Nursery Manual for Native Plants

A Guide for Tribal Nurseries

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VOLUME 1 | NURSERY MANAGEMENT

U.S. DEPARTMENT OF AGRICULTURE | FOREST SERVICE | AGRICULTURE HANDBOOK 730

Luna, Tara; Wilkinson, Kim; Dumroese, R. Kasten. 2022. Chapter 8: Seed germination and sowing options. In: Dumroese, R. Kasten; Luna, Tara; Landis, Thomas D., editors. Nursery manual for native plants: A guide for tribal nurseries - Volume 1: Nursery management (revised edition). Agriculture Handbook 730. Washington, D.C.: U.S. Department of Agriculture, Forest Service. p. 132-151.

Seed Germination and Sowing Options

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Seeds of many native species are challenging to germinate. One important thing a grower can do is learn as much as possible about the life history, ecology, and habitat of the species they wish to grow. What processes do seeds of this species go through in nature? Any observations will be valuable when trying to germinate and grow species that have little or no published information available. How seeds are handled, treated, and sown will affect the quality of the seedling produced. Several sowing options are best suited to seeds with certain characteristics. In this chapter, we discuss seed dormancy treatments that can be used to stimulate germination, and different types of sowing options.

SEED DORMANCY

Dormancy is an adaptation that ensures seeds will germinate only when environmental conditions are favorable for survival. The conditions necessary to allow seeds to "break" dormancy and germinate can be highly variable among species, within a species, or among seed sources of the same species. This degree of variability is advantageous because seeds will germinate at different times over a period of days, weeks, months, or even years, ensuring that some offspring will be exposed to favorable environmental conditions for survival. Horticultural practices may tend to discourage dormancy either intentionally through breeding programs or unintentionally by favoring seedlings that germinate more quickly under nursery conditions. There are several types of seed dormancy. Before attempting to grow a plant, it is important to know the seed

Hand-sowing by Tara Luna.

dormancy type. A simple key to determine the type of seed dormancy is provided in the following sections. Knowing the ecology and life history of the species will help you develop treatments and provide conditions to dissipate, or "break," seed dormancy and achieve good rates of germination.

Types of Seed Dormancy

Nondormant Seeds

Nondormant seeds can germinate immediately after maturation and dispersal from the mother plant. The length of time, however, required for the initiation of germination is variable. Some species may germinate immediately (most willows, quaking aspen, and cottonwoods), whereas others may take up to a month to germinate after sowing (some species of white oaks).

Dormant Seeds

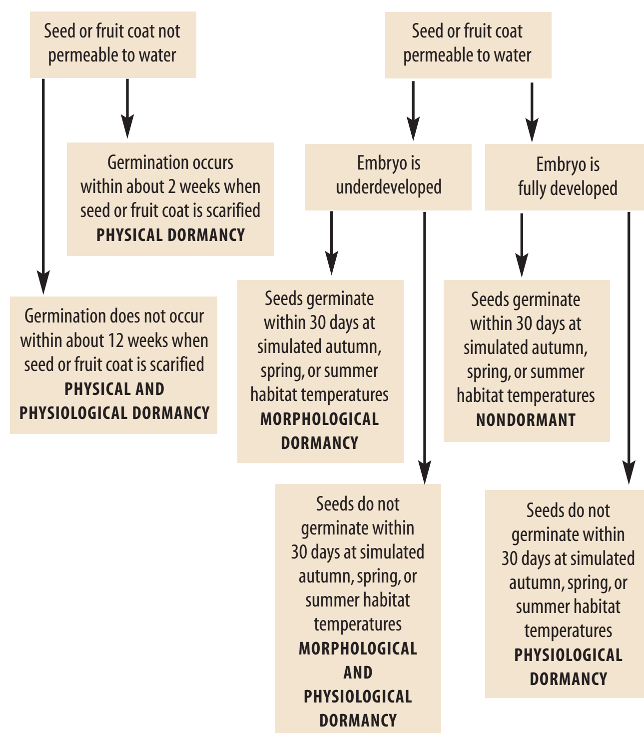
Dormant seeds will not germinate immediately even when ideal environmental conditions exist. Dormant seeds may take several months or even years before they germinate. Dormancy may be caused by factors inside (internal) or outside (external) the seeds. Some species have a combination of internal and external dormancy, a condition known as double dormancy.

Internal dormancy may be physiological, morphological, or both (Baskin and Baskin 1998). Physiological dormancy is the most common type seen in temperate and arctic native plants. Seeds are permeable to water but certain environmental conditions are necessary to modify the internal chemistry of the seed and thus allow germination. Usually a period of cold, moist conditions or holding seeds in dry storage overcomes physiological dormancy. Seeds with morphological dormancy have an underdeveloped embryo when dispersed from the mother plant. A period of after-ripening (usually warm and moist conditions) is needed for the embryo to fully mature before the seed is capable of germination. Seeds with morphological-physiological dormancy usually require a combination of warm and cold conditions, often over an extended period of time, before they are capable of germination.

External seed dormancy may be physical or physical-physiological (Baskin and Baskin 1998). Seeds that have hard, thick seedcoats that physically prevent water or oxygen movement into seeds have physical dormancy. These seeds normally germinate over a period of several years. Depending on species and habitat, various environmental factors cause these seeds to become permeable over time. Seeds that require additional exposure to particular temperatures after they become permeable have physical-physiological dormancy.

Determining Seed Dormancy Type

Knowing the type of seed dormancy is essential for successful propagation. The following key to dormancy types is based on the permeability of seeds to water, the size and characteristics of the embryo (which can often be obtained from other literature sources), and whether seeds germinate in 30 to 45 days at temperatures similar to those found in the natural habitat at the time of seed maturation (Baskin and Baskin 2004).



Move-Along Experiment

Information collected from a "move-along" experiment can be very useful for learning about the dormancy breaking and germination requirements of a species. This technique allows a grower to determine if summer only, winter only, or a summer-to-winter sequence of temperatures is required for breaking dormancy in seeds with permeable seedcoats (or fruitcoats) (Baskin and Baskin 2003, 2004). Two temperature profiles simulating 1-year cycles from winter to winter or summer to summer and control treatments are run concurrently. Under this experiment, seeds are exposed to 14 hours of light per day and are subjected to alternating temperatures. The following information provides general guidelines for simulating temperatures, moving from summer through autumn, winter, and spring:

- Summer: 86 °F daytime and 59 °F nighttime (30 and 15 °C).
- Early autumn: 68 °F daytime and 50 °F nighttime (20 and 10 °C).
- Late autumn: 59 °F daytime and 43 °F nighttime (15 and 6 °C).
- Winter: 34 to 41 °F daytime and nighttime (1 and 5 °C).
- Early spring: 59 °F daytime and 43 °F nighttime (15 and 6 °C).
- Late spring: 68 °F daytime and 50 °F nighttime (20 and 10 °C).

Temperature regimes can be modified to reflect more specific conditions. Controls for the experiment are incubated continuously at each temperature regime.

Seeds can be placed in a refrigerator with a thermometer to simulate the winter treatment. Seeds can be placed in trays under a grow light in a heated nursery office to simulate the summer, spring, and autumn temperatures. Ideally, you will need to adjust the temperature of the refrigerator and office in the evening to reflect cooler nighttime temperatures. By moving seeds through this experiment a grower can determine whether only a warm, moist treatment is needed or if only a cold, moist treatment (stratification; see the following paragraphs) is needed or if both are required to break dormancy (figure 8.1).

TREATMENTS TO OVERCOME DORMANCY AND ENHANCE GERMINATION

A variety of treatments are used by native plant nurseries to prevent seed diseases and to break dormancy. It is important to remember that a degree of variability in dormancy can occur within a species, among seedlots of that species, or even between the same seed sources from year to year. Thus, seed treatments may need to be adjusted to compensate for these differences. For example, seeds from high elevations or far northern latitudes may require a much longer cold treatment to break seed dormancy than do seeds of the same species collected at lower elevations or from more southerly latitudes.

Figure 8.1—*The move-along experiment to determine seed dormancy type can be employed by using simple equipment such as placing seed flats under grow lights for the warm period and a refrigerator for the cold period.* Photo by Tara Luna.

A variety of seed treatments has been developed in response to the diversity of plants grown in nurseries. Before treating seeds, be sure to consult available references to see what treatments have been used on that species; see the literature cited at the end of this chapter and the Native Plant Network (https://npn.rngr.net). If no information is available, check references for closely related species. Any personal observations made on the species in the habitat may also provide some clues on how to germinate the seeds. In general, however, the process of treating seeds follows the fairly standard progression outlined below. Some steps are optional or mandatory depending on whether the seeds are nondormant or have internal or external dormancy.

1. Seed Cleansing

Any seeds can be cleansed of bacterial and fungal infestation; this treatment is necessary for species that easily mold (figure 8.2). Often, molding can be related to the most common disease seen in nurseries, damping-off. Seed cleansing is especially important in humid climates and for species that take a long time to germinate. Often, without treatment, seeds can be lost to pathogens before they are planted in the nursery.

One of the best cleansing treatments is to simply soak seeds in a stream of running water for 24 to 48

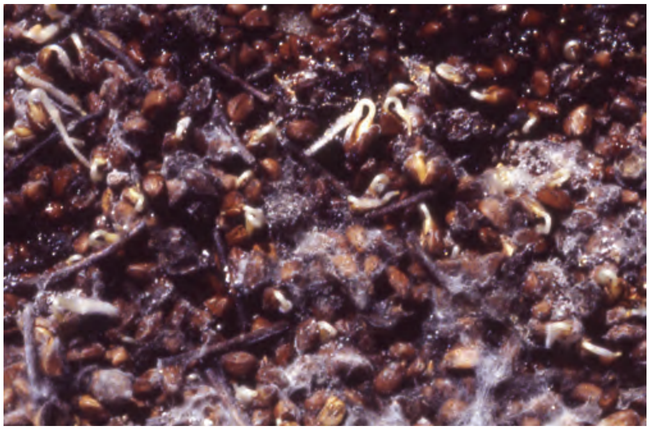


Figure 8.2—*Seeds that are not cleansed before treatment or sowing can easily mold or be susceptible to serious pathogens such as damping-off disease.* Photo by Thomas D. Landis.

hours. The running water flushes bacterial and fungal spores from the seeds (James and Genz 1981), and this treatment can be used to satisfy the soaking requirement described in the next section. Seeds can also be cleansed with several chemicals, and some of these also act to stimulate germination. Bleach is the most common chemical used to cleanse seeds; depending on the species, the solutions range between one part bleach (5.25 percent sodium hypochlorite) in eight parts water to two parts bleach in three parts water. With most species, treatment duration is 10 minutes or less. Species with very thin seedcoats should not be cleansed with bleach. Hydrogen peroxide can be an effective cleanser and can sometimes enhance germination (Narimanov 2000). The usual treatment is one part peroxide (3 percent solution) in three parts water solution. Many native species of the rose family, such as serviceberry and Woods' rose, benefit from this treatment.

2. Scarification

Scarification is any method of disrupting an impermeable seedcoat so that water and oxygen can enter seeds with external dormancy. In nature, hard seedcoats are cracked or softened by fire, extreme temperatures, digestive acids in the stomachs of animals, or by the abrasion of blowing sand or ice. After the seedcoat has been disrupted, oxygen and water pass into the seeds and germination can proceed. Species with external dormancy include many of the legumes, globemallows, and other species that are adapted to fire or inhabit dry or desert environments.

Seeds can be scarified many ways. How well the method works depends on the species and the thickness of the seedcoats. Whichever method is chosen, it is very important not to damage the endosperm, cotyledons, or embryo during the treatment. Taking time to learn seed anatomy of the species is helpful. Trying several methods and recording the results will help determine the best method for that species and seed source.

Mechanical scarification includes filing or nicking seeds by hand and is most often used on large-seeded species such as locust, acacia, mesquite, and whitebark pine (figure 8.3). Be sure to scarify on the side of the seed opposite the embryo. This method is time consuming and requires precision to adequately modify the seedcoat without damaging the internal portions of the seed. Sandpaper can be used on smaller-seeded species such as sedges; placing seeds into a shallow wooden box and then rubbing them under a block of wood covered in sandpaper is the simplest technique. Often, however, the degree of scarification achieved with sandpaper can be variable.

Many species, especially those from fire-adapted ecosystems, respond to germination cues from heat. In nurseries, this response can be simulated by using either wet or dry heat to scarify the seeds. Using wet heat is an effective method for many small-seeded species because it provides a rapid, uniform treatment that can be assessed within a few hours. Native legumes (lupine, milkvetch, Indian breadroot, and wild licorice), ceanothus, buckthorn, and wild hollyhock can be scarified by wet heat (figure 8.4). Because the thickness of the seedcoat may vary among sources, it is wise to dissect a few seeds and examine the thickness of their seedcoats to help determine treatment duration . Seeds are added to boiling water for just 5 to 10 seconds and then immediately transferred to a vat of cold water so that they cool quickly to prevent embryo damage. Seeds imbibe the cool water for 1 day and are ready for sowing or for stratification. Some species cannot tolerate excessively high temperatures, so you may want to heat the water to only 158 °F (70 °C) and monitor your results.

Dry heat is most commonly used on fire-adapted species such as laurel sumac and ceanothus. Seeds are placed in an oven at temperatures ranging from 175 to 250 °F (80 to 120 °C) from a few minutes to 1 hour, depending on the species. The seedcoat cracks open in response to the heat. To avoid damaging seeds, this treatment should be monitored closely.

Figure 8.3—*Hand-scarified seeds of American lotus.* Photo by JF New Nursery.

Sulfuric acid is most commonly used on species with very thick seedcoats and with stony endocarps that surround the embryo. Blackberry, kinnikinnick, manzanita, and skunkbush sumac are species with very thick seedcoats and have been scarified with sulfuric acid. Treatment length varies with the species and often among seed sources, and it must be carefully monitored because seeds can be destroyed if the treatment is too long. A simple way to monitor the process is by removing seeds at regular intervals and cutting them with a sharp knife. When the seeds are still firm but can be cut fairly easily, the treatment is probably sufficient. Another way is to run a pilot test on a subsample of seeds. Again, remove some seeds periodically and evaluate how well they germinate. Once the best duration is known, the entire seedlot can be treated. Sulfuric acid is very dangerous to handle and requires special equipment, personal protective gear, and proper disposal after use (figure 8.5). Some species, such as wild raspberry and salmonberry, have thick seedcoats but can easily be damaged by sulfuric acid. Instead, citric acid or sodium or calcium hypochlorite baths with longer treatment durations may be used, especially for species with thinner seedcoats.

The safe use of sulfuric acid requires the following criteria and procedures:

- Treat seeds that are dry and at room temperature.
- Require workers to wear safety equipment, including face shield, goggles, thick rubber gloves, and full protective clothing.
- Add acid to water, never water to acid.

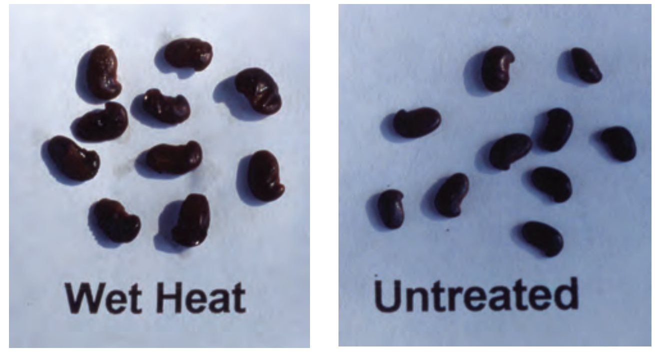


Figure 8.4—*Seeds, such as these of New Mexico locust, that have been scarified by hot water are visibly larger than untreated seeds since the seed coat has been breached and seeds can then absorb water, increasing their size.* Photo by Tara Luna.

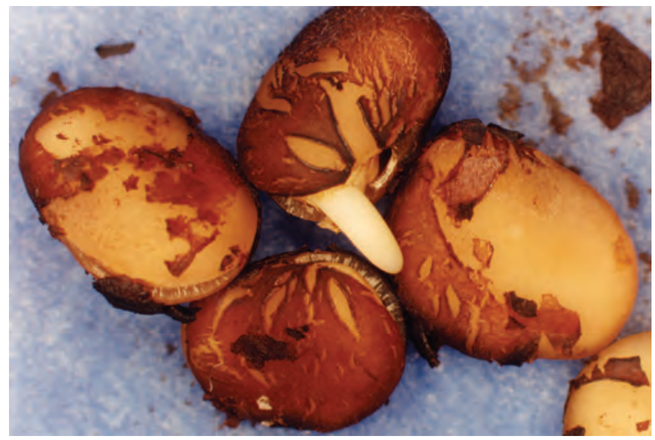


Figure 8.5—*Smooth sumac seeds that have been treated with sulfuric acid.* Photo by Nancy Shaw.

- Immerse seeds in an acid-resistant container, such as a glass, for the duration required.
- Stir seeds carefully in the acid bath; a glass rod works well.
- Immerse the container with seeds and acid in an ice bath to keep temperatures at a safe level for the embryos (this temperature depends on the species; many do not need this step).
- Remove seeds from the acid by slowly pouring the seed-acid solution into a larger volume of cool water, ideally one in which new, fresh water is continually being added.
- Stir seeds during water rinsing to make sure all surfaces are thoroughly rinsed clean.

Hobby-size rock tumblers can be used to scarify seeds and to avoid seed destruction that can occur with sulfuric acid or heat scarification (figure 8.6). Dry tumbling involves placing seeds, a coarse carborundum grit (sold by rock tumbler dealers), and pea gravel in the tumbler. The duration is usually for several days, but this method is an effective and safe way of scarifying many species. Wet tumbling, a method in which water is added to the grit and gravel, has been an effective treatment for redosier dogwood, golden currant, and wolfberry (Dreesen 2004). A benefit of wet tumbling is that seeds are soaked in well-aerated water and chemical inhibitors may be leached.

3. Soaking

After cleansing and/or scarification, seeds must have exposure to water and oxygen before germination can occur. The standard procedure is to soak seeds in running water for 1 to several days until they are fully hydrated. This condition can be checked by weighing a subsample: pull a sample; allow it to dry until the seedcoat is still wet but dull, not glossy; and weigh it. When the weight no longer increases substantially with additional soaking time, the seeds have absorbed sufficient water. Scarified seeds will be more obvious; the seeds will enlarge drastically during the soak. Seeds that only had physical dormancy can be immediately planted. As mentioned previously, running water rinses are good seed cleaning treatments and are effective in reducing the need for fungicides in nurseries (Dumroese and others 1990). Running water soaks also help to remove any chemical inhibitors present on or within the seeds, and an aquarium pump can be used to agitate the seeds to improve the cleaning effect and keep the water well aerated. If seeds are not soaked with running water, change the water often (at least a couple of times each day).

4. Germination Stimulators

Several chemicals are known to increase germination of many native plants. These chemicals are usually applied after seeds are fully hydrated. As with the other treatments already discussed, species, seed source, and other factors will affect how well the treatment works. In general, only seeds with internal dormancy receive this treatment. Germination stimulators include gibberellic acid, ethylene, smoke, and potassium hydroxide.

Gibberellic Acid. Gibberellic acid is the most important plant hormone for the regulation of internal seed dormancy and is often used on seeds with complex internal dormancy and with those species having underdeveloped embryos. In some cases, it has been used to substitute for a warm, moist treatment and to hasten embryo after-ripening. Gibberellic acid can be purchased from horticultural suppliers. A stock solution of 1,000 parts per million (ppm) is prepared by dissolving gibberellic acid in distilled water at the rate of 1 mg in 1 ml. A 100-mg packet is dissolved into 100 ml (about one-half cup) of water. Preferred concentrations vary, but most nurseries use 500 to 1,000 ppm. High concentrations can cause seeds to germinate, but the resulting seedlings may be of poor quality. Therefore, it is best to experiment with low concentrations first.

Figure 8.6—*Hobby-size rock tumblers can be used to scarify seeds. This method is an effective alternative to acid or heat scarification.* Photo by Tara Luna.

Ethylene. This gas occurs naturally in plants and is known to stimulate the germination of some species. Ethylene gas is released from ethephon, a commercially available product. Ethephon, used either alone or in combination with gibbrellic acid, has enhanced the germination of species such as blacksamson echinacea and arrowleaf balsamroot (Chambers and others 2006; Feghahati and Reese 1994; Sari and others 2001). It may inhibit germination in other species, so consult the lit-erature and/or experiment.

Smoke Treatments. Smoke stimulates germination in many fire-adapted native species from the California chaparral, especially those that have thin, permeable seedcoats that allow entry of smoke into the seeds (Keeley and Fotheringham 1998). Seeds can be treated with smoke fumigation, a method in which smoke is piped into a specially constructed smoke tent containing seeds sown in trays (figure 8.7A), or with smoke

TIPS FOR USING GIBBERELLIC ACID

—Because gibberellic acid takes a long time to dissolve, stir it constantly or prepare it the day before use.
—Store unused solution away from direct sunlight.
—Using unbleached coffee filters, cut the filters into squares and fold them diagonally to form a container.
—Pour gibberellic acid solution evenly into an ice cube tray to a depth sufficient to cover the seeds.
—Place each folded coffee filter containing the seeds into the wells of the tray.
—After 24 hours, remove the seeds, rinse them with water and either sow them or prepare them for stratification.

water. Smoke water is an aqueous solution of smoke extract made by burning vegetation and piping the smoke through distilled water or allowing the smoke to infuse into a container of water. Seeds are then soaked in the treated water (figure 8.7B). Conversely, growers can experiment with commercially available smoke products such as liquid smoke, smoke-infused paper discs, and ash that is added to growing media. Many variables, such as the material used for combustion, the combustion temperature, and the duration of exposure, will need to be determined on a species-by-species basis. Experiments performed by Keeley and Fotheringham (1998) found that the length of exposure to smoke was very important in some species; a 3-minute difference in exposure resulted in seed mortality. Some fire species did not germinate under heat or smoke treatments alone. With some species, such as beargrass, seed burial for 1 year or stratification is required in addition to smoke exposure.

All these factors can have an effect on germination and should be considered when using smoke or chemicals in smoke to induce germination. Some native species that responded favorably to smoke treatments include antelope bitterbrush, big sagebrush, Great Plains tobacco, Indian ricegrass, white sage, beargrass, scarlet bugler, and big sagebrush (Blank and Young 1998; Landis 2000). Success with this novel treatment will require trials; keep good records.

Potassium Hydroxide Rinses. Potassium hydroxide has been used to stimulate germination in several native plant species. Optimum concentration varies from 5.3 to 7.6 Molar for 1 to 10 minutes depending on the species, but longer soaks at higher concentrations were found to be detrimental (Gao and others 1998).

5. Stratification

Fully soaked seeds with internal dormancy are treated with stratification. Historically, stratification was the process of alternating layers of moist soil and seeds in barrels and allowing these "strata" to be exposed to winter temperatures. For centuries, people have known that this treatment causes seeds to germinate because it mimics what occurs naturally during winter. Nowadays, stratification is often used more generically to describe the combined use of moisture

Figure 8.7—*Smoke treatments have been used to overcome seed dormancy and enhance germination rates for many native species inhabiting fire-dependent ecosystems. (A) A smoke tent for treating seeds. (B) Smoke water-treated seeds of angelica.*
Photo A by Kingsley Dixon, B by Tara Luna.

and any temperature to overcome seed dormancy. We use the term "stratification" to refer to only cold, moist treatments and the term "warm, moist treatment" instead of warm, moist stratification.

Many native species with double internal seed dormancy require a combination of a warm, moist treatment for a period of time followed by stratification. Remember that some species or seedlots may require only a few days or weeks of stratification, while other species or seedlots may require several months. Therefore, as a general rule, it is best to use the maximum recommended treatment. Also keep in mind that what works well at one nursery may not necessarily work well at another nursery because of differences in seed source, handling, processing, cleaning, and storage.

Another valuable advantage to stratifying seeds is that it speeds up germination and makes it more uniform, which is desirable in a container nursery. Therefore, instead of having germination occur sporadically over several months, it all occurs within a few days or weeks, making it much easier to care for the crop.

Stratification Techniques

Seeds sown in flats or containers in late summer or autumn and left outdoors during winter undergo "natural" stratification. This technique may be preferred if the species has double dormancy (requires both a warm, moist treatment and stratification), requires a very long stratification, and/or requires low temperatures or fluctuating temperatures for a long period of time (figure 8.8A). Conversely, "artificial" stratification involves placing seeds, sometimes within a moist medium such as peat moss, inside permeable bags or containers under refrigeration for a period of time. Artificial stratification has several advantages: (1) it allows for a routine check of seeds to ensure they are moist and not moldy, (2) a large number of seeds can be stratified in a small space, and (3) seeds or seedlots that begin to germinate can be removed from the treatment and planted in the nursery as they become available. Artificial stratification is preferred over natural stratification unless the natural treatment provides higher rates of germination (figure 8.8B).

Artificial stratification can be accomplished a couple of ways. For small seedlots and/or small seeds, seeds can be placed between sheets of moistened paper towels and inserted in an opened plastic bag or sown on a medium in flats with drainage holes (figures 8.9A and B). For paper towels, first moisten them with clean water and let excess water drain away from the towel by holding it up by one corner. The paper towel should remain moist but not waterlogged. Second, be sure to distribute the seeds evenly across the moist paper towel or the flat to help prevent the spread of mold to other seeds. If necessary, seeds can then be first exposed to warm temperatures before exposure to cold temperatures. The paper towel method also works well for those species that require only a few weeks of stratification.

Another technique is "naked" stratification. Most conifer seeds, for example, are stratified this way (figures 8.10A and B). Seeds are placed in mesh bags and then soaked in running water as described previously. After the seeds are hydrated, the bag is pulled from the soak, allowed to drip dry for 30 to 90 seconds, and then suspended in a plastic bag. Make sure the seeds are not in contact with standing water in the bag and hang the bags in the refrigerator. If naked seeds need a warm, moist treatment before stratification, it is easiest to first spread the seeds onto moistened paper towels enclosed in large plastic bags. After the warm treatment, the seeds can be returned to the mesh bags for stratification. One other hint: if a particular species or seedlot has a tendency to begin germinating during stratification, surface-dry the seedcoats—seeds should be moist and dull, not shiny—and then put the seeds into the bag for refrigeration. The seeds should still have enough moisture for chemical processes that dissipate dormancy to occur but not enough moisture to allow germination.

Many wetland and aquatic species can be treated with naked stratification in water. In general, these species can be easily stratified in Ziploc®-type bags filled with water. Insert a soda straw into the bag, ensuring that the end is sticking out of the bag, and seal the rest of the bag securely. Place under refrigeration for the stratification period.

SEED TREATMENT TEMPERATURES

Stratification—34 to 38 °F (1 to 3 °C)
Warm, moist treatment—72 to 86 °F (22 to 30 °C)

Figure 8.8—*(A) Natural stratification works well for seeds with a long stratification requirement or those requiring cool or fluctuating temperatures for germination. (B) Artificial stratification enables the inspection of seeds during treatment. Although some seeds will not show any signs that the stratification duration was sufficient others will begin to crack open or sprout when sufficient chilling has occurred.* Photos by Tara Luna.

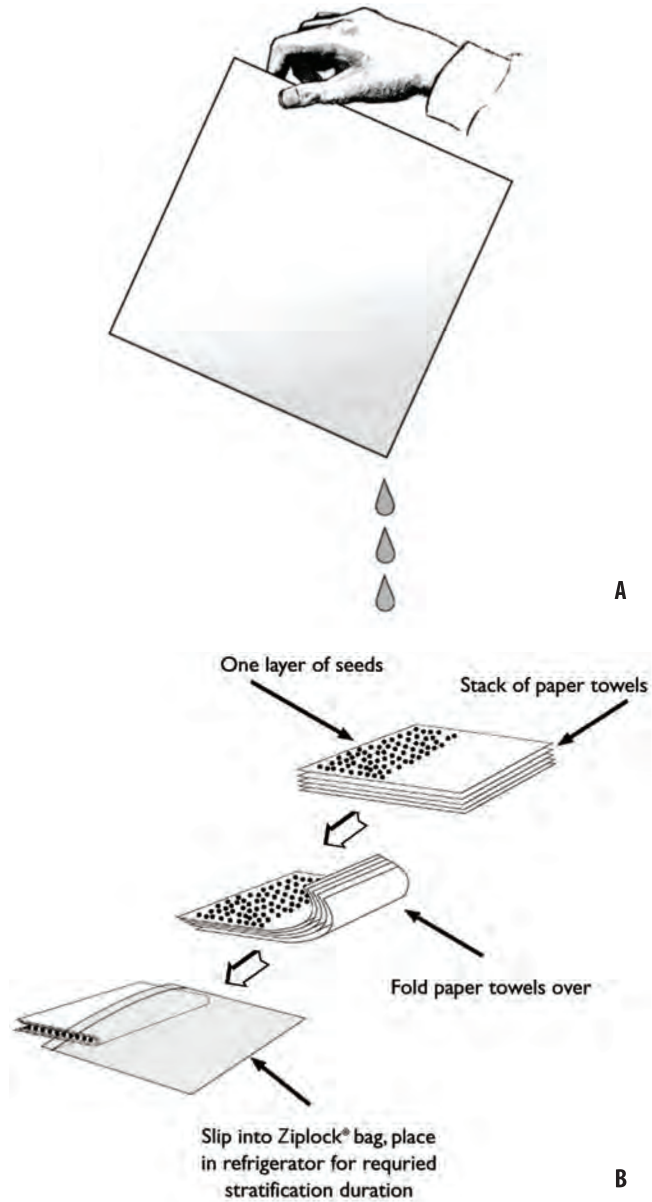
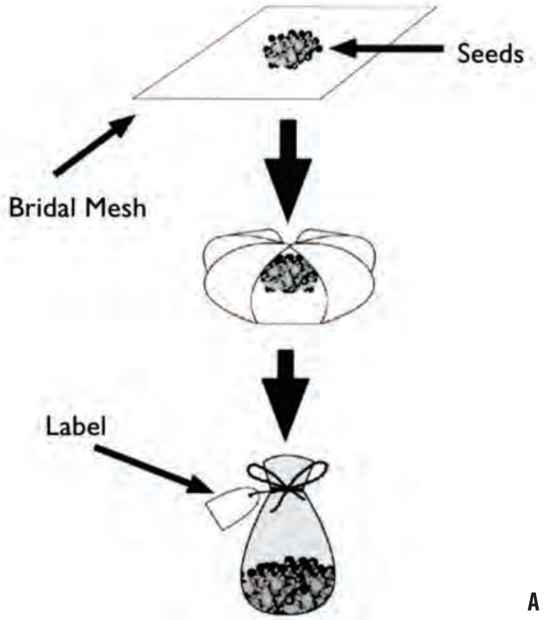


Figure 8.9—*(A) Small seeds requiring only a few weeks of stratification can be stratified on moistened paper towels within a plastic bag inside a refrigerator. The paper towels should be moist; hold them by an end to allow excess water to drain away. (B) Place the seeds evenly on the towels and insert them into a Ziploc®-type bag.* Illustration from Dumroese and others (1998).

ENVIRONMENTAL FACTORS INFLUENCING GERMINATION

Four environmental factors, light, water, oxygen, and temperature, are normally required for germination. Native plants often have specific germination requirements, however, so enviornmental conditions will vary from species to species. These result from their specific ecological adaptations and the environmental cues that trigger germination. For example, light quality and duration can influence germination. Some species, such as sedges, bulrushes, and rushes, have very small dust-like seeds that require light for germination, so they should be sown on the surface of the



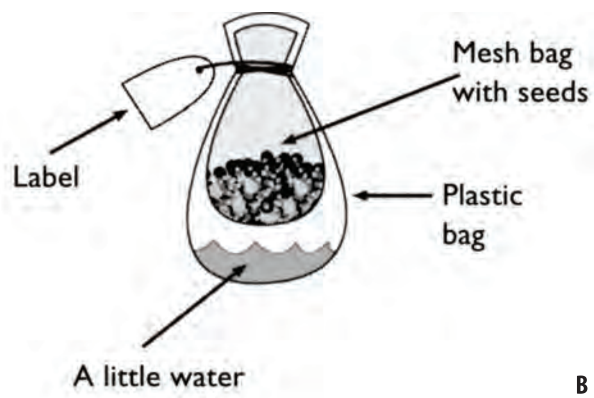


Figure 8.10—*(A) This is an easy way to handle seeds under naked stratification: Cut a square piece of mesh. Place the seeds in the center and fold up the corners of the mesh to make a bag. Make sure there is plenty of room in the bag for the seeds to expand when they absorb water. Place the bag full of seeds into a running water soak for 24 to 48 hours. Remove the bag and allow the seeds to drip dry for a minute or two before suspending the mesh bag inside a plastic bag. (B) Make sure the seeds hang above any water that collects in the bottom of the plastic bag and hang the bags in a refrigerator.* Illustrations from Dumroese and others (1998).

medium and left uncovered. Some species are light sensitive and will fail to germinate if they are buried too deeply. Many native species fall into this category. Species with larger-sized seeds are conditioned to germinate only if they are buried in the soil. Wetness is also important. Overwatering seeds during germination results in reduced levels of oxygen in the medium and promotes tissue breakdown and disease whereas underwatering delays or prevents germination. Therefore, seeds should be kept evenly moist during germination. Although oxygen is needed for respiratory processes in germinating seeds, some aquatic species may require low oxygen levels for germination.

Temperature plays an important role in germination. Species that require "cool" temperatures for germination will germinate only when temperatures are below 77 °F (25 °C). In this case, flats or seeded containers should be left outside the greenhouse to germinate under the natural fluctuating temperatures during spring.

Species that tolerate cool temperatures will germinate over a wide range of temperatures from 41 to 86 °F (5 to 30 °C). These species can probably be germinated outside or inside a warm greenhouse. Species requiring warm temperatures will germinate only if temperatures are above 50 °F (10 °C) and should be kept in a warm greenhouse. Some species germinate better when exposed to alternating temperatures. The fluctuation of day and night temperatures often yields better germination than do constant temperatures for seeds such as antelope bitterbrush, mountain mahogany, and cliffrose. The most effective alternating temperatures have a difference of at least 18 °F (10 °C) between the daytime and nighttime temperature. Native species that require alternating temperatures are probably best germinated directly outdoors (autumn seeding), where they are exposed to the naturally fluctuating temperatures of the seasons.

SEED SOWING OPTIONS

Native plant growers often work with seeds of species that have not yet been propagated in nurseries. Usually, little literature or experience is available to answer questions about seed dormancy-breaking requirements, germination percentages, and other factors. "Standard" sowing options, such as direct seeding, are often not ideal when working with unfamiliar species. Even when key questions about seed performance have been answered, the actual process of sowing seeds into containers will vary with the species, type of seed, and seed quality. Nurseries have several options for improving the efficiency and effectiveness of seed sowing. Several sowing techniques have been used for native plants (Table 8.1) and are described below.

Direct Sowing

Direct sowing is fast, easy, and economical because it minimizes seed handling and labor. It can be mechanized when done on a large scale. For direct sowing to be efficient, the seeds must be uniform in size and shape, easy to handle, abundant in supply; have simple dormancy treatments; and have a known, high germination rate (figures 8.11A–C). The success of direct seeding depends on the accuracy of seed germination information. Growers must realize that actual seedling emergence may be different from the results of laboratory germination tests that are conducted under ideal environmental conditions. Nursery managers must adjust for this discrepancy based on their own operational experience. Growers should conduct a small germination test of each seedlot to determine the percentage of germination that they will obtain in "real life" and use those percentages when deciding the number of seeds to direct sow (see table 8.2). Follow these steps for successful direct sowing:

- Determine how many seeds must be sown to obtain the production target.
- Treat seeds as necessary to break dormancy.
- Sow seeds, ideally centering the seeds in each container. Some seeds require a specific orientation for optimal growth and development; if so, make sure seeds are sown in the correct orientation.

Table 8.1—Options for sowing seeds (modified from Landis and others 1999)

Propagation Method	Good Method for Seeds with the Following Characteristics	Advantages	Disadvantages
Direct sowing: Seeds are sown into containers	—Have a known, high-percentage germination —Are inexpensive —Are in abundant supply —Have uniform, smooth shapes	—Fast and easy —Economical —Minimizes seed handling —Seeds are all sown at once	—Less efficient use of space, seeds, and/or growing medium —Causes of poor germination are difficult to track —May require thinning and/or consolidation and associated labor costs —Not good for large or irregularly shaped seeds
Planting germinants: Seeds sprouting or germinating in trays or bags are sown into containers while roots are just beginning to emerge	—Are of unknown viability —Are valuable or rare —Have unknown germination requirements —Germinate over a period of time during stratification	—Efficient use of seeds —Efficient use of nursery space —Can adjust for unknown seed quality or performance	—Labor intensive —May result in nonuniform crop development —Root deformation possible —Requires frequent, skilled monitoring
Transplanting emergents: Seeds are sown into flats or seedbeds for germination; once germinated and leaves appear, seedlings are transplanted to containers	—Are being tested but will not be transplanted to produce a crop —Do not respond well to other sowing methods —Have long or unknown dormancy —Good for trials to observe seed performance	—Useful with fibrous rooted species —Efficient use of seeds —Efficient use of nursery space —Can adjust for unknown seed quality or performance	—Not recommended for woody and/or taprooted species because of problems with transplant shock and/or root deformation —Requires skilled labor
Miniplug transplants: Seeds are sown directly into small containers. After germination, they are transplanted into larger containers	—Are of unknown quality —Are valuable or rare —Have unknown germination requirements —Have very tiny seeds —Will be transplanted into large containers	—Efficient use of space —Uniform crop development —Low risk of transplant injury	—Requires two sets of containers —Timing is critical —Transplanting by hand is labor intensive

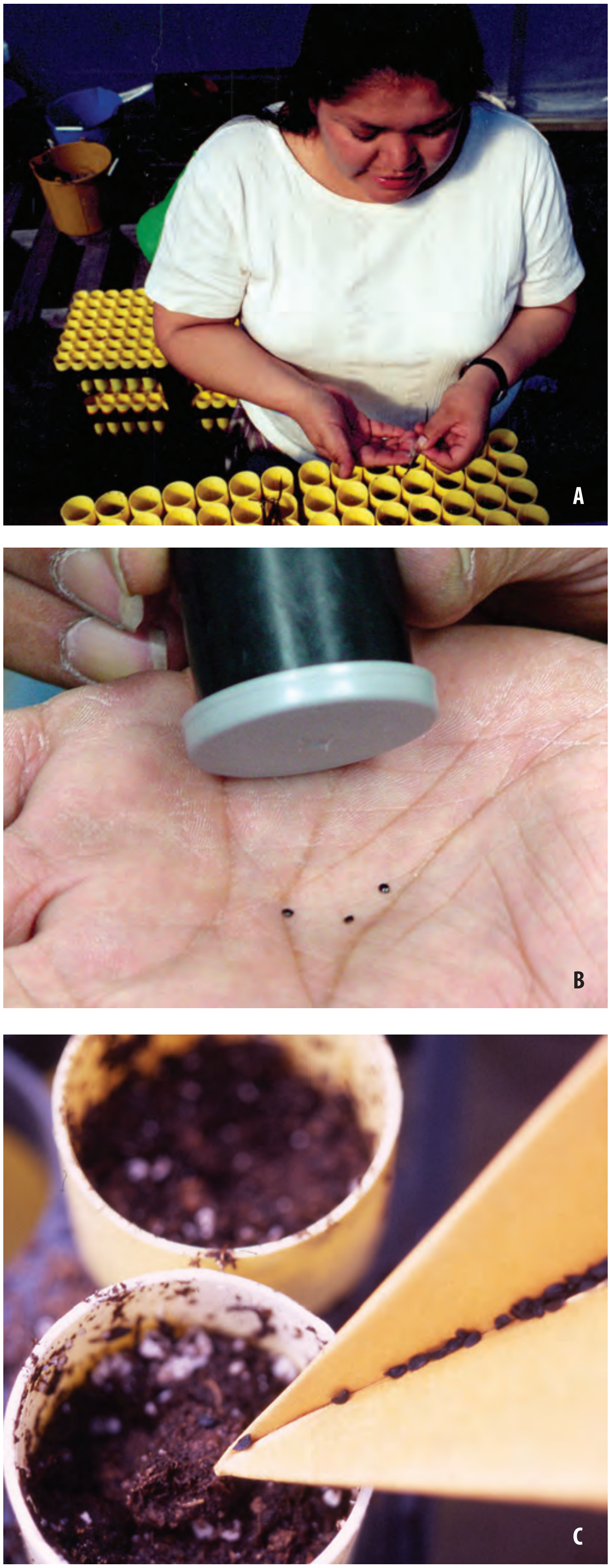


Figure 8.11—*(A) Direct sowing works well for seeds that have a known dormancy, are easy to handle, and are in abundant supply. (B) Simple tools such as a film canister or (C) a folded envelope can be used to accurately sow small seeds of native plants.*
Photo A by Tara Luna, B and C by Dawn Thomas.

- Depending on the light requirements of the species, cover seeds with the correct amount of mulch.
- Gently water the seeds with a fine watering head to press them into the growing media.

Seeds can be direct sown in one of two ways in containers: multiple seeds or single seeds.

Multiple-Seed Sowing and Thinning

"Multiple sowing," the most common direct sowing practice, is a method in which several seeds are sown into each container with the expectation that at least one will germinate. The number of seeds to sow can be calculated based on the percentage of germination of the seeds. Commonly, two to five seeds are sown per container. As a general rule, seeds with less than 50 percent germination are not recommended for direct sowing because the high density of nonviable seeds in the container may cause disease problems, more containers will need to be thinned, and many plants will be wasted (figure 8.12). Table 8.2 provides general recommendations for the number of seeds to sow per container based on the germination percentage. At some point, adding more seeds per container does not really increase the number of containers with plants but does drastically increase the number of containers with too many plants (table 8.3). Sometimes it may be better to single-sow a few containers than thin extra seedlings from many containers. For example, sowing a single seed per container of a seedlot with 85 percent germination yields 15 percent empty containers whereas sowing two seeds per container yields only 2 percent empty containers, but sowing the extra seed requires thinning 72 percent of the containers. The nursery manager may have been better off, in terms of seed use efficiency and labor, to have just oversown 10 percent more containers rather than pay for the labor to thin. Therefore, the amount of seeds to sow per container is a function of germination, seed availability, nursery space, thinning costs, and so on.

If more than one plant emerges per container, the extra(s) must be removed or clipped ("thinned"). When several seedlings emerge in the same container, they compete for light, water, and nutrients. The result is lower initial growth rates of seedlings until they are thinned. For this reason, thinning should be done as soon as possible after seedlings emerge. Thinning is a labor-intensive practice that can damage remaining seedlings if done improperly. Train workers to thin plants carefully and to follow these guidelines:

- Thin germinants as soon as possible; the more developed the root system becomes, the more difficult it is to thin.
- Retain the strongest seedling closest to the center of the container; thinning is an opportunity for selecting the healthiest seedling while removing inferior plants.
- Pull or cut extra plants. For species with a long, slender taproot at germination (for example, pines), extra seedlings can be easily pulled until they develop secondary roots. For species with vigorous, fibrous root systems, cutting extra plants with scissors or nipping them with fingernails may be better.
- Discard removed plants into compost or waste.
- Check the remaining seedling. If thinning disrupted the mulch, adjust it so the seedling has the best environment possible.

Single-Seed Sowing

Sometimes, particularly when seeds are scarce or costly, single seeds can be directly sown into containers. This practice ensures that every seed has the potential to become a plant. If a particular number of

Figure 8.12— *Calculating and testing germination rates help reduce costs and problems associated with thinning.* Photo by Thomas D. Landis.

Table 8.2—For a given seed germination percentage, increasing the number of seeds sown per container increases the number of filled containers. Generally, a target of 90 to 95 percent filled containers is reasonable (from Dumroese and others 1998)

Seed Germination Percentage	Seeds To Sow per Container	Percentage of Containers with at Least One Seedling
90 +	1 to 2	90–100
80–89	2	96–99
70–79	2	91–96
60–69	3	94– 97
50–59	4	94–97
40–49	5	92–97

Table 8.3—A sowing example for a seedlot of chokecherry having 65 percent germination. Assuming 1,000 seedlings are desired and that many containers are sown, notice that adding more than three seeds per container really does not improve the number of containers with seedlings, but does use (waste) many seeds and increases the number of containers that will require thinning (modified from Dumroese and others 1998)

Seeds Sown per Container	Total Seeds Sown	Containers with at Least One Seedling	Empty Containers	Additional Seedlings Produced per Additional 1,000 Seeds Sown	Containers Requiring Thinning To Remove Extra Seedlings
1	1,000	650	350		
2	2,000	880	120	230	420
3	3,000	960	40	80	720
4	4,000	990	10	30	870
5	5,000	1,000	0	0	945

plants are required, then extra containers are planted, often referred to as "oversowing," to make up for any empty cells. The number of extra containers to sow can be calculated based on the percentage of germination. If a seedlot has only 78 percent germination, for 100 plants you must sow at least an extra 28 containers (100 desired seedlings/0.78 success rate = 128 containers required). The number of oversown containers may need to be increased to account for seedling losses during the growing cycle.

Oversowing works best if the nursery has extra space and is using containers with individual, exchangeable cells because, containers with live plants can be consolidated and the extra containers can be removed (see Chapter 6, *Containers*, for example). Single sowing is efficient because no seeds are wasted and plants that do emerge are not subjected to competition or the stresses of thinning as they are with the multiple-sowing technique. Oversowing does, however, waste potting materials and bench space. Consolidating the empty containers, however, can be a labor-intensive and expensive process.

Planting Germinants

Germinant sowing ("sowing sprouts") is the practice of sowing seeds that are germinating (or "sprouting") into the container just as their young root emerges (figure 8.13). When done properly, germinant sowing ensures that one viable seed is placed in each container. The resulting seedlings are often larger because they can begin to grow immediately without competition. This technique results in minimal waste of materials, labor, and space, and works best for seeds that:

- Are from a rare or valuable seedlot.
- Have a low or unknown germination percentage.
- Are large or irregularly shaped.
- Germinate in stratification
- Have deep dormancy and germinate over a long period of time.
- Rapidly produce a long root after germination (such as many desert and semidesert species).

Germinant sowing is a relatively simple process. Seeds are treated as necessary, but, rather than being direct sown into containers, they are germinated in trays or placed in bags. Trays can be very simple; Styrofoam™ meat trays, cake pans with clear plastic lids, or layers of paper towels or fabric on a sheet of plastic or cardboard all work well. Ideally, seeds are dispersed enough on the trays to prevent mold. Larger seeds are sometimes placed in plastic bags filled with a moist medium such as *Sphagnum* peat moss. Seeds are routinely checked every few days or weeks. After seeds begin to germinate, they should be checked daily. Germinated seeds are removed daily and planted directly into their containers. Larger seeds can be planted by hand; smaller seeds must be sown with tweezers.

Two factors are critical when sowing germinants: timing and root orientation. Seeds should be sown into containers as soon as the root emerges. The embryonic root, often called a "radicle," should be short, ideally no longer than 0.4 in (1 cm). If the radicle becomes too long, it may be difficult to plant without causing root deformation (figures 8.14A and B). Some growers like to prune the radicle of taprooted species, such as oaks, prior to planting to ensure a more fibrous root system. No more than the very tip (up to 0.1 in [3 mm]) is trimmed with clean scissors or clipped with the thumbnail. The germinating seed is carefully placed in the container, either sown on its side or with the radicle extending downward. After the seeds are properly planted, the medium should be firmed around the root and the seed covered with mulch.

Planting germinants is highly effective because it makes efficient use of space and seeds. All containers are filled with one growing plant and subsequently losses are minimal. Another advantage is that the germination process is more visible to the growers than when seeds are direct sown. This means that germination timing can be better monitored and the causes of germination problems are easier to track. On the other hand, because seeds in trays or bags are very close together, a mold or pathogen can contaminate all the seeds. Labor is required to routinely check for germination, skill is required to achieve proper planting orientation of the seeds, and planting must be done in a timely fashion. Because germinants may emerge over several weeks or longer for some species, crop development wil be more variable and require special cultural treatments.

Transplanting Emergents

Transplanting emergents ("pricking out") is a common practice, but is not recommended for taprooted

Figure 8.13—*Planting germinants works well for species that require cool temperatures for germination and break dormancy over a prolonged period during stratification.* Photo by Tara Luna.

woody plants because root problems often result (table 8.1). Seeds are hand-sown in shallow trays that are usually filled with about 2 in (5 cm) of peat moss-vermiculite growing medium (figure 8.15). After the seeds germinate, they are "pricked out" of the tray and transplanted into a container.

Transplanting emergents works best when:

- Species have a fibrous root system that recovers well from transplanting (herbaceous forbs without a taproot, grasses, sedges, and rushes).
- Tests or trials are being used to observe germination timing, seed treatments, observations of root development, or early growth.
- Seeds are too small or fragile to be sown by any other method.
- Seeds have very complex dormancy and/or germinate over an extended period of time.
- Limited nursery growing space makes direct seeding uneconomical.

Some key disadvantages include the following:

- Disease potential is very high in densely planted trays.
- Root orientation and timing is critical; poor root form and other problems can result.
- Transplanting is very skill and labor intensive.

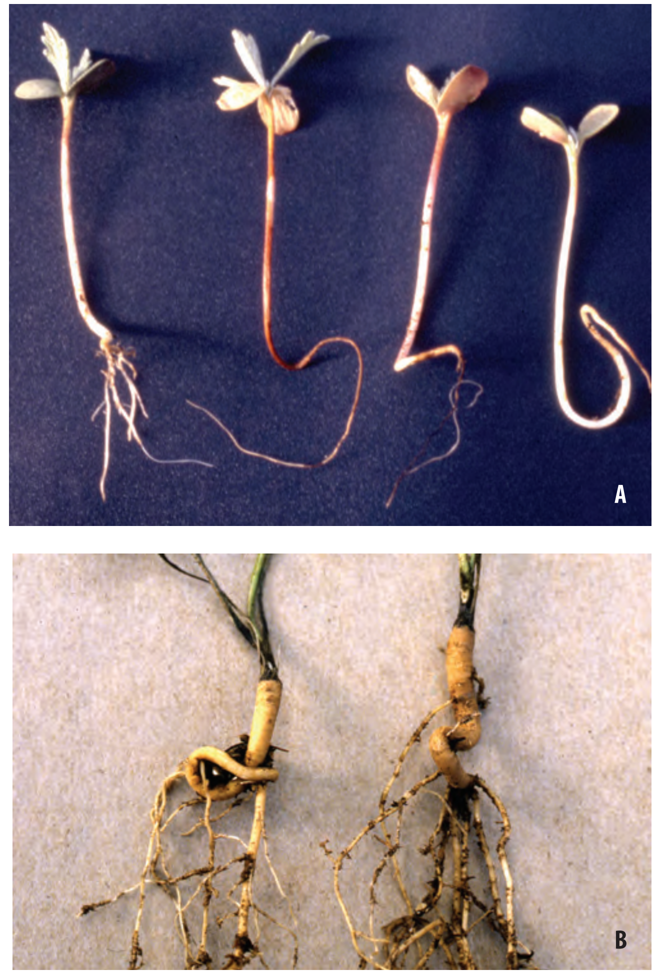


Figure 8.14—*When planting germinants, seeds must be sown as soon as the radicle is visible and must be oriented correctly when planted. Incorrect orientation leads to severe root deformation in woody species such as (A) bitterbrush and herbaceous species such as (B) arrowleaf balsamroot.* Photo A by Thomas D. Landis , B by R. Kasten Dumroese.

Great care and proper technique must be used during sowing and transplanting. Larger seeds are scattered by hand over the surface of the moistened medium. Smaller seeds can be sown with a salt shaker with enlarged holes. Sown seeds are covered with a light application of fine-textured mulch, irrigated, and placed in the greenhouse. Although the exact size or age to transplant the germinating seedlings varies by species, it is usually done at the primary leaf stage. Emergents are carefully removed from the tray, usually by gently loosening the medium around them (figure 8.16A). A small hole is made in the medium of the container and the germinant is carefully transplanted, ensuring proper root orientation (figure 8.13). Some species benefit from root pruning prior to transplanting. The potting medium is then firmed around the root and stem (figure 8.16B). When done improperly on taprooted woody species, this practice can produce a "J-root" or kink in the seedling stem that can reduce growth in the nursery and cause mechanical weakness or mortality after outplanting. Therefore, unless no other sowing method works, transplanting emergents of woody plants is discouraged.

Transplanting Miniplugs

A miniplug is a small-volume container or expanded peat pellet in which seeds are direct sown (see Chapter 6, *Containers*). After the seedlings are well established, they are transplanted into a larger container (figure 8.17). Transplanting miniplugs has a number of benefits. The miniplug container preserves healthy root form because damage to roots during transplanting is eliminated. Planting miniplugs also makes efficient use of growing space. Large numbers of miniplugs can be started in a very small area and managed intensively during germination and early growth, avoiding the expense associated with operating the entire nursery. For nurseries that produce large container stock, planting miniplugs can result in a more efficient use of potting materials and space than other sowing methods.

Seeds are direct seeded into the miniplug containers or peat pellets. Timing this practice is very important because plants in miniplug containers must have a firm enough root plug to withstand the transplanting process, but they must not have so many roots that they are rootbound or that the roots may become deformed after transplanting. If peat pellets are used, too few roots are not a problem because the entire pellet can be transplanted. Seedlings with enough roots to hold the mini-plug together are carefully extracted. A hole large enough to accept the plug is made in the medium of the larger container, and the miniplug-grown seedling is carefully inserted. Planters should ensure that the roots go straight down and are not deformed during transplanting. The medium is gently firmed around the root system, mulch is applied, and the plant is watered.

Transplanting miniplugs is labor intensive and requires skill. Another drawback with miniplugs is the need for two sets of containers; one for miniplugs and one for the product. The savings of space and climate control in the greenhouse, however, may compensate for the extra expense. Before investing in miniplugs on a large scale, a small trial is advised.

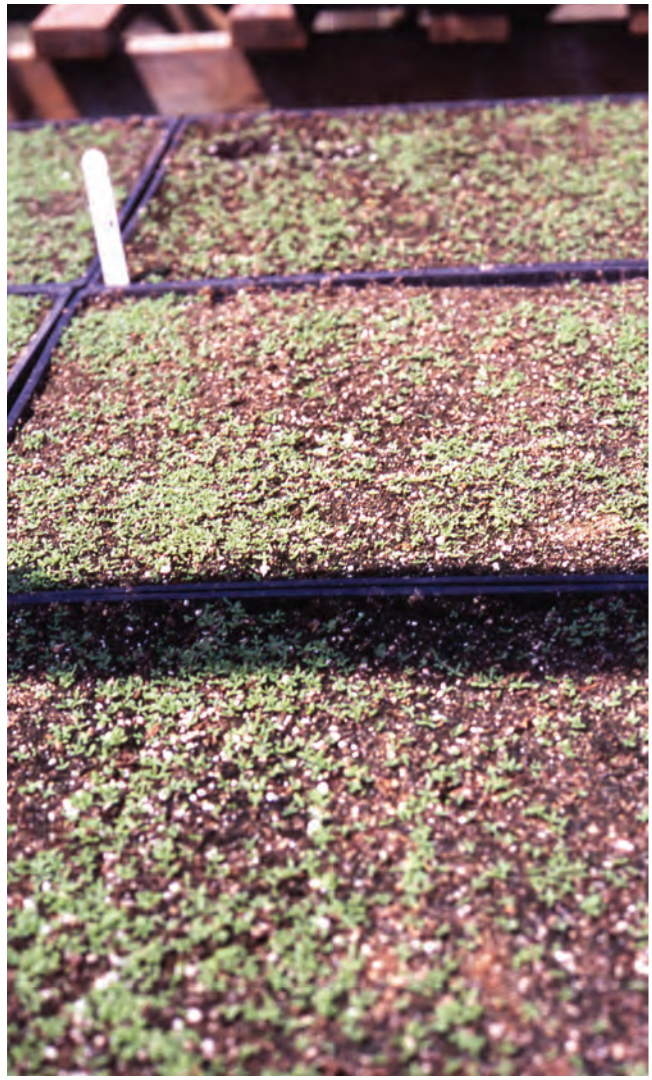


Figure 8.15—*Pricking out trays for transplanting emergents.* Photo by Tara Luna.

SEED COVERINGS (MULCH)

Regardless of the seed sowing method, a seed cover or "mulch" is necessary to create an optimal environment for germinating seeds. The only exception is for species that require light to germinate. Mulch is usually a light-colored, nonorganic material spread thinly over the seeds. Examples of mulches include granite grit (such as poultry grit) (figure 8.18A), pumice, perlite (figure 8.18B), coarse sand, or vermiculite (figure 8.18C). When properly applied, mulches:

- Create an ideal "moist but not saturated" environment around germinating seeds by making a break in the texture of the potting medium (water will not move from the medium into the mulch).

Figure 8.16—*Transplanting emergents works well for fibrous rooted shrubs, forbs, and grasses. Great care must be taken to lift the emergent from the pricking out tray without damaging the roots and to carefully and properly transplant it into a the new container filled with moistened growing media.* Photos by Tara Luna.

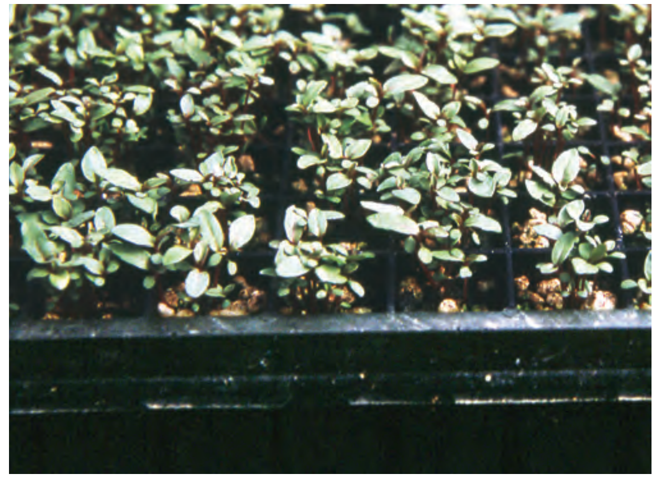


Figure 8.17—*Miniplugs are a viable option for growing seedlings that will later be transplanted to a larger container. Miniplugs work very well with species with very tiny seeds.* Photo by Tara Luna.

- Keep seeds in place. This practice improves contact with the medium and minimizes the number of seeds washed out of the containers by irrigation or rainfall.
- Reflect heat when mulches are light colored, so seeds do not get too hot on bright, sunny days.
- Reduce the development of moss, algae, and liverworts (figure 8.18D).

The recommended depth of the seed covering varies by species; a general rule is to cover the seed twice as deep as the seed is wide. If mulch is too shallow, seeds may float away in the irrigation water. If the mulch is too deep, small plants may not be able to emerge above it (figure 8.19).

Seeds requiring light should be left uncovered. Very small seeds should be left uncovered or barely covered with a fine-textured material such as fine-grade perlite or milled *Sphagnum* peat moss. Uncovered and barely covered seeds must be misted frequently to prevent them from drying out. After light-requiring and light-sensitive species have emerged and are well established, mulch can be applied to prevent moss and liverwort growth and to help keep the medium moist.

TRY DIFFERENT SOWING TECHNIQUES AND KEEP DETAILED RECORDS

Germinating and growing native plants is directly tied to the natural processes they go through in nature. Understanding the biology and ecology of native plants

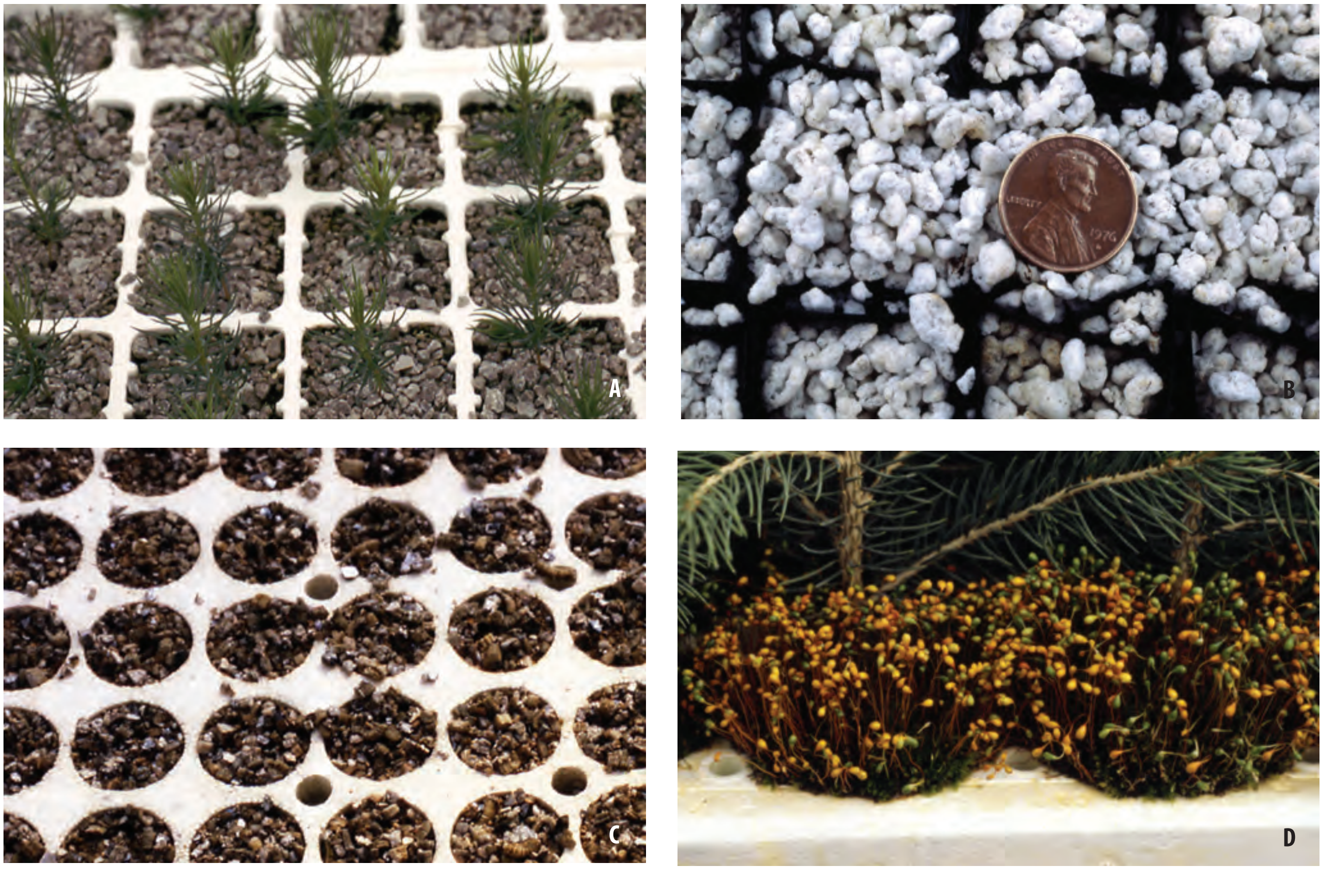


Figure 8.18—*Seed mulches are important to hold the seeds in place and to moderate the surface temperature of the medium during germination. Common mulches include (A) grit,(B) perlite, and (C) vermiculite. (D) Mulches help to prevent the development of mosses and liverworts, which can compete with the seedling.* Photos by Thomas D. Landis.

will provide important clues on how to overcome seed dormancy (if any) and provide the correct environmental conditions needed for germination.

It is important to develop a good recordkeeping system to refine and improve results over time and prevent the loss of valuable information. Keep details on the general information of the species and seedlot and the seed treatments and resulting germination. Because growers have a number of options for sowing seeds, it may be a good idea to do small trials of several of the methods described; see Chapter 17, *Discovering Ways to Improve Crop Production and Plant Quality*, for proper ways of conducting trials. Although several methods may "work"—that is, result in a viable plant produced—the question during the trials should be: Which method is optimal?

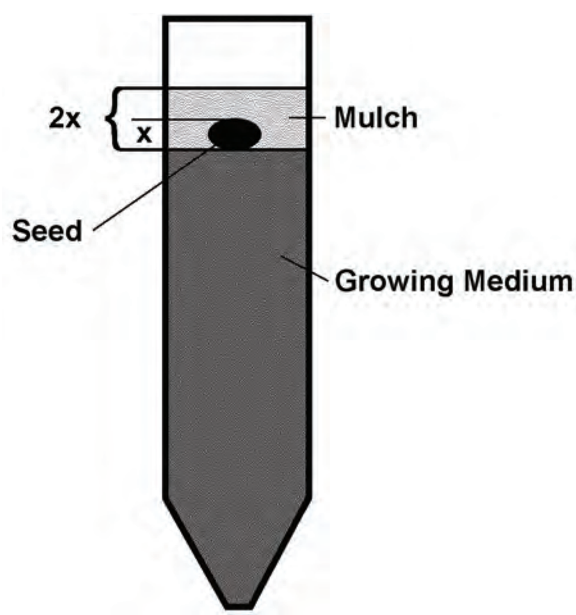


Figure 8.19—*A general rule of thumb for covering seeds with mulch is to cover the seed twice as deep as the seed is wide. Species requiring light for germination should never be covered with mulch, although mulch can be added after germination to reduce the growth of moss and liverworts.* Illustration by Jim Marin.

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APPENDIX 8.A. PLANTS MENTIONED IN THIS CHAPTER

acacia, *Acacia* species
American licorice, *Glycyrrhiza lepidota*
American lotus, *Nelumbo lutea*
angelica, *Angelica* species
antelope bitterbrush, *Purshia tridentata*
arrowleaf balsamroot, *Balsamorhiza sagittata*
beargrass, *Xerophyllum tenax*
big sagebrush, *Artemisia tridentata*
blackberry, *Rubus* species
blacksamson echinacea, *Echinacea angustifolia*
buckthorn, *Rhamnus* species
bulrush, *Schoenoplectus* species
ceanothus, *Ceanothus* species
cliffrose, *Purshia stansburiana*
cottonwood, *Populus* species
globemallow, *Sphaeralcea* species
golden currant, *Ribes aureum*
Great Plains tobacco, *Nicotiana attenuata*
Indian ricegrass, *Achnatherum hymenoides*
kinnikinnick, *Arctostaphylos uva-ursi*
large Indian breadroot, *Pediomelum esculentum*
laurel sumac, *Malosma laurina*
locust, *Robinia* species
lupine, *Lupinus* species
manzanita, *Arctostaphylos* species
mesquite, *Prosopis* species
milkvetch, *Astragalus* species
mountain mahogany, *Cercocarpus ledifolius*
New Mexico locust, *Robinia neomexicana*
quaking aspen, *Populus tremuloides*
redosier dogwood, *Cornus sericea*
rushes, *Juncus* species
salmonberry, *Rubus spectabilis*
scarlet bugler, *Penstemon centranthifolius*
sedges, *Carex* species
serviceberry, *Amelanchier alnifolia*
skunkbush sumac, *Rhus trilobata*
smooth sumac, *Rhus glabra*
white oaks, *Quercus* species
white sage, *Salvia apiana*
whitebark pine, *Pinus albicaulis*
wild hollyhock, *Iliamna* species
wild raspberry, *Rubus idaeus*
willow, *Salix* species
wolfberry, *Lycium* species
Woods' rose, *Rosa woodsii*