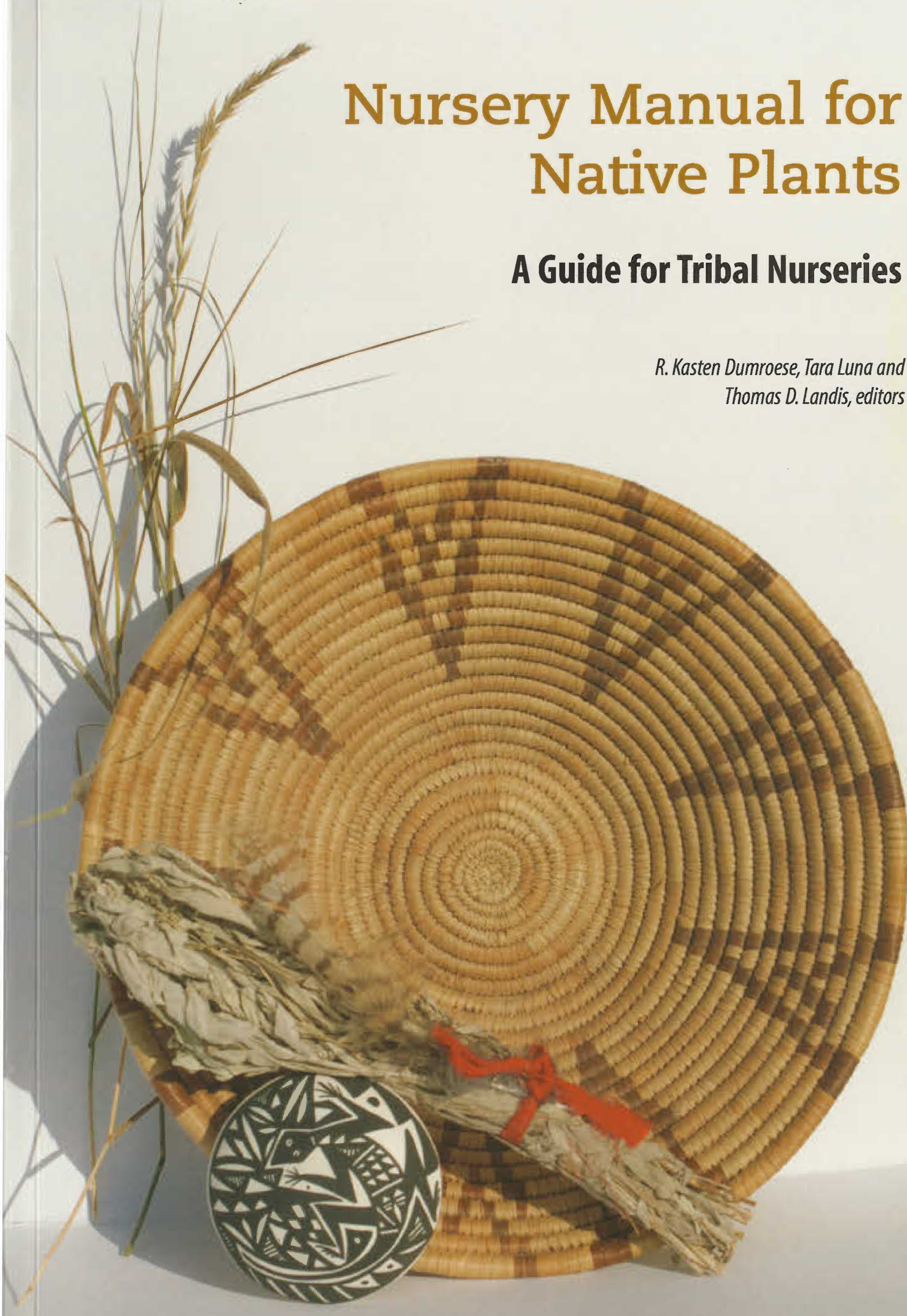
Nursery Manual for Native Plants

A Guide for Tribal Nurseries

R. Kasten Dumroese, Tara Luna and Thomas D. Landis, editors



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Growing Media

Douglass F. Jacobs, Thomas D. Landis, and Tara Luna

Selecting the proper growing medium is one of the most important considerations in nursery plant production. A growing medium can be defined as a substance through which roots grow and extract water and nutrients. In native plant nurseries, a growing medium can consist of native soil but is more commonly an "artificial soil" composed of materials such as peat moss or compost.

When people first began to grow plants in containers, they used ordinary field soil but soon found that this practice created horticultural problems. The very act of placing soil in a container produces conditions drastically different from those of unrestricted field soil. In the first place, plants growing in containers have access to a very limited amount of growing medium compared to field-grown plants. This limited rooting volume means that nursery plants can access only a small amount of water and mineral nutrients and these resources can change quickly. Second, containers create a perched water table, which means that water cannot drain freely out the bottom of the container (Swanson 1989). Third, native soils contain many microorganisms, such as bacteria and fungi, which do not exist in artificial growing media. Finally, native soils have texture (particle size) and structure (particle aggregations) that create porosity. An artificial growing medium has a texture based on the size and shape of its particles but does not have structure because the individual particles of the various components do not bind together. Therefore, the textural properties of

Potential components of growing media by Tara Luna.

growing media components must be carefully chosen and blended to produce the right mixture of porosity that will persist throughout the growing cycle.

It is important to realize that three different types of growing media are used in container nurseries:

1. Seed Propagation Media. For germinating seeds or establishing germinants, the medium must be sterile and have a finer texture to maintain high moisture around the germinating seeds.
2. Media for Rooting Cuttings. Cuttings are rooted with frequent mistings, so the growing medium must be very porous to prevent waterlogging and to allow good aeration, which is necessary for root formation.
3. Transplant Media. When smaller seedlings or rooted cuttings are transplanted into larger containers, the growing medium is typically coarser and contains compost instead of *Sphagnum* peat moss. Native plant growers often add 10 to 20 percent of soil or duff to encourage the development of mycorrhizal fungi and other beneficial microorganisms.

In this chapter, we explore the important media characteristics that can affect plant growth and discuss how nursery growers may use these basic principles to select and manage their growing media. More detailed information can be found in Bunt (1988) and Landis and others (1990).

FUNCTIONS OF GROWING MEDIA

In a native plant nursery, a growing medium serves four functions: (1) it physically supports the plant, (2) large pores promote oxygen exchange for root respiration, (3) small pores hold water, and (4) mineral nutrients are carried in the water to plant roots (figure 5.1).

1. Physical support

Although it might seem obvious, the growing medium must be porous to allow roots to grow out and provide physical support. Young plants are very fragile and must remain upright so that they can photosynthesize and grow. With larger nursery stock in individual containers, a growing medium must be heavy enough to hold the plant upright against the wind. Bulk density is the responsible factor and will be discussed in a later section.

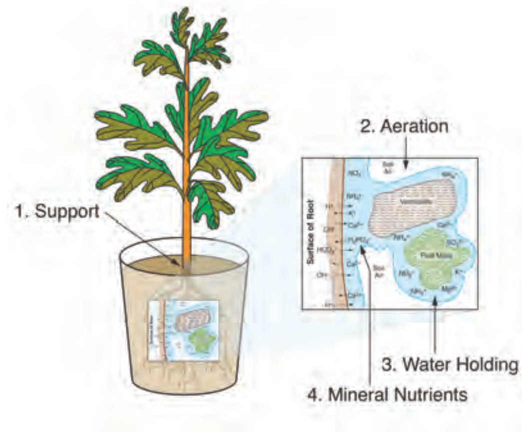

Figure 5.1—*Primary functions of growing media include the capacity to hold water and nutrients for root uptake, providing adequate root aeration, and ensuring structural support to the plant.* Illustration by Jim Marin.

2. Aeration

Plant roots need oxygen to convert the photosynthate from the leaves into energy so that the roots can grow and take up water and mineral nutrients. This process is called "aerobic respiration" and requires a steady supply of oxygen. The by-product of this respiration is carbon dioxide that must be dispersed into the atmosphere to prevent the buildup of toxic concentrations within the root zone. This gas exchange occurs in the large pores (macropores) in the growing medium. Because nursery plants are growing rapidly, they need a medium with good porosity—a characteristic termed "aeration" that will be discussed in more detail in the next section.

3. Water Supply

Nursery plants use a tremendous amount of water for growth and development, and this water supply must be provided by the growing medium. Artificial growing media are formulated so they can hold water in the small pores (micropores) between their particles. Many growing media contain a high percentage of organic matter such as peat moss and compost because these materials have internal spaces that can hold water like a sponge. Therefore, growing media must have adequate microporosity to absorb and store the large amounts of water needed by the growing plants.

4. Supply of Mineral Nutrients

Most of the essential mineral nutrients that nursery plants need for rapid growth must be obtained through the roots from the growing medium. When they are taken up by plants, most mineral nutrients are electrically charged ions. Positively charged ions (cations) include ammonium nitrogen (NH_4^+), potassium (K^+), calcium (Ca^{+2}), and magnesium (Mg^{+2}). These cations are attracted to negatively charged sites on growing medium particles until they can be extracted by roots (figure 5.1). The capacity of a growing medium to adsorb these cations is referred to as cation exchange capacity (CEC), and this important characteristic is discussed in the next section. Different types of media components vary considerably in their CEC, but peat moss, vermiculite, and compost have high CEC values, which explains their popularity in artificial growing media.

CHARACTERISTICS OF AN IDEAL GROWING MEDIA

Because no single material can meet all of the above criteria, artificial growing media often consist of at least two components. Therefore, growers must be familiar with the positive and negative characteristics of the various components and how they will affect plant growth in order to select a commercial medium or make their own. For our discussion, these characteristics can be divided into physical and chemical properties.

Physical Properties

Water-Holding Capacity

Micropores absorb water and hold it against the pull of gravity until plants can use it (figure 5.2). The water-holding capacity of a medium is defined as the percentage of total pore space that remains filled with water after gravity drainage. A good growing medium will have a high water-holding capacity but will also contain enough macropores to allow excess water to drain away and prevent waterlogging. Water-holding capacity is determined by the types and sizes of the growing medium components. For example, a peat moss particle will hold much more water than a piece of pumice. The degree of compaction is also extremely important. If growing medium particles are damaged during mixing or compacted when the containers are filled, the percentage of macropores is severely reduced. Overmixed or compacted media will hold too much water and roots will suffocate. Finally, the height of the growth container affects the water-holding capacity. Because nursery stock must be supported to allow air pruning of the roots, a certain amount of water will always remain in the bottom of the container. When filled with the same medium, short containers will have a higher percentage of waterlogging than taller ones (see figure 5.2).

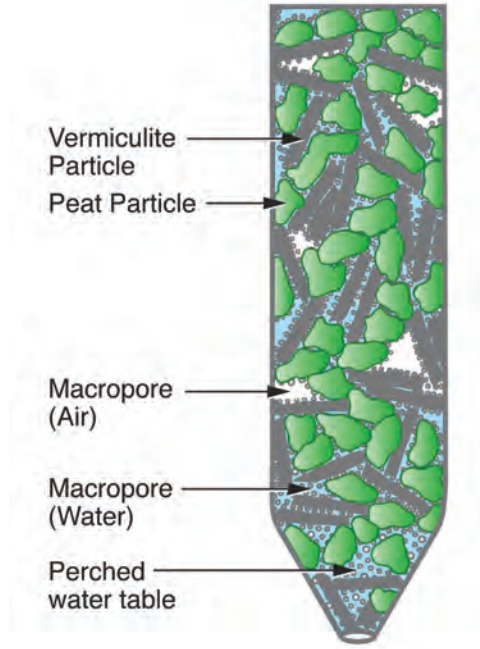

Figure 5.2—*A good growing medium contains micropores, which hold water, and macropores, which allow for air exchange. All containers also have a perched water table in the bottom.* Illustration by Jim Marin.

Aeration

The percentage of total pore space that remains filled with air after excess water has drained away is known as "aeration porosity." As we have already discussed, oxygen for good healthy roots is supplied through the larger macropores (figure 5.2), which also allow carbon dioxide from respiration to dissipate. A good growing medium, especially for rooting cuttings, contains a high percentage of macropores.

Porosity

The total porosity of a growing medium is the sum of the space in the macropores and micropores; as we have discussed, plants need both. A growing medium composed primarily of large particles will have more aeration and less water-holding capacity than a medium of smaller particles (figure 5.3). Either of these media would restrict plant growth. Plants growing in a medium with all large particles would dry out too quickly, and those growing in a medium with all small particles would suffer from waterlogging. For a single-component medium, the ideal particle range to promote both water-holding capacity and aeration is about 0.8 to 6 mm. In actual practice, however, a good growing medium will contain a mixture of components with different particle sizes and characteristics, for example, peat moss and vermiculite.

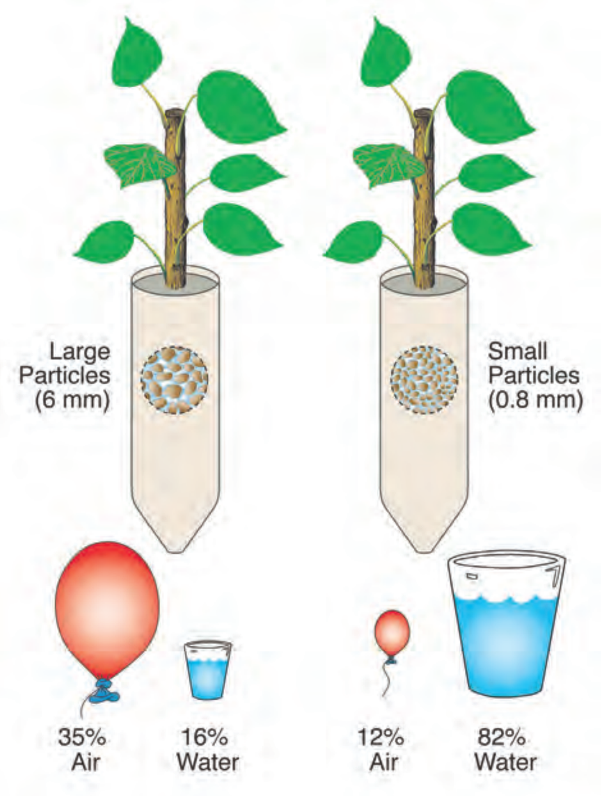

Figure 5.3—*These two containers each contain growing media with different particle sizes, either large (left) or small (right). The corresponding ballons show relative amounts of air being held, and the glasses show relative amounts of water being held.* Illustration by Jim Marin.

Shrinking and Swelling

Some soil-based media, especially those containing clays, shrink when drying or swell when wet. Shrinking and swelling is not a problem with the artificial growing media typically used in native plant nurseries.

Bulk Density

Bulk density means weight per volume. For any container type, weight per volume varies with the inherent bulk density of the growing medium components and how much they are compressed. For small-volume containers, an ideal growing medium will be lightweight to facilitate handling and shipping. For larger, free-standing containers, however, a good growing medium must have enough weight to provide physical support.

For a given container type and growing medium, excessive bulk density is a measure of compaction. Bulk density and porosity are inversely related; when bulk density increases, porosity decreases. Even a very porous growing medium can be ruined if it is compressed when the containers are filled.

Chemical Properties

Fertility

Because proper nutrition is so important for growing healthy nursery stock, fertility is the most important chemical property. Rapidly growing young plants use up the stored nutrients in their seeds soon after emergence. For the rest of the season, plants must rely on the growing medium to meet their increasing demands for mineral nutrients. As described in Chapter 11, *Fertilization*, many container nurseries prefer media with inherently low fertility (for example, peat-vermiculite) and add soluble fertilizers to media throughout the growing season. If fertilizers are difficult to obtain or cost prohibitive, organic amendments such as mature compost can be included in the growing media. Some native plants just grow better under low fertilization; in addition, beneficial microorganisms, such as mycorrhizal fungi, sometimes require low fertility to become established on plant roots. See Chapter 14, *Beneficial Microorganisms*, for more discussion on this topic.

pH

Another important chemical property is pH of growing medium, which is a measure of its relative acidity or alkalinity. pH values range from 0 to 14; those below 7 are acidic and those above 7 are alkaline. Most native plants tend to grow best at pH levels between 5.5 and 6.5, although some species are more pH tolerant. The main effect of pH on plant growth is its control on nutrient availability (figure 5.4). For example, phosphorus availability drops at extreme pH values because it binds with iron and aluminum at low pH levels and with calcium at high pH levels. The availability of micronutrients, such as iron, is even more affected by pH. Iron chlorosis, caused by high pH, is one of the most common nutrient deficiencies around the world. Exceptionally high or low pH levels also affect the abundance of pathogens and beneficial microorganisms. For example, low pH can predispose young plants to damping-off fungi.

CEC

CEC refers to the ability of a growing medium to chemically hold positively charged ions. Because most artificial growing media are inherently infertile, CEC is a very important consideration. In the growing medium, plant roots exchange excess charged ions for charged nutrient ions (see figure 5.1), and then these nutrients are transported to the foliage, where they are used for growth and development. Because the CEC of a growing medium reflects its nutrient storage capacity, it provides an indication of how often fertilization will be required. Because substantial leaching occurs with high irrigation rates, container nurseries prefer a growing medium with a very high CEC. One reason why native soils are not recommended for growing media is that clays adsorb cations so strongly that the cations may become unavailable for plant uptake, while the very low CEC of sandy soils causes most nutrients to be lost by leaching.

Biological Properties

Artificial growing media are preferred in nurseries because they are generally pest free. Although peat moss is not technically sterile, it should not contain pathogens or weed seeds when obtained from reliable sources. Vermiculite and perlite are rendered completely sterile during manufacturing, when they are exposed to temperatures as high as 1,832 °F (1,000 °C). In comparison, one of the most serious problems with soil-based growing media is that native soil can contain a variety of pests, such as pathogenic fungi, insects, nematodes, and weed seeds. For this reason, soil needs to be pasteurized with heat or sterilized with chemicals before it is used in growing media.

Well-prepared composts, however, are generally pest free because high temperatures during composting kill all pathogens. Another benefit of composting is that beneficial microorganisms increase in the final stages of the process. Composted pine bark, for example, contains microbes that suppress common fungal pathogens and nematodes. These suppressive effects depend on the parent material and composting time (Castillo 2004). Some commercial mixes advertise that they contain products that are antagonistic to pathogenic fungi.

COMPONENTS OF ARTIFICIAL MEDIA

Most native plant nurseries prefer artificial growing media and either mix it themselves or purchase premixed commercial brands. Although pure peat moss is used in some northern container tree nurseries, most growing media consist of two or more components that are selected to provide certain physical, chemical, or biological properties. Other amendments, such as fertilizer or wetting agents, are sometimes added during the mixing process. By definition, a growing medium component usually constitutes a large percentage (more than 10 percent) of the mixture, whereas an amendment is defined as a supplemental material that contributes less than 10 percent.

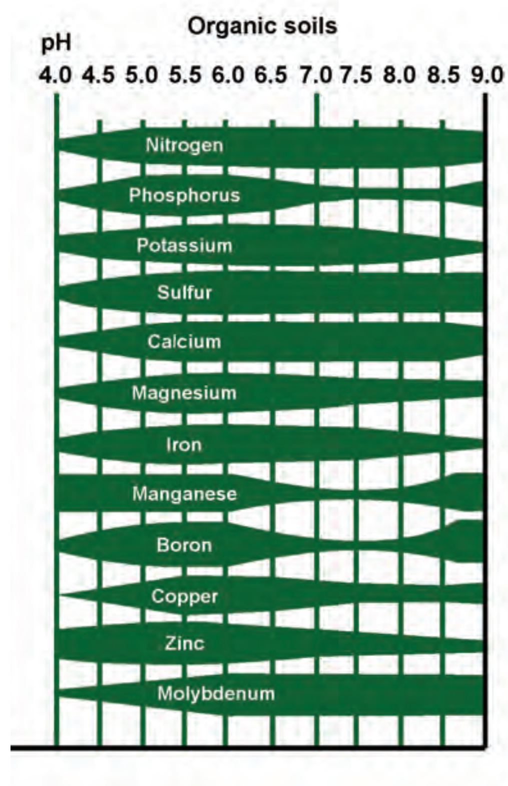

Figure 5.4—*The availability of all mineral nutrients is affected by the pH of the growing medium. In growing media such as organic soils, maximum availability occurs between 5.5 and 6.5.*

A typical growing medium is a composite of two or three components. Mixtures of organic and inorganic components are popular because these materials have opposite, yet complementary, physical and chemical properties (table 5.1). Common organic components include peat moss, bark, compost, rice hulls, coconut coir, and sawdust. These materials are generally low in weight and have high water-holding capacity. In addition, organic components generally have a high resistance to compaction, a high CEC, and may contain significant quantities of nutrients. Inorganic components of artificial media include gravel, sand, vermiculite, perlite, pumice, and polystyrene beads. Inorganic components improve media properties by increasing aeration pore space, adding bulk density, and enhancing drainage.

Table 5.1—Different chemical and physical properties of some common materials used to create an artificial growing medium

Component	Bulk Density	Porosity		pH	Cation Exchange Capacity
		Water	Air		
Peat Moss					
Sphagnum	Very low	Very high	High	3 - 4	Very high
Hypnum	Low	Very high	Moderate	5 - 7	Very high
Vermiculite	Very low	Very high	High	6 - 8	High
Perlite	Very low	Low	High	6 - 8	Very low
Bark	Low	Moderate	Very high	3 - 6	Moderate
Sand	Very high	Low	Moderate	Variable	Low

Figure 5.5—*Common organic components of growing media. (A)* Sphagnum *peat moss is the most popular because (B) its leaves contain open pores that create a high waterholding capacity. (C) Growers should avoid cheaper types of peat moss (*Sphagnum *on left;* Hypnum *on right) that can severely reduce plant growth. (D) Sawdust and (E) coconut coir have recently been used as a peat moss substitute.* Photos A-D by Thomas D. Landis, E by Tara Luna.

Organic Components

Peat moss is the most common component of artificial growing media (figure 5.5A). Peats can be composed of several species of plant, including mosses, sedges, and grasses. The species of plant, its degree of decomposition, variation in the local climate, and water quality all contribute to differences in peat moss quality and determine its value as a growing media component (Mastalerz 1977). Because *Sphagnum* moss leaves have open pores like a sponge (figure 5.5B), *Sphagnum* peat moss has a very good water-holding capacity, high CEC, low nutrient levels, and a comparatively low pH, often ranging from 3 to 4.5. In addition, the spongy texture of *Sphagnum* peat moss helps resist compaction and maintain porosity. Although types of peat moss may appear similar, they can have very different physical and chemical properties. *Sphagnum* peat moss must contain 75 percent mosses of the genus *Sphagnum*, and other peat products should never be considered (figure 5.5C). The ideal horticultural properties of *Sphagnum* peat moss (table 5.1) make it the only choice for growing native plants. In this handbook, when we use the generic term "peat moss," we mean *Sphagnum* peat moss.

Although peat moss is most popular, other organic materials such as bark, sawdust, compost, and coconut coir (figures 5.5D and E) have potential as growing media, especially in warmer climates where the cost of peat moss can be prohibitive. Tree bark is probably the most promising of alternative organic materials, and, when prepared properly, both pine and hardwood bark have found wide acceptance, especially for larger volume containers. One reason is that particle size can be controlled by the hammermilling and screening process (Gordon 2004). Composted pine bark, which has natural fungicide properties, can be produced on a small scale and has reduced pesticide use in nurseries (Castillo 2004). Raw Douglas-fir sawdust, combined with peat moss and vermiculite, has recently been used as a component in growing media for conifer seedling nurseries.

Growing media containing composts made from yard waste or pine bark were shown to be a viable alternative for peat moss when growing a variety of native plants in Florida (Wilson and others 2004). The chopped fiber from coconut husks is known as "coir" and has proven to be an excellent organic component for container growing media. Mixes containing coir are commercially available but are relatively more expensive than those with *Sphagnum* peat.

Inorganic Components

Inorganic materials are added to growing media to produce and maintain a structural system of macropores that improves aeration and drainage and decreases water-holding ability (Mastalerz 1977). Many inorganic components have a very low CEC and provide a chemically inert base for the growing medium. Inorganic materials with high bulk densities provide stability to large, freestanding containers.

Several materials are routinely being used as inorganic components in growing media in container tree nurseries in the United States and Canada. Vermiculite is the most common component (figure 5.6A) and is a hydrated aluminum-iron-magnesium silicate material that has an accordion-like structure (figure 5.6B). Vermiculite has a very low bulk density and an extremely high water-holding capacity, approximately five times its weight. This material also has a neutral pH, a high CEC (table 5.1), and contains small amounts of potassium and magnesium. Vermiculite is produced in four grades. The grades are based on particle size, which determines the relative proportion of aeration and water-holding porosity. Grades 2 and 3 are most commonly used in growing media; grade 2 is preferred when more aeration porosity is desired, whereas grade 3 produces more water-holding porosity. A mixture of 50 percent *Sphagnum* peat moss and 50 percent coarse vermiculite is considered a standard artificial growing media.

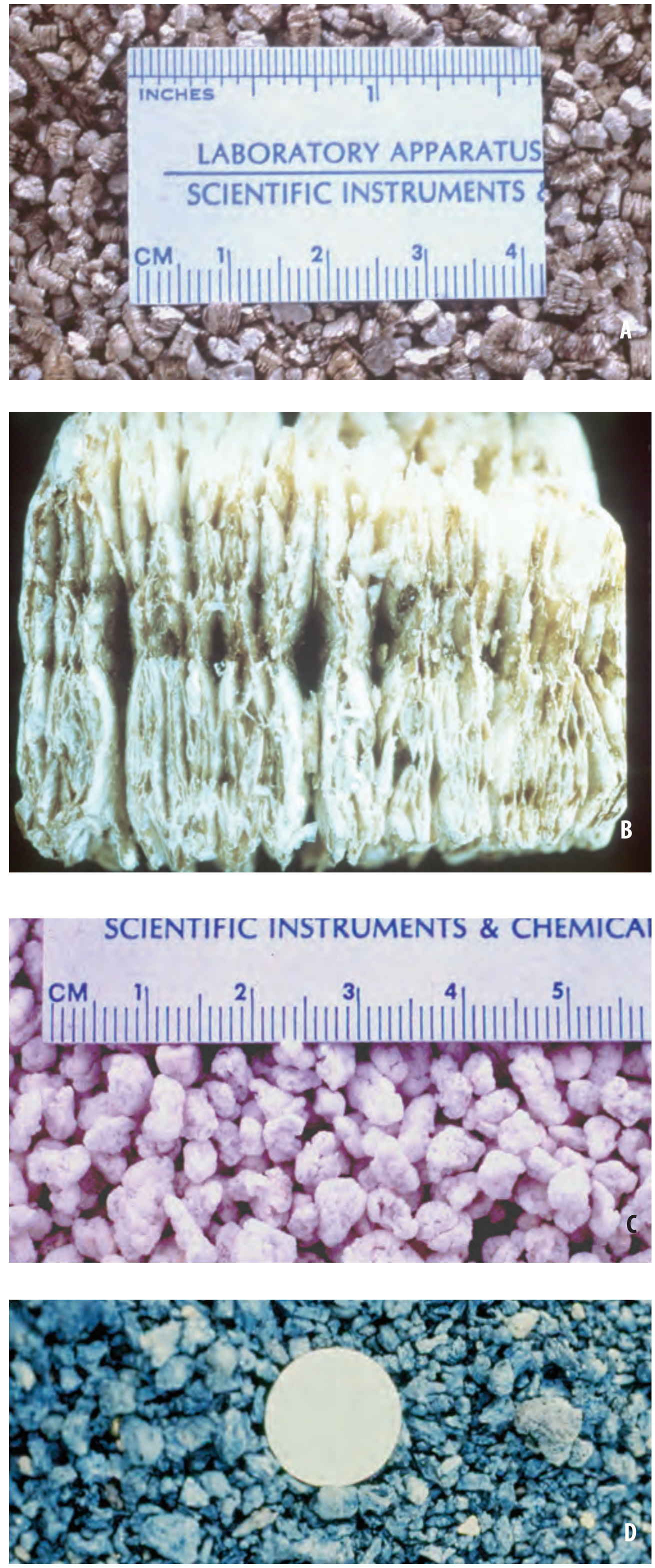

Figure 5.6—*Common inorganic components of growing media. (A) Horticultural vermiculite particles (B) look like accordions because of their expanded structure of parallel plates, which allow vermiculite to absorb water and mineral nutrients like a sponge. (C) Perlite particles have a closed-cell structure that prevents water absorption and improves aeration and drainage. (D) The particles of pumice also improve aeration but do absorb some water.* Photos by Thomas D. Landis.

Perlite is the second most popular inorganic component (figure 5.6C) and is a siliceous material of volcanic origin. Perlite particles have a unique closed-cell structure so that water adheres only to their surface; they do not absorb water as peat moss or vermiculite do. Therefore, growing media containing perlite are well drained and lightweight. Perlite is also rigid and does not compress easily, which promotes good porosity. Because of the high temperatures at which it is processed, perlite is completely sterile. It is essentially infertile, has a minimal CEC, and has a pH around neutral (table 5.1). Perlite is typically included to increase aeration, and commercial mixes contain no more than 10 to 30 percent of perlite. Perlite grades are not standardized, but grades 6, 8, or "propagation grade" are normally used in growing media. Perlite grades often contain a range of particle sizes, depending on the sieve sizes used during manufacturing. One safety concern is that perlite can contain considerable amounts of very fine particles that cause eye and lung irritation during mixing.

Pumice (figure 5.6D) is a type of volcanic rock consisting of mostly silicon dioxide and aluminum oxide with small amounts of iron, calcium, magnesium, and sodium. Readily available and relatively cheap in most of the Western United States, the porous nature of pumice particles improves aeration porosity but also retains some water within the pores. Pumice is the most durable of the inorganic components and so resists compaction.

Sand was a traditional component in the first artificial growing media but is almost never used now because of its weight (Gordon 2004). If you must use sand, choose siliceous sands because those derived from calcareous sources such as coral can have dangerously high pH values.

SELECTING A GROWING MEDIUM

A wide variety of commercial mixes are available that feature combinations of the components mentioned above (figure 5.7A). Although most media, such as peat-vermiculite, contain only two to three components, the exact composition of a brand may vary by location (figure 5.7B). Always read the label before purchasing a commercial mix. To appeal to a broader market, many brands contain a wide variety of additional amendments including fertilizers, wetting agents, hydrophilic

Figure 5.7—*(A) Many commercial growing media are available (B) so always check the label to determine the exact composition and whether amendments such as pine bark, coconut coir, or sand, have been added. (C) Many native plant growers prefer to mix their own species-specific media using a variety of components.* Photos A and B by Thomas D. Landis, C by Tara Luna.

gels, and even beneficial microorganisms. Again, always check the label to be sure of exactly what is being purchased. More details on amendments are provided in a later section.

Many native plant growers prefer to purchase components separately and mix their own custom growing media (figure 5.7C). In addition to saving money, custom mixing is particularly useful in small native plant nurseries, where separate mixes are needed to meet propagation requirements of different species. A very porous and well-drained medium, for example, might be needed for plants from very dry habitats.

When considering a new growing medium, first test it on a small scale with several species. In this way new media can be evaluated and plant quality compared before making a major change with the whole crop. Because of the diverse characteristics of the various growing media components, a grower can formulate a growing medium with almost any desired property. Be aware, however, that the physical, chemical, and biological properties of each growing medium are strongly affected by cultural practices, particularly irrigation, fertilization, and the type of container. Because the growing medium controls water and nutrient availability, it is easiest and most efficient to design custom mixes when several species are grown in the same irrigation zone. For the same reason, it is not a fair test to place a few containers of a new medium on a bench under existing irrigation and fertilization. See Chapter 17, *Discovering Ways to Improve Crop Production and Plant Quality*, for proper ways to install tests in the nursery.

CREATING A HOMEMADE GROWING MEDIUM

Although standard commercial mixes, such as peat-vermiculite, are generally superior for growing crops, some native plant nurseries prefer to formulate their own homemade medium. Reasons include poor availability of commercial media, price, shipping costs, lack of adequate storage, or simple preference. Many native plant nurseries are located in remote areas, where shipping costs for media components or commercial mixes may exceed their actual price.

Use of Field Soil

Most container nurseries prefer artificial growing media, but owners of some native plant nurseries think that soil-based media are more natural or organic. When considering native soil, several things should be kept in mind. Soils are naturally variable, so it is difficult to maintain the same quality from container to container or crop to crop. Ecological sustainability should also be considered. Harvesting topsoil is actually a mining operation that uses up a limited resource that took thousands of years to develop. If the decision is made to use native soil, we still recommend a sterile, uniform artificial media for germinating seeds, rooting cuttings, and any plants growing in smaller containers. The safest use of native soils is to incorporate a small amount (10 to 20 percent) into the mix when transplanting into larger containers. Adding a small amount of topsoil introduces desirable microorganisms into the medium and adds weight for greater stability. Be aware that most topsoil contains weed seeds that will germinate quickly in the ideal growing environment of a nursery.

When selecting soil, use dark topsoil that has a high percentage of organic matter; and lighter sandy loams are better than heavy clays. Harvesting soil from beneath healthy plants of the same species being grown ensures that the proper microorganisms will be present. For example, to grow normally in nurseries, the roots of *Ceanothus* plants must be inoculated with a bacterium called *Frankia*. Tests revealed that neither *Frankia* grown in artificial cultures or crushed *Frankia* root nodules were effective. However, 75 percent of the plants inoculated with soil that was collected under native *Ceanothus* stands became inoculated and exhibited superior vigor and growth (Lu 2005). After collection, sift the soil through a 0.5 in (12 mm) screen to remove debris and large objects such as rocks. When using native soils, heat pasteurization (described in the following paragraphs) will eliminate fungal pathogens, insect pests, nematodes, and weeds.

Making Compost

Because of the risks of using soils, many native plant nurseries prefer organic compost as a "green" alternative to peat moss. Composts are an excellent sustainable organic component for any growing medium and significantly enhance the medium's physical and chemical characteristics by improving water retention, aeration porosity, and fertility. Some compost has also been found to suppress seedborne and soilborne pathogens.

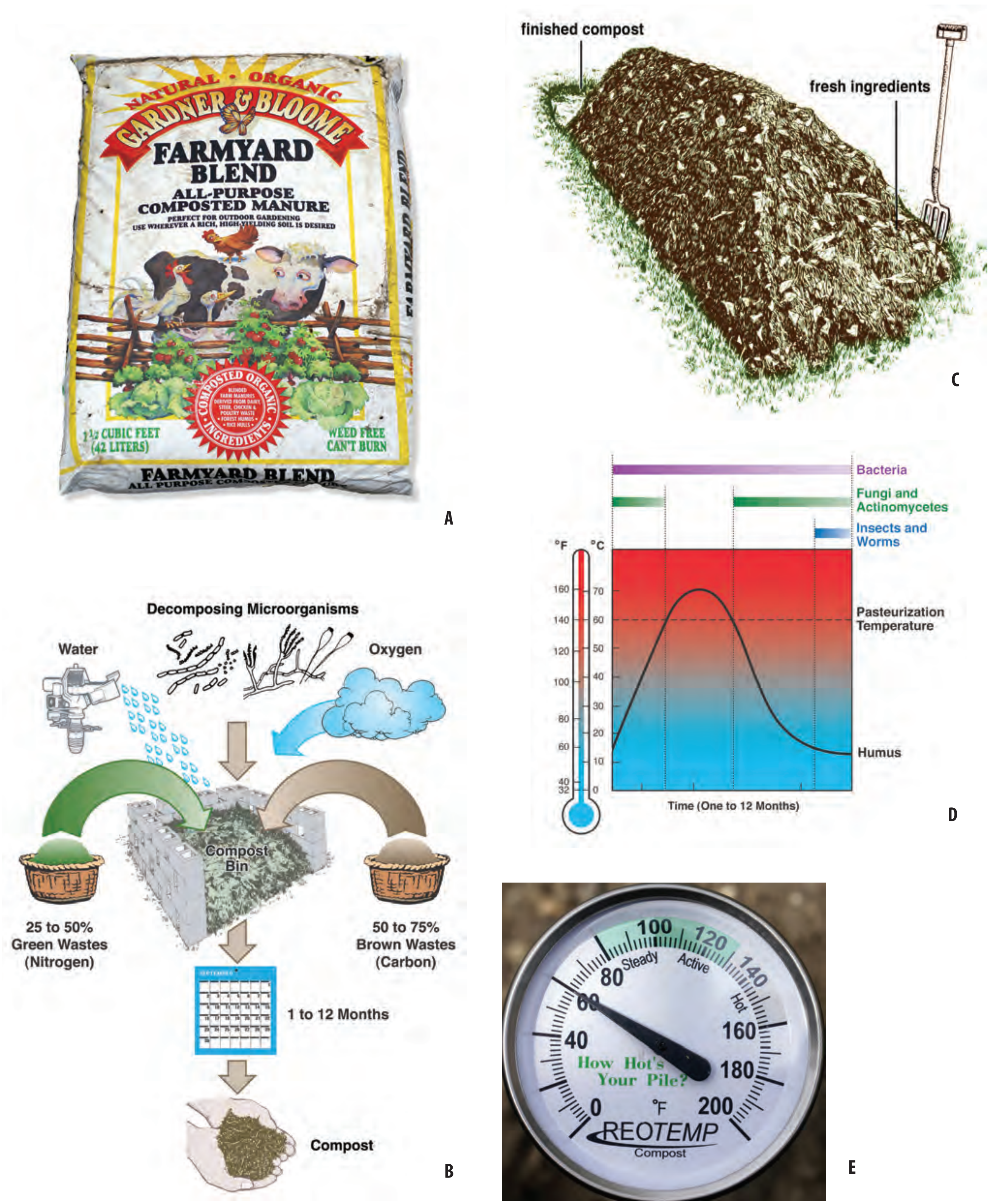

Figure 5.8—*(A) Many commercial composts are available. (B) Creating good compost takes several months and requires the proper mix of organic materials and creating the ideal environment for the microorganisms that decompose the materials. (C) Frequent mixing to foster good aeration is critical. (D) Compost goes through a typical temperature curve due to a succession of different microorganisms, (E) so the process should be monitored with a long-stemmed thermometer.* Photos by Thomas D. Landis, illustrations by Jim Marin.

Many brands of commercial compost are available (figure 5.8A). Compost can also be made on-site. Locating suitable organic materials for composting will vary considerably depending on the region where the nursery is located. Examples include grass, leaves, fruit wastes, coffee shells, rice hulls, wood waste such as sawdust or bark, sugar cane, manure, and even chicken feathers. Another benefit is that organic nursery wastes, such as used growing media or cull seedlings, can be composted, which reduces the costs and hassle of their disposal.

Making good compost is a rather technical process and takes some practice to learn. Here, we present some of the basic principles for creating compost for use in container production of native plants. To present these principles, we have synthesized information on composting from several excellent publications, including Martin and Gershuny (1992), Wightman (1999), and Castillo (2004). The Internet also has many sites devoted to composting. This brief description is meant only to introduce basic concepts and principles, not to serve as a step-by-step guide.

Composting is a natural process in which a succession of insects, fungi, and bacteria decompose organic matter and change its composition. The purpose of composting is to accelerate and control this process by modifying environmental conditions, especially moisture and temperature. Other factors that can be controlled include carbon-to-nitrogen ratio (C:N), aeration, and particle size (figure 5.8B).

Finished composts should have a C:N of about 30:1. Materials such as sawdust have much higher C:N that slows the composting process unless nitrogen fertilizer is added. When choosing materials for composting, maintain a mixture of 25 to 50 percent green organic matter and 50 to 75 percent brown organic matter (figure 5.8B). Green organic materials (fresh grass and fruit wastes) have a higher proportion of nitrogen compared with brown materials (tree leaves or sawdust), which contain more carbon. The particle size of your organics is very important. Particles that are too large reduce the surface area available for microbial attack whereas particles that are too small become compacted and create anaerobic conditions. A mixture of particles in the 0.5-to-2 in (1.2-to-5 cm) range works best. In well-aerated compost piles, however, particles can generally be at the smaller end of this range.

Maintaining adequate aeration is an important, yet often overlooked, factor. Microorganisms need an adequate and continual supply of oxygen, so it is important to turn over your compost pile once or twice a week. Poor aeration can delay or even stop the composting process. One good procedure to make certain the components are well mixed and all parts of the pile get proper aeration is to create an elongated windrow by turning over the pile in one direction (figure 5.8C). Moisture is another critical factor; the moisture content must be high enough to promote microbial activity but not so high as to reduce aeration and decrease temperature. Compost with a moisture content of approximately 50 to 60 percent has the feel of a damp sponge, which is ideal.

Several independent microbial decomposition phases occur during the composting process, creating a distinctive temperature sequence (figure 5.8D). Within the first few days, temperatures rise steadily to 100 to 120 °F (38 to 49 °C) as the smaller and easily biodegradable materials decompose. In the next step, temperatures rise to 130 to 150 °F (54 to 65 °C) as materials that are more resistant decay. A peak temperature of about 160 °F (71 °C) should be maintained for several days to kill weed seeds and fungal pathogens. Finally, temperatures fall to around 105 °F (40 °C) and lower during the "curing" stage. Growers can check the progress and detect problems in their compost heaps by monitoring with long-stemmed thermometers (figure 5.8E).

Determining When Compost Is Mature

Mature compost should be dark in color and have a rich, earthy smell (figure 5.9A). The texture should be friable and crumbly; the original organic materials should not be recognizable. Earthworms and soil insects invade mature composts and are an excellent sign that the compost is complete and ready to use (figure 5.9B).

Several tests help determine if your compost is mature and safe to use. These procedures, described in the following list, should also be used when purchasing commercial composts:

- **Sniff-and-Feel Test.** Place a small amount of compost into a plastic bag and seal it. Let this mixture sit for a day. If it feels hot or smells like manure or ammonia, it has not yet finished composting and should not be used.

Figure 5.9—*(A) The maturity of commercial or homemade compost should be checked before use in growing media.(B) In a mature compost, original components are no longer visible, earthworms and other soil insects are often visible, and it feels crumbly.* Photos by Tara Luna.

- **Germination Test.** Collect a sample of compost and put it into a small container. Sow seeds of a rapidly growing plant such as radish or lettuce, and place the sample in a window or in the greenhouse. If the compost is mature, the seeds should germinate and grow normally within a week or so.
- **Compost Maturity Tests.** Commercial test kits, such as the Solvita®, use a colorimetic process to measure the carbon dioxide and ammonium levels in a sample of compost. The level of these two factors correlates well with compost maturity.

After making the first batch of compost, it is a good idea to have a soils laboratory test it so that any nutritional deficiencies can be detected and corrected. Finally, before using composts, they should be sifted through a screen to remove large particles.

MIXING GROWING MEDIA

The mixing process is critical to producing custom growing media; the quality of the best components is compromised if the growing medium is improperly mixed. Whitcomb (2003) emphasized that improper mixing is one of the major causes of variation in container plant quality. The proper operating procedures are just as important as purchasing the right type of mixing equipment. Mixing should be performed by diligent, experienced workers who will faithfully monitor the quality of the growing media.

The special paddle-and-belt mixers used by commercial growing media companies do the best job of thoroughly mixing components without breaking down their structure. Most small native plant nurseries, however, cannot afford such specialized equipment and prefer to prepare small batches of growing medium by hand. Up to 5 or 6 cubic ft (0.15 cubic m or 155 L) of a medium can be mixed on any clean, hard surface by workers with hand shovels. Be sure to screen soil or compost to remove sticks and break up large clods (figure 5.10A). Pile the components on top of one another and broadcast any amendments over the pile. Then work around the edge of the pile with a large scoop shovel, taking one shovel full of material at a time and turning it over onto the top of the pile. As this material is added to the top, it tumbles down all sides of the pile and is mixed (figure 5.10B). Make sure that the center of the pile is mixed by gradually moving the location of the pile to one side during the mixing procedure. Some organic components repel water when dry, so misting the pile with water at frequent intervals during mixing makes the medium absorb water better. Continue this procedure until samples from the pile appear to be well mixed.

Nurseries that require larger quantities of custom growing media on a regular basis should purchase a mixer. A cement mixer (figure 5.10C) is often used and works well as long as care is taken to avoid excessive mixing ("overmixing"), which breaks down the size and texture of components. Fragile materials such as vermiculite and peat moss are particularly vulnerable to overmixing. Mechanized mixing can be easily overdone if the mixers are run too long or are overfilled or if the components are too wet. All too often, workers think that more mixing is better than less. On the contrary, overmixed media compacts easily during container filling and leads to reduced aeration and waterlogging.

Safety Considerations

Workers should follow certain precautions when handling growing media or its components. Dust is the most common concern, so work areas should be well ventilated. Spraying growing media and work areas with a water mist will also reduce dust. Workers handling and mixing growing media should wear protective dust masks and safety glasses (figure 5.11A). These same safety precautions should be taken when filling containers (figure 5.11B).

All growing media and components will generate dust, but perlite has been linked to silicosis, an inflammation that occurs over time when dust containing silica is inhaled into the lungs. Based on medical studies, however, no relationship exists between handling perlite and the development of silicosis (Schundler Company 2002). Still, dust is irritating and common sense dictates that masks should be worn when handling growing media or filling containers.

Asbestos contamination of vermiculite became another concern after the W.R. Grace mine in Libby, Montana, was closed in 1990. This mine produced a unique type of vermiculite that contained asbestos. Because of concerns about horticultural vermiculite, the National Institute for Occupational Safety and Health studied a broad range of commercial growing media containing vermiculite. It found that the use of commercial vermiculite hor-

Figure 5.10—*(A) Nurseries that mix their own media should first screen materials and then (B) mix them thoroughly using the moving pile technique. (C) To reduce labor, a cement mixer can also be used but care must be taken to avoid overmixing and the resultant damage to particle size and structure.* Photos A and B by Thomas D. Landis, C by Tara Luna.

Figure 5.11—*(A) When mixing growing media (B) or filling containers, nursery workers should wear dust masks and safety glasses.* Photo A by J. Chris Hoag, B by Thomas D. Landis.

ticultural products presents no significant asbestos exposure risk to commercial greenhouse or home users (Chatfield 2001).

Workers handling and mixing *Sphagnum* peat moss should not have cuts or abrasions on their hands because of the possibility of infection. A more serious concern is sporotrichosis, which is an infection caused by a fungal pathogen sometimes found in peat moss and other organic materials. The spores of this fungus can invade cuts on the hands or arms of workers or can even be inhaled (Padhye 1995). Preventative measures include:

- Storing peat moss and peat-based growing media under dry conditions.
- Ventilating work areas well.
- Wearing gloves, dust masks, and long-sleeved shirts to protect hands and arms.
- Thoroughly washing arms and other exposed parts of the body with soap and water to reduce the risk of infection.
- Treating any injury that breaks the skin with a disinfectant, such as tincture of iodine.
- Regularly sweeping and washing the work areas.

Sterilization of Growing Media

Sterilization refers to the complete elimination of all living organisms in the medium; pasteurization is less drastic. Completely sterile growing media may not be particularly desirable because many beneficial microorganisms, including bacteria, actinomycetes, and fungi, normally found in growing media can actually be antagonistic to pathogens. Some commercial brands of growing media are sterilized to prevent the introduction of pests, weeds, and diseases into the nursery (figure 5.12A). If concerned, growers should contact their supplier to find out if their media has been treated. For those mixing their own media, common inorganic components, such as vermiculite and perlite, are inherently sterile, but peat moss and other organic components are suspect. When using field soil or compost, growers should seriously consider pasteurization.

Although chemical fumigation is very effective, it is also expensive and hazardous and should be done only by registered pesticide personnel. Besides, the most common and effective chemical fumigant, methyl bromide, is being phased out because of concerns about ozone degradation. Heat pasteurization is the most common way of treating growing media and is traditionally done with steam. The standard recommendation is to heat the growing medium to 140 to 177 °F (60 to 80 °C) for at least 30 minutes. Commercially, media is pasteurized with large, expensive equipment but some native plant nurseries have developed their own portable pasteurization equipment (figure 5.12B). A practical technique would be to enclose small batches of media in black plastic tarps on an inclined table to expose it to maximum sunlight. Long-stemmed thermometers should be used to make sure that temperatures stay in the recommended range for the proper amount of time.

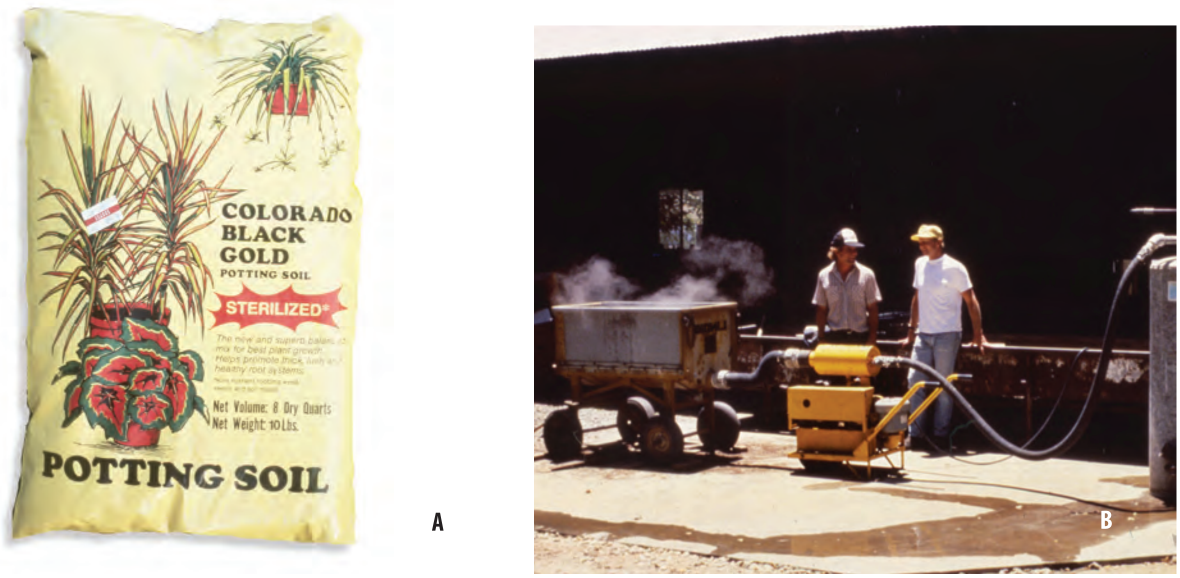

Figure 5.12—*(A) Some commercial growing media have been pasteurized to kill pathogens. (B) For nurseries making their own media, pasteurization with steam or solar heat is simple, effective, and done with portable equipment.* Photos by Thomas D. Landis.

INCORPORATION OF AMENDMENTS IN GROWING MEDIA

A variety of materials are routinely added to growing media during the mixing process; these include fertilizers, lime, surfactants, superabsorbents, and mycorrhizal inoculum. The uniform incorporation of these materials is important because plant roots have access to only a limited volume of growing media in the relatively small containers used in native plant nurseries Whitcomb (2003). When purchasing commercial media, growers should check the label and question the supplier to find out exactly what amendments have been added (see figure 5.7B).

Limestone. Called "lime" in horticulture, dolomitic limestone has traditionally been added to growing media to raise the pH and to supply calcium for plant nutrition. Better ways of supplying calcium exist, so we do not recommend limestone amendments unless you are growing plants that require a neutral or alkaline pH.

Starter Fertilizers. Some commercial media contain a small "starter dose" of soluble granular fertilizer. If fertigation (irrigation water containing liquid fertilizer) is not possible, then starter fertilizer may be a good idea to ensure that young, developing plants have quick access to mineral nutrients. Incorporating larger quantities of soluble fertilizer is never recommended because of the high potential for salt injury.

Controlled-Release Fertilizers. Several brands of growing media contain controlled-release fertilizers, and it is important to know their formulation and release rate. See Chapter 11, *Fertilization*, for more discussion about these fertilizers.

Surfactants. These chemical amendments, also known as "wetting agents," break down the surface tension of water and increase the wettability of hydrophobic organic materials such as peat moss and pine bark. Some surfactants have been shown to adversely affect the growth of pine seedlings. Because even less is known about their effects on other native plants, growers should ask other nurseries about their experiences and perform small tests before using surfactants operationally. See Chapter 17, *Discovering Ways to Improve Crop Production and Plant Quality*, for proper ways to set up tests.

Superabsorbents. Superabsorbents are cross-linked polymers that absorb many times their own weight in water. They have been proposed as additives to increase the water-holding capacity of growing media. Several brands of growing media contain superabsorbents but this is mainly an advertising gimmick. Because nursery crops are regularly irrigated, the use of superabsorbents is rarely justified. If growers want to try them, they should first test them on a limited basis.

Mycorrhizal Inoculum. One method of inoculating native plants with beneficial mycorrhizal fungi is to incorporate inoculum into the growing medium at the time of mixing. Again, this practice should be confirmed with small tests before adopting it on a large scale. See Chapter 14, *Beneficial Microorganisms*, for more discussion on this topic.

SUMMARY AND RECOMMENDATIONS

The selection of a growing medium is one of the most important decisions in the container culture of native plants. The physical, chemical, and biological characteristics of a growing medium affect not only seedling growth but also other aspects of nursery operations. Growers should carefully consider both biological and operational aspects when evaluating different types of growing media.

The decision to purchase a commercial brand of growing media or to custom mix depends on many factors, including the availability of components and mixing equipment and the size of the nursery operation. Several good commercial brands of growing media are available, but, for complete quality control, nursery managers should consider custom mixing their own media.

Whether purchasing a commercial media or custom mixing, the selection of growing medium components is critical. For most native plants, a growing medium consisting of *Sphagnum* peat moss and vermiculite is a good first choice if these materials are available and reasonable in price. The proportion of peat moss to vermiculite on a volume-to-volume basis can range from 1:1 to 3:1. Coarse-grade peat moss should be used whenever possible, and the coarser grades of vermiculite are preferred. A small proportion of perlite (10 to 30 percent) can be substituted for part of the vermiculite if better drainage is desired. Tree bark, especially composted pine bark, has shown promise, and sawdust has also been used as a peat moss substitute. Substitution of alternative organic materials for peat moss should be approached cautiously, however, and only composted organics should be considered.

When making your own growing media, make sure that mixing is complete but not so severe as to damage particle size or structure. Even though most components are considered sterile, nursery managers should consider pasteurization to eliminate any pathogens. As far as incorporating limestone, fertilizers, mycorrhizal fungal inoculum, surfactants, or superabsorbents, small-scale trials are always recommended before using the growing medium operationally.

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ADDITIONAL READING

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APPENDIX 5.A. PLANTS MENTIONED IN THIS CHAPTER

ceanothus, *Ceanothus* species

Douglas-fir, *Pseudotsuga menziesii*