Seed Acquisition, Conditioning, and Storage

2

R.P. Karrfalt and C. Pike

Robert P. Karrfalt is emeritus scientist, USDA Forest Service, West Lafayette, IN

Carolyn (Carrie) Pike is regeneration specialist, USDA Forest Service Eastern Region, State and Private Forestry, West Lafayette, IN

Outline

Facing Page: *Acorns. (Photo by C. Pike, USDA Forest Service.)*

Introduction

The production of most hardwood seedlings begins with acquisition of seeds, exceptions being stem cuttings (cottonwoods, willows, and hybrid poplars), or grafted stock (high-value hardwoods such as black walnut (*Juglans nigra* L.). This chapter discusses the various technologies involved in producing and wisely managing high-quality seedlots. Some nurseries collect and process their seed requirements completely in house. Other nurseries, either by choice or obligation, contract part or all of this process. In either case, knowledge of the entire process is important to assess the qualifications of contractors and suppliers, as well as to judge the quality of their product.

Readers should become familiar with the *The Woody Plant Seed Manual* (Bonner and Karrfalt 2008), which discusses a full range of seed topics. That book features both general material on the topics and species- or genera-specific information such as seed collection dates, numbers of seeds per pound, and germination requirements. This chapter covers those latter topics in more detail and some seed-related topics that have emerged since the publication of *The Woody Plant Seed Manual.* (See the glossary in Appendix 2-1 of this chapter.)

Seed Development

Hardwood trees are phylogenetically classified as angiosperms—plants that produce their seeds in fruits that develop from flowers. Seed development starts with flowering and ends with seeds (formed from ovules in the ovaries of the flowers) and fruit (formed from the ripening of the ovaries). By observing the flowering, seed collectors can gain information about the quality and quantity of a future seed crop. The number of flowers will be a good predictor of the seed crop unless flower structures are damaged by frost or herbivory before the seeds fully develop.

Flowers occur in a diverse array of structures and habits. Perfect flowers contain both male and female parts (such as those of tulip poplar, *Liriodendron tulipifera* L.), while imperfect flowers are either male or female (such as those of oaks, *Quercus* spp.). Generally, if flowers are imperfect, both the male and female flower will still occur on the same tree, a condition named monoecious, although some species (for example ashes, *Fraxinus* spp.) will produce male flowers exclusively on one tree and the female flowers exclusively on another tree, a condition named dioecious. There is a third habit, polygamous, in which both perfect and imperfect flowers occur on the same tree (such as red maple, *Acer rubrum* L.). Knowing the type of flowers and how they occur on the parent facilitates assessing the presence and abundance of a flower crop and provides the earliest information on when and how many seeds might be available. Trees with no or few flowers will produce low- seed crops. *The Woody Plant Seed Manual* describes the flower type for a large number of genera.

Seed Bearing Age

The age at which trees first produce seed varies among and within species. Some species produce large quantities of seed within a few years of planting (European alder, *Alnus glutinosa* L., for example), but generally seed production is highest for middle-aged trees, 15 to 20 years after planting. Seed production in other species takes decades: bur oak (*Quercus macrocarpa* Michx.) for example, does not bear commercial quantities of seed until 35 years or older.

Seed collectors generally favor open-grown trees with large full crowns because such trees have a high number of branches capable of flower production and often produce seed prolifically. In contrast, trees growing within the tight confines of the forest often have limited crowns and produce fewer seeds, so are not as sought after by seed collectors. Trees with full crowns may also produce seed sooner than a similar-aged tree growing in a natural forest with restricted light. Lastly, open grown trees may produce flowers closer to the ground and on different sides of the crown facilitating collection. However, convenience should not override the need to have a sufficiently broad genetic makeup represented in a collection of seeds. A bulked seedlot ideally has an even proportion of seeds from at least 10 unrelated mother trees. Trees with poor form or that are diseased should not be used as seed trees.

Frequency of Seed Crops

Seed production is highly cyclical in hardwood trees, although some species, such as silver maple (*Acer saccharinum* L.), produce at least a small crop every year. Bumper seed-crops occur periodically, typically at intervals of 2 to 5 years, as exemplified with sugar maple (*Acer saccharum* Marsh.). Seed quality is usually the highest during bumper seed years because the number of seeds is usually sufficient to compensate for predation and infestation by insects. Abundant seed crops also lead to lower seed costs because more seeds can be collected per hour in the field and higher amounts of seeds can be extracted per unit weight of fruits. Therefore, seed collections should be focused on bumper years and poor seed years passed over when possible. Such a strategy can only be followed, however, if the seeds can be stored for several years. When long-term storage is not possible, seeds must be collected as needed. Refer to *The Woody Plant Seed Manual* to learn if the seed of a specific species can be stored.

Determining When to Collect Seeds

For most trees, seed should be picked when the fruit is ripe or physiologically mature. At this stage, seeds will have maximum viability and vigor (fig. 2.1). Seed collectors and buyers should become knowledgeable of physical cues that indicate maturity because most hardwood seed cannot mature after separation from the mother plant. Seed maturity is frequently indicated by a change of the fruit color from green to yellow, greenish yellow, or red and purple. The softening of fleshy fruits is another indicator. Note that the color changes may not be the same with every individual or population of plants. Seasoned collectors learn to recognize the physical signs of maturity for species they collect. Novices should seek out seed maturity indices from the appropriate genus chapter in *The Woody Plant Seed Manual*.

Most hardwood seeds ripen in the fall, but notable exceptions include seeds of red maple and elms (*Ulmus* spp.), which ripen in the spring, and mulberry (*Morus* spp.), which ripens in the summer. Maturity can vary spatially within the crown of a single tree with seeds on a southern aspect possibly maturing sooner than those on a northern aspect. A stand of trees with a southerly aspect may mature sooner than a stand with a northerly aspect, or a stand at a different elevation. Lastly, maturity can vary by genotype, as observed in common garden studies and seed orchards.

Seed quality is a critical consideration for collectors and encompasses both maturity and absence of insects or pathogens. Quality must be assessed in the field by cutting (known as a cut test) or tearing open a sample of seeds to observe the embryo and food storage tissues (endosperm and/or perisperm) if present (fig. 2.2). The internal parts in an immature seed are soft and milky, whereas in a mature seed, they are firm, white or cream-colored, and the embryo generally fills the seed or the embryonic cavity. Seeds that lack mature internal structures or ones that are damaged by disease or insects should not be collected. Signs of insect damage include the presence of frass, larvae, or feeding galleries or holes. Refer to the drawing of the internal seed anatomy in the appropriate genus chapter in *The Woody Plant Seed Manual*.

Figure 2.2—*A longitudinal cut of this ash seed shows it has a fully developed seed and embryo. (Photo by R. Karrfalt, USDA Forest Service.)*

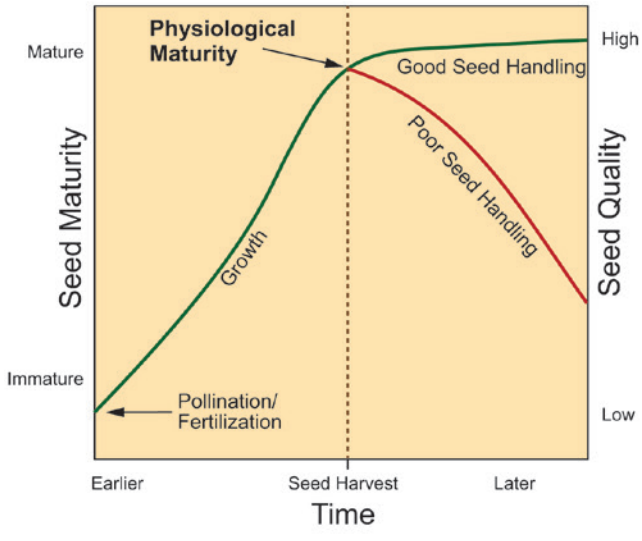


Figure 2.1—*Seed quality and maturity changes over time.*

Several factors must be considered when scheduling the seed collection. Seeds that disseminate quickly after ripening, such as cottonwood (*Populus deltoides* Bartr.), require diligent forecasting. The seeds of blue (*Fraxinus quadrangulata* Michx.) and black (*Fraxinus nigra* Marsh.) ash shed shortly after maturity, while green ash (*Fraxinus pennsylvanica* Marsh.) and sycamore (*Platanus occidentalis* L.) can retain the seeds for months after reaching maturity. Predation from squirrels, deer, and birds can rapidly deplete a seed crop, especially crops of nuts or fleshy fruits that are rich food sources for the predator. Seed drop can indicate seed maturity, but caution needs to be exercised because the earliest seeds to fall can often be aborted or insect damaged and not an indicator of seed maturity. A cut test can assess quality. Strong winds or warm, dry conditions can accelerate seed dispersal and end seed collection efforts. Monitor weather forecasts and consider their possible effect on planned seed collections. *The Woody Plant Seed Manual* lists approximate maturity dates for most genera as a baseline, but is not a substitute for a field assessment.

Calculating Seed Requirements

Nursery managers must figure out the amount of seed needed to produce a certain number of seedlings for sale. Given the periodicity of good seed years, calculations of seed requirements should be projected across multiple

years. However, for recalcitrant species that cannot be stored long-term, projections are usually based on annual needs. Appendix 2-1 provides definitions for these terms: pure live seed, seed purity, seed weight, germination, and viability. Chapter 5 of *The Woody Plant Seed Manual* gives a thorough discussion of these terms and how their values are determined. Table 2.1 describes the steps to calculate the amount of seeds needed. Pure seed has a specific definition in official testing rules (AOSA, Association of Official Seed Analysts). Pure seeds are the seeds that appear undamaged to the naked eye and may or may not be viable (or have the potential to germinate). Seed weight is expressed as the number of seeds per pound, ounce, gram, or kilogram. A hypothetical seedlot might have a seed weight of 48,000 seeds per pound. However, because it has a purity of 75 percent, a pound of this seedlot will only contain 36,000 pure seeds for sowing. A test of viability does not involve any attempt to germinate the intact seed. Instead, viability is estimated when germination is difficult or takes a long time to complete because the seeds are highly dormant. Tests of viability include tetrazolium staining, embryo excision, and x-ray tests. Refer to chapter 5 in *The Woody Plant Seed Manual* for a complete explanation of the viability test. Pure live seed (PLS) is the product of seed weight, purity, and germination, expressed as a number of pure live seeds by a given weight (pound, ounce, gram, or kilogram). This allows estimating the value of a seedlot for reforestation because it gives the likely maximum number of plants that can be obtained from the given weight. The PLS is the actual number of seed to prepare for sowing to reach a specific number of seedlings.

Seed Purity X Seed Weight X Germination = PLS

or

Seed Purity X Seed Weight X Viability = PLS

Every seedlot will have specific values for the above factors and, therefore, a specific pure live seed value. The nursery manager should keep a record of these values for each seedlot of each species and calculate average values to plan seed requirements. When lacking historical data from the nursery, a manager can refer to the average values for any specific genus as listed in *The Woody Plant Seed Manual.*

With the number of pure live seeds (PLS) per unit weight determined, the next step is to divide the number of seedlings needed by the PLS to arrive at the weight of seeds required. This seedling production target can be on either an annual or multiyear basis. The initial estimate of needed pounds of seed must, however, be further adjusted for losses in the nursery that can occur from imperfect germination rates, premature death of seedlings, or seedlings that grow slowly and fail to meet grade standards. These losses in the nursery are collectively represented by the nursery survival factor (table 2.1), which is the percentage of pure live seeds that germinate and grow into plantable seedlings, calculated as the number of plantable seedlings divided by the number of pure live seeds:

Number of plantable seedlings = (PLS)/(survival factor)

Permanent sample plots, sometimes called history plots (Landis and Karrfalt 1987), located within nursery beds can be used to estimate the survival factor. For example,

Table 2.1—*Stepwise assessment questions to compute the amount of seeds to collect for a known production number.*

Question	Value	Calculated quantity of seeds needed
How many plants are to be produced?	200,000/yr	
How many years of production will this collection provide?	3	200,000 x 3 = 600,000
What is the ratio of seedlings to viable seeds? [1]	80%	600,000 / 0.8 = 750,000
What is the viability of the seeds?	80%	750,000 / 0.8 = 937,500
How many seeds are there per unit weight?	99,000	937,500 / 99,000 = 9.5 lbs
What is the purity?	95%	9.5 / 0.95 = 10 lbs
What volume of the "raw" collection unit? [2, 3]	0.8 lbs/bu	10 lbs / 0.8 lbs/bu = 12.5 bu

bu = bushels. lbs = pounds. yr = year.

[*] This is the nursery survival factor.

[**] That is, how many seeds, fruits, or cones must be collected to obtain the desired weight of pure seeds?

[***] Is there sufficient capacity for postharvest storage and timely conditioning for the desired volume of seeds?

1,250 pure live seeds are needed to produce 1,000 plantable seedlings if the nursery survival factor is 80 percent.

The formula to calculate the number of plantable seedlings, as shown in chapter 4b of this guide, is equivalent to this formula, but factors nursery density into the calculation.

The history plot also provides information on how the crop is progressing through the growing season. This information informs the manager whether production targets will be met and whether any corrections to cultural practices, pest control, or the number of trees available for distribution are necessary. History plots are covered in greater detail in chapter 10 of this guide.

Seed Acquisition

Seed Collection

The first four sections of this chapter laid the ground-work for seed collection by describing the biology needed for predicting the occurrence of seed crops, determining when they are ready to collect, assessing their likely quality, and estimating how much seed should be collected. With that information, the work can be scheduled and appropriate resources acquired and prepared.

Nurseries or their parent organizations that have the personnel and equipment for seed collection can potentially exercise the necessary control over the process by directly supervising operations. When the collections are not made by nursery staff, seed can be acquired with formal contracts or by local collectors, provided there is good communication between nursery and collectors. This communication can be in the form of a formal contract or simple information sharing, stating clearly the species to collect, collection sites, timing, criteria for seed quality, amount of reimbursement, and the method of reimbursement. Nurseries that purchase raw fruits and seeds need to assess seed quality at the point of arrival, or may find they have acquired poor-quality seeds or an inordinate quantity of trash. Long-term relationships with experienced collectors are beneficial for nursery operations to meet their seed needs with locally sourced material.

Methods of Seed Collection

The actual gathering of the seed or fruit from the plant takes many forms, depending on the botanical characteristics of the mother plant. The seed-bearing structure can portend the effort required. Fruits that are persistent and/or tightly bound to the tree, such as sweet gum (*Liquidambar styraciflua* L.) and sycamore, require more effort to collect. Persistent fruits may require hand twisting or a sharp cutting tool, such as pruning shears, to sever the connection. Fruits that are not persistent can be easily picked by hand or pulled off with rakes, hooks, or vacuum. Some fruits fall naturally upon ripening and can be collected from the ground, or the tree can be shaken to release fruits. Acorns and walnuts are actually not ripe until they drop naturally and should only be taken from the ground. Yard tools such as rakes, leaf blowers/vacuums, forks, and shovels can be useful in gathering seeds from the ground or off low plants (fig. 2.3). Persistent fruits that are high in the crown require some other means of reaching them, such as climbing or bucket trucks. Climbing requires adequate training and equipment to be done safely; bucket trucks allow quick access to the crown with a high degree of worker safety. Another method for obtaining seeds from tall trees is to collect them from trees felled for harvest or fallen over from storm damage (Bonner, 1970), but make certain that the seeds are sufficiently mature at the time the tree fell. The fruits may appear mature, but the appearance could be due to the general drying of the whole treetop rather than a true maturation. Collect promptly after felling to forestall losses to birds or mammals. Collecting from felled trees may not be cost-effective because fruits or cones may shatter or become deeply covered by limbs, tops, and foliage. Sometimes destructive sampling, such as cutting a seed-laden branch with a pole pruner, is effective but future seed may be limited. Striking limbs with long poles or shaking them with ropes can cause seeds to drop into a tarp or netting below. Ropes can be thrown over limbs by hand if the limbs are not too high, or a large slingshot can be used to shoot a weight and draw string over the limb. (Knight, Karrfalt, and Mason, 2010) (fig. 2.4).

Postharvest Storage

Raw seed and fruit that arrive at a nursery must be stored properly until seed is cleaned. Proper postharvest storage is

Figure 2.3—*Fruits such as acorns can be gathered from the ground after natural seed drop. (Photo by R. Karrfalt, USDA Forest Service.)*

Figure 2.4—*Tarps are sometimes necessary to catch small seeds that are shaken from the tree. ((Photo by R. Karrfalt, USDA Forest Service.)*

Figure 2.5—*Screen-bottomed racks for postharvest drying of seeds. Spacers allow natural air flow around each rack in the stack. (Photo by R. Karrfalt, USDA Forest Service.)*

critical to avoid reduced seed quality and expensive losses in viability. The seed or fruit type dictates the method of handling. Three types of hardwood seeds and postharvest storage recommendations are described below. See page 66 in *The Woody Plant Seed Manual* for a more complete discussion of postharvest seed storage.

Desiccation-tolerant seeds with dry fruits. Seeds in this group, also called orthodox seeds, maintain high viability when dried to low moisture content. In general, desiccation-tolerant seeds are dried in ambient conditions and sheltered from precipitation. Examples include tulip poplar and elms. Seeds are stored postharvest in layers only a few inches deep on screen or mesh-bottomed trays (fig. 2.5). This allows moisture in the seed to diffuse into the air.

Desiccation-tolerant seeds with a fleshy fruit. Orthodox seed with a fleshy fruit must be kept moist until the seed is separated from the fruit; examples include cherries (*Prunus* spp.) and dogwoods (*Cornus* spp.). If the fruit is allowed to dry, it can become very difficult to remove later. The consequences of not removing the fruit include a substantial increase in the bulk of the seedlot, greater difficulty in removing empty seeds, and, upon rehydration, the pulp will serve as a source of trash and microbial contamination. Postharvest, fleshy fruit can be watered or placed in high humidity until the seed is extracted. Seeds are often held in tubs, trays, or plastic bags. Storing seed in a cooler offsets heat that builds from fermentation that could damage seeds. Aeration can prevent excessive fermentation and mold growth. Once the seed is extracted, it should be dried in the same way as desiccation-tolerant seeds from dry fruits (see section on seed storage).

Desiccation-intolerant or recalcitrant seed. Drying these types of seeds to a low-moisture content kills them. As a general rule, moisture content must be kept at above 25 percent. Examples include oaks and buckeyes (*Aesculus* spp.). Recalcitrant seeds are typically held in trays, tubs, or plastic bags (Bonner 1973; Bonner and Vozzo 1987; Tylkowski 1984) in a cooler or occasionally in a root cellar or other cool location but usually cannot be stored for extended periods of time.

The length of time seeds are held in postharvest storage is as important as the method for storing them because quality declines over time in storage. Species vary in how quickly a measurable loss in seed quality will occur. Species that are dormant can be held longer in postharvest storage than species that are not dormant. For example, desiccation-intolerant white oak (*Quercus alba* L) or live oak (*Quercus virginiana* Mill.), which do not go dormant, must be processed within a few days of collection to ensure germination does not commence or proceed too far (Bonner and Vozzo 1987; McDonald 1969). In these cases, germination can be retarded by storing the acorns in plastic bags in a cold room as close to 34 °F (1 °C) as possible and in layers only a few inches thick. Germination may commence rapidly in the white oak group when acorns are stored in deep layers.

Seed Extraction, Hulling, and Singularizing

Seed must be separated from its hull, fruit, and impurities to prevent spoilage, prepare for sowing, and to reduce the bulk for storage. The primary objective in all fruit han-

dling and extraction is to obtain as much viable seed as possible and to maintain a high extraction factor, which is the yield of clean seed expressed as a percent of rough fruit. Seed may be cleaned in-house or contracted to a seed-cleaning facility. Any contract with an external cleaner should include specifications on seed purity, percentage of full seed, and moisture content, along with expected completion date. Most contractors process seed for a variety of customers simultaneously, which can occasionally lead to processing delays. Removing pulp, pods, husks, twigs, and other debris substantially reduces the weight.

Desiccation-tolerant dry fruits have a variety of fruit types: globose heads of achenes, pods, capsules, clusters of samaras, or single fruits. Many species have an appendage (wing, a pappus, or bract) to remove before the seed can be cleaned or sown mechanically. Hullers or scarifiers used to remove these appendages must be operated carefully. Hulling and scarifying applies force to the seeds to separate the appendage, which may be tightly bound to the fruit, like the wing on tulip poplar fruits, for example. Excessive force can damage seeds, while too little force may fail to remove the appendage. Some level of mechanical damage generally occurs. The seed for some species may be too delicate for these machines and require hand rubbing (for example, red maple). The brush machine (Karrfalt 1992) is an alternative hulling device that imparts minimal damage on a variety of species (figs. 2.6 and 2.7). Hammermills are sometimes used but can cause higher levels of mechanical injury to the seeds (Young et al. 1983). Note that hulling operations generate high amounts of dust, and machine operators need to use a mask or respirator. The macerators used for dry fruits also generate copious amounts of fine dust.

Desiccation-tolerant species with fleshy fruits are often cleaned with macerators, which use water to wash away pulp

Figure 2.7—*Tulip tree and green ash seeds after treatment with the brush machine. (Photo by R. Karrfalt, USDA Forest Service.)*

as it is forced off the seed (fig. 2.8). Blenders with rubber tubing over the blades can serve as macerators for small seeds or small seed-lots. In some cases, the fruits can be simply crushed and the pulp rinsed away. Generally, a presoak of 1 to several days softens the pulp and makes for an easier separation from the seed. This accelerates the cleaning process and reduces the chances for mechanically injuring the seeds. Water must be changed daily to prevent fermentation and to control mold.

Desiccation-intolerant seeds can have a fruit with either a dry (oaks) or a fleshy exterior (redbay, *Persea borbonia* L. Sprang.). These fruits are handled just like the fruits of dessication-tolerant species, but the seed must be kept from drying.

Cleaning Seed

One goal of hulling/extraction is to produce a seedlot that flows freely, allowing individual seeds to be separated. Once in a flowable state, seeds are cleaned further to remove

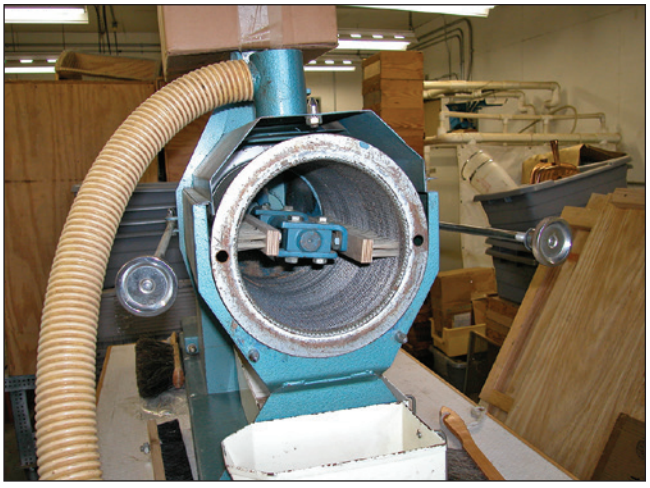


Figure 2.6—*Brush machine for hulling indehiscent fruits, dewinging and singularizing seeds. (Photo by R. Karrfalt, USDA Forest Service.)*

Figure 2.8—*A macerator for de-pulping fleshy fruited seeds. (Photo by R. Karrfalt, USDA Forest Service.)*

Figure 2.9*—This small blower removes trash with positive pressure. (Photo by R. Karrfalt, USDA Forest Service.)*

Figure 2.10*—A small aspirator removes trash with vacuum. (Photo by R. Karrfalt, USDA Forest Service.)*

trash and empty seeds using a variety of machines, mainly with forced air. A blower applies air as a positive pressure (fig. 2.9), essentially blowing away the unwanted trash. An aspirator applies negative pressure (fig. 2.10), sucking away the trash. Screens (fig. 2.11) can separate the seeds from trash that is both larger and smaller than the seed. A machine can be equipped only with screens, or combined with forced air in an air-screen machine, sometimes called a fanning mill (fig. 2.12). The seed-cleaning discussion in *The Woody Plant Seed Manual* focuses on the use of expensive machinery. Brandenburg (1977) and Brandenburg and Park (1977) discuss the mechanical methods and principles of seed cleaning in detail. Efficient nursery operation often requires investment in this type of equipment to obtain the needed quantities of high-quality seed. But it is also possible to adequately clean smaller amounts of seed with low-cost tools such as the aspirator (fig. 2.10) and hand-held screens (fig. 2.11).

For mechanical cleaning to be effective, there must be some physical difference between the seed and the trash, and between the good seed and empty seed. Physical differences include width, thickness, length, weight or density, shape, surface texture, or color. Round-hole screens separate differences of width, while oblong-hole screens separate differences in thickness. Seed of different length may be separated using indent cylinders (fig. 2.13). The aspirator, blower, or air-screen machine use forced air to separate seeds by weight separations. Density separations can occasionally be made with water (fig. 2.14) or on a specific-gravity table (fig. 2.15), that uses forced air to make a gentle stratification of the light and heavier particles (e.g., seeds). A shake of the table pulls the strata apart. Inclined drapers (fig. 2.16) and spiral separators rely on particle shape and the ability to roll downhill to make a separation. If one particle has a surface texture with more friction than another particle, a vibratory separator (fig. 2.17) can separate the two. Color separation has had no application in forestry.

Seed Purchase

Many nurseries prefer the convenience of purchasing clean seed from reputable seed suppliers, when the quality and

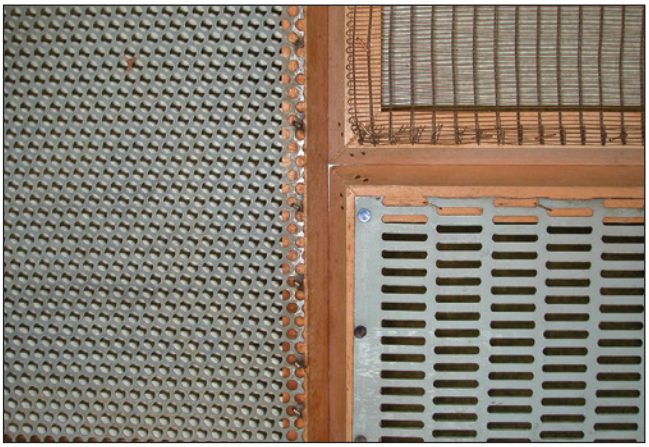


Figure 2.11*—Hand screens showing the three main types of screens used to clean seedlots (counter-clockwise from left): perforated metal round hole, perforated metal oblong holes, and woven wire. (Photo by R. Karrfalt, USDA Forest Service.)*

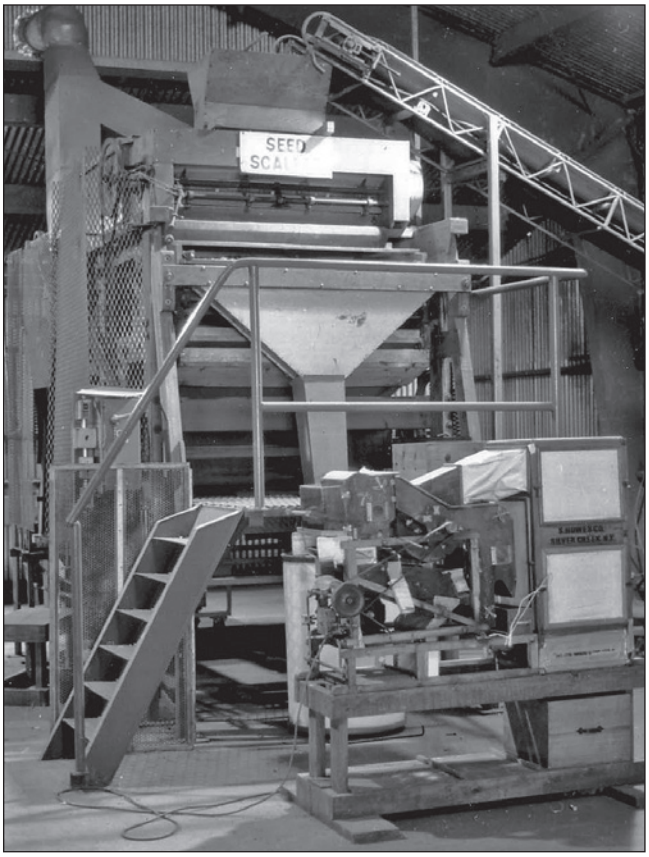


***Figure 2.12**—Air-screen machines come in many sizes and are used for basic seed cleaning; a small cleaner is in front of a very large cleaner. (Photo by R. Karrfalt, USDA Forest Service.)*

quantity desired is available on the open market. Ideally, the genetic source (describing the origin) and the quality of the seed (germination rate) are third-party verified at an accredited laboratory 6 to 9 months before the purchase. All requests or contracts for purchase should state the desired genetic source, germination, purity, and moisture content. In some cases, the seed should be tested for potential diseases. Each State generally has its own crop improvement association that certifies genetic origin, but sometimes interstate agreements apply.

Seed Testing

Seedlot Sampling

Seed that is extracted and cleaned is referred to as "finished seed." This seed should be evaluated in a seed-testing laboratory for its reproductive potential, economic value, and quality. As stated above, the reproductive potential is calculated by the pure live seed or PLS. Seed testing—the process to determine seed quality—begins by drawing a sample of seeds from the seedlot in a manner that will accurately represent the entire seedlot as a whole. A poorly drawn seed

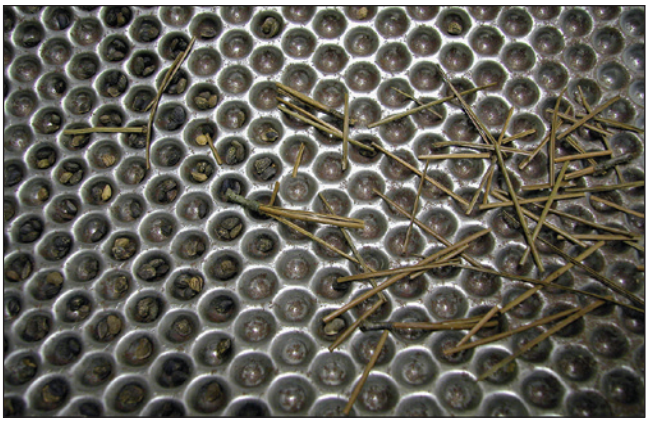


***Figure 2.13**—Seeds are caught in the indents of the cylinder, while long objects slide away. (Photo by R. Karrfalt, USDA Forest Service.)*

sample may result in serious failures in seedling culture months later. Appendix 2-2 provides a detailed procedure for sampling seedlots for testing.

The timing of seed testing is critical in managing seed supplies. An initial test needs to be made on the entire seedlot once it is in the final finished state, including a full test of purity, 1,000 seed weight (number of seeds per unit weight), and germination or viability. From this data, the manager will know if the seed collection succeeded in producing the desired quantity of pure live seeds. High-quality seedlots of desiccation-tolerant species will maintain germination for decades when properly stored. However, periodic retests of germination are necessary during storage. As long as moisture content does not change in storage (and it should not if the seed is stored correctly), purity and 1,000 seed weight do not need to be retested after the initial test. In general, viability is retested at 3- to 5-year intervals to monitor changes

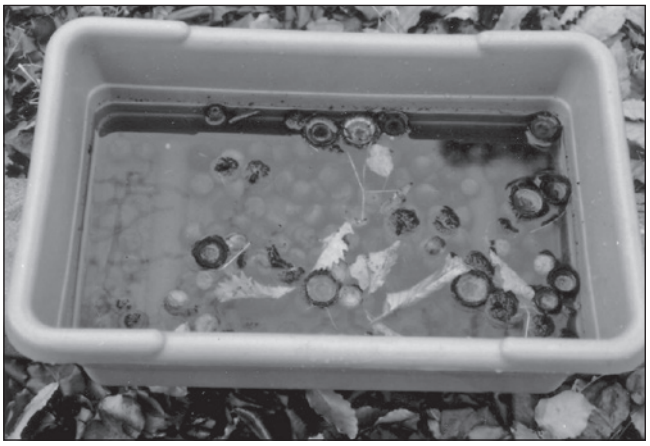


***Figure 2.14**—Floating acorns in water separates good seeds (sinkers) from damaged seeds (floaters) and trash. (Photo by R. Karrfalt, USDA Forest Service.)*

Figure 2.15*—A specific gravity table for separating seeds from trash using weight differences. (Photo by R. Karrfalt, USDA Forest Service.)*

Figure 2.17—*The vibratory separator removes trash from seeds by differences in surface texture. (Photo by R. Karrfalt, USDA Forest Service.)*

in germination that would require additional collections. The actual interval depends on projections of seed requirements to meet seedling production goals.

Seed should be tested for germination sometime within the 6 months before sowing in the nursery. Managers using seed without a current season germination test risk a costly crop failure. Schedule seed tests well in advance of sowing or shipping because a full test on a seedlot can take up to 3 months or more to complete, depending on the germination requirements of the species. Other tests may be done in 1 week or less. Coordination with the seed laboratory on scheduling tests is helpful for both the laboratory and the nursery.

Testing Seed Moisture

Seed moisture has traditionally been tested using a constant-temperature oven or electronic moisture testers that have been calibrated using the oven method. Chapter 5 of *The Woody Plant Seed Manual* describes both methods. However, the most appropriate and uniformly applicable way to assess seed moisture is the equilibrium relative humidity test (eRH) (Karrfalt 2014). As seeds dry, they will eventually come into equilibrium with the air around them as long as that air is held relatively constant at one relative humidity. Figure 2.18 shows the relationship of the range of relative humidities and the moisture content of green ash. At 30-percent relative humidity, seed moisture content is approximately 7 percent, a safe moisture content at which this species can be stored (Bonner 2008). A seed equilibrium relative humidity of 30 percent would be a good general target to dry seed for long-term storage and is usually achievable with dehumidifiers or heating the air.

Figure 2.16*—The inclined draper separates particles on their ability to roll or slide down an inclined belt. (Photo by R. Karrfalt, USDA Forest Service.)*

Tests of eRH are conducted using any quality hygrometer with a probe that can be isolated with the tested seed in a sealed chamber (see examples in figs. 2.19 and 2.20). Seeds usually equilibrate to the relative humidity of the air around them. In the closed test chamber, the air is no longer the dominant factor and the relative humidity of the chamber equilibrates to that of the seed. If a seed had been equilibrated at 30-percent relative humidity, the air in the test chamber would adjust to 30-percent relative humidity. If the relative humidity of the ambient air in the chamber was 25 percent, the seed would lose moisture to the jar air until jar air was also at 30-percent relative humidity. If the ambient air was 35-percent relative humidity, then the seed would absorb moisture until the jar air was at 30-percent relative humidity. The amount of moisture lost or gained during the test is negligible. This test can be run on seed at any level of purity, full seed percentage, or viability. This makes it useful in evaluating the condition of seed in postharvest storage.

Several important facts must be recognized in testing eRH. First, the eRH of seed just off the seed dryer will usually be

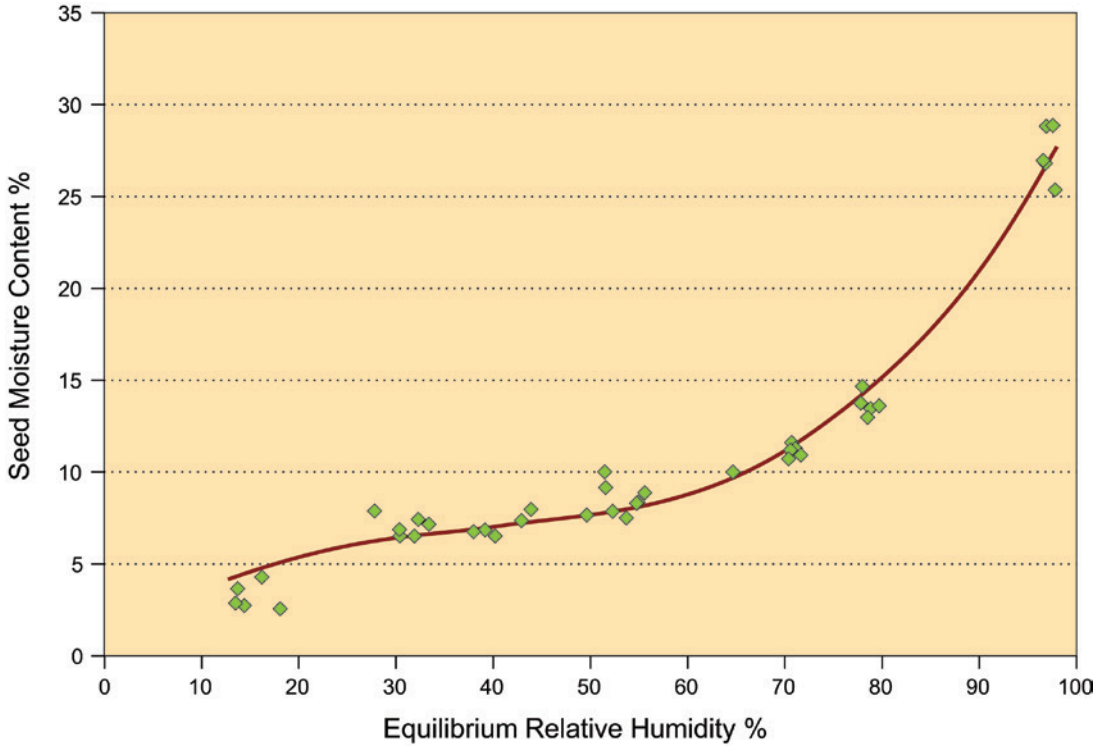


Figure 2.18—*Green ash moisture content graphed against relative humidity.*

lower than the inner seed because the surface of the seed dries faster than the seeds' interior. Larger seed, for example walnuts (*Juglans* spp.), persimmons (*Diospyros* spp.), and plums (*Prunus* spp.) will often also require time to reach internal equilibrium. In these cases, seed should be held in the test jar overnight to achieve equilibrium, improving the accuracy of the eRH. The hygrometer need not be attached to the test jar as the sample equilibrates overnight. If test chambers are inexpensive, it is possible to have many samples equilibrating at one time. The hygrometer can be attached at the end of the overnight equilibration period and a reading taken after 10 minutes. If the seed is at a higher-than-desired eRH, it can be returned to the dryer immediately. In this case, an overnight equilibration period is not needed. When the eRH is found to be acceptable, then an overnight equilibration is recommended to be sure the seed is at internal equilibrium and the true eRH is not too high.

Figure 2.19—*Handheld hygrometer for measuring equilibrium relative humidity of a seed lot. (Photo by R. Karrfalt, USDA Forest Service.)*

Dormancy and Preparation for Sowing

Operational Timing

Dormancy is an adaptive trait with different seeds following different maturation paths, depending on the strategies that result in successful reproduction. Seed that is shed in the fall

Figure 2.20—*A recycled peanut butter jar used as a test chamber for measuring equilibrium relative humidity (eRH) to test if the seed is dry for storage. A 30-percent eRH is good for all seeds that should be dried. (Photo by R. Karrfalt, USDA Forest Service.)*

is usually unable to germinate immediately and is considered dormant. Seed dispersed in the spring lacks dormancy and requires timely handling to place them into storage and/or sown in the nursery. This is especially true for the small seed of *Populus* spp. and *Salix* spp., which must be sown within a few weeks or placed into dry freezer storage. Some species, such as those in the genus *Quercus*, maintain high moisture at maturity and must find conditions favorable for germination and seedling establishment soon after falling from the mother plant. In contrast, seeds with deep dormancy, such as *Prunus* spp. and tulip poplar, can live for years in the soil and forest litter until conditions are good for seedling establishment, when germination commences.

From a nursery standpoint, species with no dormancy require little handling to get complete germination and a full stand of seedlings, provided that seed is handled properly and timely. Most species in temperate climates develop "desiccation tolerance," or the ability to dry to low-moisture content, and dormancy accompanies this tolerance. Dormant seed can be stored because the desiccation suspends respiration, putting the seed into stasis. A few desiccation-tolerant species are shed from the mother in spring or early summer, including cottonwoods and aspens (*Populus* spp.) and red maple. Because these seed are shed early in the growing season, they can germinate easily upon rehydration and produce a seedling in the same growing season in which they were formed.

The seed coats of legumes are impermeable to water and can remain dormant for extremely long periods. Once the seed coat is ruptured, even slightly, the seed will take up water and swell. The condition of not being able to absorb water is referred to as "hard-seeded." Many hardwoods have a very hard seed coat but are not "hard-seeded" because they can absorb water. Therefore, a simple test to tell if a species is hard-seeded is to soak the seed. If the weight of the seed increases after soaking, it is not hard-seeded. Methods for dealing with impermeable seed coats are discussed in *The Woody Plant Seed Manual*.

Dormancy

Seed dormancy is common among hardwood species, but with a few exceptions, seed can be treated to stimulate germination. Dormancy has two main causes:

- Seed coat dormancy caused by an impermeable or hard seed coat that prevents water or oxygen from reaching the embryo or prevents the embryo from breaking out of the seed coat even if water and oxygen pass in.
- Internal physiological dormancy or a morphologically undeveloped immature embryo.

Usually only one type of dormancy is present, but some seeds exhibit double dormancy, a combination of seedcoat and internal dormancy, such as redbud (*Cercis canadensis* L).

Stratification is the most common technique to break internal dormancy. During stratification, seed is subjected to cold, moist conditions that release the germinative capacity of the seed. Although it is traditional to think of dormancy as a barrier to germination, it is perhaps more appropriate to think of it simply as arrested development and growth necessary for various regeneration strategies in the wild. Biochemical-level studies of the germination process have found that germination occurs once there is the proper amount and proportion of growth-promoting and growth-regulating hormones at the meristematic regions of the embryo. Seeds that shed naturally with immature embryos, such as black and blue ash, will mature under moist conditions at temperatures between 59 to 68 °F (15 to 20 °C).

Stratification Procedures

A dry seed goes through two major periods of water uptake in order to germinate. The first is when the seed first comes into contact with water. The second is when the radicle emerges and germination commences. Between these two periods of

water uptake, the moisture content of the seed is relatively constant (see fig. 2.21). The first period of water uptake needs to be complete for stratification to occur. Trees are typically prepared for stratification by soaking in water overnight or for 1 to 2 days. After draining the water, seed is placed into plastic bags and stored in a cold room for a specified period. This process, used for at least 50 years, has produced workable results for many species but had two faults. First, the surplus water tended to pool on the bottom of the bag and submerge some seeds, depriving them of oxygen and causing anaerobic respiration, evidenced by the foul odor when the bag was opened. The second fault was that excess water could result in radicles emerging from some or all the seeds once the dormancy was overcome. Seeds with emerging radicles are not desired because they are difficult to sow and may be killed or weakened when the radicle breaks off during sowing.

One approach to controlling radicle emergence was to use shorter stratification periods. This approach, however, forfeits the benefit of faster germination and increased seed vigor that can be obtained with longer periods of stratification. Seeds with higher vigor can germinate under less-than-optimal conditions, such as temperatures that are lower or higher than optimal. This is an advantage when weather conditions are abnormally warm or cold during germination. Also, faster germination shortens the establishment period of seedling development, when seedlings are most vulnerable to damping off or to being washed out of the soil with heavy rains. For species that require stratification longer than 60 days, the extra water can be an issue in breaking dormancy because of the wide range of time required to break dormancy among individual seeds in these more-dormant species. The period to break dormancy in the most-dormant individual seeds can be so long that the least-dormant seeds will germinate before the full seedlot is ready to grow. Trials over the last 20 years have shown that removing the capillary water from around the seeds will keep them from germinating, regardless of how long the stratification period is. Therefore, the objective in preparing seeds for stratification is to have them fully imbibed but denied the water needed for germination to commence.

Once seed is fully imbibed, the seeds' surface must be dried. The seed must be exposed to air that is dry enough to remove the water. This is generally at 60-percent relative humidity or less. When this step is completed the seed will no longer have a shine from capillary water or a surface water film. Seed will appear to be damp and not as they were when dry. As only the surface water is to be removed, the seed must be constantly rotated so they are uniformly dried. The dryer used to dry seed for storage can be used if the seed in the drying basket are continually turned in some way so that no drying front develops. The ancient method of spreading the seed out in thin layers will also work but is labor-intensive and requires a good bit of space, as well as generally favorable weather. A more mechanized method is to place the seed in a tumbler, such as a small concrete mixer, and blow air across the seed as they are turned in the tumbler. A pedestal fan makes a convenient tool to blow air over the seed, as it can be adjusted to the height of the drum. The drying must be closely observed and stopped immediately upon the disappearance of the surface film of water.

The final step for stratification is to place the seed into a 4-mil (1 mil = 1000th of an inch) poly bag, weigh the bag of seed, and place it in the cold room at temperatures between 32 and 40 °F (between 0 and 4.5 °C). The bags should be weighed at weekly intervals to be sure they are not drying as would be indicated by a decrease in weight. Should the weight decrease, add just enough water to the bag to bring the weight back to the original value. Seed are kept in the cooler for as long as dictated by experience, a reliable reference, or a laboratory germination report. The last point to be made on seed stratification is to count back from the desired sowing date to determine when to start seed preparation.

Fall Sowing

Many nurseries will plant hardwood seed in the fall to take advantage of natural conditions, as an alternative to stratifying seed in a cooler. Fall sowing requires that seed be available before the ground freezes. The beds must also be protected from predation through the winter. Over the last decade, this practice has failed in some cases because the winters are too mild or there is a mild period in between two

Seeds soaked in water for a sufficient length of time will become fully imbibed, unless they have impermeable seed coats. The question then is what steps can determine a sufficient length of time for the soak. Step one is to take some seeds and weigh them. Step two is to place them in a water soak for 24 hours. Then take them out of the water, surface dry them, weigh them again, and return them to the water for another 24-hour soak. These steps are repeated until the weight gain between 2 days is essentially 0. There may be some fluctuation at the later weighings with different amounts of water drained from the seed on different days. Once the number of days of water soak to full imbibition is determined, it can be used operationally. Time to full imbibition for specific species may sometimes be found in the literature. Assistance may also be available from a seed laboratory such as the National Seed Laboratory.

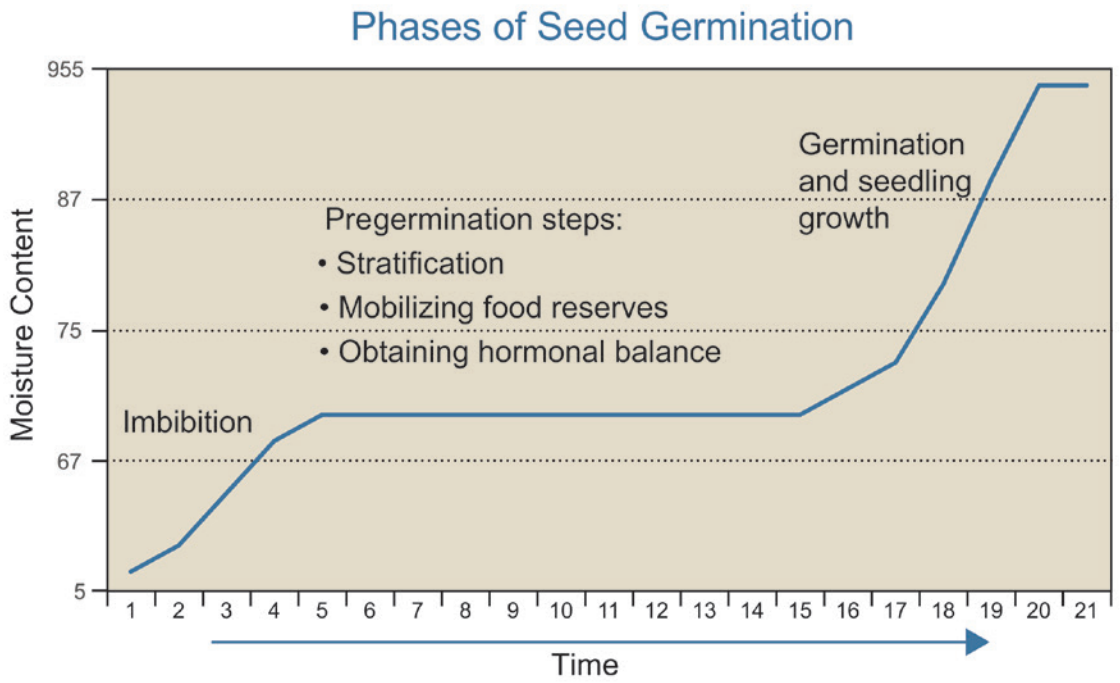


Figure 2.21—*A generalized curve of water uptake during different phases of germination. The actual timing, in terms of days, will vary by species.*

extended freezing periods. In the first case, stratification is incomplete and in the second, germination occurs during the winter instead of in the spring and the seedlings are killed in the second period of freezing weather. Fall sowing does have the advantage of not requiring a cooler for stratifying seed.

Seed Storage

Managing Seed Moisture

Seed moisture is the single most important factor in maintaining seed vigor in storage (Justice and Bass 1978). A nursery with any significant amount of seed in storage must be able to manage seed moisture to prevent spoilage. Therefore, whether seeds are produced in-house or purchased, the nursery needs the capacity to dry seeds and to test their moisture status. When buying fully finished seed, the seed should be dry as specified in the purchase contract but should be checked once the containers are opened. Test the moisture any time a seedlot is opened for any reason. As seedlots are repeatedly sampled for testing or withdrawing seeds to sow, moisture from the outside can enter the bag. The preceding section on seed storage has information on storage containers, as well as chapter 5 in *The Woody Plant Seed Manual.*

The ancient method of drying seed is to spread it in thin layers and continually turn it as it is exposed to dry air. Often that means spreading the seed in a warm, dry building or out in the sun on tarps. The faster and vastly more efficient method is to place the seed in a pressurized dryer (fig. 2.22). Pressurizing the air in the dryer causes the air to spread uniformly through the seed. The seed at the bottom of the seed tray will dry first and the upper layers in succession. There is no need to turn the seed; in fact, it is counterproductive.

Storage Length

Seeds that are desiccation-tolerant can be stored for extended periods of time; in some cases for decades, provided they

Figure 2.22—*A small pressurized seed drier. (Photo by R. Karrfalt, USDA Forest Service.)*

are equilibrated at a relative humidity of approximately 30 percent, sealed in a moisture-proof container, and stored between 0 and 20 °F (between -18 and -7 °C). A 6-mil thick poly bag can usually serve as the moisture-proof container, but plastic, glass, or metal cans or bottles also work. Keep the container as full as possible to minimize the amount of moisture carried in the air that will be absorbed by the seed as the container cools in the freezer. Although 0 °F (-18 °C) is optimal for long-term storage, its benefits might not be realized, as operational seedlots are normally consumed before the advantage of the lower temperature can be observed.

Several exceptions are worth noting. For one, red oak (*Quercus rubra* L.) is desiccation-intolerant but can be stored just below freezing or slightly above freezing for up to 3 years. Seed will perish over time and usually be completely dead by the end of the fourth year. Not all seedlots or species will respond the same. Hickories (*Carya* spp.) are desiccation-tolerant but are damaged by freezing temperature and should be stored at temperatures slightly above freezing. They should be prepared for storage the same as other desiccation-tolerant species—dried and placed in moisture-proof containers. The appropriate genus chapter in *The Woody Plant Seed Manual* provides known storage conditions for a given species.

References

Bonner, F.T. 1970. Hardwood seed collection and handling. In: Silviculture and management of southern hardwoods. Louisiana State University 19th Annual Forestry Symposium: 53–63.

Bonner, F.T. 1973. Storing red oak acorns. Tree Planters' Notes. 24(3): 12–13.

Bonner, F.T. 2008. *Fraxinus*. In: Bonner F.T.; Karrfalt R.P., eds. 2008. The woody plant seed manual. Agric. Handb. 727. Washington, DC: U.S. Department of Agriculture, Forest Service: 537–543.

Bonner, F.T.; Karrfalt, R.P., eds. 2008. The woody plant seed manual. Agric. Handb. 727. Washington, DC: U.S. Department of Agriculture, Forest Service: 274–280.

Bonner, F.T.; Vozzo, J.A. 1987. Seed biology and technology of *Quercus*. Gen. Tech. Rep. SO-66. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 21 p.

Brandenburg, N.R. 1977. The principles and practice of seed cleaning: separation with equipment that senses dimensions, shape, density, and terminal velocity of seeds. Seed Science and Technology. 5(2): 173–186.

Brandenburg, N.R.; Park, J.K. 1977. The principles and practice of seed cleaning: separation with equipment that senses surface texture, colour, resilience and electrical properties of seeds. Seed Science and Technology. 5(2): 187–198.

Justice, O.L.; Bass, L.N. 1978. Principles and practice of seed storage. Agric. Handb. 506. Washington, DC: U.S. Department of Agriculture, Forest Service.

Karrfalt, R.P. 1992. Increasing hardwood seed quality with brush machines. Tree Planters' Notes. 43(2): 33–35.

Karrfalt, R.P. 2014. Assembling seed moisture testers, seed dryers, and cone dryers from repurposed components. Tree Planters' Notes. 57(2): 11–17.

Knight K.S.; Karrfalt, R.P.; Mason, M.E. 2010. Methods for collecting ash (*Fraxinus* spp.) seeds. Gen. Tech. Rep. NRS-55. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 14 p.

Landis, T.D.; Karrfalt, R.P. 1987. Improving seed-use efficiency and seedling quality through the use of history plots. Tree Planters' Notes. 38(3): 9–15.

McDonald, P.M. 1969. Silvical characteristics of California black oak (*Quercus kellogii* Newb.). Res. Pap. PSW-53. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 20 p.

Tylkowski T. 1984. The effect of storing silver maple (*Acer saccharinum* L.) samaras on the germinative capacity of seeds and seedling growth. Arboretum Kornikie Rocznik. 29: 131–141.

Young, J.A.; Budy, J.D.; Evans, R. 1983. Germination of seeds of wildland plants. In: Proceedings, Intermountain Nurseryman's Association Conference. Las Vegas, NV. 93 p.

Appendix 2-1

Glossary of Terms

Achene: Small, dry, indehiscent, single-seeded fruit with seed attached to ovary wall at only one point.

Bract: Modified leaf subtending a flower or flower cluster.

Dioecious: Flowering habit in plants in which male (staminate) and female (pistallate) flowers are borne on separate plants as in *Acer*, *Fraxinus*, and *Ilex*.

Equilibrium relative humidity: The humidity established in a sufficiently small sealed test chamber by seeds that indicates the moisture level of those seeds. It is measured by a hygrometer, the humidity sensor of which is sealed in the closed chamber.

Germination: The emergence of the embryo from the seed to the point that it is clear that the embryo has the potential to develop into a normal seedling.

Hard-seeded: The condition of a seed in which the seed is not able to absorb water. Seed coats of hard-seeded species must be broken in order to facilitate water entry.

Imperfect flower: A flower containing only one set of reproductive structures, either male or female.

Live seeds: Seed that germinate or are estimated to be alive by a viability test.

Monoecious: Flowering habit in which male (staminate) and female flowers (pistallate) occur on the same plant.

Mother tree: A tree from which seed is collected.

Orthodox seed: Seed that maintain high viability when dried to low-moisture content. Orthodox seed can generally be stored for long periods of time under the correct conditions.

Pappus: A tuft of delicate fibers or bristles that form a feathery appendance of an achene as in *Baccharis* and *Chrysothamnus*.

Perfect flower: A flower that contains both male and female structures, as in tulip poplar (*Liriodendron tulipifera*).

Polygamous: Bearing both bisexual and unisexual flowers on the same plant, or on different plants of the same species.

Pure live seed (PLS): The number of pure live seeds in a given weight (pound, ounce, gram, or kilogram).

Samara: Dry, indehiscent, winged fruit. Can be 1-seeded as in *Fraxinus* or *Ulmus*, or 2-samaras fused, as in *Acer*.

Scarify: A process to induce germination by disrupting the seed coats, usually with mechanical or chemical means, to increase permeability to water and gases or to lower mechanical resistance to radicle emergence.

Seed Purity: The ratio of pure seeds to the weight of pure seeds plus inert matter, or trash.

Recalcitrant seed: Seed that dies when dried to low moisture content, and generally cannot be stored long-term. Also known as desiccation-intolerant.

Seedlot: A single, uniform collection of seeds.

Seed quality: An assessment of a seedlot that encompasses both the maturity of seed, and the absence of insects or pathogens.

Stratification: A technique to break internal dormancy. During stratification, seed is subjected to cold, moist conditions that release the germinative capacity of the seed.

Seed weight: The weight of 1,000 pure seeds. It is used to determine the number of pure seeds contained in a given weight of seeds.

Viability: The percentage of a seedlot that is estimated to be capable of germination.

Appendix 2-2

Procedures for Seedlot Sampling

1. Number of Samples

If a seedlot is in more than one container, sample every container. A tree seedlot is rarely more than five containers, but if that is the case, contact the National Seed Laboratory for assistance. If only a portion of the seedlot will be sown in a particular season, then only that container or containers should be tested.

2. Sampling Preparation

Seed can be sampled immediately if the seed container has not yet been in cold storage. If the seeds have been kept in a cooler or freezer, however, the first step is to bring the container into ambient conditions and allow the seeds to reach ambient temperature before opening the container. This prevents moisture from condensing on the cold seeds, which will lead to an undesired increase in seed moisture. A 1-quart container or smaller might reach ambient temperatures in about 2 hours, while larger containers would take longer. The safest procedure is to pull the container 16 to 24 hours in advance of opening.

3. Sampling

Using a probe. Open the container and obtain samples, by hand or with a probe. A probe must be able to reach all points in the seedlot and should have uniformly spaced sampling gates. Insert the probe with the gates closed until it reaches the bottom or far side of the container. Open gates and use a slight rotating back and forth to allow seeds to flow into the probe. Gently close the gates so as not to cut or crack any seeds, withdraw the probe, and empty the seeds into a container. If the probe is inserted vertically, it must have divisions forming a separate chamber for each gate opening. If each gate does not have a separate chamber, the probe can only be used correctly in the horizontal position.

Hand-drawn samples. Two methods are recommended for hand-drawn samples. The first method involves collecting handfuls of seeds from the top, middle, and bottom of the container. To reach the middle and bottom of the container, insert an open hand into the seeds and move down to the appropriate level, close the hand around the seeds, and withdraw it. Where the container is too deep, the seeds will be packed too tightly to work the hand down far enough to reach the bottom of the container. If the container is too small, or the seeds are packed too tightly, remove some seeds from the top and pour the remainder into a second container, pausing half-way

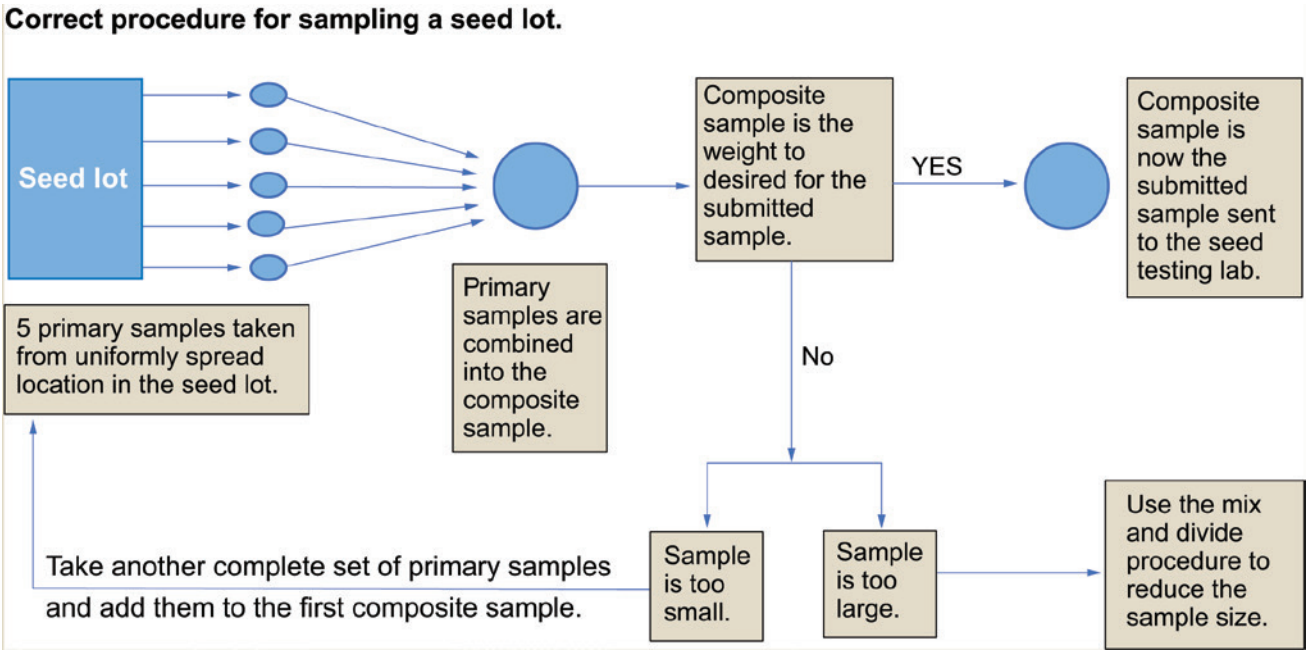


Figure 2.23—*Flow of work in sampling a seedlot for testing its quality.*

through to sample a handful of seeds. Take a third handful of seeds from the top of the second container (which has seeds from the bottom of the original container). To sample more intensely, take five handfuls: a handful of seeds from the top, from one quarter of the way down, half-way down, three-quarters of the way down, and from the bottom. Any number of handfuls over three is appropriate as long as they are evenly spaced down through the container. Alternatively, fill a spoon or small cup at each interval instead of a handful. Figure 2.25 outlines the drawing of samples.

4. Making a Composite Sample

Using table 2.2. Each handful or measure of seeds taken is called a primary sample. These primary samples are combined into a composite sample. For valid seed test results, this composite sample needs to contain at least 5,000 seeds. To determine the count, weigh the composite sample and compare the weight against the weight for the submitted sample in table 2.2. If the sample is too small, draw another complete set of primary samples. Taking only a partial set will bias the sample towards the conditions found in the part of the seedlot from which the partial set was taken and will not represent the values for the entire seedlot. For future sampling, increase the size or number of primary samples to avoid having to take an entire set of primary samples twice.

For species not listed in table 2.2, use the following procedure. First, take small amounts of seeds from at least five evenly spaced points in the composite sample and combine them. Weigh this combined subsample and count the number of seeds. Multiply the weight of the composite sample by the number of seeds in the subsample and then divide by the weight of the subsample to estimate the number of seeds in the composite sample. If the number is less than 5,000, resolve the problem by using the sampling procedures outlined in step 3 above.

5. Preparing the Sample for Testing

The sample to be submitted to the seed testing laboratory should consist of at least 5,000 seeds. However, if the weight of this sample exceeds the 5,000 minimum by more than 10 percent, reduce the sample to avoid an inaccurate test result. Using a soil sample or riffle divider (fig. 2.24), mix and divide the composite, or working, sample. Pour the full sample through the divider twice to mix it thoroughly. After a third division, take one-half of the composite sample from one side of the divider and weigh it to determine if the weight is sufficient to give 5,000 seeds. If not, record the weight and divide the other half into quarters. Weigh one of these quarters and add the weight to the first half. Do not combine the seeds until the weights added together produce a total weight sufficient to give 5,000 seeds. Then, combine the appropriate seeds to form a sample for submission and return the rest to the seed storage container. See figure 2.25 for the flow of this process.

If a riffle divider is not available, use four seamless metal or glass bowls large enough to hold the composite sample. Place the composite sample in one bowl. Then, using a

Table 2.2—*Minimum weights in grams for seed samples submitted for seed tests. The submitted sample is provided by the nursery. The working sample is a subset of the submitted sample used for testing purposes by the lab.*

Common name	Species	Submitted sample	Working sample
Boxelder	*Acer negundo* L	200	100
Japanese maple	*Acer palmatum* Thunb.	100	50
Red maple	*Acer rubrum* L.	100	50
Silver maple	*Acer saccharinum* L	1,000	500
Sugar (hard) maple	*Acer saccharum* Marshall	360	180
Horse-chestnut	*Aesculus hippocastanum* L. *	500	500
Red alder	*Alnus rubra* Bong.	4	2
False indigo bush	*Amorpha fruticosa* L.	300	150
Paper birch	*Betula papyrifera* Marshall	10	3
Silver birch	*Betula pendula* Roth	10	1
Downy birch	*Betula pubescens* Ehrh.	10	1
Hornbeam	*Carpinus betulus* L.	500	250
Catalpa	*Catalpa* spp.	120	60
Cotoneaster	*Cotoneaster* spp.	40	20
Ash	*Fraxinus* spp.	400	200
Honey locust	*Gleditsia triacanthos* L.	800	400
Sweetgum	*Liquidambar styraciflua* L.	30	15
Tulip poplar	*Liriodendron tulipifera* L.	180	90
Apple	*Malus* spp.	50	25
Mulberry	*Morus* spp.	20	5
Sycamore	*Platanus* spp.	25	6
Poplar, cottonwood, aspen	*Populus* spp.	5	2
Mazzard cherry	*Prunus avium* (L.) L.	900	450
European bird cherry	*Prunus padus* L.	360	180
Peach	*Prunus persica* (L.) Batsch *	500	500
Black cherry	*Prunus serotina* Ehrh.	500	250
Cherry, peach, and plum	*Prunus* spp. (TSW ≤ 200 g)	1,000	500
Cherry, peach, and plum	*Prunus* spp. (TSW > 200 g) *	500	500
Pear	*Pyrus* spp.	180	90
Oak	*Quercus* spp. *	500	500
Black locust	*Robinia pseudoacacia* L.	100	50
Rose, briar	*Rosa* spp.	50	25
Willow	*Salix* spp.	5	2
Mountain ash	*Sorbus* spp.	25	10
Littleleaf linden	*Tilia cordata* Mill.	180	90
Bigleaf linden	*Tilia platyphyllos* Scop.	500	250
American elm	*Ulmus americana* L.	30	15
Chinese elm	*Ulmus parvifolia* Jacq.	20	8

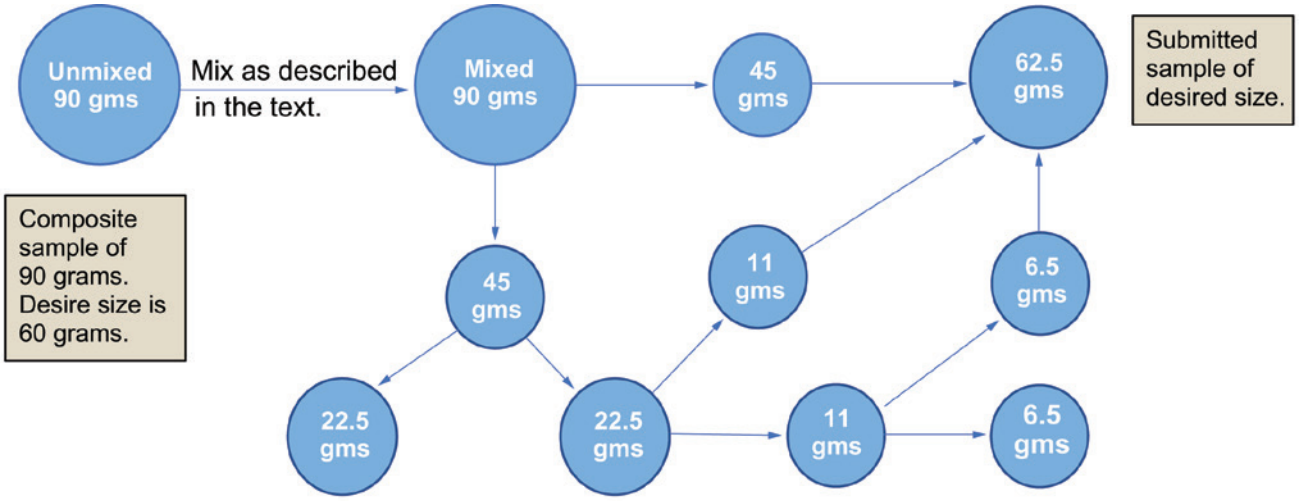
TSW = The sample weight.
* Values are number of seeds, not grams of seed.

Figure 2.24—*Riffle divider. (Photo by R. Karrfalt, USDA Forest Service.)*

small spoon, place a rounded spoonful of seeds alternately into bowl 2 and bowl 3 until the entire composite sample is divided into two equal portions, one in bowl 2 and one in bowl 3. Then, starting with bowl 2, repeat the process by alternately placing one spoonful of seeds from bowl 2 into bowl 1 and then into bowl 4 until bowl 2 is empty. Do the same with bowl 3. Now weigh the seeds in either bowl 1 or bowl 4. Proceed with weighing and dividing the seeds in this manner, as if using the riffle divider, to obtain an acceptable "submitted sample."

6. Forwarding the Sample to the Laboratory

The submitted sample then goes to the laboratory for testing. As moisture control is so important to maintain seed quality, transfer the seed samples to the lab in moisture-proof containers. Use a 4-mil poly bag or a plastic jar with a tight-fitting lid, but avoid glass containers that can break during shipping.



Flow of material using the correct procedure for reducing a composite sample to the desired weight for a submitted sample.

Mix and divide procedure is described in the text.

Figure 2.25—*Flow of work in mixing and dividing a seed testing sample that is too large.*