than commercial nurseries, and that's okay. Growing native plants is always a balance between ideal conditions and what you can actually afford.

The simplest propagation environment is an open compound where container seedlings are grown outside in an area with plenty of sunlight but protected from the wind (Figure 3.15A). It's possible to grow a few seedlings in a sunny window or under grow lights (Figure 3.15B), but, as we'll discuss later, native plants need to acclimatized to the outside environment. Plastic-covered cold-frames (Figure 3.15C), hobby-sized greenhouses (Figure 3.15D), and similar structures work well. A good structure will allow air circulation on sunny days, block precipitation, and provide good light transmission. One problem with greenhouses is that they heat-up rapidly so adequate cooling requires an investment into controllers and constant monitoring.

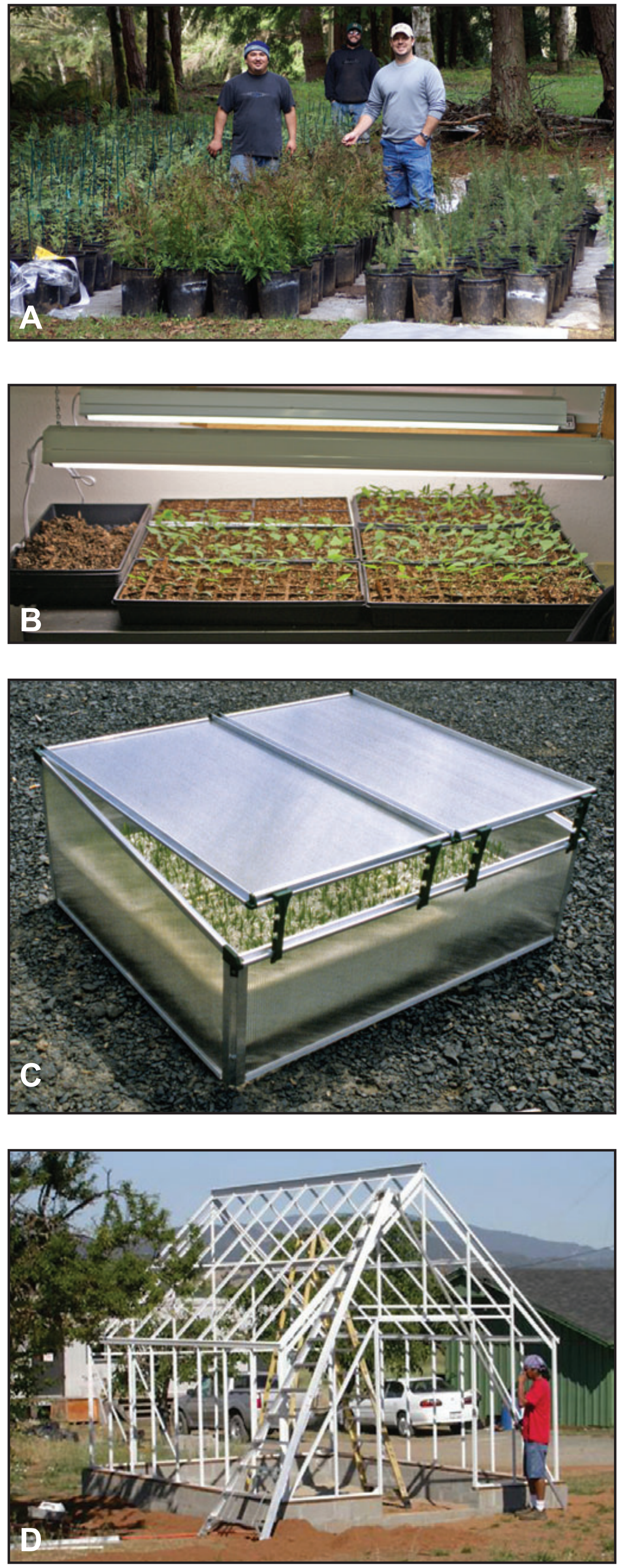


__Figure 3.15__—Propagation environments can vary from open compound (A) to grow lights (B), to cold frames (C), or hobby greenhouses (D).

3.3.1.1 Growing Media—Garden soils are generally too heavy and lack sufficient pore space to grow a good container seedling, which is why professional nursery managers use soilless potting mixes ("growing media"). Many popular growing media use Sphagnum peat moss as the major component because of its high water-holding capacity and ability to hold nutrients. Because peat moss holds a lot of water, however, it is often mixed with other components, such as perlite, pumice, or vermiculite to increase aeration within the container. Be careful of off-the-shelf mixes often sold in garden centers or chain stores; sometimes these mixes are just floor sweepings after companies package their "professional" grade mixes and contain too many "fine" particles that reduce aeration and hamper seedling growth.

3.3.1.2 Containers—Professional growers use a variety of specialized containers. Common, suitable containers have drainage holes in the bottom and vertical ribs on the sides to prevent root spiraling (Figure 3.16), which is a serious problem with most woody plants. Current nursery jargon for containers can be somewhat confusing. For the scope of this booklet, an individual container in which the seedling grows will be called a "container" and the aggregation of "containers" (what holds the containers together) will be called a "block."

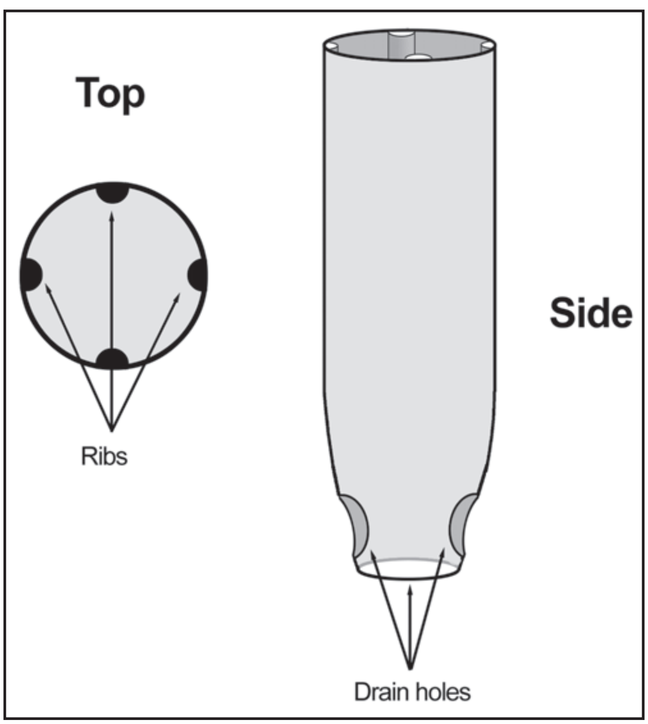


***Figure 3.16**—Good containers for growing native plants have ribs or slits in the sides to keep roots from spiraling, and drain holes in the bottom.*

Hard-sided plastic containers come in a variety of sizes and shapes, and any of them will work well, provided they have adequate drainage holes at the bottom, and ribs or angular construction (not round in cross section) to keep roots from spiraling. This requirement rules out using nearly all containers used to grow annual flowers or vegetables and found at most garden centers, including pre-formed peat pots. Some of the newer containers have slits cut in the sides or copper coatings to prevent root spiraling. When seedling roots touch the copper, the growing tip is stunted, causing the root to branch. The result is a more fibrous root system and better root growth all along the sides of the root plug.

Two good container types for beginners are flexible plastic cells held in hard plastic racks such as the Ray Leach Cone-tainer™ (Figure 3.17A) or the Deepot™ (Figure 3.17B). Both containers come in several sizes. The main advantage of these single cell containers is that cells can be moved around and consolidated—empty containers can be removed and replaced with containers with seedlings, which saves space. This feature can be especially important when growing species with poor or slow germination, like many native woody plants. Blank containers provide breeding places for nuisance insects like fungus gnats, that when present in sufficient quantities, can damage seedlings. Also, seedlings will generally grow more uniformly if empty containers are removed. If you only plan to grow a few crops, these containers are a good choice.

Another good option for beginning growers is peat pellets, such as Jiffy pellets. Peat pellets are shipped and stored as hard, flat disks of peat moss covered by plastic mesh. When watered, the discs expand vertically (Figure 3.17C). These also come in a variety of sizes and have blocks to hold individual pellets (Figure 3.17D). Don't confuse them with peat pots, which are smooth-sided and will allow roots to circle. Like single cell containers, peat pellets can be consolidated. One advantage is that when you get ready to plant your seedlings, you plant the whole peat-pellet as well, without the bother of empty containers to clean before the next crop. Also, roots will grow out the sides of peat pellets, so when outplanted, the root system often takes on a more natural looking shape than seedlings grown in hard-sided containers that lack a copper coating. Another advantage is that the containers need not be cleaned between crops, and they are very economical if you plan on growing only a few crops. The downside of this feature, however, is that you may have to prune the roots between peat pellets every month or so to keep the seedling roots from intertwining, although the newer style blocks that hold the pellets are designed to reduce this problem, and they can dry out rapidly in arid conditions.

Figure 3.17*—It's best to use specialized containers for growing native plants such as the Ray Leach Cone-tainer™ (A), the Deepot™ (B), or Jiffy™ pellets that expand when irrigated (C & D).*

3.3.1.2.1 Filling Containers—When filling, it's important to put a uniform amount of growing medium in each container and tamp it down firmly—don't compact it. If containers are filled with varying amounts or density of growing medium, seedlings will also vary in size. Overcompacted growing medium restricts root growth, reduces shoot growth, and disrupts water drainage, all of which increase the susceptibility of your seedlings to root diseases.

Spread growing medium evenly over the tops of containers, and gently tap the block a time or two on the table or ground to allow settling. Gently dropping it from a height of 6 inches onto a concrete floor works well. Then, topdress growing medium over the containers and tap the block once again. Next, take a hand brush and sweep extra medium out of the containers until the surface is about ¼ inch below the top of the container (deeper for larger seeds). This space will be needed to sow your seeds and add some mulch.

If you are going to sow seeds in the same spot as you plan to grow the seedlings, go ahead and water your medium until water is dripping out the bottoms of the containers. If you need to carry containers from where you plan to sow them to where you plan to grow them, it will be easier to water after sowing.

3.3.2 Sowing and Germination

Depending on your local climate, your propagation environment, and the temperatures you can maintain around your seedlings, plan on sowing in early spring. If you can't control temperatures well, you may wish to hold off sowing until late spring to avoid problems with frost. Good air temperatures during the germination period range from 65 to 80 °F. If you have access to bottom heat, use it! Warm growing media will help promote faster germination and decrease the possibility of disease.

Prepare seeds as described in Section 2.8 (Seed Treatments). Three different techniques are used for sowing native plants based on seed size, shape, and ease of germination (Table 3.4).

3.3.2.1 Direct Sowing (20% of Species)—This method is best for seeds large enough to handle easily, and for species that germinate with few problems. Although it is less commonly used than the other techniques, direct sowing is the standard for most tree species. For less than a few thousand seedlings, it's easiest and quickest to sow by hand. Coating seeds with a little baby powder makes them easier to sow and easier to see on top of the medium. The number of seeds to put into each container will depend on the germination expected from the seeds. Use Table 3.2 for an approximate number of seeds to sow per container to end up with 90% or more of your containers with one seedling. Ideally, you'd like to minimize the number of empty containers, but, as you can see in the example in Table 3.3, you reach a point when adding another seed fails to result in appreciably more filled containers. You'll have to decide whether seed economy (saving seeds for next time) is more important than a few empty cells. Using more seeds than is necessary will also require you to do more thinning after germination. If you'd like to be more precise and don't mind a little math, the direct calculations for determining seeds per container to sow are relatively simple and are provided in Appendix 6.3.

Seeds of most species should be barely covered with a thin mulch of perlite or coarse grit, with mulch depth being no more than twice the thickness of the seeds (see Figure 3.7). Make sure the covering material doesn't have too many fine particles that can cause crusting. A good mulch keeps seeds from splashing out during watering, helps retard algae and moss growth, keeps the surface of the medium cool and moist but not wet, and keeps the zone around the young stems drier, thus reducing disease problems. Seeds that should not be covered include those that are very small (for example, sagebrush) or require light for germination (for example, birch).

Table 3.2—Based on germination of your seedlot, sow the appropriate number of seeds so 90% or more of your containers will have at least one seedling.

Seed germination percentage	Seeds to sow per container	Percentage of containers with at least one seedling
90+	1 to 2	90 to 100
80 to 89	2	96 to 99
70 to 79	2	91 to 96
60 to 69	3	94 to 97
50 to 59	4	94 to 97
40 to 49	5	92 to 97

3.3.2.2 Sowing Germinants (15% of Species)—This method is recommended for large seeds with deep, complex, or unknown dormancy requirements (Table 3.4). Sowing germinants is particularly useful for seeds of variable or unknown germination. It is a good technique for beginning growers because it ensures that a live seed is placed in every container and that the crops will grow uniformly. To sow germinants, soak your seeds and place them in stratification (if necessary) like you would for a germination test (see Section 2.10, Germination Testing). Very large seeds (for example, acorns) are mixed with a moist medium such as *Sphagnum* moss, whereas smaller seeds are scattered between layers of moist paper towels. Place the seeds in a plastic ziplock-type bag, label, and keep in the refrigerator. Check the seeds at least weekly and, as soon as the seed begins to germinate (Figure 3.18A), place that germinant on top of moistened growing medium in the container and gently cover with mulch (Figure 3.18B).

Table 3.3—A sowing example for a seedlot of common milkweed having 65% germination. Assuming 1,000 seedlings are desired, notice that adding more than 3 seeds per container really doesn't improve the number of containers with seedlings but does waste many seeds. Refer to Appendix 6.3.

Seeds sown per container	Empty containers	Containers with at least one seedling	Seeds sown	Seedlings produced	Additional seedlings produced per additional 1,000 seeds sown
1	35%	65%	1,000	650	—
2	12%	88%	2,000	880	230
3	4%	96%	3,000	960	80
4	1%	99%	4,000	990	30
5	0%	100%	5,000	1,000	0

Table 3.4—Characteristics of the main seed propagation methods for forest trees and other native plants.

Planting method	Best method for:	Advantages	Disadvantages
Direct seeding: Seeds are sown into growth containers with or without treatment	• Seeds of medium to large size • Uniformly shaped seeds with smooth seed coats • Seeds of high quality with viability test information	• Quick • Minimizes seed handling • Mechanical (automated) seeding possible • Less labor required • Planting occurs all at once	• Requires seeds of known high quality • Dormant seeds must be treated (or sown containers must be placed into conditions to meet dormancy requirements) • Requires thinning and/or consolidation for difficult-to-germinate seeds
Planting germinants: Seeds germinating (no leaves visible) in stratification trays or bags are planted into growth containers ("sowing sprouts")	• Very large or irregularly shaped seeds • Seeds of unknown quality or low purity • Valuable or scarce seed lots • Seeds requiring warm moist treatments or stratification	• Good growing space utilization • Efficient use of seeds • Can adjust for unknown seed quality	• Slower and more labor intensive than direct seeding • Sowing can take weeks or months to complete • Crop development will not be uniform because of staggered sowing • Sowing date depends on seed treatment requirements • Root deformation possible if poorly transplanted
Transplanting emergents: Seeds are sown into trays or pots filled with medium; a few days or weeks after germination and when leaves are present, seedlings are transplanted into growth containers ("pricking out")	• Small or fragile seeds • Seeds of unknown quality or low purity • Valuable or scarce seed lots	• Good growing space utilization • Efficient use of seeds • Can adjust for unknown seed quality • More uniform crop development	• Transplanting requires skill and is labor intensive • Difficult to control density in seed trays so disease potential can be high • Root deformation possible if poorly transplanted

3.3.2.3 Transplanting Emergents (65% of Species)—This technique, commonly called "pricking out," is better for small or fragile seeds that would be difficult to direct sow or sow as germinants (Table 3.4). The process begins with sowing seeds in shallow germination trays or small pots filled with a standard peat growing medium that is lightly tamped until it is firm, but not compacted (Figure 3.18C). Larger seeds are scattered over the surface of the medium by hand, or smaller seeds can be sown with a salt shaker with the holes in the top enlarged. The sown seeds are covered with a light application of fine-textured mulch (unless they are very tiny or need light for germination), irrigated, placed into a greenhouse, and misted lightly. Transplanting should be completed as soon after germination as possible, especially before the new root sends out lateral roots (Figure 3.18C, D, and E). Gently pull the germinant from the medium, make a dibble hole in the growing medium of an empty container, gently place the plant in the hole, firm the medium around the stem, and water thoroughly. This procedure sometimes produces a "J-root" or kink in the seedling stem; while not as important for grasses or many herbaceous plants, this may, for species that produce a strong taproot and/or woody species, reduce growth in the nursery and/or cause mechanical weakness or mortality after outplanting (Figure 3.18F). If the root has grown too long to easily transplant, you may reduce its length before transplanting, but don't remove more than half of the root. Transplanting germinated seeds or young seedlings requires some degree of skill but can be easily mastered with a little practice.

Figure 3.18*—Many native plants should be propagated by sowing germinating seeds (A & B), or transplanting young emerging seedlings (C & D). Herbaceous species with strong taproots (for example, arrowleaf balsamroot) and woody species (for example, longleaf pine) are best transplanted before lateral root development (E), and these transplants should have their roots oriented vertically without kinking to avoid root deformation (F).*

3.3.3 Irrigation and Fertilization

Once your plants are established in their containers, it's time to start watering and fertilizing on a regular basis.

3.3.3.1 Irrigation—You'll need to water 1 to 3 or more times per week, depending on the size of the container, media, seedling size, conditions in your propagation environment, and ambient weather. Always water early in the morning so that foliage will dry completely during the day, reducing disease problems and incidence of fertilizer burn.

An easy and repeatable way to determine when to water is by using an ordinary bathroom scale. Right before sowing, and about an hour after you've saturated the medium in your containers, weigh the block on a scale. Let's say it weighs 26 pounds. This is your "field capacity" block weight; it reflects how much water is held in your containers. When the weight drops to a certain percentage of field capacity weight, it's time to water your seedlings (Table 3.5). We call this target block weight and it changes somewhat with the age of your crop. When seedlings are small, it may take several days, or even a week, depending on weather to dry from saturated to target block weight. Once seedlings are larger, however, and depending on your climate, the change in block weight from field capacity to target can happen often, perhaps every other day or even daily! About once every 6 weeks or so, obtain a new field capacity weight to compensate for the weight of the seedlings. Note: This works well if you have plants in nearly all of the containers. If your block of seedlings has many blanks, those will lose water more slowly making this technique less useful.

The simplest way to water your seedlings is with a watering can (Figure 3.19A), or a hose-end nozzle (Figure 3.19B). Make sure you apply an even amount of water across all the containers, and that you apply enough water so that some drips out the bottom of the containers. Often containers around the edges of the crop will dry down more than those in the center and may require additional water. A hose with a fine spray nozzle, or even a lawn sprinkler, will also work well. If you plan on growing many seedlings, you may wish to construct a permanent irrigation system. For any type of sprinkler system, check the output to make sure all the seedlings receive about the same, and adequate, moisture.

An innovative way to irrigate container plants is known as subirrigation, which involves holding plants in a structure where they can be watered from below (Figure 3.19C). The water is absorbed into the growing media and moves upward by capillarity. Subirrigation is particularly useful when broadleaved plants get larger and it's almost impossible to water each container from above because the leaves shed the water. It also works very well for growing wetland native plants, such as sedges and rushes (Figure 3.19D).

3.3.3.2 Fertilization—Please refer to the fertilizer discussion in Section 3.2.3.1 (Fertilizers: Organic vs. Synthetic) because much of that is relevant to growing seedlings in containers. For container seedlings, the two options for keeping your plants well supplied with nutrients are:

1. Incorporating controlled-release fertilizers into the growing media prior to sowing, or top dressing.
2. Liquid feeding or "fertigating" throughout the growing season.

For beginners, the best plan may be to use a combination of both.

The three nutrients, nitrogen (N), phosphorus (P), and potassium (K), are the most important, in terms of amounts needed, for healthy shoot and root growth, and are commonly added via fertilizers (Figure 3.20A). N is critical for aboveground seedling growth, especially new shoots, needles, and buds. Plants lacking sufficient N grow slowly or are stunted and have pale green or yellow needles near their bases. P is important for root growth and bud development, and K is important for root growth, efficient water use by the plant, and improving disease resistance.

Because container seedlings do not have the benefit of basic soil fertility and are grown in an artificial media, fertilizer application is more critical than with bareroot seedlings. On the other hand, this also makes it much easier to apply too much fertilizer, resulting in tall, spindly seedlings. Many factors influence how much fertilizer should be applied, including the species being grown, container size, seedling age, weather, type of medium, and so on.

Table 3.5—An example weekly record of block weights assuming a field capacity block weight of 26 lbs., and that seedlings will be watered when target block weight reaches 85% of the field capacity weight (26 lbs. x 0.85 = 22 lbs.)

	July 22	July 23	July 24	July 25	July 26	July 27
Field capacity weight	26.0	26.0	26.0	26.0	26.0	26.0
Actual weight	22.0	25.0	23.5	20.8	24.5	21.5
Percentage difference	85%	96%	90%	80%	94%	83%
Need to water?	Yes	No	No	Yes	No	Yes

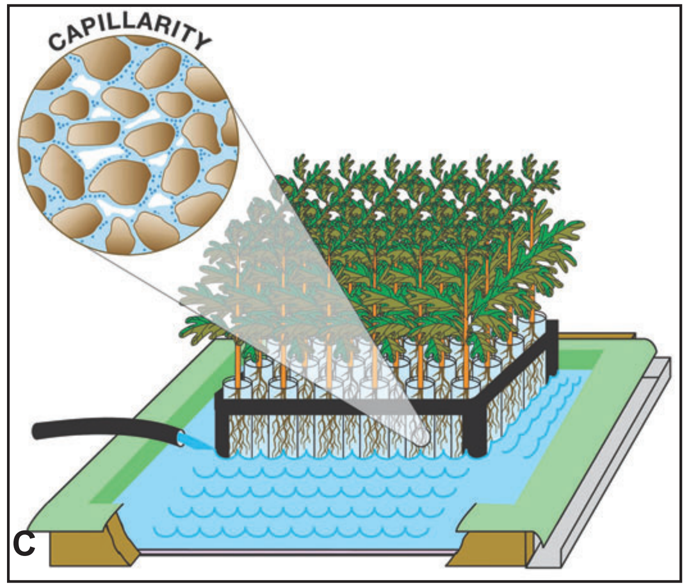


Figure 3.19*—Using a watering can (A) or hose-end nozzle (B) is the easiest way to water container seedlings. Watering from below ("subirrigation") is effective on larger broadleaved plants when it's ineffective to sprinkle irrigate (C); this method is very useful for growing wetland native plants (D).*

3.3.3.2.1 Controlled-Release Fertilizers—These fertilizers generally contain all the macro and micronutrients. The fertilizer is encapsulated by a thin, plastic shell that forms a round "prill." The composition and thickness of the shell, along with water availability and temperatures, control the rate of release of the fertilizer from the prill (Figure 3.20B). Typical release rates range from 3 to 18 months. The most effective way to apply controlled-release fertilizers is to incorporate the prills into the growing medium at label rates when you are filling the containers. Keep in mind that if you store that medium for a length of time before using it, conditions may be sufficient for the fertilizer to be released. Prills can also be "top-dressed" to individual containers during the growing season (Figure 3.20C). Although controlled release fertilizers are easy to use, they suffer the drawback of not being able to completely control when the nutrients become available. This can cause problems, particularly when you want to stop height growth and begin dormancy.

3.3.3.2.2 Fertigation—Soluble fertilizers are easily and uniformly applied with water. The type and amount of fertilizer is discussed in the next section. You can apply liquid fertilizers dissolved in water by hand with a watering can (Figure 3.19A). A more accurate way to apply liquid fertilizers is to use a siphon injector such as the Hozon™ (Figure 3.20D). The flow of water through the hose causes a suction that pulls the fertilizer stock solution up and mixes it with the water in the hose at a 1:16 ratio (Figure 3.20E).

You should check the injection ratio of your siphon occasionally. Put a known amount of water into a container (this is your "stock solution"), put the siphon hose in it, and then measure how much water comes through the hose (use a 5-gallon bucket or some other container of known volume to measure out flow) until the stock solution container is empty. For example, if you had 1 quart of stock solution, and collected 4 gallons (16 quarts) of water while waiting for the stock solution to be used up, your siphon has an injection ratio of 1:16. In Section 3.3.3.2.4 (Sample Fertigation Schedule) you'll see why this is important. Note: Laws require anti-siphon devices on any irrigation system connected to a domestic water source. Hozon™ injectors are designed to prevent contaminated water from siphoning back into your drinking water supply.

3.3.3.2.3 Seedling Growth Phases—It's really difficult to give a "recipe" for fertilizing container seedlings because different species require immensely different amounts of fertilizer, different seed sources for a species may have different requirements, and a species requires different amounts of fertilizer as it goes through the growing season. Therefore, use the following methods for a conifer seedling as a general guide. Be prepared to modify it as your seedlings develop.

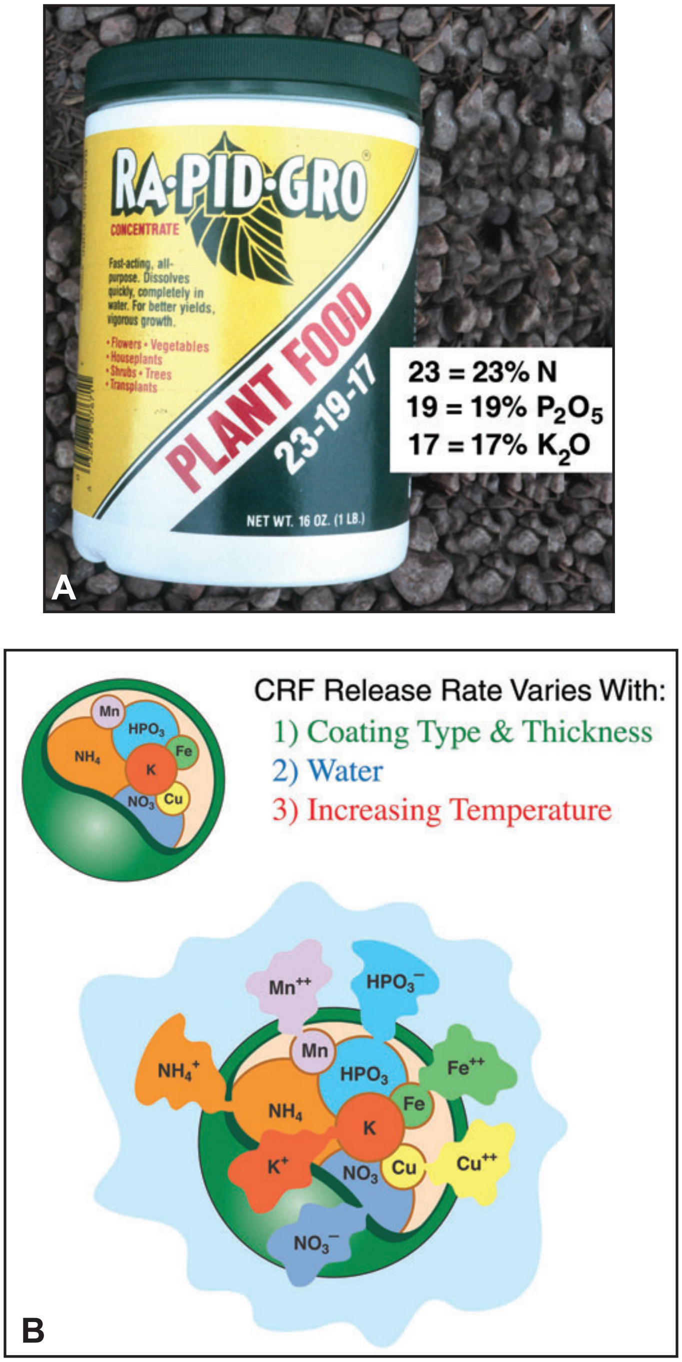
Use Table 3.6 as a guide to determine how much and how often to fertilize. All seedlings have three distinct growth phases: establishment, rapid growth, and hardening. During each phase, you manipulate fertilizer and water to control seedling growth. During the establishment phase, seedlings should be well watered (80 to 85% block weights) and receive daytime temperatures between 65 to 80 °F and nighttime temperatures above 60 °F. This phase lasts about a month and helps get seedling root systems started. During the rapid growth phase, seedlings receive their highest doses of N to encourage height growth. Target block weights are still 80 to 85% and temperatures are similar to the initial growth phase. Depending on species, the rapid growth phase may last from 3 to 15 weeks. When seedlings are about as tall as desired, the rapid growth phase ends and hardening begins.

Hardening is the most important part of growing container seedlings. During the first stage of hardening, levels of N in the applied fertilizer solution are greatly reduced and target block weights are gradually lowered to 60 to 70%. This stage encourages seedlings to decrease shoot growth and for some species, stop shoot growth and form terminal buds. The appearance of brown buds at the tip of the shoot usually takes a few weeks to a month or so. Sometimes pines, which usually form terminal buds, will form a rosette of dense needles at the tip of the shoot. This is okay. Some native plants don't form buds, so your objective is to slow shoot growth and keep seedlings stocky.

After a month or so, the objective is to increase seedling stress resistance, especially to cold temperatures. Levels of N can be slowly increased, but target block weights are usually still low (60 to 70%). Increasing N in the applied fertilizer helps the seedling increase in stem diameter, form a big bud, and continue to develop roots. Temperatures are allowed to go to ambient, especially at night, and along with the low target block weights help condition the seedling for life on the planting site.

So, the general guideline for fertilizing and watering low, medium, or fast growing seedlings can be approximated by using Table 3.7. A more advanced guideline can be found in Appendix 6.4.

3.3.3.2.4 Sample Fertigation Schedule—Let's assume you're growing ponderosa pine seedlings. Table 3.7 shows ponderosa pine is a "medium" grower. Let's also assume the crop is in the accelerated growth phase; Table 3.7 indicates seedlings with a "medium" growth rate should get 130 ppm N. Using Miracle-Gro, Table 3.8 shows that we need 1 teaspoon of fertilizer per gallon of water to get 130 ppm N. Now let's assume a few thousand seedlings are watered with a hose. Use a siphon injector (1:16) to apply 32 gallons of fertilizer solution containing 130 ppm N. That means you'll need 2 gallons of concentrated fertilizer stock solution to run through the siphon (32 gallons/16 [the injection ratio] = 2 gallons stock solution). To make the concentrated fertilizer solution, mix 32 teaspoons (1 teaspoon for every gallon) of fertilizer into 2 gallons of water.



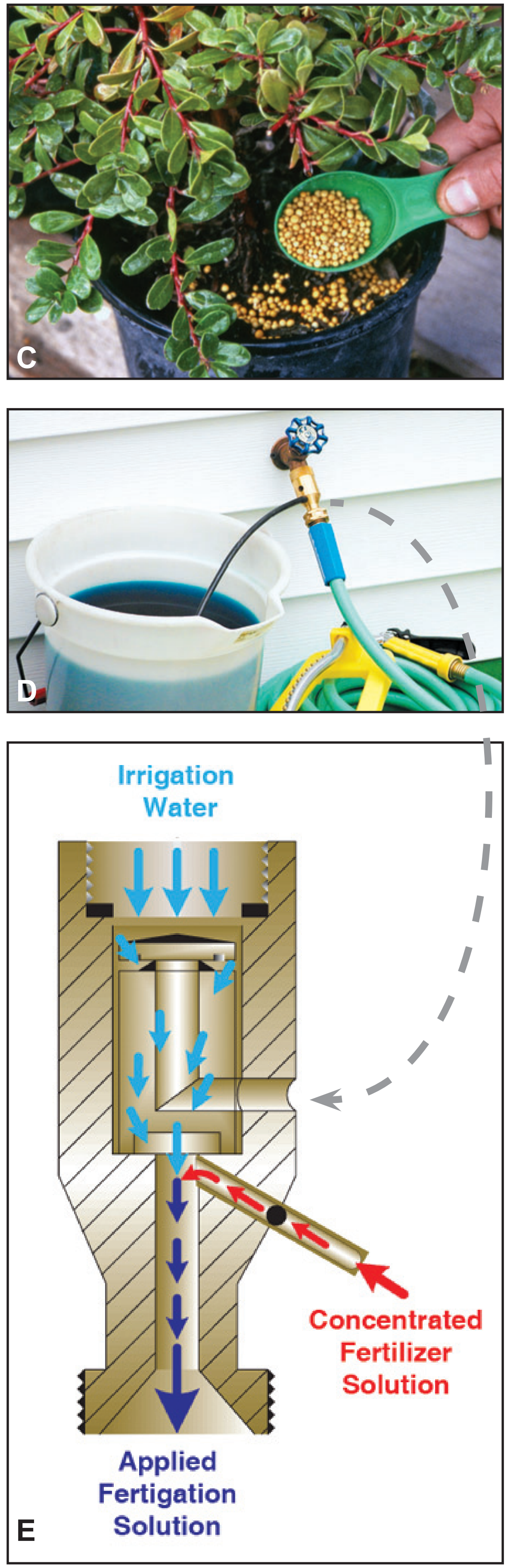


Figure 3.20*—All fertilizers are required by law to show their composition of nitrogen (N), phosphorus (P), and potassium (K). Controlled-release fertilizer particles (“prills”) consist of soluble fertilizers inside thin plastic shells; after water penetrates the prills, soluble nutrient ions move outward into the growing medium (B). Controlled-release prills can be top-dressed on larger container plants (C). The Hozon™ (D & E) is a simple fertilizer injector that attaches to a garden hose and sucks concentrated fertilizer solution and mixes it with water at an approximate ratio of 1 part fertilizer to 16 parts water (D & E courtesy of Hummert™ International).*

Table 3.6—An approximate amount of N in parts per million (ppm) to apply to seedlings for each growth phase and an approximate target block weight. See Table 3.8 for converting ppm.

	Plant Growth Phases			
			Hardening	
Fertilizer levels (Table 3.7)	Establishment	Rapid growth	Bud formation period	Remainder ofhardening period
	ppm Nitrogen			
Low	33	65	0	33
Medium	65	130	0	65
High	65	200	33	65
Target block weights	80%	80%	60 to 70%	75%

Table 3.7—Fertilizer application guidelines for some native plants.

Low	Medium	High
Grasses and sedges	Cow parsnip	Huckleberry
Lupine [1]	Monarda	Whitebark pine
Salvia	Chokecherry	Pinyon pine
Buffaloberry [1]	Cottonwood	Interior Douglas-fir [2]
Ceanothus [1]	Elderberry	
Hawthorn	Red-oiser dogwood	
Sagebrush	Serviceberry	
Coastal Douglas-fir [2]	Jack pine	
Quaking aspen	Ponderosa pine	

[1] = Nitrogen-fixing species inoculated with appropriate beneficial microorganism
[2] = Ecotype differences

Table 3.8—Teaspoons of Miracid® or Miracle-Gro® to add per gallon to achieve desire parts per million (ppm) of nitrogen (N) for container seedlings. If you use any other type of fertilizer, you'll need to calculate ppm using directions found in Appendix 6.4.

	ppm Nitrogen	
Teaspoons per gallon of water	Miracid 30:10:10 (N:P:K)	Miracle-Gro 15:30:15 (N:P:K)
¼	65	33
½	130	65
¾	195	98
1	260	130
1½	195	
2	260	

Having said all of this, remember that the amount of fertilizer you'll have to apply will depend on the type of container, growing medium, and other environmental factors. If seedlings seem to be growing too fast (they're too spindly or flop over when not supported), then reduce the rate of fertilizer (less N), or reduce how often you fertilize (every other watering or less). Conversely, if they're growing too slowly, you may increase the rate of fertilizer (more N) to encourage growth. It's extremely important to keep detailed records of what you do to your crop and how the seedlings grow. Measuring seedling height every 2 to 3 weeks and matching that to the amount of fertilizer applied will help you adjust your fertilizer schedule to grow even better seedlings.

3.3.4 Light

As mentioned earlier, most species require full intensity sunlight for proper growth and development. That means they can't be grown on a windowsill and it's not economical to raise them with only grow lights. Many species are, however, very sensitive to slight changes in daylength. A species like interior Douglas-fir grown under normal daylight conditions will form buds before they are as tall as desired. It's fairly easy to "fool" seedlings, however, into "thinking" the day is longer by providing some periods of light to break up the night. A single 300-watt bulb suspended 4 to 5 feet above the crop for every 60 to 80 square feet of containers is sufficient light. The easiest way to "fool" your seedlings is to put the light on a timer set to come on before sundown and to extend the length of day to 18 or 20 hours. Once your seedlings are as tall as you'd like them, turn off the light. The abrupt change in daylength, along with changes in target block weight and fertilization rate, will encourage your crop to cease shoot growth and form buds.

3.3.5 Hardening

Once your plants have reached the desired height, it's time to harden your crop. Hardening means slowing their growth rate and getting them ready for the cooler temperatures of fall and winter. The first step in hardening is to reduce irrigation to stress the plants slightly. If you have your plants in a greenhouse or cold frame, the next step to induce hardiness is to expose your plants to full sunlight (the exception being shade-loving plants), wind, and ambient temperatures. Induce a mild nutrient stress by first leaching the growing medium with water, and then reducing the amount of fertilizer you are applying, especially nitrogen. You should be able to see some color changes in the foliage and the leaves or needles should feel tougher to the touch. The leaves of deciduous plants will become yellow and eventually drop. These changes are desirable and mean that your crop is ready for outplanting or overwintering.

3.3.6 Pest Management

Disease can occur rapidly in a crop of container seedlings because the nursery environment is also conducive to diseases. Sanitation is key to minimizing disease problems. Always remove diseased material immediately and either burn it, bury it, or send it away in the trash.

The first disease you may encounter is damping-off (see text box on page 32). It affects germinating seeds and very young seedlings. Damped-off seedlings tip over at the ground line and shrivel up. You can help prevent it by watering sparingly when seedlings are small, and by quick removal of dead and dying seedlings. The second important disease is root rot, and it usually becomes a problem when seedlings are larger. Seedlings turn brown, often from the top of the stem. Generally, once you see symptoms, it's too late to do much about it. Root rot can be prevented by using clean containers, proper watering, and keeping seedlings and their roots from getting too hot. Use a 1 inch by 6 inch piece of wood laid on end to shade the edges of blocks exposed to direct sunlight.

At the end of the growing season Botrytis disease is often a problem. The fungus *Botrytis* forms a gray web-like growth on needles, eventually infecting seedling stems and causing death. Botrytis generally becomes a problem when foliage from one seedling touches foliage from another seedling. The fungus gets its start on dead foliage and disease is favored by cool temperatures and high humidity. Botrytis disease can be controlled by proper watering, removing dead and dying seedlings as you see them, and brushing foliage after watering. A piece of PVC pipe works well as a brush, but be gentle so shoots aren't damaged. During hardening, you can also spread seedlings out to encourage air movement between them, thus reducing disease. If you're using Ray Leach cells or peat pellets, you can rearrange them to have an empty row between rows of seedlings.

One last problem with container seedlings is fungus gnats. These small, dark flies are more nuisance than problem, although in large enough quantities their larvae will feed on seedling root systems and can kill seedlings. They're usually more troublesome when seedlings are watered too often, and their populations soar if you have a lot of moss and algae, especially in blank cells. Fungus gnats are best controlled through proper irrigation. Yellow sticky cards, which are available through garden catalogs, trap the insects and make you aware of a potential problem. Place the cards at or near the surface of the containers and when the flies land on it, they become entangled. The cards work best when laid flat.

3.3.7 Beneficial Microorganisms

Because container plants are growing in an artificial growing medium, some native plants will benefit from inoculation with mycorrhizal fungi or nitrogen-fixing bacteria (see Section 3.2.3.3, Young Seedlings: Establishing Your Crop). Inoculation should not be seen as a "magic bullet" but as a way to make good plants better. Because large amounts of fertilizer generally inhibit mycorrhizal formation, it's usually best to wait to inoculate until the hardening period. Inoculation with beneficial microorganisms is a complicated subject and the benefits vary from species to species, so do some research online or check with a native plant nursery for advice.

3.3.8 Harvesting, Handling, and Storage

The outplanting season, or "window," will determine when seedlings are harvested ("lifted"), handled, and stored. Properly hardened seedlings can be planted whenever adequate site conditions exist (good soil moisture and warm soil temperatures). In the southeastern U.S., seedlings can be outplanted from late fall through early spring. At more northerly latitudes or at higher elevations in the western U.S., seedlings can be planted during fall if good soil moisture and warm soil temperatures are present (see Section 5.2, Outplanting Windows). If the end of seedling production coincides with a good outplanting window (for example, seedlings are hardened in fall and the outplanting site has good soil moisture), then seedlings can be pulled directly from containers and immediately outplanted without storage.

If, however, properly hardened seedlings must be held during the winter until the outplanting site is ready, then seedlings will need to be stored. Plants growing in an enclosed structure can be kept in their containers until about mid-November through mid-December. Keep the plants as cold as possible, but try not to let the root plugs freeze by placing the containers close together on the ground, and insulating around the roots with sawdust or Styrofoam™ panels. A few gentle freezes of 28 °F or higher are probably okay, especially if you've exposed seedlings to cold temperatures before freezing. However, seedlings suddenly exposed to a drastic drop in temperature can be damaged or even killed. Then, if you have access to refrigeration, seedlings should be removed from their containers in mid-December to mid-January, enclosed in plastic bags, and kept at 28 to 34 °F until you are ready to plant them. Seedlings can be stored in this manner for up to 6 months. Thaw frozen seedlings slowly, at low temperatures, and out of direct sunlight before planting. If you don't have access to refrigerated storage, keep your plants in a cool, shady, protected location, such as a shade-frame or lath house. In open storage, plants may need to be irrigated during warm or windy periods in the late winter and early spring.

Regardless of storage method, check seedlings often for molds. Storage molds usually begin growing on dead foliage. Therefore, when you put seedlings into storage, remove any dead foliage. Storing seedlings in an upright position also helps reduce mold problems. Remove moldy seedlings immediately.

3.3.9 Holding Seedlings Over

If your seedlings have sufficient roots to be pulled from the containers but are too small to plant, you have two options: transplanting into larger containers or growing them as bareroot transplants. Seedlings at this stage cannot be held over in the same container for a second growing season because they become rootbound. Unless transplanted, seedlings will have too many roots for the container and won't grow well after outplanting. Seedlings can be transplanted into larger containers anytime from fall to spring.

3.3.10 Cleaning Containers Between Crops

In between crops, containers should be thoroughly cleaned of old growing medium, algae, and other debris. Fungal spores can still remain after vigorous cleaning, however, waiting to infect your next crop. Dipping containers in very hot water (160 to 180 °F degrees) for 15 seconds to 2 minutes (depending on the temperature and type of container) will kill nearly all the fungal spores. Soaking containers in a 10% bleach solution and then rinsing with fresh water is also effective.

3.4. Additional Reading.

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Chapter 4. Growing Plants From Cuttings

Many native plants can be grown from cuttings. Cuttings are portions of plants (stems, leaves, roots) that when treated and planted will develop into new plants complete with stems, leaves, and roots. Although shoots, roots, bulbs, corms, tubers, and rhizomes all offer possible material to reproduce plants, shoots are perhaps the most commonly used for vegetative propagation. These vegetative propagules (see Section 1.3, Seeds and Other Propagules) can be collected from wild plants or from plants specifically maintained at the nursery for this practice. You may want to grow plants from cuttings, particularly if the plant is difficult to propagate from seeds or if the desired plant has an unusual growth habit or flower color. Using cuttings maintains these desired tracts because, as we discussed in Section 1.3 (Seeds and Other Propagules) and showed in Figure 1.5, all new daughter plants that arise from cuttings are genetically identical to the parent plant. Another advantage is that sometimes using cuttings will result in a larger plant in a shorter time than the plants can be grown from seeds. A disadvantage is that cuttings generally require more care and can be more expensive to produce than plants from seeds. If you plan to grow plants from cuttings, follow the procedures described below to ensure success.

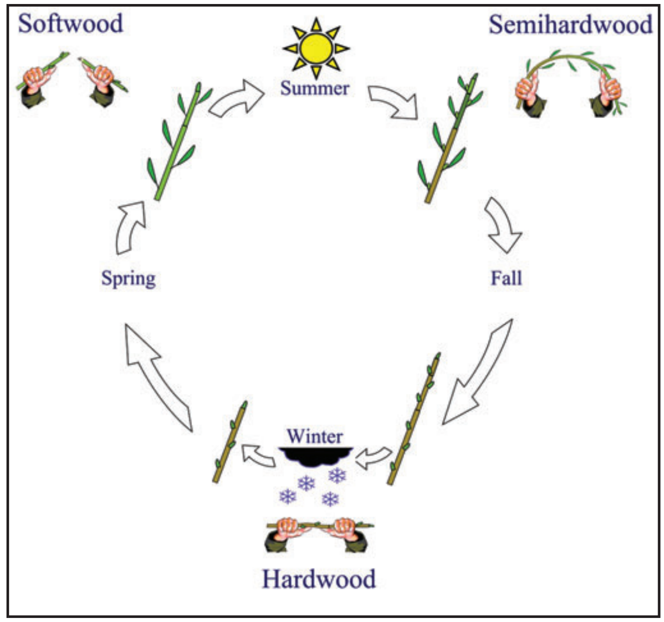

Figure 4.1—Hardwood cuttings are collected during winter dormancy. In late spring and early summer, softwood cuttings are taken from new shoots that bend but do not break. Cuttings of non-woody herbaceous plants are considered softwood as well. Semi-hardwood cuttings come from hardened stems later in the growing season.

4.1 Shoot Cuttings

Although cuttings can be taken from a variety of plant parts, using portions of the shoots is the most common method. Some species, such as cottonwood and willow, have shoots containing pre-formed roots, an adaptation to living near streams, and therefore are very easy to root. Most species lack this adaptation and must be given special treatment before roots develop. Cuttings are classified as hardwood, softwood, or semi-hardwood (Figure 4.1) depending on when they are collected.

Hardwood shoot cuttings are collected during the winter dormant season. Softwood cuttings, which includes cuttings of herbaceous plants, are collected in the spring and early summer when shoots are actively growing and leaves are present. Semi-hardwood cuttings are collected in late summer and early fall when shoot tissue has hardened and terminal buds are set.

4.1.1 Hardwood Cuttings

Hardwood cuttings are collected during the winter dormant season. Many woody species can be grown from hardwood cuttings. With easy-to root species, like willow and cottonwood, you can collect shoot cuttings that are large or small, depending on how you are using them. Large cuttings of willows and poplars, or "live stakes," can be outplanted directly, foregoing any time in the nursery (Figure 4.2A). Smaller cuttings (2 to 6 inches long) are used for propagation in the nursery. Some native plants, such as juniper, rhododendron, and manzanita (Figure 4.2B & C), may be easier to grow from cuttings than from seeds. Species other than the willows and cottonwoods typically require treatment with a rooting hormone, and even then, may require several weeks or even months before roots appear. Placing the cuttings in hot frame or rooting chamber usually improves rooting success (see Section 4.3.3, Rooting Environment).

4.1.2 Softwood Cuttings

Softwood shoot cuttings are prepared from the new, succulent growth of herbaceous and woody deciduous or evergreen species. They generally require more attention, treatment with rooting hormones, and a specialized propagation environment. For woody plants, the best softwood cutting material has some flexibility but is mature enough to break when bent sharply (Figure 4.2D); avoid using the extremely fast-growing, tender shoots.

4.1.3 Semi-Hardwood Cuttings

As the name implies, this type of cutting is intermediate between the succulent growth of a softwood cutting and the completely dormant stage of a hardwood cutting. Semi-hardwood (or greenwood) cuttings are usually taken from woody species during the late summer and early fall after the last flush of growth and as the wood is partially mature, often with a terminal bud present for the next growing season (Figure 4.2F).

4.2 Collecting and Storing Shoot Cuttings

Regardless of when you collect cuttings, some important points must be remembered. As with seeds, collect cuttings near the area where you intend to outplant them to ensure they are properly adapted to the environment (see Section 2.1.2, Seed Source). A good cutting will always consist of healthy stem tissue with some intact buds or leaves, and with enough stored food reserves to sustain it until new roots are formed. Also recall that for dioecious species (see Section 1.3, Seeds and Other Propagules),

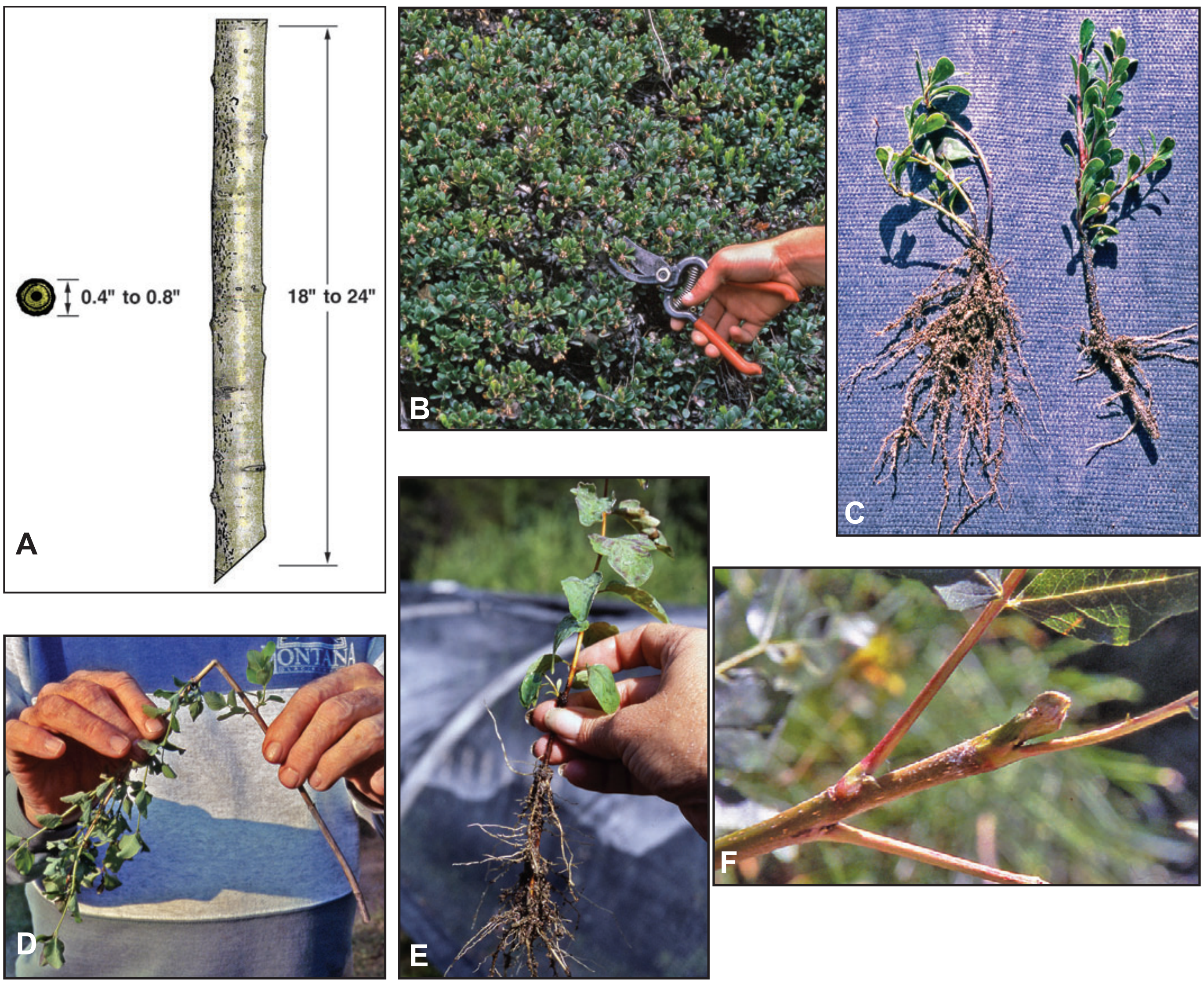

Figure 4.2*—Types of cuttings. Large, dormant hardwood cuttings ("live stakes") of willow and cottonwood can be stuck directly into the soil on the outplanting site without any nursery culture (A). Other hardwood cuttings, such as bearberry (B & C), require rooting hormones and special propagation structures. Softwood cuttings of woody plants have some degree of flexibility but are mature enough to break when bent sharply (D). Rooted softwood snowberry shoot cutting (E). Semi-hardwood cuttings, collected from lateral branches, should have a maturing terminal bud when collected in late summer (F).*

such as willow, cottonwood, and buffaloberry, individual plants are either male or female (Figure 1.5), requiring you to identify the sex of the parent plant in advance to ensure that you collect both male and female cuttings. Where you collect the cutting on a plant can also influence your success.

Older, large woody plants, such as shrubs and trees, are composed of two types of tissue: juvenile and mature. Cuttings from the juvenile parts of plants root much more easily than those from mature tissue, which produces flowers and fruits. In some plants, juvenile tissue can be distinguished from the adult phase by differences in leaf shape or color, and the overall habit of the plant. This is easily seen in junipers, where juvenile leaves are feathery and needle-like and often differ in color from mature leaves that are more rounded at the tips that bear cones. In other conifers, juvenile wood is usually found on the lower portion of the tree crown. In deciduous plants, juvenile wood is found near the stem base or root crown and can be discerned as "sucker" shoots (Figure 4.3A). In some extreme cases, difficult-to-root species will only root from stems collected from young seedlings. One way to ensure a good source of juvenile material for cuttings is to grow a few "mother plants" at your nursery that can be trimmed regularly to produce long, straight juvenile cuttings. "Donor plants" in natural stands can also be selected for hedging on an annual basis if cuttings will be collected from the area for several years. Note however, cuttings taken from mature lateral branches of trees will often continue to grow sideways. Therefore, collect cuttings from upright branches to obtain upright plants in the nursery (Figure 4.3B).

4.2.1 Cutting Size, Labeling, and Temporary Storage

When collecting cuttings from donor plants, make a cut just below a node; rooting is more likely to occur there. Make sure that some buds or leaves are present. The best size of cutting varies from species to species and the time of year it is collected. Small micro-cuttings, typically less than 2 inches long but having at least a bud, can be taken from easily rooted species (Figure 4.4A). Most other species, however, are rooted from cuttings that are 4 to 18 inches long and contain at least two buds (Figure 4.4B). Don't worry about making the cuttings to exact sizes in the field; just cut them half again as long as you think you'll need and trim them to desired size back at the nursery. Try to collect cuttings during mornings on cloudy, cool, humid days so the donor plants and cuttings are subject to less stress. Immediately place cuttings inside white plastic bags that don't allow sunlight to penetrate, label them noting origin and date, and place them in a cooler with some "blue ice" (Figure 4.4C & D). Never expose bags of cuttings to full sun.

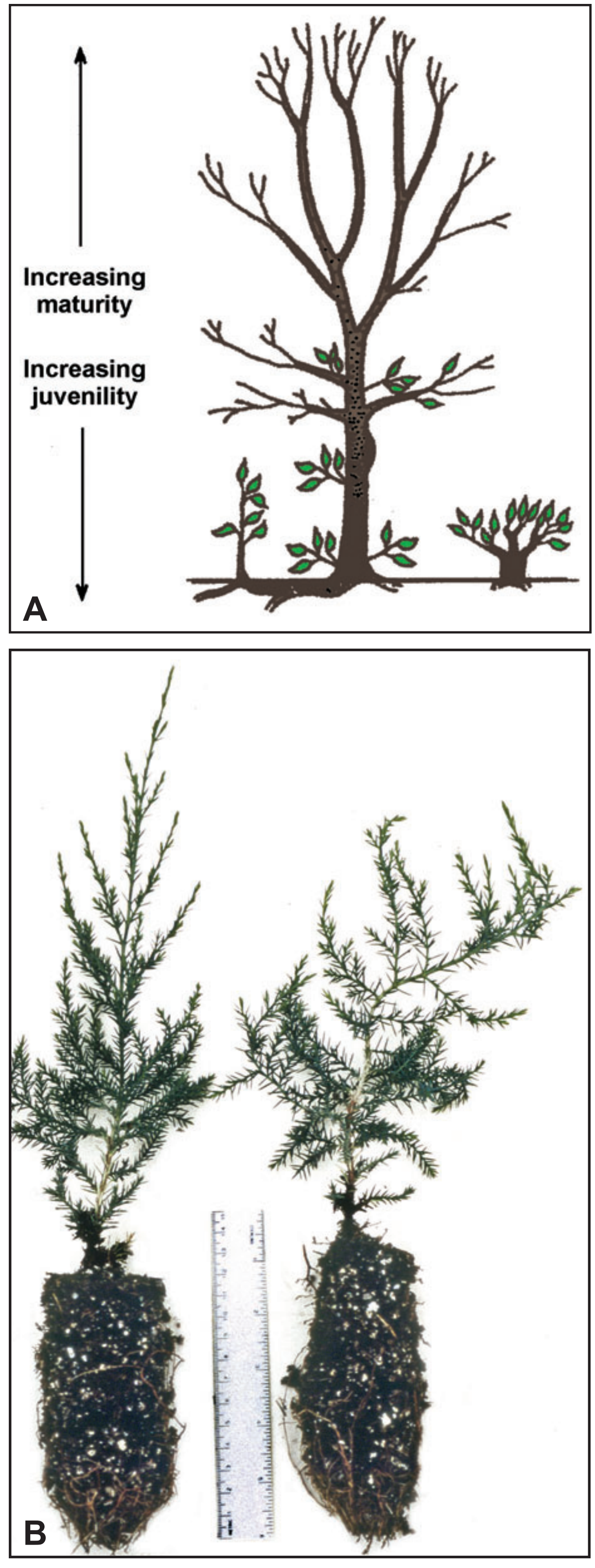

Figure 4.3*—The part of the plant where you collect your cuttings is important. Although counterintuitive, the fact is that cuttings collected from the lower parts of large woody plants root easier than those higher up (A). With most woody plants, especially trees, cuttings should be collected from upright branches (B, left) or they may grow sideways after rooting (B, right).*

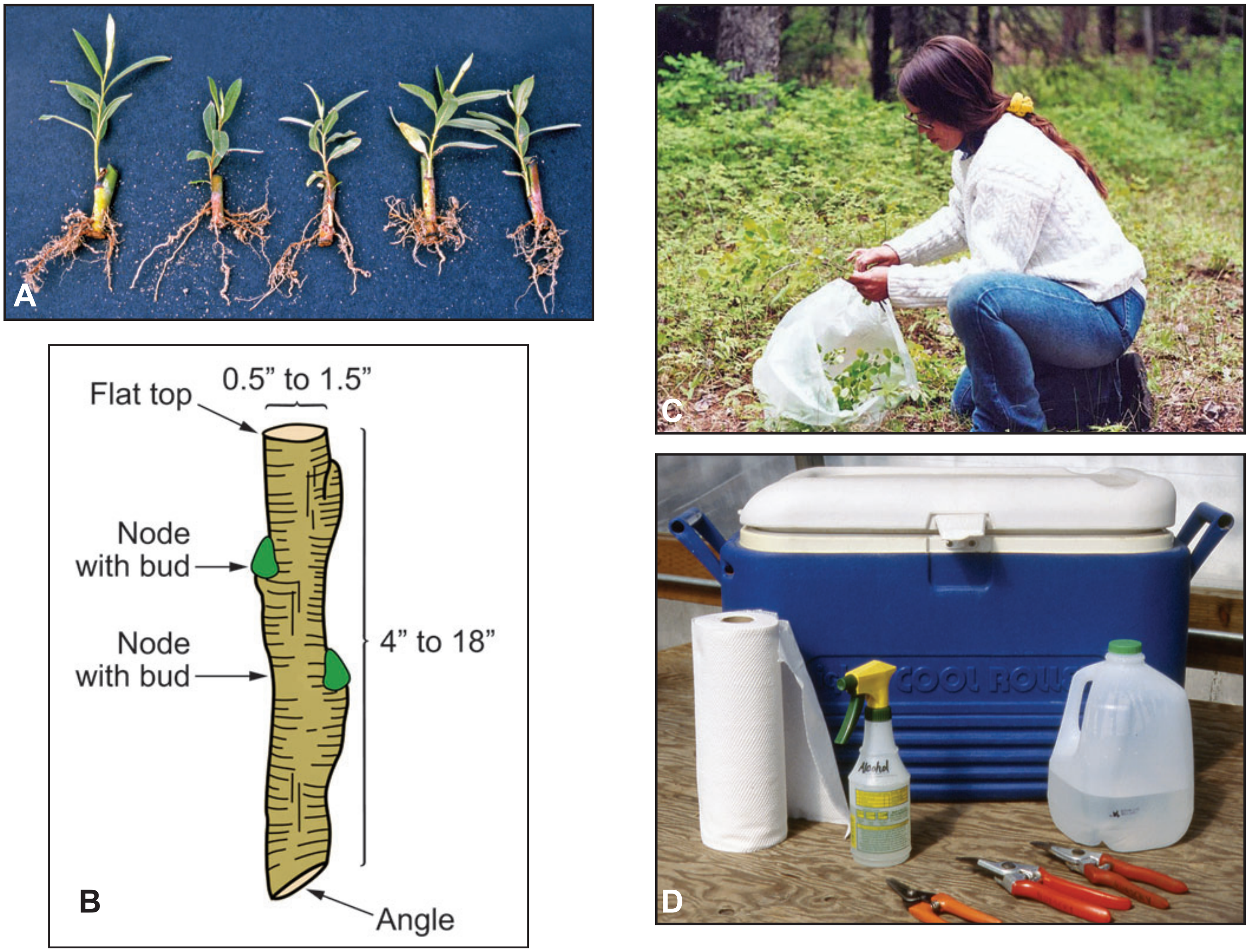

***Figure 4.4**—Small “micro cuttings” are suitable for easy-to-root species (A), but most cuttings for most species should be 4 to 18 inches and contain at least two lateral buds (B). Hardwood cuttings collected during winter are dormant and hardy, but nondormant softwood cuttings must be handled more carefully (C). Your cutting collection kit should include “blue ice” and a cooler to keep cuttings cool during harvest and transportation (D).*

4.2.2 Storing Cuttings at the Nursery

Back at your nursery, deciduous hardwood cuttings should be wrapped in moist paper towels, peat moss, or burlap before being placed into refrigerated storage. Depending on species, cuttings can be stored for several days, weeks, or even months. Inspect stored cuttings frequently to ensure they are slightly moist and mold-free. Conifer hardwood cuttings, softwood cuttings, and semi-hardwood cuttings, because they have foliage, must be treated promptly and struck (that is, inserted) into the medium used to root them.

4.3 Rooting Shoot Cuttings

Because of their open wounds, cuttings are very susceptible to diseases. So, while preparing cuttings for planting, it is important to keep the work area sanitized by using a disinfectant like household bleach (Figure 4.5A) mixed 1 part bleach to 9 parts water. Use sharp, well-maintained shears and knives to make clean cuts, and disinfect them often with alcohol. Trim cuttings to a standard size and shape, which promotes side shoots and eliminates shoot tips that could die back during rooting. Leafy cuttings should have about one-third to one-half of the foliage removed to minimize water loss from the cutting. It is very important, however, to have some leaves so that the cutting can photosynthesize during rooting.

Shoot cuttings can be either directly struck (that is, inserted) into individual containers used to grow them to their final size, or into communal trays in a rooting chamber from which they will be transplanted once they form roots.

Easy-to-root hardwood cuttings can be struck directly into containers without any treatment or special environment. Most other species must be treated with hormones, struck into special media, and placed into a special propagation environment.

4.3.1 Rooting Hormones

Auxins are natural plant hormones that encourage root formation. Two common types are IAA (indole-3-butyric acid) and NAA (naphthaleneacidic acid). Although natural sources of auxins can be used, nurseries rely on synthetic sources because of purity, higher concentrations, and availability of ready-to-use liquid and powder forms, and because some preparations also contain fungicides (Figure 4.%B). Synthetic hormones can be purchased at specific concentrations (either expressed in parts per million or as a percentage) or you can mix your own to specific concentrations. The best type of auxin, IAA or NAA, or relative combination of auxins and their application rates will vary among species.

4.3.2 Rooting Media

An ideal rooting medium provides a good balance of aeration and moisture but is firm enough to support the cuttings. The optimum pH is 5.5 to 6.5 for most plants, but acid loving plants prefer a pH of 4.0 to 5.0. Some common components of rooting media generally include a combination of two or more of the following: large grade (#2) perlite, pumice, *Sphagnum* peat moss, coarse sand, and fine bark chips. Different combinations of the components are used depending on the species being propagated, but perlite is one of the most common ingredients in rooting media. Avoid very fine or very coarse grade sands because they tend to discourage root development, and roots that do form tend to be brittle and break off. Formulating a good rooting medium promotes development of fibrous root systems that retain a quantity of the rooting medium during lifting. This aids in establishment by reducing chances of transplant shock during transplanting.

4.3.3 Rooting Environment

Cuttings need moderate light levels so that their foliage can continue to photosynthesize and produce the necessary energy and hormones that stimulate rooting. Unfortunately, shoots and leaves of cuttings lose water as they photosynthesize, but lacking roots, the cuttings cannot replace that lost water. Therefore, you must keep the humidity around them high to reduce water loss. A good rooting environment protects the cuttings from excessive sunlight, wind, and precipitation and keeps the humidity around the cuttings high. Although a plastic bottle will work for an individual cutting (Figure 4.5C), or a plastic tent for a few seedlings, a hot frame is more appropriate if you plan to root any cuttings. Because the temperature can increase rapidly inside any rooting environment, diligent daily inspection is required to ensure proper rooting conditions. Frequent light waterings with a misting nozzle are recommended to keep humidity high. If large numbers of cuttings are being rooted, an automated misting system can reduce the labor required. In general, cuttings should not be fertilized until after roots form, but cuttings that take a long time to root may benefit from a dilute liquid fertilizer application. Many species root better if the rooting medium is warmer than the air, so some growers place heating cables underneath the flats of cuttings.

4.4 Transplanting

Transplanting is always one of the major stress periods during nursery culture, and transplant shock is even greater with rooted cuttings. Therefore, prepare containers, media, labels, wet paper towels, and transplanting tools ahead of time. Fill the containers about halfway, and water so that the growing medium is “moist, but not wet.” Transplant rooted cuttings early or late in the day while keeping them out of direct sunlight. More than likely, all of your cuttings will not all be ready to transplant at the same time. Hold the cutting gently by the stem, carefully remove it from the rooting media without disturbing any media that remains attached to the roots, examine the root development, and select only those with an adequate root system (Figure 4.5D). Loosely wrap a moist paper towel around the root systems and keep the cuttings in the shade until they are transplanted. Hold the rooted cutting by the stem, insert it into the half-full container, and then backfill around the root system with moistened growing medium. Gently tamp the medium around the plants and then label, water, and move them to the growing area.

If cuttings lack a good root system by the end of summer, they should be left in the rooting media and transplanted the following spring. These cuttings should be hardened, as described above, at least 6 weeks before the first frost.

If, during fall, cuttings are just beginning to form new roots, these cuttings will need extra protection during the winter. Ideally, the root temperature should be kept at 34 to 41 °F. Placing cuttings inside a well-insulated cold frame works well.

4.5 Other Propagules Used in Vegetative Propagation

Bulbs, tubers, corms, and rhizomes are specialized plant structures that function in the storage of food, nutrients, and water. Bulbs are underground storage organs consisting of a short fleshy stem surrounded by fleshy modified

Figure 4.5*—Sanitation is critical while preparing cuttings for striking, and a dilute solution of household bleach is an excellent disinfectant (A). Most cuttings require treatment with special rooting hormones (B) and a protected environment to keep humidity high (C). Cuttings will develop roots at different rates, so transplant only those with adequate roots (middle and right) and return the others to the rooting chamber (D).*

leaves (scales). Tunicate bulbs have outer scales that are dry and membranous that can be used for propagation (Figure 4.6A). Corms are very similar to tunicate bulbs and are comprised of a swollen stem base enclosed by the dry scale-like leaves (Figure 4.6B). Cormels are miniature corms that form between the old and new corms which, because of their small size, require more time in the nursery to produce an acceptable plant for outplanting. Tubers, like the common garden potato, are swollen modified stems that serve as underground storage organs, and the "eyes" are actually nodes containing buds. Propagation by tubers involves planting the entire tuber or dividing it into sections containing at least one eye. Rhizomes are specialized stems in which the main axis of the plant grows horizontally or vertically at or below the soil surface. Many herbaceous plants and woody shrubs can be easily propagated with rhizomes (Figure 4.6C). Rhizomes are cut into sections containing some roots and at least one shoot or bud; these "divisions" can then be planted in containers or bareroot beds. Many herbaceous forbs, grasses, and grass-like plants can be multiplied by dividing their crowns; crown division is usually done just before shoot growth begins in the spring. Plants are dug up and the crown cut into sections that contain a substantial portion of the root system; these divisions are then planted into containers or bareroot beds. Plants that produce runners, like strawberries, can be propagated by cutting the nodal sections of the runners containing roots, and planting them (Figure 4.6D).

4.6 Post Transplanting Care

Transplanted cuttings should be placed in a shaded, protected area of the nursery. During the next month or so, cuttings should be hardened by exposing them to progressively more sunlight by moving them to different areas of the nursery. Be vigilant to ensure the rooted cuttings are not stressed. Once the rooted cuttings have acclimated to conditions outside the rooting environment, they can be cultured in the same manner as container seedlings (see Chapter 3).

Figure 4.6—*In addition to shoot cuttings, native plants can also be propagated using other vegetative structures, such as bulbs (A), corms (B), rhizomes (C), and runners (D).*

4.7 Additional Reading

Cullina, W. 2000. Growing and propagating wildflowers of the United States and Canada. The New England Wild Flower Society. New York: Houghton Mifflin Company. 322 p.

Landis, T.D.; Tinus, R.W.; Barnett, J.P. 1999. The container tree nursery manual. Volume 6, Seedling propagation. Agric. Handb. 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 167 p.

Luna, T. 2008. Vegetative propagation. In: Dumroese, R.K.; Luna, T.; Landis, T.D., eds. Nursery manual for native plants: a guide for tribal nurseries. Volume 1, Nursery management. Agric. Handb. 730. Washington, DC: U.S. Department of Agriculture, Forest Service: 152-175.

Chapter 5. Outplanting

5.1 Care During Outplanting

Nursery plants are in a period of high risk from when they leave the protected environment of the nursery to when they are outplanted. It is important to remember that nursery plants are alive and perishable, and therefore should be treated with utmost care at all times. Stressful injuries incurred between harvesting and outplanting, however, are often not evident until several weeks or even months after planting. Because all types of abuse or exposure are cumulative, it is helpful to think of native plant quality as a checking account. Immediately before harvesting, plants are their maximum quality (100%), but all subsequent stresses are withdrawals from the account (Figure 5.1). It is impossible to make a deposit—nothing can be done to increase plant quality after leaving the nursery.

Temperature stress is important because warm seedlings use stored energy that could be used for growth after outplanting. It's best to keep seedlings cool, shaded, and out of the wind right up until the moment you outplant them. On the outplanting site, temporarily store seedlings in a snow bank, a cooler, or at least in deep shade. Don't set them in full sun. Be careful with tarps. Placing most types of tarps on top of seedlings to shade them from sun actually makes them warmer than being in direct sunlight. If you use a tarp, select one made of reflective material and suspend it at least 3 feet above the seedlings so air will circulate between the tarp and the seedlings. Remove only as many plants as you can install in an hour or two.

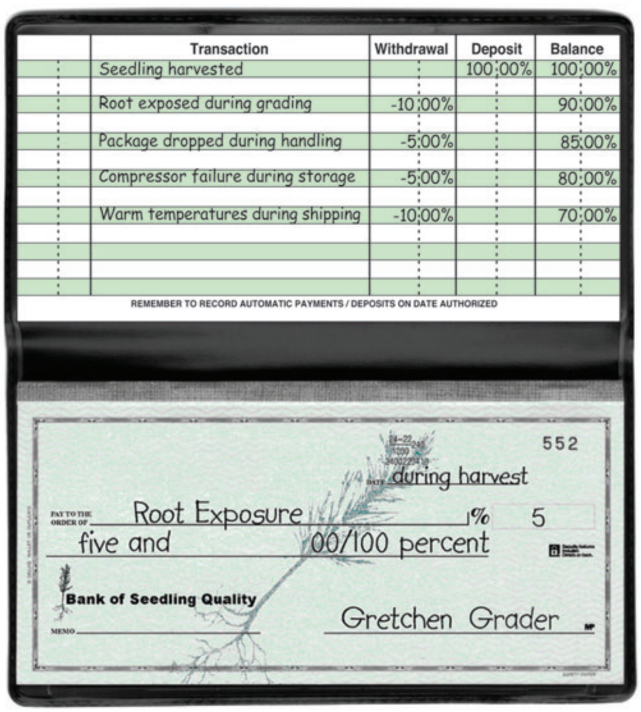

***Figure 5.1**—Think of native plant quality as a checking account in which all types of abuse or stress are withdrawals. Note that all stresses are cumulative and no deposits can be made—it is impossible to increase plant quality after you harvest them.*

5.2 Outplanting Windows

Years of experience have proven that, in general, the best time to outplant most native plant nursery stock is when they are dormant and least susceptible to the stresses of harvest, storage, shipping, and planting. The outplanting window is defined as the period of time during which environmental conditions on the site most favor survival and growth of nursery stock, and it varies considerably across the country (Table 5.1). Therefore, you should give some thought to what factors would be most limiting where you will be outplanting your plants. Although soil moisture and temperature are the usual constraints on most sites (Figure 1.1A), other environmental or biological factors can also limit plant survival and growth. For example, animal predation by rabbits and deer can be the most limiting factors to outplanting success.

Although good quality, nursery plants can be outplanted almost any time of year, the primary outplanting windows are in spring or fall in more northerly latitudes, as well as throughout the winter months in the southeastern United States. Fall-planted seedlings should go into the ground when enough soil moisture is available to support them, provided seedlings will have 6 to 8 weeks or so to grow roots before winter weather begins. That root growth makes them less likely to frost-heave and suffer from winter desiccation. Fall-planted seedlings have an extra advantage of beginning root growth in the spring before you could typically outplant. This extension of the growing season improves first year survival and growth.

In spring, seedlings should be outplanted when the ground has dried enough to dig a proper hole. If the soil is too wet you may cause serious soil compaction and restrict seedling root growth. Here's an easy way to see if your soil is too wet: dig a hole, then shovel the soil back into the hole—if the soil doesn't fit easily back into the hole, it's too wet. The earlier you can plant, the better; early spring planting allows seedlings to take full advantage of the growing season and available water.

Table 5.1—If site conditions are favorable, container plants can be outplanted year-round. Here are some potential outplanting windows; not every potential window is presented.

Region	Potential outplanting windows	Outplanting conditions
Great Lakes states	April and May	Typical spring outplanting
Rocky Mountains (higher elevations)	June and July	Good soil moisture and warmer soil temperatures; spring access prohibited by snow
Southwestern U.S.	August	Coincides with summer rains
Northern California	September and October	Adequate soil moisture exists and spring outplanting is hampered by poor access
Southeastern U.S.	November through February	Outplanting conditions favorable throughout winter
Pacific Northwest (coastal)	February through March	Typical spring outplanting

5.3 Outplanting Tools and Techniques

Your plants will have the greatest chance of surviving and growing if you select the best possible location for outplanting. Be sure to consider the natural habitat of your plant—does it occur on well-drained, upland sites or wetter bottom sites? Although a planting location may seem exactly the same, there are "microsites" where conditions are better. Exposure to afternoon sun can generate severe moisture stress, especially before the plant has had time to extend new roots out into the soil. So, look for places with natural shade such as the north and east sides of downed logs, stumps, or large rocks. Slight soil depressions where rainfall can accumulate are good planting sites for upland species, but don't plant them in low areas where water will stand for any amount of time. Compacted soil is detrimental because all the large pores spaces for water and air exchange have been squeezed out, so avoid ruts or other areas where vehicles have traveled.

Nursery stock can be outplanted with a variety of different tools but the objective is to safely and efficiently dig a hole deep enough to allow proper root placement without soil compaction. Planting bars or dibbles require the least effort but, because no soil is actually removed, they compact the soil to the sides and bottom of the hole. In clay soils, this compaction seriously reduces new root growth. Planting bars and dibbles are popular, however, when installing wetland plants. For upland plants, the best all-around planting tool is a shovel. Root plugs on nursery stock used for reforestation or restoration are longer and narrower than plant materials used for landscaping and gardening, so specialized planting tools have been developed. Planting shovels are tile spades that have blades that are long enough to match the depth of the plant root system (Figure 5.2A). Padded foot rests and reinforced blades make it much easier to penetrate the soil and lever back and forth to create the hole.

Whatever outplanting tool is used, the hole should be dug deep enough to so that it is deeper than the full length of the root plug. Once the hole is excavated to the proper depth, hold the plant vertically slightly below ground level and gradually backfill mineral soil by hand around the root plug (Figure 5.2B), gently tamping to remove air pockets. This ensures good root-to-soil contact that enables plants to access water and nutrients. A well-planted seedling is not outplanted too deep or too shallow; no foliage is buried; the orientation is straight, especially on steep ground; planting holes are backfilled with mineral soil, (avoiding grass, sticks, rocks, or snow) that is gently tamped to remove air pockets (Figure 5.3).

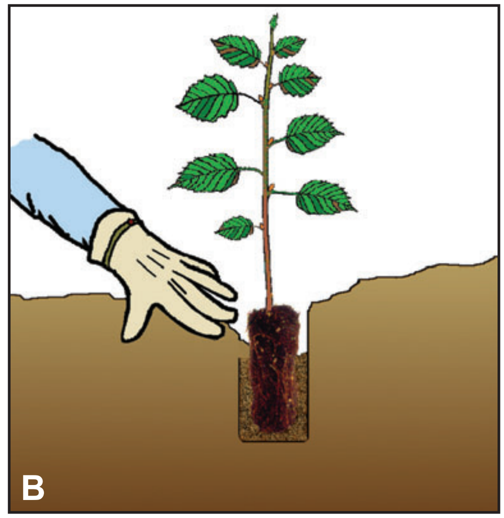

Figure 5.2—*The best planting tool for all types of plants and soil conditions is a shovel with a long narrow blade that is as deep as the root plug (A). Once the hole is deep enough, suspend the plant with roots in a vertical plane and fill around them with soil, gently tamping the soil to prevent air pockets (B).*

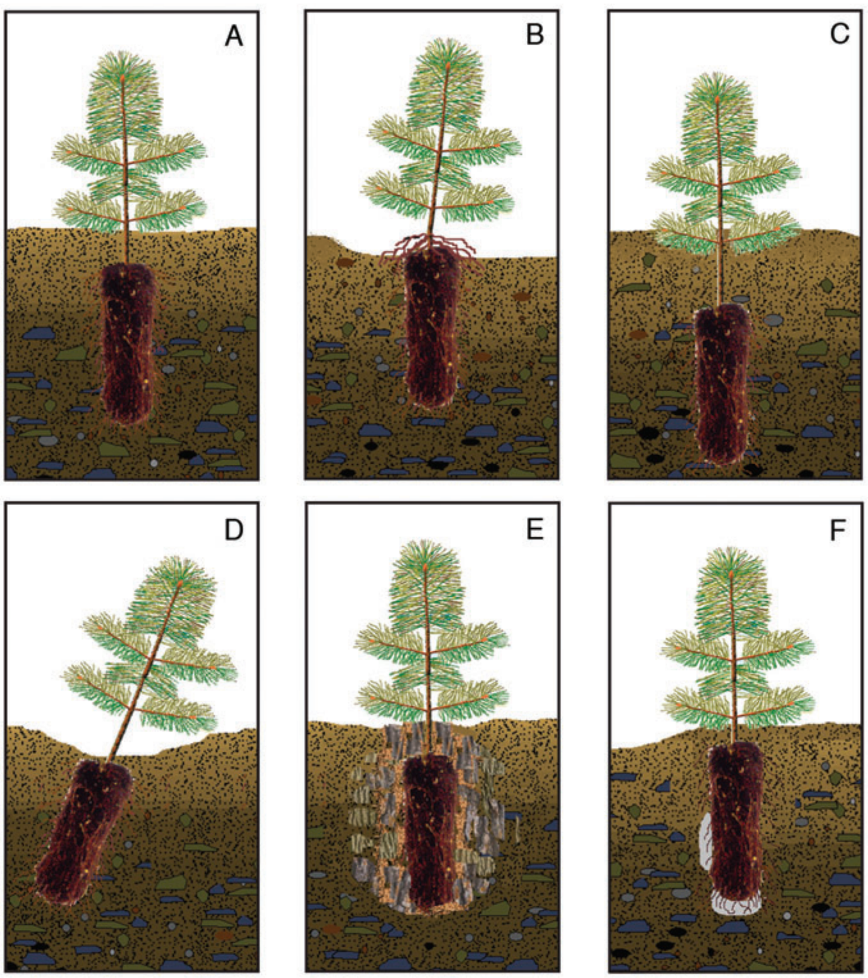

Figure 5.3—*Nursery stock should be planted properly (A). Common problems include planting too shallow (B), planting too deep (C), improper vertical placement (D), filling the hole with debris (E), or poor compaction that leaves air pockets around the root plug (F).*

The following 10 steps will help you get your plants in the ground properly:

1. Protect seedlings from sunlight, wind, and high temperatures. Carrying plants inside a white 5-gallon bucket with their roots wrapped in moist cloth is a good way to handle plants on the outplanting site.

2. On forested lands, plant on the north or east sides of stumps and logs if possible. Forest floor litter should be scraped (scalped) away to expose mineral soil, but replaced around the seedling after planting. At any planting site, scalp dense weedy vegetation. Scalps should be at least 30 inches square and expose mineral soil (Figure 5.4A)

3. Dig a hole large enough for the root plug. We don't recommend dibbles except for wetland plants. Spades, shovels, and hoedads work well for upland plants. Placing the plug into a slit made by rocking a spade or shovel is not recommended because rocking may compact the soil and hamper root growth.

4. Keep foreign matter (leaves, sticks, duff, rocks, snow, and so on) out of the planting hole.

5. If you add fertilizer to the outplanting hole, place it deeper than, or to the side of, the root plug so the roots are not in immediate contact. Allow roots to grow to the fertilizer. Adding fertilizer to a dibble hole next to the plant avoids this problem and reduces the chance that weeds will intercept the fertilizer.

6. After the hole is ready, remove only one seedling from the storage container. This prevents unnecessary exposure of the roots of remaining plants. If roots appear dry, dip them in a bucket of cool water for a couple of seconds to remoisten them.

7. Place your plant near the center of the hole, with the top of the root plug about 0.5 to 1 inch below the soil line. Planting too deep is better than too shallow as long as you don't bury any foliage.

8. As you fill the hole, gently firm the soil around the roots. Leave no air spaces. Be sure to use moist soil to fill the hole, but don't use heavy pressure that will compact the soil.

9. Watering plants, if practical, immediately after outplanting is probably the single best thing you can do because it not only provides moisture but gently settles soil particles around the roots (Figure 5.4B).

10. Surround the plant with a protective fabric or organic mulch to reflect sunlight, retard moisture loss, and discourage weed growth (Figure 5.4C). On exposed sites, shade cards held upright with stakes can greatly reduce sunscald and moisture loss. Broad shingles or commercially available plastic cards should be placed on the south and southwest sides of outplanted seedlings.

5.4 Care After Outplanting

Now that the plants are in the ground, you can promote greater survival and growth by addressing four important factors: water, fertilization, weeds, and animals.

5.4.1 Water

Native plants are resilient and well-adapted to their environment. If grown well, properly hardened, and outplanted correctly in the absence of weeds, most species should survive and grow well without supplemental water. They will, however, respond if provided additional water after outplanting, especially during hot weather. If you decide to water plants after outplanting, remember that how often you need to water will depend on the soil and weather. Sandy soils don't retain moisture well so you'll have to water more often. On the other hand, clay soils hold moisture very well so you may not need to water for 2 or 3 weeks after a thorough watering. Water long enough to thoroughly moisten the root zone and encourage deep rooting (Figure 5.4B). If you are installing a windbreak of native trees and shrubs, a drip irrigation line is the most efficient way to water seedlings because it delivers moisture directly to each plant in a controlled and consistent manner—less water is wasted to run-off or evaporation. Stop watering about 1 month before the first frost.

5.4.2 Fertilization

Controlled-release fertilizers can be applied at the time of outplanting, either in the hole, in a dibble hole next to the plant, or around the base of the plant. In general, placing the fertilizer in a dibble hole alongside the plant makes the most sense because it reduces the possibility of fertilizer burn to roots and prevents nutrients from being "stolen" by competing vegetation. If you are watering your plants, it would be easy to dissolve soluble fertilizers in the solution (see Section 3.3.3.2.2, Fertigation); liquid fertilization ensures quick uptake and prevents possible fertilizer burn.

5.4.3 Weeds

Native plants grow better when weeds are controlled because weeds out-compete desired plants for water and nutrients. Good weed control greatly reduces the need for adding extra water and fertilizer. For reforestation, when outplanting on recently harvested sites, weeds generally aren't a major problem, although resprouting brush can limit seedling survival and growth. Planting former agricultural land is probably the worst-case scenario for weeds; maintain at least a 3 feet by 3 feet weed-free square around each plant for at least the first 2 to 3 years;

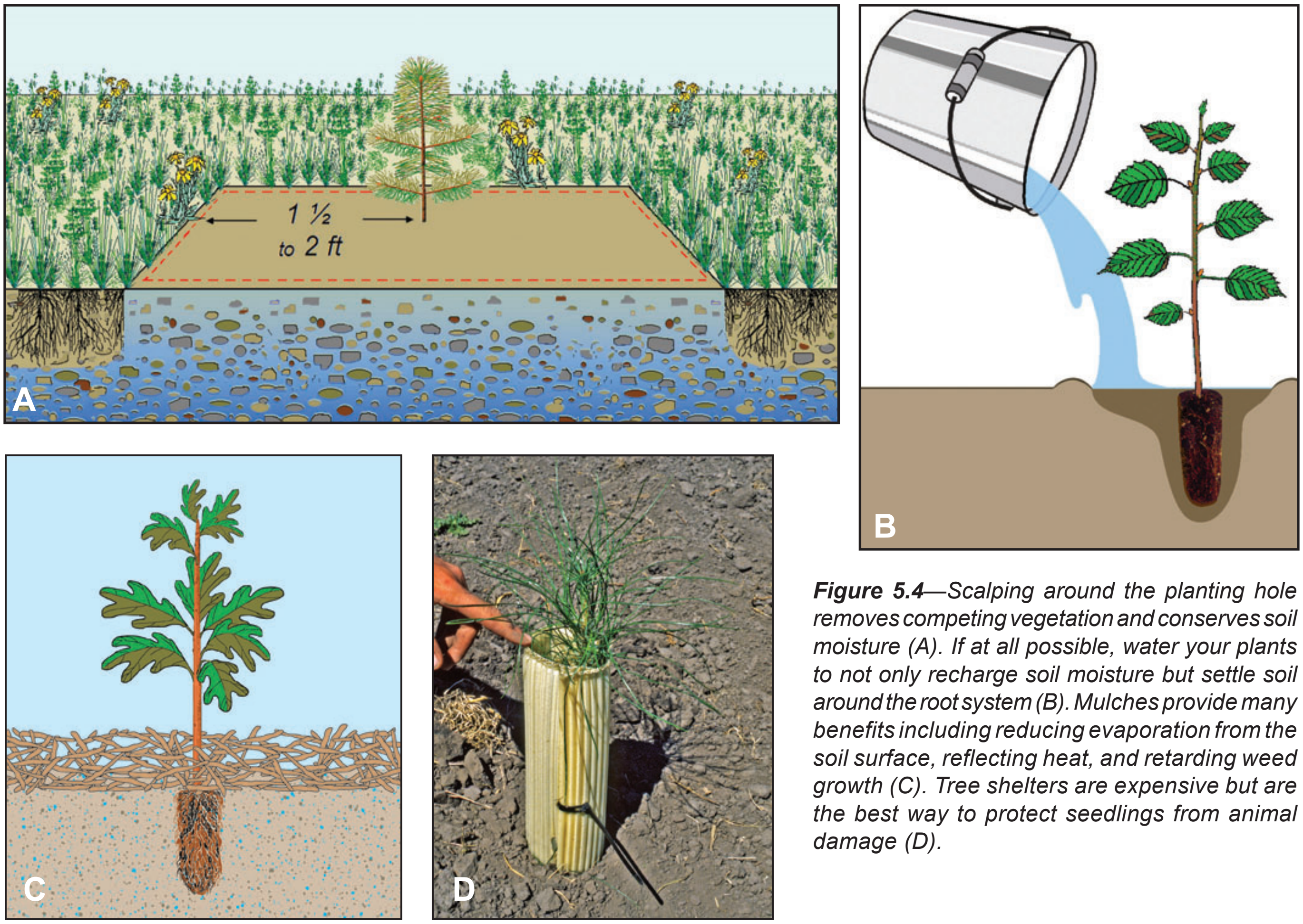

***Figure 5.4**—Scalping around the planting hole removes competing vegetation and conserves soil moisture (A). If at all possible, water your plants to not only recharge soil moisture but settle soil around the root system (B). Mulches provide many benefits including reducing evaporation from the soil surface, reflecting heat, and retarding weed growth (C). Tree shelters are expensive but are the best way to protect seedlings from animal damage (D).*

the longer the better (Figure 5.4A). Weed-free zones can be accomplished with hand weeding, herbicides, or fabric weed barriers. Maintaining shade and mulches (Figure 5.4C) may also increase seedling survival and growth. Using a pre-emergent herbicide immediately after outplanting can control weeds, especially annual weeds. Because pre-emergent herbicides can often be sprayed over the top of desired species, the application is much easier to perform; using herbicides on established weeds is more difficult because desired plants must be shielded from the spray. Before you use any herbicides, contact your local state forester, university county extension agent, or Natural Resources Conservation Service (NRCS) representative for information on the products currently available for your species. Always follow label directions to protect yourself, others, and the environment.

5.4.4 Animal Damage

Many critters eat native plants. Mice, moles, gophers, deer, elk, rabbits, and porcupines are just a few of the animals that can be troublesome. Solid plastic tubes or plastic mesh cylinders (Figure 5.4D) are products specifically made to reduce browse damage. If you plan to mow weeds around your plants, these tubes also protect against accidental damage, or "mower blight." Populations of small rodents can also be reduced by natural predators like hawks and owls. Placing some wooden fence posts or larger "snags" around the outplanting site offers predatory birds a place to sit and hunt. Remember that populations of small rodents are cyclic, so not observing a problem one year does not guarantee the same result in subsequent years. Rodenticides are also available, but great care should be taken not to accidentally poison non-target species like dogs, cats, hawks, and owls. Fencing works well for deer and elk but can be extremely expensive. A variety of spray-on repellents are available—they generally reduce, but don't eliminate, browsing. For best results, they should be reapplied frequently to cover new foliage.

5.5 Additional Reading

Landis, T.D.; Dumroese, R.K.; Haase, D.L. 2010. The container tree nursery manual. Volume 7, Seedling processing, storage, and outplanting. Agric. Handb. 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 200 p.

Appendix 6.1 Seed Characteristics of Some Common U.S. Plants

This appendix provides seed characteristics and treatments important for growing some common native plants of the United States. Information is provided by life form (conifer trees, deciduous trees, woody shrubs, forbs [wildflowers], grasses, and grass-like plants) and by very general distribution within the United States (eastern and western). Please consult local field guides to understand which plants are native to your area.

Refer to explanations in sections 2.6 (Seed Storage), 2.7 (Seed Dormancy), and 2.8 (Seed Treatments) when using this appendix.

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Appendix 6.1.1—Conifer Trees

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Eastern			
Abies balsamea	Balsam fir	11,000	28 days stratification
Larix laricina	Tamarack	250,000	60 days stratification
Picea rubens	Red spruce	139,000	None required
Pinus banksiana	Jack pine	131,000	0 to 7 days stratification
echinata	Shortleaf pine	46,000	60 days stratification
palustris	Longleaf pine	4,900	0 to 30 days stratification
resinosa	Red pine	52,000	0 to 30 days stratification
rigida	Pitch pine	62,000	None required
strobus	Eastern white pine	26,000	60 days stratification
taeda	Loblolly pine	18,200	30 to 60 days stratification
virginiana	Virginia pine	55,000	30 days stratification
Taxodium distichum	Bald cypress	5,000	30 days stratification
Taxus canadensis	Canada yew	21,000	270 days of stratification
Thuja occidentalis	Arborvitae	346,000	30 to 60 days stratification

(continued)

Appendix 6.1.1—(Continued)

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Western			
Abies amabilis	Pacific silver fir	12,000	28 days stratification
concolor	Concolor fir	11,000	28 to 60 days stratification
grandis	Grand fir	19,000	21 to 42 days stratification
lasiocarpa	Subalpine fir	34,000	28 to 42 days stratification
magnifica	California red fir	7,000	28 to 42 days stratification
procera	Noble fir	13,500	21 to 42 days stratification
Chamaecyparis lawsoniana	Port Orfordcedar	210,000	0 to 14 days stratification
nootkatensis	Alaska yellowcedar	108,000	30 to 90 days stratification
Juniperus californica	California juniper		30 to 120 days stratification
communis	Common juniper	36,000	45 to 90 days moist, warm treatment then 90 to 120 days stratification
occidentalis	Western juniper	12,000	45 to 90 days moist, warm treatment then 90 to 120 days stratification
osteosperma	Utah juniper	5,000	45 to 90 days moist, warm treatment then 90 to 120 days stratification
scopularum	Rocky Mountain juniper	27,000	45 to 90 days moist, warm treatment then 90 to 120 days stratification
Larix lyallii	Subalpine larch	142,000	28 days stratification
occidentalis	Western larch (tamarack)	137,000	28 days stratification
Libocedrus decurrens	Incense-cedar	15,000	28 to 60 days stratification
Picea breweriana	Brewer spruce	61,000	0 to 28 days stratification
engelmannii	Engelmann spruce	135,000	0 to 28 days stratification
pungens	Blue (Colorado) spruce	106,000	0 to 28 days stratification
sitchensis	Sitka spruce	210,000	None required
Pinus albicaulis	Whitebark pine	2,600	Tumble or sandpaper scarification, then 120 to 180 days stratification
aristata	Bristlecone pine	18,000	0 to 28 days stratification
attenuata	Knobcone pine	25,000	60 days stratification
balfouriana	Foxtail pine	17,000	90 to 120 days stratification
contorta var. *contorta*	Shore pine (coastal)	135,000	0 to 28 days stratification
contorta var. *latifolia*	Lodgepole pine (interior)	94,000	0 to 28 days stratification
edulis	Pinyon pine	1,900	0 to 60 days stratification
flexilis	Limber pine	4,900	21 to 90 days stratification
jeffreyi	Jeffrey pine	3,700	0 to 60 days stratification
lambertiana	Sugar pine	2,100	60 to 120 days stratification
monophylla	Singleleaf pinyon	1,110	28 to 90 days stratification
monticola	Western white pine	27,000	30 to 150 days stratification (14 days of warm, moist treatment prior to stratification may help)
ponderosa	Ponderosa pine	12,000	30 to 60 days stratification
Pseudotsuga menziesii			
var. *glauca*	Rocky Mountain Douglas-fir	44,000	21 to 42 days stratification
menziesii var. *menziesii*	Coastal Douglas-fir	39,000	14 to 21 days stratification
Taxus brevifolia	Pacific yew	15,000	90 to 200 days moist, warm treatment, then 60 to 120 days stratification
Thuja plicata	Western redcedar	414,000	0 to 21 days stratification
Tsuga heterophylla	Western hemlock	280,000	21 to 90 days stratification
mertensiana	Mountain hemlock	114,000	90 days stratification

Appendix 6.1.2—Deciduous Trees

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Eastern			
Acer saccharinum	Silver maple	1,780	42 to 90 days stratification
saccharum	Sugar maple	7,000	120 days stratification
Aesculus glabra	Ohio buckeye	58	60+ days stratification
Betula nigra	River birch	375,000	90 to 150 days stratification; sow seeds on the soil surface and kept moist during germination
Carya ovata	Shagbark hickory	100	60 days stratification
Cercis canadensis	Eastern redbud	18,000	Scarification, then 120 days stratification
Cornus florida	Dogwood	4,500	90 days stratification
Fagus grandifolia	Amrican beech	1,600	210 days stratification
Fraxinus pennsylvanica	White ash	19,000	60 days warm, moist treatment then 60 to 210 days stratification
Gleditsia triacanthos	Honey locust	2,800	Scarification
Gymnocladus dioicus	Kentucky coffee tree	230	Scarification, then 60 to 90 days stratification
Liriodendron tulipifera	Tuliptree	12,250	30 days stratification
Maclura pomifera	Osage orange	14,000	30 to 120 days stratification
Morus rubra	Red mulberry	360,000	30 to 120 days stratification
Nyssa sylvatica	Blackgum	2,500	30 to 120 days stratification
Platanus occidentalis	American sycamore	160,000	None required
Populus deltoides	Eastern cottonwood	350,000	None required; seeds need light to germinate so sow on soil surface and keep them moist during germination
Prunus serotina	Black cherry	2,400	120 to 180 days stratification (14 days warm, moist treatment before stratification may help)
Quercus alba	White oak	215	None required
bicolor	Swamp white oak	120	None required
rubra	Red oak	105	30 to 60 days stratification
velutina	Black oak	245	30 to 60 days stratification
Robinia pseudoacacia	Black locust	24,000	Scarification
Sassafras albidum	Sassafras	5,500	120 days stratification
Tilia americana	American basswood	3,000	Scarification, then 120 to 150 days stratification
Ulmus americana	American elm	70,000	None required; sow seeds on the soil surface and keep them moist during germination

(continued)

Appendix 6.1.2—(Continued)

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Western			
Acer glabrum	Rocky Mountain maple	13,430	90 to 180 days warm, moist treatment then 120 to 180 days stratification
grandidentatum	Bigtooth maple	6,350	120 days stratification
macrophyllum	Bigleaf maple	3,250	40 to 60 days stratification
Alnus incana	Thinleaf alder	675,000	60 to 90 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
rubra	Red alder	776,000	0 to 30 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
viridis	Sitka alder	998,000	60 to 90 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Arbutus menziesii	Pacific madrone	258,500	42 to120 days stratification
Betula papyrifera	Paper birch	1,380,000	60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Chilopsis linearis	Desert willow	86,000	0 to 60 days stratification
Cercis orbiculata	California redbud	27,460	Scarification then 0 to 120 days stratification
Cornus nuttallii	Pacific dogwood	4,700	Scarification then 90 days stratification
Corylus cornuta var. *californica*	California hazelnut	486	60 to 120 days stratification
Frangula purshiana	Cascara	12,000	Scarification then 30 to 140 days stratification
Fraxinus latifolia	Oregon ash	12,000	30 to 90 days warm, moist treatment then 90 days stratification
velutina	Velvet leaf ash	20,600	30 to 90 days stratification
Populus balsamifera	Black cottonwood		None required; seeds need light to germinate so sow on soil surface and keep them moist during germination
fremontii	Fremont cottonwood		None required; seeds need light to germinate so sow on soil surface and keep them moist during germination
tremuloides	Quaking aspen	3,600,000	None required; seeds need light to germinate so sow on soil surface and keep them moist during germination
Prosopis juliflora	Mesquite	12,500	Scarification
Quercus gambelii	Gambel oak	325	60 to 90 days stratification
garryana	Oregon white oak	85	None required
kelloggii	California black oak	95	30 to 45 days stratification
Robinia neomexicana	New Mexico locust	21,600	Scarification
Salix species	Willow	Millions	None required; seeds need light to germinate so sow on soil surface and keep them moist during germination
Sorbus scopulina	Cascade Mountain ash	138,000	120 to 180 days stratification

Appendix 6.1.3—Woody Shrubs

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Eastern			
Amelanchier laevis	Serviceberry	80,000	30 to 60 days stratification
Asimina triloba	Pawpaw	700	60 days stratification
Callicarpa americana	Beautyberry	272,000	60 days stratification
Calycanthus floridus	Eastern sweetshrub	85,000	30 days stratification
Cornus obliqua	Silky dogwood	12,000	100 to 120 days stratification
sericea	Redoiser dogwood	18,500	90 days stratification (scarification before stratification may help)
Corylus americana	American hazelnut	490	60 to 180 days stratification
Euonymus americanus	Bursting-heart	35,000	140 days stratification
Gaultheria hispidula	Creeping snowberry	3,000,000	83 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
procumbens	Eastern teaberry	3,000,000	None required; seeds need light to germinate so sow on soil surface and keep them moist dur ing germination
Hamamelis virginiana	American witchhazel	9,000	120 days stratification
Juniperus communis	Common juniper	36,000	30 to 180 days stratification
Lindera benzoin	Northern spicebush	4,500	90 days stratification
Prunus americana	American plum	870	90 to 120 days stratification (may need to remove pit)
virginiana	Chokecherry	4,800	90 to 120 days stratification
Symphoricarpos albus	Common snowberry	140,000	60 to 90 days warm, moist treatment then 90 to 120 days stratification
Vaccinium angustifolium	Lowbush blueberry	2,000,000	0 to 60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
corymbosum	Highbush blueberry	1,000,000	0 to 60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination

(continued)

Appendix 6.1.3—(Continued)

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Western			
Amelanchier alnifolia	Serviceberry	82,000	120 to 150 days stratification
Arctostaphylos patula	Manzanita		Scarification (may need 90 days of warm, moist treatment before germination occurs)
uva-ursi	Bearberry	58,000	Scarification, then 60 to 90 days warm, moist treatment then 90 to 120 days stratification
Artemisia cana	Silver sagebrush	1,300,000	60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
tridentata	Big sagebrush	2,140,000	30 to 90 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Atriplex canescens	Fourwing saltbush	23,000	After-ripen in dry storage for 90 days then 60 days stratification
Ceanothus velutinus	Snowbrush ceanothus	94,000	Scarification, then 90 days stratification
Cercocarpus ledifolius	Curlleaf mountain mahogany	48,200	14 to 120 days stratification
Cornus sericea	Redoiser dogwood	18,500	90 days stratification (scarification before stratification may help)
Crataegus douglasii	Black hawthorn	22,600	90 to 120 90 days stratification (scarification before stratification may help)
Ephedra species	Mormon tea	19,000	60 to 90 days stratification
Ericameria nauseosa	Rubber rabbitbrush	600,000	60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Holodiscus discolor	Oceanspray	5,000,000	120 days stratification
Mahonia repens	Creeping Oregon-grape	51,000	90 to 120 days warm, moist treatment then 90 to 120 days stratification
Philadelphus lewisii	Lewis' mockorange	5,300,000	21 to 75 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Physocarpus malvaceus	Western ninebark	748,800	90 to 120 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Prunus americana	American plum	870	90 to 120 days stratification (may need to remove pit)
virginiana	Chokecherry	4,800	90 to 120 days stratification
Purshia mexicana	Mexican cliffrose	75,000	60 to 90 days stratification
tridentata	Antelope bitterbrush	15,400	60 to 90 days stratification
Rhus trilobata	Skunkbush sumac	20,300	Scarification, then 90 days stratification
Rosa woodsii	Woods' rose	50,000	60 to 90 days warm, moist treatment then 90 days stratification
Sambucus nigra var. *cerulea*	Blue elderberry	234,000	90 to 120 days stratification
Shepherdia argentea	Silver buffaloberry	40,000	60 to 90 days stratification
Symphoricarpos albus	Common snowberry	140,000	60 to 90 days warm, moist treatment then 90 to 120 days stratification
Vaccinium species	Huckleberry	1,500,000	0 to 60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination

Appendix 6.1.4—Forbs (Wildflowers)

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Eastern			
Aquilegia canadensis	Eastern columbine	504,000	90 days stratification
Asclepias syriaca	Common milkweed	48,000	90 days stratification; sow seeds on the soil surface and keep them moist during germination
tuberosa	Butterfly milkweed	70,000	90 days stratification; sow seeds on the soil surface and keep them moist during germination
Aster novae-angliae	New England Aster	1,200,000	60 days stratification
Baptisia australis	Blue false indigo	26,000	Scarification (seeds may benefit from stratification after scarification)
Bidens cernua	Nodding bur marigold	130,000	84 days stratification
Coreopsis lanceolata	Lance leaved coreopsis	220,000	90 days stratification
Dalea purpurea	Purple prairie clover	290,000	Scarification
Echinacea purpurea	Eastern purple coneflower	115,000	90 to 120 days stratification
Eupatorium fistulosum	Joe-pye weed	2,000,000	90 days stratification
Gaillardia pulchella	Firewheel	238,000	None required
Heliopsis helianthoides	Smooth oxeye	105,000	None required
Liatris spicata	Blazing star	100,000	None required but 90 days stratification may help
Lobelia cardinalis	Cardinal flower	1,000,000	None required; seeds need light to germinate so sow on soil surface and keep them moist during germination
Monarda fistulosa	Wild bergamot	1,250,000	90 days stratification
Oenothera speciosa	Showy evening primrose	3,000,000	None required
Penstemon digitalis	Smooth beardtounge	1,800,000	90 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Ratibida pinnata	Grey headed coneflower	1,000,000	30 days stratification
Rudbeckia triloba	Browneyed Susan	500,000	None required
Senna marilandica	Maryland senna	20,500	Scarification then 90 days stratification
Solidago nemoralis	Gray goldenrod	1,000,000	90 days stratification
Tephrosia virginiana	Goats rue	32,000	14 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Verbena hastata	Blue vervain	1,600,000	None required; seeds need light to germinate so sow on soil surface and keep them moist during germination
Vernonia gigantea	Giant ironweed	300,000	90 to 140 days stratification
Veronicastrum virginicum	Culver's root	7,750,000	21 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination; seeds do not tolerate any drying

(continued)

Appendix 6.1.4—(Continued)

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Western			
Achillea millefolium	Yarrow	2,770,000	0 to 14 days stratification
Aquilegia species	Columbine	432,000	60 to 90 days stratification
Asclepias speciosa	Showy milkweed	245,000	30 to 60 days stratification; sow seeds on the soil surface and keep them moist during germination
Aster laevis	Smooth blue aster	1,100,000	0 to 30 days stratification
Balsamorhiza sagittata	Arrowleaf balsamroot	55,000	90 to 120 days stratification
Dodecatheon species	Shootingstar	1,200,000	60 to 90 days stratification
Castilleja linariifolia	Wyoming Indian paintbrush	4,915,000	60 to 90 days stratification
miniata	Giant red Indian paintbrush	4,900,000	60 to 90 days stratification
Echinacea angustifolia	Blacksamson echinacea	128,000	30 to 90 days stratification
Eriogonum umbellatum	Sulfur buckwheat	209,000	60 to 90 days stratification
Gaillardia aristata	Indian blanketflower	132,000	0 to 30 days stratification
Heuchera cylindrica	Alumroot	6,363,000	30 to 60 days stratification
Iliamna rivularis	Mountain hollyhock	45,450	Scarification then 60 days stratification
Liatris punctata	Dotted blazing star	139,000	30 days stratification
Lupinus sericeus	Silky lupine	12,900	Scarification then 30 to 60 days stratification
Monarda fistulosa	Wild bergamot	1,498,000	30 to 60 days stratification
Oenothera pallida	White evening primrose	2,500,000	30 to 60 days stratification
Oxytropis species	Locoweed	594,000	Scarification then 0 to 60 days stratification
Penstemon eatonii	Firecracker penstemon	600,000	60 days stratification
nitidus	Shining penstemon	550,000	60 to 90 days stratification
strictus	Rocky Mountain penstemon	592,000	60 to 90 days stratification
Ratibida columnifera	Prairie coneflower	1,230,000	0 to 30 days stratification
Rudbeckia hirta	Blackeyed Susan	1,710,000	0 to 30 days stratification
Sphaeralcea coccinea	Scarlet globe mallow	500,000	Scarification then 0 to 30 days stratification
Wyethia amplexicaulis	Mule ears	24,625	0 to 60 days stratification

Appendix 6.1.5—Grasses and Grass-Like Plants

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Eastern			
Agrostis perennans	Upland bentgrass	8,000,000	None required
Andropogon gerardii	Big bluestem	144,000	90 days stratification
Bouteloua curtipendula	Sideoats gamma	710,000	None required
Calamagrostis canadensis	Bluejoint	3,300,000	None required
Carex scoparia	Blunt broom sedge	1,300,000	60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Chasmanthium latifolium	Indian woodoats	90,000	None required
Danthonia spicata	Poverty oatgrass	448,000	None required (tumble scarification may help)
Elymus canadensis	Canada wildrye	114,000	None required but 14 days stratification improves germination
virginicus	Virginia wild rye	100,000	None required
Juncus effusus	Common rush	4,500,000	0 to 270 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Leersia oryzoides	Rice cutgrass	5,000,000	None required
Panicum virgatum	Switchgrass	259,000	14 days stratification
Schizachyrium scoparium	Little bluestem	240,000	30 to 60 days stratification
Scirpus cyperinus	Wool bulrush	9,000,000	30 to 120 days stratification; sow seeds on the soil surface and keep them moist during germination
Sorghastrum nutans	Indian grass	175,000	Dry, cool storage for 90 days; or, 90 days cold stratification
Sporobolus compositus	Tall dropseed	750,000	None required
Tridens flavus	Purpletop tridens		14 to 90 days stratification

(continued)

Appendix 6.1.5—(Continued)

Scientific name	Common name	Average seeds per pound	Seed treatment(s)
Western			
Achnatherum hymenoides	Indian ricegrass	141,000	Tumble or sandpaper scarification then 0 to 30 days stratification
Bouteloua curtipendula	Sideoats grama	191,000	0 to 30 days stratification
Carex aquatilis	Water sedge	485,000	30 to 90 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
*micropter*a	Small wing sedge	847,000	60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
nebrascensis	Nebraska sedge	534,100	60 to 90 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
urticulata	Beaked sedge	444,000	30 to 60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Eleocharis palustris	Common spikerush	620,000	0 to 90 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Festuca idahoensis	Idaho fescue	450,000	0 to 30 days stratification
Hesperostipa comata	Needle and thread	115,000	0 to 14 days stratification
Juncus balticus	Baltic rush	10,900,000	60 to 90 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
torreyi	Torrey rush	12,300,000	30 to 90 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
Nassella viridula	Green needlegrass	181,000	0 to 30 days stratification
Schoenoplectus acutus	Hardstem bulrush	377,600	Tumble or sandpaper scarification then 30 to 60 days stratification
americanus	Chairmaker's bulrush	179,800	30 to 60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination
tabernaemontani	Softstem bulrush	550,000	30 to 60 days stratification; seeds need light to germinate so sow on soil surface and keep them moist during germination

Appendix 6.2. More Intensive Fertilization for Bareroot Seedlings: An Introduction

The percentage of N, P, and K in a bag of fertilizer is always given in the order of N:P:K. Well, that's not quite right. Because of some archaic convention, the percentages of P and K are really given as percentages of the oxides of P and K: P_2O_5 and K_2O. Therefore, a bag of 8:10:3 has 8% N, 10% P_2O_5, and 3% K_2O by weight. To convert P_2O_5 to P, you'll need to multiply the percentage of P_2O5 by 0.437. Similarly, to convert K_2O to K, multiply K_2O by 0.83. This process may sound confusing, but let's work through an example using this equation:

Let's say we want to use some 8:10:3 fertilizer, we want to apply 35 pounds of N per acre, and our nursery bed is 4 feet wide and 45 feet long (180 square feet).

First, divide 35 pounds of N by the percentage of N in the fertilizer (0.08):

$35 \div 0.08 = 438$ pounds of fertilizer per acre to get 35 pounds of N per acre.

Divide the 438 pounds of fertilizer by 43,560 (the number of square feet in an acre):

$438 \div 43{,}560 = 0.01$ pounds of fertilizer per square foot.

Multiply 0.01 pounds of fertilizer per square foot by the 180 square feet in the nursery bed:

$0.01 \times 180 = 1.8$ pounds of fertilizer should be applied to the nursery bed.

Okay, how much P and K were applied at the same time?

For P, multiply the 1.8 pounds of fertilizer by 0.1 (remember there's 10% P_2O_5 in the fertilizer):

$1.8 \times 0.1 = 0.18$ pounds of P_2O_5 were also applied to the nursery bed.

Convert that to P:

$0.18 \times 0.437 = 0.08$ pounds of P were applied to the nursery bed.

You may convert that back to a pounds-per-acre rate by dividing it by 180 (that gives you pounds of P per square foot) and then multiplying by 43,560:

$0.08 \div 180 = 0.000044$ and $0.000044 \times 43{,}560 = 19$ pounds of P per acre.

Similarly, to determine how much K was applied, take the 1.8 pounds of fertilizer and multiply it by 0.03 (3% K_2O in the fertilizer); we applied 0.05 pounds of K_2O. Convert that to K by multiplying 0.05 pounds of K_2O by 0.83; 0.04 pounds of K. Like P, you can convert back to pounds of K per acre by dividing by 180 and multiplying by 43,560; we applied 9.7 pounds of K per acre.

In commercial bareroot nurseries, commonly used fertilizers are ammonium phosphate (11:55:0), ammonium nitrate (33:0:0), ammonium sulfate (21:0:0), calcium superphosphate (0:20:0), triple superphosphate (0:45:0), and potassium sulfate (0:0:50). In general, if you have a soil with pH less than 6.0, your fertilizers of choice would be ammonium phosphate and ammonium nitrate. These fertilizers help maintain your pH around 5.0 to 6.0. However, if your soil pH is on the high side (over 6.0) use ammonium sulfate.

One advantage of using single element fertilizers is the ease of manipulating the amounts of each nutrient applied; only one nutrient is in each fertilizer formulation. Commercial operators have the luxury of using a particular fertilizer to apply a particular nutrient. Novice growers who wish to use an organic alternative may find that their choices for fertilizers usually include multiple nutrients per fertilizer formulations (for example, 9:1:1 or 0:3:1). This means more arithmetic for organic farmers because they may have to do some "tinkering" with their formulations and application amounts to achieve recommended fertilizer rates.

Regardless of your situation, right before the first growing season, plan on incorporating P and K into your nursery beds. If you have a good sandy soil, add some N as well. If your soil is too acidic (pH under 5) or too basic (pH over 6) for conifer seedlings, this is also the time to add lime to bring the pH back up or sulfur to lower pH. Use a whirly-bird-type spreader or drop-type spreader to apply fertilizer. You may have to mix it with sand to have enough material to fill your spreader and ensure an even application. Make sure it's applied evenly! Spade or rototill the fertilizer into the soil. Once your crop is growing, you'll need to topdress N and K over the top of your seedlings. If damping-off is a problem, avoid early applications of N during the first season.

Appendix 6.2.1.—Intensive Bareroot Fertilization for Soil With Ph Less Than 6.0.

Year	Timing	Nutrient	Number of applications	Rate (pounds per acre)	Fertilizer (see footnote)	Ounces of fertilizer per 100 square feet
First Season	Pre-sow	N	1	35	11:55:0 [A]	12
		P	1	120	0:20:0	18
		K	1	45	0:0:62	3
	Top-dress	N	4 (mid-June, early and mid-July, & late September)	20	33:0:0	2
		K	1 (mid-summer)	20	0:0:62	1.5
Second Season	Top-dress	N	1 (March)	35	33:0:0	3.5
		K	1 (March)	20	0:0:62	1.5
		N	4 (May, June, July, late September)	20	33:0:0	2
		K	2 (early and mid-summer)	20	0:0:62	1.5
Transplants	Pre-plant	P	1	60	0:20:0	25
		K	1	45	0:0:62	1.5
	Top-dress	N	4 (May, June, July, late September)	40	33:0:0	4
		K	2 (early and mid-summer)	20	0:0:62	1.5

Fertilizers:
11:55:0 Ammonium phosphate
33:0:0 Ammonium nitrate
0:20:0 Calcium superphosphate
0:0:62 Potassium chloride

[A] Note the application of 12 oz of 11:55:0 supplies the necessary rate of N (35 lbs per acre) and 78 lbs of the suggested 120 lbs of P per acre. Therefore, the amount of 0:20:0 supplies only 42 lbs of P per acre (the difference between 120 and 78).

Adapted from: van den Driessche, R. 1984. Soil fertility in forest nurseries. In: Duryea, M.L.; Landis, T.D., eds. Forest nursery manual: production of bareroot seedlings. The Hague; Boston; Lancaster: Martinue Nijhoff/Dr. W. Junk Publishers. For Forest Research Laboratory, Oregon State University, Corvallis: 63-74.

Appendix 6.2.2.—Intensive Bareroot Fertilization for Soil With Ph Greater Than 6.0.

Year	Timing	Nutrient	Number of applications	Rate (pounds per acre)	Fertilizer (see footnote)	Ounces of fertilizer per 100 square feet
First Season	Pre-sow	N	1	35	11:55:0 [A]	12
		P	1	120	0:45:0	8
		K	1	45	0:0:50	4
	Top-dress	N	4 (mid-June, early and mid-July, & late September)	20	21:0:0	3.5
		K	1 (mid-summer)	20	0:0:50	2
Second Season	Top-dress	N	1 (March)	35	21:0:0	6
		K	1 (March)	20	0:0:50	2
		N	4 (May, June, July, late September)	20	21:0:0	3.5
		K	2 (early and mid-summer)	20	0:0:50	2
Transplants	Pre-plant	P	1	60	0:45:0	11
		K	1	45	0:0:50	2
	Top-dress	N	4 (May, June, July, late September)	40	21:0:0	7
		K	2 (early and mid-summer)	20	0:0:50	2

Fertilizers:
11:55:0 Ammonium phosphate
21:0:0 Ammonium sulfate
0:45:0 Triple superphosphate
0:0:50 Potassium sulfate

[A] Note the application of 12 oz of 11:55:0 supplies the necessary amount of N (35 lbs per acre) and 78 lbs of the suggested 120 lbs of P per acre. Therefore, the amount of 0:45:0 supplies only 42 lbs of P per acre (the difference between 120 and 78).

Adapted from: van den Driessche, R. 1984. Soil fertility in forest nurseries. In: Duryea, M.L.; Landis, T.D., eds. Forest nursery manual: production of bareroot seedlings. The Hague; Boston; Lancaster: Martinue Nijhoff/Dr. W. Junk Publishers. For Forest Research Laboratory, Oregon State University, Corvallis: 63-74.

Appendix 6.2.3.—Organic Fertilization of Bareroot Seedlings

Year	Timing	Nutrient	Number of applications	Rate (pounds per acre)	Fertilizer (see footnote)	Ounces of fertilizer per 100 square feet
First Season	Pre-sow	N	1	35	9:1:1 [A]	14
		P	1	120	0:7:0	98
		K	1	45	0:3:1	58
	Top-dress	N	4 (mid-June, early and mid-July, & late September)	20	9:1:1 [B]	8
		K	1 (mid-summer)	20	0:0:7	8
Second Season	Top-dress	N	1 (March)	35	9:1:1 [C]	14
		K	1 (March)	20		
		N	4 (May, June, July, late September)	20	9:1:1	8
		K	2 (early and mid-summer)	20	0:0:7	10
Transplants	Pre-plant	P	1	60	0:3:1 [D]	168
		K	1	45	0:0:7	4
	Top-dress	N	4 (May, June, July, late September)	40	9:1:1 [E]	16
		K	2 (early and mid-summer)	20	0:0:7	8

Fertilizers:
9:1:1 Ocean Fresh Fish Powder
0:7:0 Budswel
0:3:1 Earth Juice Bloom
0:0:7 Greensand

[A] Applying 14 oz of 9:1:1 supplies 34 lbs of N, 16 lbs of P, and 32 lbs of K per acre. Applying 58 oz of 0:3:1 supplies the remaining 13 lbs of K (45 lbs total) and 21 more lbs of P Since we've only applied 37 lbs of P, apply 98 oz of 0:7:0 to supply the final 82 lbs of P suggested (120 lbs total).
[B] Four applications of 9:1:1 also supply 7.2 lbs of K (1.8 lbs per application). Therefore, we only need 8 oz of 0:0:7 (12.6 lbs of K) to achieve the suggested 20 lbs of K.
[C] Applying 14 oz of 9:1:1 supplies 34 lbs of N and 32 lbs of K per acre, which also satisfies our K requirement.
[D] Applying 168 oz of 0:3:1 provides 60 lbs of P and 38 lbs of K, so an additional 4 oz of 0:0:7 supplies 7 lbs of K to bring the total to the recommended rate of 45 lbs.
[E] Four applications of 9:1:1 also supply 14.4 lbs of K (3.6 lbs per application). Therefore, we only need 2 applications of 8 oz of 0:0:7 (12.6 lbs of K each application) to achieve the suggested 40 lbs of K.

Adapted from: van den Driessche, R. 1984. Soil fertility in forest nurseries. In: Duryea, M.L.; Landis, T.D., eds. Forest nursery manual: production of bareroot seedlings. The Hague; Boston; Lancaster: Martinue Nijhoff/Dr. W. Junk Publishers. For Forest Research Laboratory, Oregon State University, Corvallis: 63-74.

Appendix 6.3. Calculating the Number of Seeds to Sow per Container Using a Hand-Held Calculator

The technique is based on the concept that a seed either grows or it doesn't (binomial probability). If "X" equals the probability of a seed germinating and "Y" equals the probability of it failing to germinate, a binomial expansion can be constructed that includes all possible occurrences. The following example shows the possibilities when 2 seeds are sown per container:

$$(X+ Y)^2 = X^2 + 2XY + Y^2$$

where: X^2 = the probability of both seeds germinating
$2XY$ = the probability of only one germinating
Y^2 = the probability of neither seed germinating

So, as long as germination test data are known, the proper number of seeds to sow per container can be easily determined by entering the "germination failure" on a hand-held calculator with a universal power key (Y^X , X^Y, x^y, or something similar). The procedure consists of keying in the decimal equivalent of the germination failure, pushing the universal power key, entering the number of seeds you might sow, and finally pushing the "equals" key. If your calculator doesn't have a universal power key, then just use repeated multiplication. For example, a seedlot with 78% germination has a 22% failure score:

Seeds per container	Percentage of Empty Containers	
	Using Y^X key	Using repeated multiplication
1	$(0.22)^1$ = 0.22 = 22%	0.22 = 22%
2	$(0.22)^2$ = 0.0484 = 4.8%	0.22 x 0.22 = 0.0484 = 4.8%
3	$(0.22)^3$ = 0.0106 = 1.1%	0.22 x 0.22 x 0.22 = 0.0106 = 1.1%
4	$(0.22)^4$ = 0.0023 = 0.2%	0.22 x 0.22 x 0.22 x 0.22 = 0.0023 = 0.2%

You can see that the calculation becomes a "law of diminishing returns," and the best number of seeds to sow will depend on seed availability, seed cost, cost of thinning, and the reliability of the germination test. In this example, most nurseries would be satisfied with sowing 2 to 3 seeds per container.

Source: Schwartz, M. 1993. Germination math: calculating the number of seeds necessary per cavity for a given number of live seedlings. Tree Planters' Notes 44(1):19-20.

Appendix 6.4. Soluble Fertilizer Chemicals that Provide Macronutrients for Custom Fertilizer Solutions for Container Seedlings

		% of Nutrient Supplied						
Compound	**Chemical formula**	**NH_4-N**	**NO_3-N**	**P**	**K**	**Ca**	**Mg**	**S**
Ammonium nitrate	NH_4NO_3	17	17	—	—	—	—	—
Ammonium sulfate	$(NH_4)_2SO_4$	21	—	—	—	—	—	24
Calcium nitrate	$Ca(NO_3)_2$	—	15	—	—	17	—	—
Diammonium phosphate	$(NH_4)_2HPO_4$	21	—	24	—	—	—	—
Dipotassium phosphate	K_2HPO_4	—	—	18	45	—	—	—
Magnesium sulfate	$MgSO_4$	—	—	—	—	—	10	13
Monoammonium phosphate	$NH_4H_2PO_4$	11	—	21	—	1	—	3
Monopotassium phosphate	KH_2PO_4	—	—	23	28	—	—	—
Nitric acid	HNO_3	—	22	—	—	—	—	—
Phosphoric acid	H_3PO_4	—	—	32	—	—	—	—
Potassium carbonate	K_2CO_3	—	—	—	56	—	—	—
Potassium chloride	KCl	—	—	—	52	—	—	—
Potassium nitrate	KNO_3	—	13	—	37	—	—	—
Potassium sulfate	K_2SO_4	—	—	—	44	—	—	18
Sodium nitrate	$NaNO_3$	—	16	—	—	—	—	—
Sulfuric acid	H_2SO_4	—	—	—	—	—	—	33
Urea	$CO(NH_2)_2$	45	—	—	—	—	—	—

Adapted from: Table 4.1.23—Soluble fertilizer chemicals that provide macronutrients for custom fertilizer solutions. Found in: Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. 1989. The container tree nursery manual. Volume 4, Seedling nutrition and irrigation.. Agric. Handb. 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 119 p.

Appendix 6.5. Calculating Parts Per Million and More Intensive Fertilization for Container Seedlings

If you use any other fertilizers than the ones listing in Table 3.8, you'll need to determine how much fertilizer to mix in a volume of water to get the suggested ppm. Before we calculate ppm, let's first review fertilizer in general. As discussed for bareroot seedlings, the percentage of N, P, and K in a bag of fertilizer is always given in the order of N:P:K. And as was the case for bareroot seedlings, that's not quite right. The percentages of P and K are really given as the percentages of the oxides of P and K: P_2O_5 and K_2O. Therefore, a bag of 30:10:10 has 30% N, 10% P_2O_5, and 10% K_2O by weight. To convert P_2O_5 to P, you'll need to multiply the percentage of P_2O_5 by 0.437. Similarly, to convert K_2O to K, multiply K_2O by 0.83.

Fortunately, for fertilization of container seedlings more interest is on the rate of N. Many professional growers fertilize their crops with rates expressed in "some weight of fertilizer mixed in some volume of water" (ounces per 100 gallons, or pounds per 1,000 gallons). Some growers use some weight of N per volume of water. Finally, some growers fertilize using parts per million (ppm) or even milligrams of a nutrient per volume of water, both of which are just a more refined version of "some weight of fertilizer mixed in some volume of water."

Calculating ppm's isn't really that difficult. A good rule of thumb is that one ounce of granular fertilizer in 100 gallons of water equals about 75 ppm of fertilizer. If your fertilizer is 30% N, then the ppm N in that solution is 75 x 0.3 = 22.5 ppm N.

If you wanted 135 ppm N, you would have to divide 135 ppm N by the percentage of N in the fertilizer (30%) and divide that by 75:

135 ppm ÷ 0.3 ÷ 75 = 6 ounces of fertilizer in 100 gallons.

If your fertilizer is 10% P_2O_5, then the ppm P_2O_5 when you mix 1 ounce of fertilizer in 100 gallons of water is 75 x 0.1 = 7.5 ppm P_2O_5. Remember to multiply 7.5 by 0.437 to convert P_2O_5 to P (7.5 x 0.437 = 3 ppm P) and multiply 7.5 by 0.83 to convert K_2O to K (7.5 x 0.83 = 6 ppm K).

Some professional growers strictly use premixed fertilizers (like Peters Conifer Grower®), some use a combination of premixed and custom-mixed fertilizers, and some only used custom-mixed. The discrepancy usually depends on the background of the grower. Growers using custom-mixed fertilizer feel they have better control over the growth of their seedlings, and can manipulate fertilizers to achieve particular growth responses in the crop. Customized fertilizers blend the "science" of growing seedlings with the "art" of growing seedlings, and usually experience is key. Most growers like to add calcium to their fertilizers (not found in Miracid or Miracle-Gro) to promote stem diameter development in their seedlings. Some growers like to reduce the rate of N while maintaining high levels of K to promote bud initiation and hardening; raising K levels can be easily done with a custom-mixed fertilizer. Commonly used fertilizers for growing container seedlings can be found in Appendix 6.4.

As mentioned earlier, the actual rates necessary vary from locale to locale, and the following example in Appendix 6.5.1 shows the tremendous variability found among four nurseries in the northern Rocky Mountains in regard to how they fertilize a crop of ponderosa pine seedlings. Amazingly, all four nurseries grow excellent seedlings that thrive once outplanted. So go ahead, experiment! Keep detailed notes so you can develop your own "art" in seedling production.

Appendix 6.5.1. Fertilization of a Container Crop of Ponderosa Pine

Ratios of N:P:K:Ca (ppm) applied to ponderosa pine crops up to the time of bud initiation at four nurseries in the northern Rocky Mountains. Stock solution recipes for these ppm rates are provided below as amounts of fertilizer per 100 gallons of water. See Appendix 6.4 for fertilizer abbreviations.

Nursery	Weeks after sowing								
	2	3	4	5	6	7 to 9	10	11 to 12	13
1	70:120:110:140			110:80:120:140	140:80:120:140	185:80:105:120	230:80:120:120		
2	42:176:83:0					60:82:47:0 alternated with 81:0:0:42		81:0:0:42	
3	59:134:49:0	92:0:0:101 alternated with 163:0:452:0							
4	30:69:172:0	44:30:51:31	88:30:102:62	179:30:136:149 alternated with 186:30:0:198					

Nursery #1

Weeks 2 to 4
3.5 fluid oz CAN-17
4 oz KH_2PO_4
1 oz K_2SO_4

Week 5
3 fluid oz CAN-17
1 oz NH_4NO_3
2 oz KNO_3
3.5 oz $CaCl_2$
1.5 oz KH_2PO_4
1 oz K_2SO_4

Week 6
3.5 fluid oz CAN-17
2 oz NH_4NO_3
2 oz KNO_3
3.5 oz $CaCl_2$
1.5 oz KH_2PO_4
1 oz K_2SO_4

Weeks 7 to 9
5.5 fluid oz CAN-17
2 oz NH_4NO_3
2 oz KNO_3
2 oz $CaCl_2$
1.5 oz KH_2PO_4
1 oz K_2SO_4

Weeks 10 to 12
6.5 fluid oz CAN-17
3 oz NH_4NO_3
2 oz KNO_3
1 oz $CaCl_2$
1.5 oz K_3PO4_4
1 oz K_2SO_4

Nursery #2

Weeks 2 to 6
8 oz Peters Conifer Starter (7:40:17)

Weeks 7 to 10
8 oz Peters Conifer Grower (20:17:19) alternated with 4 fluid oz CAN-17

Weeks 11 to 12
4 fluid oz CAN-17

Nursery #3

Week 2
8 oz 10:52:10

Weeks 3 to 13
8 oz $Ca(NO_3)_2$ alternated with 16 oz KNO_3

Nursery #4

Week 2
8 oz 5:15:35

Week 3
2.5 oz $Ca(NO_3)_2$
1.5 oz KNO_3

Week 4
5 oz $Ca(NO_3)_2$
3 oz KNO_3

Weeks 5 to 12
12 oz $Ca(NO_3)_2$
4 oz KNO_3 alternated with 16 oz $Ca(NO_3)_2$

Nursery	Weeks after sowing						
	13	14	15	16	17 to 19	20 to 22	23 to extraction (30 to35)
1	20:90:120:190				60:90:120:185		
2	81:0:0:42				24:138:173:0 alternated with 162:0:0:84		
3		69:0:0:75 alternated 61:0:169:0					
4	0:30:94:106 alternated with 0:165:169:0 alternated with 0:30:314:0		44:30:51:31		88:30:102:62	133:30:136:99	179:30:136:149 alternated with 186:30:0:4198

Nursery #1	**Nursery #2**	**Nursery #3**	**Nursery #4**
Weeks 13 to 16 1 fluid oz CAN-17 6.5 oz $CaCl_2$ 2.5 oz KH_2PO_4 2 oz K_2SO_4 Weeks 17 to extraction 3 fluid oz CAN-17 1 oz KNO_3 5.5 oz $CaCl_2$ 2.5 oz KH_2PO_4 1.5 oz K_2SO_4	Weeks 13 to 16 4 fluid oz CAN-17 Weeks 17 to extraction 8 oz Peters Conifer Finisher (4:25:35) alternated with 8 fluid oz CAN-17	Week 14 to extraction 6 oz $Ca(NO_3)_2$ alternated with 6 oz KNO_3	Weeks 13 to 14 4 oz $CaCl_2$ 2.4 oz KCl alternated with 8 oz K_3PO_4 alternated with 8 oz KCl Weeks 15 to 16 2.5 oz $Ca(NO_3)_2$ 1.5 oz KNO_3 Weeks 17 to 19 5 oz $Ca(NO_3)_2$ 3 oz KNO_3 Weeks 20 to 22 8 oz $Ca(NO_3)_2$ 4 oz KNO_3 Weeks 23 to extraction 12 oz $Ca(NO_3)_2$ 4 oz KNO_3 alternated with 16 oz $Ca(NO_3)_2$

Adapted from: Dumroese, R.K.; Wenny, D.L. 1997. Fertilizer regimes for container-grown conifers of the Intermountain West. In: Haase, D.L.; Rose, R., coords. & eds. Symposium proceedings—Forest seedling nutrition from the nursery to the field; October 28-29, 1997; Corvallis, OR. Oregon State University, Nursery Technology Cooperative: 17-26.

Appendix 6.6. Handy Conversions

Multiply	By	To Obtain	Multiply	By	To Obtain
Acres	43,560	square feet	Ounces	3	tablespoons (dry)
Acres	0.4047	square hectares	Ounces	9	teaspoons (dry)
Acres	4,047	square meters	Ounces (fluid)	0.0078125	gallons
			Ounces (fluid)	0.02957	liters
Bed feet	0.3716	square meters	Ounces (fluid)	29.57	milliliters
Bed foot	4.0	square feet	Ounces (fluid)	2	tablespoons (fluid)
Bed meter	13.12	square feet	Ounces (fluid)	6	teaspoons (fluid)
Bushels	1.244	cubic feet	Ounces per gallon	7.812	milliliters per liter
Bushels	0.03524	cubic meters	Ounces per square foot	2722	pounds per acre
Centimeters	0.3937	inches	Parts per million	1	milligrams per kilo gram
Cubic feet	0.8	bushels	Parts per million	1	milligrams per liter
Cubic feet	0.02832	cubic meters	Parts per million	0.013	ounces per 100 gallons
Cubic feet	0.03704	cubic yards	Parts per million	0.0083	pounds per 1000 gallons
Cubic meters	35.31	cubic feet	Pints (fluid)	0.125	gallons
Cups	0.5	pints	Pints (fluid)	0.4732	liters
Cups	0.25	quarts	Pints (fluid)	16	ounces (fluid)
Cups	16	tablespoons	Pints (fluid)	0.5	quarts (fluid)
Cups	48	teaspoons	Pounds	453.594	grams
			Pounds	0.453594	kilograms
Feet	30.48	centimeters	Pounds	16	ounces
Feet	0.3048	meters	Pounds of water	0.1198	gallons
			Pounds per acre	1.12	kilograms per hectare
Gallons	3.785	liters	Pounds per acre	0.000377	ounces per square foot
Gallons	128	ounces (fluid)	Pounds per square foot	4.882	kilograms per square meter
Gallons	8	pints (fluid)	Quarts (fluid)	0.25	gallons
Gallons	4	quart (fluid)	Quarts (fluid)	0.9463	liters
Gallons of water	8.3453	pounds of water	Quarts (fluid)	946.3	milliliters
Grams	0.03527	ounces	Quarts (fluid)	32	ounces (fluid)
Grams	0.002205	pounds	Quarts (fluid)	2	pints (fluid)
Grams per liter	1,000	parts per million			
Grams per liter	0.1336	ounces per gallon	Square feet	0.000023	acres
			Square feet	0.0929	square meters
Hectares	2.471	acres	Square feet	0.25	bed feet
Hectares	107,000	square feet	Square feet	0.0762	bed meters
			Square meters	0.000247	acres
Inches	2.540	centimeters	Square meters	10.764	square feet
Inches	0.0254	meters			
			Tablespoons (dry)	0.0625	cups (dry)
Kilograms	1,000	grams	Tablespoons (dry)	0.333	ounces (dry)
Kilograms	35.27	ounces	Tablespoons (dry)	3	teaspoons (dry)
Kilograms	2.2046	pounds	Tablespoons (fluid)	0.0625	cups (fluid)
			Tablespoons (fluid)	15	milliliters
Liters	0.2642	gallons	Tablespoons (fluid)	0.5	ounces (fluid)
Liters	2.113	pints (fluid)	Teaspoons (dry)	0.111	ounces (dry)
Liters	1.057	quarts (fluid)	Teaspoons (dry)	0.333	tablespoons (dry)
Meters	3.2808	feet	Teaspoon (fluid)	0.0208	cups (fluid)
Meters	39.37	inches	Teaspoon (fluid)	5	milliliters
			Teaspoon (fluid)	0.1666	ounces (fluid)
Ounces	28.35	grams	Temperature (°C) +17.8	1.8	temperature °F
Ounces	0.0625	pounds	Temperature (°F) -32	0.55	temperature °C

Sources:

Bonaminio, V.P. Extension Horticultural Specialist, The North Carolina Agricultural Extension Service.

Duryea, M.L.; Landis, T.D. eds. Production of bareroot seedlings. The Hague; Boston; Lancaster: Martinue Nijhoff/Dr. W. Junk Publishers. For Forest Research Laboratory, Oregon State University, Corvallis. 386 p.

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