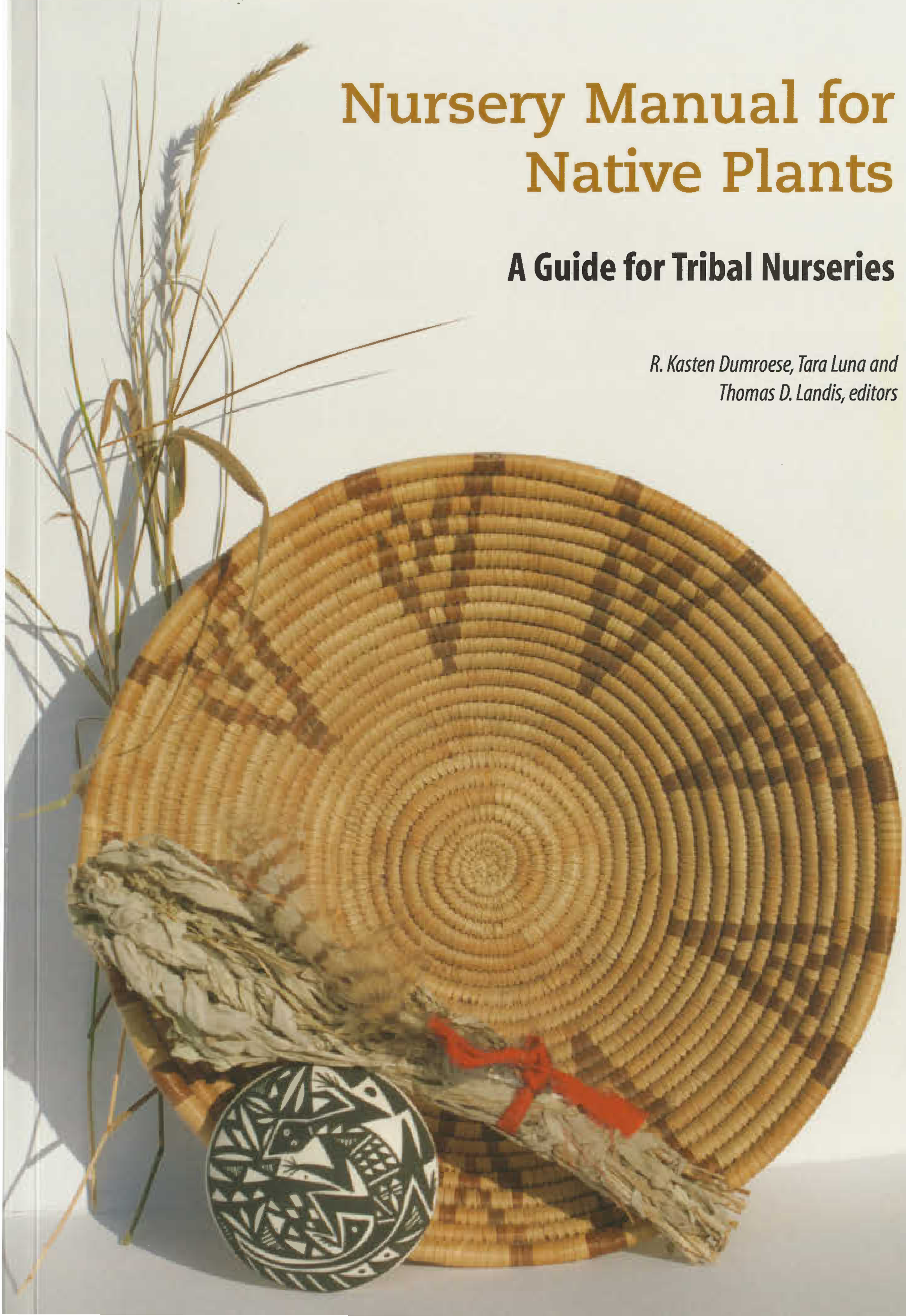
Nursery Manual for Native Plants

A Guide for Tribal Nurseries

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



VOLUME 1 | NURSERY MANAGEMENT

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


AGRA
TECH

Jacobs, Douglass F.; Landis, Thomas D.; Luna, Tara. 2022. Chapter 4: Propagation environments. In: Dumroese, R. Kasten; Luna, Tara; Landis, Thomas D., editors. Nursery manual for native plants: A guide for tribal nurseries - Volume 1: Nursery management (revised edition). Agriculture Handbook 730. Washington, D.C.: U.S. Department of Agriculture, Forest Service. p. 54-75.

4

Propagation Environments

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

An understanding of all factors influencing plant growth in a nursery environment is needed for the successful growth and production of high-quality container plants. Propagation structures modify the atmospheric conditions of temperature, light, and relative humidity. Native plant nurseries are different from typical horticultural nurseries because plants must be conditioned for outplanting on stressful sites where little or no aftercare is provided. This set of circumstances makes conditioning and hardening (see Chapter 12, *Hardening*) especially important, and these horticultural treatments require changing or modifying propagation structures.

Two essential processes in plants are photosynthesis and transpiration. Photosynthesis is the process in which light energy from the sun is converted into chemical energy in the presence of chlorophyll, the green pigment in leaves. During photosynthesis, sugars are produced from carbon dioxide from the air and water from the soil while oxygen is released back into the air (figure 4.1). Photosynthesis is a leaky process because, to allow the intake of carbon dioxide, water vapor is lost through pores, or stomata, on the leaf surfaces. This process is called transpiration. To maximize the photosynthesis necessary for plant growth, growers must manage any limiting atmospheric factors in the propagation environment.

A propagation environment is any area that has been modified to grow plants. It may or may not involve a structure like a greenhouse.

Greenhouse operated by the Confederated Salish and Kootenai Tribes in Montana by Tara Luna.

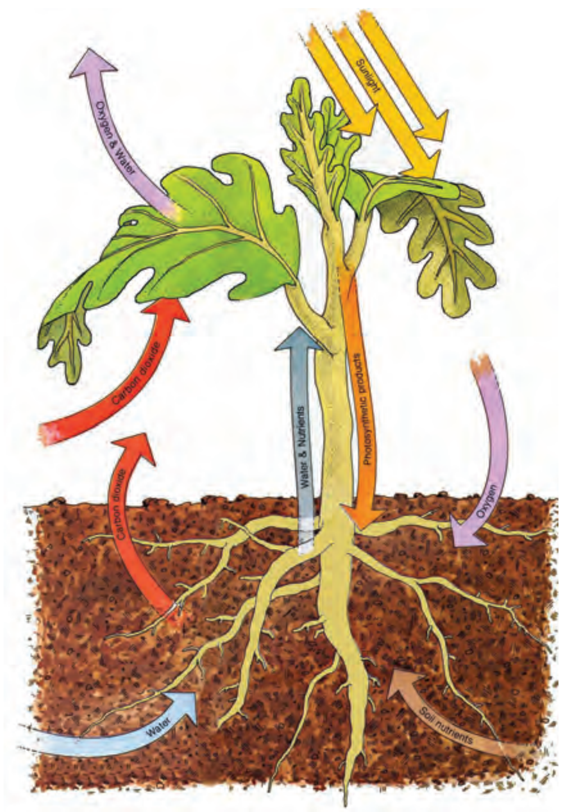


Figure 4.1—*Two important processes occur in the leaves of green plants. In photosynthesis, sunlight triggers a chemical reaction in which water from the soil and carbon dioxide from the air are converted to sugars and oxygen, which are released back to the atmosphere. During the process, water vapor is lost from the leaves in a process known as transpiration.* Illustration by Jim Marin.

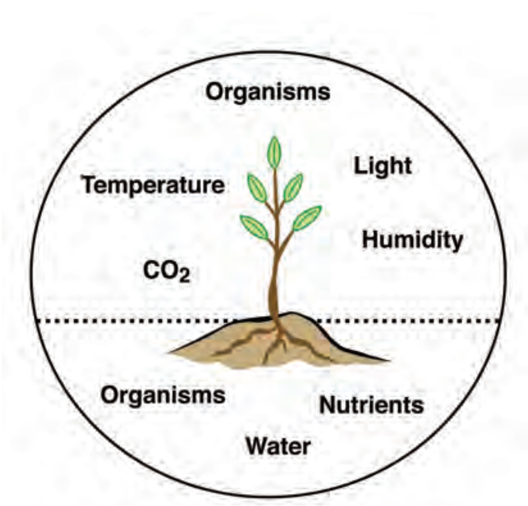


Figure 4.2—*It is useful to think of the nursery environment in terms of factors that might be limiting to plant growth. Limiting factors in the soil include water and mineral nutrients whereas, temperature, light, carbon dioxide, and humidity can be limiting factors in the atmosphere. Other organisms can either be beneficial or detrimental in both places.* Illustration by Jim Marin.

LIMITING FACTORS

Managing all the various factors that can be limiting to plant growth is the key to successful nursery management. To do this, the best possible propagation environment must be designed for a specific nursery site (Landis 1994). It is helpful to separate these limiting factors of the environment into those in the atmosphere and those in the growing medium (figure 4.2).

Atmospheric

Atmospheric limiting factors include light, temperature, humidity, carbon dioxide, and organisms that are determined by the climate at the nursery if plants are grown outside. As discussed in this chapter, propagation structures can be built to modify the local climate so that plants will grow more rapidly. For example, a greenhouse will modify light, temperature, and wind compared to the outside environment, which affects not only temperature but also humidity and carbon dioxide levels inside the greenhouse. The greenhouse also affects the organisms that interact with the crop. For example, although a greenhouse structure can exclude insect pests, it also creates a more humid environment for new pests such as algae and moss. In this chapter we discuss modifying light, temperature, carbon dioxide, and humidity with propagation structures.

Growing Medium

Growing medium limiting factors include water and mineral nutrients. The type of propagation environment can certainly affect water use; the details are discussed in Chapter 10, *Water Quality and Irrigation.* Mineral nutrients are supplied through fertilization (see Chapter 11, *Fertilization*); both water and mineral nutrients are held for plant uptake in the growing medium (see Chapter 5, *Growing Media*).

Biotic

Organisms can be limiting in either the atmosphere or the growing medium. Animal pests, including insects, can be excluded from a nursery through proper design, and beneficial microbes, such as mycorrhizal fungi, can be promoted. Beneficial organisms are covered in Chapter 14, *Beneficial Microorganisms*, and pests are discussed in Chapter 15, *Holistic Pest Management*.

Matching Propagation Environments to the Site

Whether building a new nursery or modifying an existing one, it is critical to analyze the limiting factors on the site. For example, the Hopi Reservation in northeastern Arizona is at high elevation with sunny, cloudless days for most of the year. Winters can be very cold with snow, and high winds are very common yearround. Here, the most limiting site factors are the intense sunlight, freezing temperatures, and high winds; therefore, a strong greenhouse to withstand snow and wind loads, with an aluminized shadecloth to minimize heat buildup, is desired.

A completely different propagation structure would be required on the Yurok Reservation in the coastal rainforest of the northern California coast, where fog is common and it rarely gets below freezing. Here, the limiting factors are low sunlight with heavy winter rains, so a structure with a very clear covering to maximize light transmission while protecting the crop from heavy rains would be ideal.

As expected, the costs of nursery development increase with greater control of the propagation environment. A nursery that is well matched to its environment, however, will be much less expensive to operate than a poorly designed one.

The Challenge of Growing Many Species and Stock Types

Native plant nurseries differ from other types of horticulture in which high quantities of a few crops are grown in large greenhouses. Most tribal nurseries grow small numbers of a wide variety of plants in one location. Often, these crops must be started on various dates, so, at any one time, a nursery might have everything from germinating seeds to large plants. Although some species are grown from seeds, others in the same nursery might have to be grown from rooted cuttings. So, a good native plant nursery will have to be designed with many relatively small propagation environments in which plants of similar requirements can be grown. When starting a new nursery, designing a variety of propagation environments is a luxury; unfortunately, most existing nurseries have to modify existing propagation structures.

At a given nursery, different propagation environments are needed for different growth stages at different times of the year. For example, a greenhouse is an ideal environment for germinating seeds and establishing young seedlings in their containers. Greenhouses are expensive to operate, however, because of high energy requirements. After young seedlings are established, they could be moved to a shadehouse or open compound to continue their growth. During hardening, the crops must be acclimated to the ambient environment and this is usually done in the same shadehouse or open compound. In cold climates, the crops might need to be moved to an overwintering structure to protect their root systems from freezing temperatures and the shoots from winter desiccation. Many potential problems can be averted by careful nursery design and planning.

A good nursery manager knows how to "think like a plant," and create a propagation environment that modifies all physical and biological factors that may be limiting to plant growth.

TYPES OF PROPAGATION ENVIRONMENTS

When most people think of container nurseries, they think of greenhouses; however, many other propagation environments are available. For our purposes, we define "propagation environment" as any area that is modified to encourage the growth of nursery stock. This environment could be as simple as a shady area under a tree or it could be a greenhouse with full environmental controls. It is important to realize that you do not need a greenhouse to grow native plants. Many simpler and inexpensive propagation structures can be designed to create the type of growing environments that crops require. Understanding different types of propagation structures and how they work is critical whether designing a new nursery facility or modifying an existing one.

Container nursery facilities can be distinguished by their relative amount of environmental control: minimally controlled, semicontrolled, or fully controlled. These facilities differ not only in their complexity but also in their biological and economical aspects (table 4.1).

Figure 4.3—*(A) The simplest nurseries are open compounds that use natural shade but have irrigation and are fenced. (B) Open compounds, like this one used by Roy Tyler of the Clifton-Choctaw Tribe in Louisiana, are most appropriate in areas with milder climates, where the risk of cold injury is minimal. (C) Even in colder climates, open compounds are often used for hardening crops grown in greenhouses or other structures.* Photo A by Tara Luna, B by Charles Mathern, and C by Thomas D. Landis.

Minimally Controlled Environments

A minimally controlled environment is the simplest and least expensive of all types of propagation environments. The most common type is an open growing compound. It consists of an area where plants are exposed to full sunlight and usually nothing more than an irrigation system and a surrounding fence.

Open Growing Compounds

Nurseries use open compounds as hardening areas to expose crops grown inside structures to ambient conditions. Some nurseries, such as the Temecula Band of the Luiseno Indians in southern California, use an open compound that incorporates trees for natural shade (figure 4.3A). Plants can be grown directly on the ground using landscape fabric to control weeds over a layer of gravel to provide drainage. The Banksavers Nursery of the Stillaguamish Tribe in coastal Washington State grows a variety of riparian and wetland plants in an open compound (figure 4.3B). Some nurseries prefer to grow their stock on pallets or benches to improve air pruning of the roots. If the nursery soil is heavy and poorly drained, then drainage tiles should be installed. Irrigation is provided by way of sprinklers for smaller containers or driplines for larger ones; plants obtain nutrients from controlled-release fertilizers that are incorporated into the growing media. The compound should be fenced to minimize animal damage, and, in windy areas, a shelterbelt of trees can improve the coverage of the irrigation system. Although open compounds are an inexpensive way to grow plants, they have the highest risk of freezing injury. Frost protection with irrigation is possible, however, the excess water can cause serious disease problems. For this reason, open growing compounds are more popular in milder climates; for example, in Louisiana, where the Clifton-Choctaw Nursery grows longleaf pine (figure 4.3C).

Wetland Ponds

Artificial ponds are another type of minimally controlled environment. They are used for growing riparian and wetland plants and are especially good for propagating sedges and rushes. Wetland ponds can be aboveground tanks, such as wading pools or cattle troughs, or they can be constructed with pond liners either in an excavated area or at ground level using a raised perimeter (figure 4.4A). These simple propaga-

Table 4.1—Operational considerations for selecting a propagation environment

Factors	Minimally Controlled	Semi Controlled	Fully Controlled
BIOLOGICAL			
Ambient climate	Mild	Moderate	Any
Growing season	Summer	Spring to fall	Year-round
Cropping time	6 to 24 months	3 to12 months	3 to 9 months
Risk of crop loss	High	Low	Low
ECONOMIC			
Construction costs	Low	Medium	High
Maintenance costs	Low	Medium	High
Energy use	Low	Low to medium	High

tion environments use growing media amended with controlled-release fertilizer and require only periodic flood irrigation. For example, the Shoshone-Bannock Tribes in southeastern Idaho grow a variety of wetland and riparian plants in their nursery (figure 4.4B).

Semicontrolled Environments

This next category of propagation environments is called "semicontrolled" because only a few of the limiting factors in the ambient environment are modified. Semicontrolled environments consist of a wide variety of growing structures ranging from simple cold frames to shadehouses.

Cold Frames

Cold frames are low-to-the-ground structures consisting of a wood or metal frame with a transparent covering (figure 4.5). As their name suggests, they have no heating source except the sun. Cold frames are the most inexpensive propagation structure and are easy to build and maintain. Because temperatures inside can rise quickly, cold frames can be used to extend the growing season in spring. Seeds can be germinated and cuttings can be rooted weeks before they could be in an open compound. Cold frames are also used in late summer or autumn for hardening plants moved out from greenhouses and can be used for overwintering crops. Cold frames are labor intensive, however, because they need to be opened and closed daily to control temperature and humidity levels (figure 4.5).

The ideal location for a cold frame is a southern exposure with a slight slope to ensure good drainage and maximum solar absorption. A sheltered spot against the wall of a building or the greenhouse pro-

Figure 4.4—*(A) Wetland ponds can be constructed in the outdoor nursery for growing wetland species or (B) by using plastic tubs inside a greenhouse, such as this one operated by the Shoshone-Bannock Tribes of Idaho.* Photo A by Thomas D. Landis, B by J. Chris Hoag.

Figure 4.5—*Cold frames are an inexpensive alternative to a greenhouse. (A) Cold frames should be placed in a sheltered location for additional protection. (B) Coverings may be removed or (C) held open to manage humidity and heat levels.* Photos by Tara Luna.

vides additional protection. Some nurseries sink the frame 6 to 12 in (15 to 30 cm) into the ground to use the earth for insulation. Other nurseries make their cold frames lightweight enough to be portable so they can move them from one section of the nursery to another.

It is relatively easy to build a cold frame. Frames are usually made of wood such as redwood or cedar that will resist decay; the new recycled plastic lumber also works well. Never use creosote-treated wood or wood treated with pentachlorophenol because these substances are toxic to plants. The cold frame should be built so that it is weathertight and the top lid should be constructed so that it can be propped open at different heights to allow for various levels of ventilation, watering, and the easy removal of plants. The cover must be able, however, to be attached securely to the frame to resist wind gusts. Old storm windows make excellent covers for cold frames. Heavy plastic film is an inexpensive covering but usually lasts only a single season. Hard plastic or polycarbonate panels are more durable and will last for several years. Cold frame kits may also be purchased and are easily assembled; some kits even contain automatic ventilation equipment.

Cold frames require careful management of temperature and humidity levels. A thermometer that can be conveniently read without opening the cover is mandatory. In a cold frame, cool-season plants grow best at 55 to 65 °F (13 to 18 °C), while warm-season plants grow well at 65 to 75 °F (18 to 24 °C). If air temperature goes above 85 °F (29 °C), the top must be opened to allow ventilation. Monitor the temperature to ensure that the cold frame does not cool down too much, but close it early enough before the solar heat is lost.

Hot Frames or Hot Beds

Structurally similar to cold frames, hot frames are heated with electric heating cables and are primarily used as an inexpensive way to root cuttings. They are also ideal for overwintering nonhardy seedlings or newly rooted cuttings. Cold frames can easily be converted into hot beds. Start by removing the soil to a depth of 8 or 9 in (20 cm). Lay thermostatically controlled heating cables horizontally in loops on top of 2 in (5 cm) of sand (figure 4.6). Be sure that the cable loops are evenly spaced and do not cross each other. Cover the cable with 2 in (5 cm) of sand and cover the

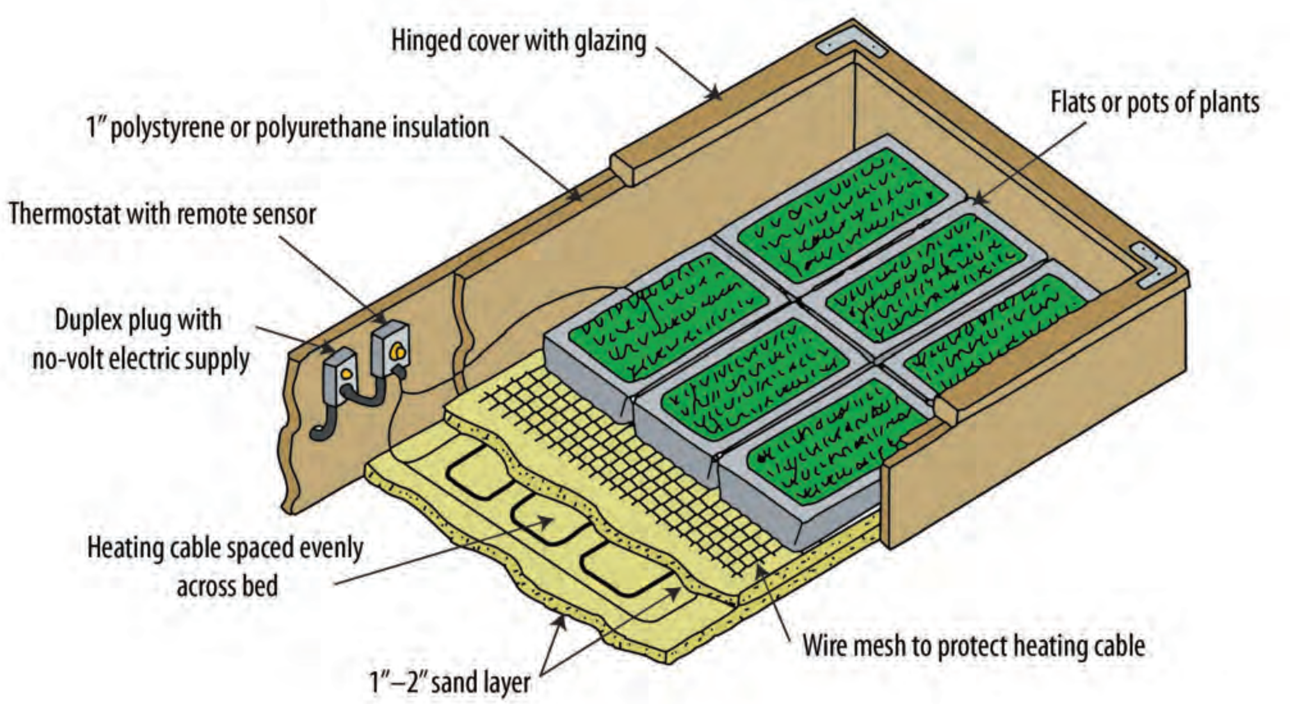


Figure 4.6—*A hot bed is structurally similar to a cold frame but is heated by electric heating cables.* Illustration courtesy of John W. Bartok, Jr.

Figure 4.7—*Hoop houses, like this one at the Colorado River Indian Tribes Nursery in Arizona, can be used for a variety of propagation environments by changing or removing the coverings.* Photo by Tara Luna.

sand with a piece of wire mesh (hardware cloth). Trays of cuttings or seedlings can be placed directly on top of the wire mesh.

Hoop Houses and Polyethylene Tunnels

Hoop houses and polyethylene ("poly") tunnels are very versatile, inexpensive propagation environments. The semicircular frames of polyvinyl chloride (PVC) or metal pipe are covered with a single layer of heavy poly and are typically quite long (figure 4.7). The end walls are made of solid material such as water-resistant plywood. The cover on hoop houses is changed during the growing season to provide a different growing environment, eliminating the need to move the crop from one structure to another. Generally, in early spring, a clear plastic cover is used during seed germination and seedling establishment. As the days become longer and warmer, the plastic cover can be pulled back on sunny days to provide ventilation. After the danger of frost is past, the plastic cover is removed and replaced with shadecloth. Sometimes, a series of shadecloths, each with a lesser amount of shade, are used to gradually expose crops to full sun. During hardening, the shadecloth is completely removed to expose the plants to the ambient environment. When covered with white plastic sheeting, hoop houses can be used for overwintering. See Chapter 13, *Harvesting, Storing, and Shipping*, for further discussion on this topic.

Shadehouses

Shadehouses are the most permanent of semicontrolled propagation environments and serve several uses. Shadehouses are used for hardening plants that have just been removed from the greenhouse and also serve as overwintering structures. In the Southwestern United States, many tribal nurseries have shadehouses similar to that of the White Mountain Apache Tribe in Arizona (figure 4.8A). Shadehouses, however, are also being used to propagate plants, especially in locations where sunlight is intense; for example, at the Colorado River Indian Tribes Nursery in Arizona (figure 4.8B). One popular shadehouse design consists of upright poles with a framed roof; snow fencing is installed over the roof and sides to provide about 50 percent shade (figure 4.8C). Other shadehouses consist of a metal pipe frame covered with shadecloth. When used for growing, they are equipped with sprinkler irrigation and fertilizer injectors (figure 4.8D). When the shade is installed on the sides of the structure, shadehouses are very effective at protecting crops from wind and so reduce transpiration. In areas with heavy snow, removable shadecloths are used for the roofing and sides so that they can be removed to avoid damageduring winter months. This can be done after plants are put into storage.

Fully Controlled Environments

Fully controlled environments are propagation structures in which all or most of the limiting environmental factors are controlled. Examples include growth chambers and greenhouses. Fully controlled environments are often used because they have the advantage of year-round production in almost any climate. In addition, most crops can be grown much faster than in other types of nurseries. These benefits must be weighed against the higher costs of construction and operation. Murphy's law of "Anything that can go wrong will go wrong" certainly applies to nurseries, so the more complicated a structure is, the more problems that can develop. This concept is particularly true in the remote locations of many tribal lands, where electrical power outages are more common and it is difficult, time consuming, and expensive to obtain specialized repair services (see table 4.1). The following is a brief description of common greenhouse designs. Some good references that provide much more detail

Figure 4.8—*(A) Shadehouses are semicontrolled environments that are used for hardening and overwintering plants and (B) are also used for propagation. (C) They are constructed of wood frames with snow fencing or (D) metal frames with shadecloth and are equipped with irrigation systems that can also apply liquid fertilizer.* Photos by Thomas D. Landis.

include Aldrich and Bartok (1989), Landis and others (1994), and Bartok (2000).

Growth Chambers

Growth chambers are high-cost options that are used almost exclusively for research. The high cost of the equipment and the expense to operate them make them unsuitable for normal nursery production.

Greenhouses

Tribes with large forestry and reforestation programs, such as the Mescalero Apache Tribe in New Mexico, the Red Lake Band of the Chippewa Indians in Minnesota, and the Confederated Salish and Kootenai Tribes in Montana, use greenhouses. In addition to growing native trees, tribes have grown many other kinds of native plants in different types of greenhouses, but all the greenhouses are transparent structures that allow natural sunlight to be converted into heat (figure 4.9A). On the other hand, greenhouses are poorly insulated and require specialized heating and cooling systems. Most people think that keeping a greenhouse warm during cold weather is the most critical consideration, but it is not that difficult to accomplish with modern heating systems. Actually, keeping a greenhouse cool during sunny days in spring and summer is more of a challenge, and so ventilation systems must be carefully engineered. In climates with periods




Figure 4.9—*(A) Greenhouses, like this one on the Hopi Reservation in Arizona, are the most sophisticated propagation environments. (B) Retractable roof greenhouses allow crops to be exposed to the outside environment during hardening. (C) Workers with specialized skills are needed from the initial surveying to (D) the final construction.* Photo A by Thomas D. Landis, B and C by Tara Luna, D by Joseph F. Myers.

of clear winter weather, greenhouses can heat up considerably during the day so, for this reason, it is usually not a good idea to use them for overwintering plants.

Retractable-roof greenhouses, the newest type of propagation structure, have become popular in temperate regions. Their major advantage is that the roof can be opened to expose plants to the outside environment when cooling is required (figure 4.9B). They are particularly useful during the hardening phase because the crop does not have to be moved to another structure such as a shadehouse. Some nursery managers without retractable-roof greenhouses remove the plastic from their greenhouses to help harden their crops.

ENGINEERING CONSIDERATIONS

It is important to understand that greenhouse construction is a very specialized business. Even a licensed contractor who is skilled at general construction will be challenged by the specialized demands of building a greenhouse (figures 4.9C and D). Here are a few general terms that anyone building a greenhouse or shadehouse should be familiar with.

Design Loads. *Dead loads* are the weight of the structure, whereas *live loads* are caused by building use. Live loads include people working on the structure and the weight of equipment, such as irrigation systems, heaters, lighting systems, and even hanging plants. Weather-related loads (snow and wind) must also be taken into consideration. In developed areas, be aware that greenhouses may be regulated by municipal building codes and zoning; this is another good reason to work with a professional firm before buying a greenhouse.

Foundations, Floors, and Drainage. The foundation connects the greenhouse to the ground and counteracts the design load forces. Inexpensive floors can consist of gravel covered with ground cloth, but the ground beneath the floor must drain water freely. Nursery crops require frequent irrigation and in most systems much of this water will end up on the floor. Drain tiles might be needed to make sure that the nursery floor will not turn into a bog. It may be necessary to design the greenhouse so that all wastewater drains into a pond or constructed wetland to prevent contamination of water sources. This water can sometimes be used for other purposes on the site, such as growing plants in wetland ponds as described previously in this chapter.

If wheeled equipment will be used to move plants, concrete walkways between the benches are necessary. Note that black asphalt heats up rapidly and becomes soft, so concrete is a better but more expensive option. Full concrete floors will eliminate many pest problems, especially algae, moss, and liverworts that thrive in the humid nursery environment. Make sure that floors are engineered to drain freely to prevent standing water, which is a safety hazard. Full floors can be engineered with drains so that all water and fertilizer runoff can be contained on site; runoff containment is a legal requirement in some parts of the country.

Framing Materials. Ideal framing supports the covering with minimal shading and heat loss while allowing ease of access and handling. Framing materials include galvanized steel, aluminum (lightweight but expensive), and treated wood.

Greenhouse Kits. The heating and cooling systems of fully controlled greenhouses must be carefully engineered to match both the size of the structure and the ambient environment. Be aware that inexpensive greenhouse kits often have vents or fans that are too small for the size of the greenhouse. Kit greenhouses were designed for some "average" environment and will probably have to be modified to handle the limiting environmental factors on your site. Before purchasing a greenhouse kit, it is a good idea to hire an experienced consultant, speak with a knowledgeable company representative, and discuss designs with other growers or professionals.

GREENHOUSE COVERINGS

A wide variety of greenhouse coverings are available and the selection of a particular type is usually based on cost, type of structure, and the environmental conditions at the nursery site.

Poly tarps are relatively cheap but require replacement every 2 to 4 years depending on the grade of plastic. Double layers of poly sheeting that are inflated with a fan are stronger and provide better insulation longer than a single layer (figure 4.10A). The two layers are attached to the framing with wooden furring strips or specially designed fasteners. This process is relatively simple so many growers change their own coverings. Because they are so well insulated and airtight, poly greenhouses require good ventilation to prevent condensation.

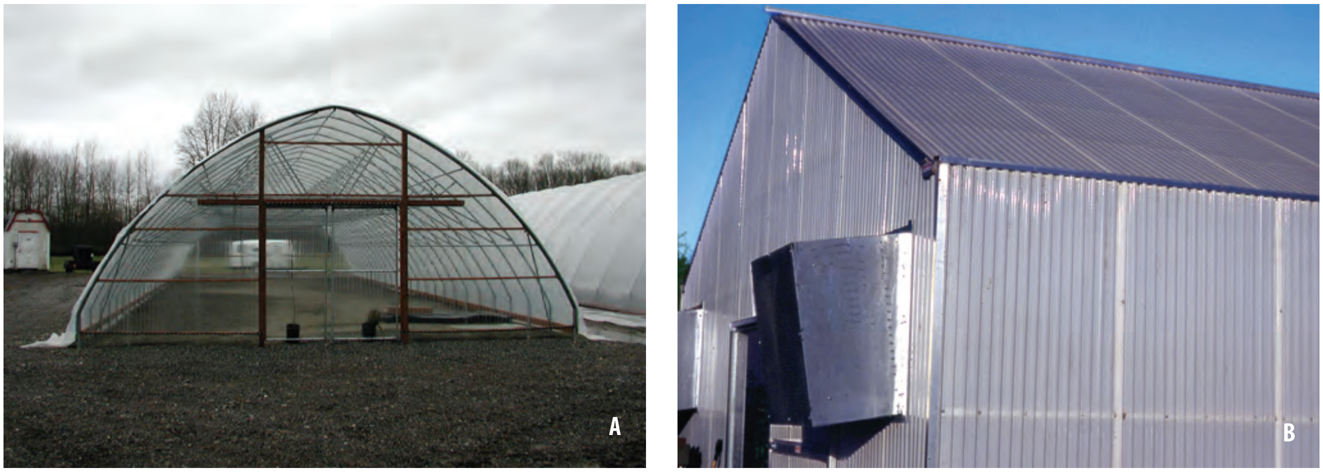


Figure 4.10—*(A) Greenhouses are covered with transparent coverings such as plastic sheeting or (B) hard plastic panels to maximize the amount of sunlight reaching the crop.* Photo A by Tara Luna, B by Thomas D. Landis.

Polycarbonate ("polycarb") panels, the most popular permanent greenhouse covering, have about 90 percent of the light transmission properties of glass. Polycarb is strong and durable but is one of the more expensive coverings (figure 4.10B).

These are the most common greenhouse coverings, and a more detailed description with costs, engineering and operational considerations can be found in Landis and others (1994) Some good references that provide much more detail on environmental controls include Aldrich and Bartok (1989), Landis and others (1994), and Bartok (2000).

SPECIALIZED PROPAGATION ENVIRONMENTS

This section discusses smaller propagation environments that have very specific functions. Often, they are constructed inside greenhouses or shadehouses.

Rooting Chambers

The most common type of vegetative propagation is the rooting of cuttings. Often, this form of propagation requires a specialized environment known as a rooting chamber that creates specific conditions to stimulate root initiation and development. Because cuttings do not have a root system (figure 4.11A), rooting chambers must provide frequent misting to maintain high humidity to minimize transpiration. Root formation is stimulated by warm temperatures and moderate light levels; these conditions maintain a high level of photosynthesis. Therefore, many rooting chambers are enclosed with poly coverings that, in addition to maintaining high humidity, keep the area warm. If the chambers are outside, the covering further protects cuttings from drying winds and rain. Usually, bottom-heating cables are placed below the flats of cuttings or rooting medium to warm the medium, which speeds root development. Experience has shown that cuttings of many native plants root better when the growing medium is kept warmer than the shoots. See Chapter 9, *Vegetative Propagation*, for more information on rooting cuttings.

The two most common rooting chambers in native plant nurseries are enclosed chambers without irrigation and chambers with intermittent-mist systems.

Enclosed Rooting Chambers

Because it is easy to construct and very economical, a simple enclosed rooting chamber is essentially the same as the hot frame discussed earlier. Because they rely on manual operation, enclosed systems require diligent daily inspection to regulate humidity and air temperatures, and the rooting medium must be watered as needed. They are typically covered with shadecloth to moderate temperatures, but, if heat or humidity becomes excessive, enclosed chambers need to be opened for ventilation. One design is known as a "poly propagator" because it is covered with plastic sheeting and is a simple and inexpensive way to root cuttings (figure 4.11B).

Intermittent-Mist Rooting Systems

These propagation environments are the most common way to root cuttings and are either enclosed (figure

4.12A) or open (figure 4.12B). Rooting cuttings is much easier in these environments because intermittent-mist rooting chambers have a high degree of environmental control (figure 4.12E). Clock timers (figure 4.12D) control the timing and duration of mistings from specialized nozzles (figure 4.12E). These frequent mistings maintain very high humidity that reduces water loss from the cuttings, while evaporation of the small droplets moderates air and leaf temperature (figure 4.12F). Bottom heat is supplied to the rooting zone of the cuttings by means of insulated electrical cables at the bottom of the rooting medium (figure 4.12G) or with specially designed rubber heating mats placed under the rooting trays.

Mist systems require high water pressure that is supplied through PVC pipes and delivered through special nozzles (figure 4.12E). Very practical timing of the mistings is controlled by a series of two timeclocks that open and close a magnetic solenoid valve in the water line to the nozzles. One clock turns the system on during the day and off at night and the other controls the timing and duration of the mists. Because the aperture of the mist nozzles is so small, a cartridge filter should be installed in the water line after a gate valve. A thermostat controls the temperature of the heating cables or mat, which are protected by a wire mesh (figure 4.12C).

Because of the proximity of water and electricity, all employees should receive safety training. All wiring used for mist propagation must be grounded and must adhere to local building codes. Electrical outlets and components must be enclosed in waterproof outlets. The high humidity encourages the growth of algae and mosses, so the mist propagation system should be cleaned regularly. Mist systems require water low in dissolved salts; "hard" water can result in whitish deposits that can plug mist nozzles. See Chapter 10, *Water Quality and Irrigation*, for more information on this topic.

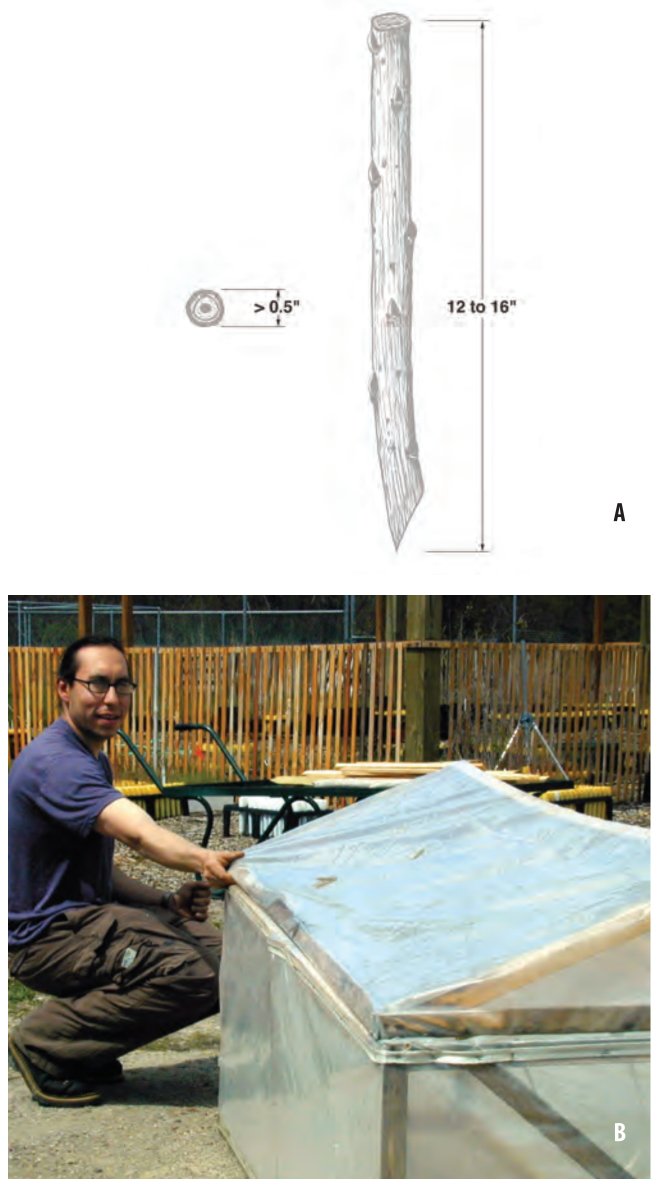


Figure 4.11—*(A) Rooting cutting requires a specialized propagation environment because cuttings lack a root system. (B) The "poly propagator" is the most simple and inexpensive rooting chamber; this one being used by Shannon Wetzel is at the Salish Kootenai College Nursery in Montana.* Illustration by Steve Morrison, photo by Tara Luna.

MANAGING THE PROPAGATION ENVIRONMENT

In nurseries, a variety of horticultural techniques can be used to modify the propagation environment. The type of propagation environment dictates the extent to which environmental conditions may be controlled. Ways of controlling the propagation environment are discussed in other chapters. The main way, and one of the most critical, in which growers control their crops is by the type of container. Container volume, plant spacing, and characteristics such as copper coating can greatly affect the size and quality of the crop (see Chapter 6, *Containers*). Different crops, as well as different stock types of the same species, may require different growing media. For example, a very porous media containing perlite or pumice is used for rooting cuttings, whereas a media with more water-holding capacity is required for germinating seedlings (see Chapter 5, *Growing Media*). A steady supply of high-quality water is one of the most critical needs of growing plants (see Chapter 10, *Water Quality and Irrigation*). It is possible to greatly accelerate the growth of native plants with fertilizer, especially for very slow-growing species (see Chapter 11, *Fertilization*). Certain organisms can be extremely important for the health and growth of some nursery crops. For example, the rooting of some difficult-to-root native plants has been shown to improve after treatment with a beneficial bacterium (Tripp and Stomp 1998) (see Chapter 14, *Beneficial Microorganisms*). Because of the high light intensity in greenhouses, controlling the light and temperature can be challenging.

Modifying Light in the Greenhouse

Light affects plants in several ways. As mentioned earlier, light is necessary for photosynthesis, which provides energy for plant growth. For light-loving species, more light equals more growth (figure 4.13A), but greenhouse light levels are often too intense to grow some native plants (table 4.2). As a result, growers apply shadecloths to lessen light intensity and the resultant heat (figure 4.13B). Shadecloths are rated by the amount of shade they produce, ranging from 30 to 80 percent. Black has been the traditional color but now shadecloth also comes in white, green, and reflective metal. Because black absorbs sunlight and converts it into heat that can be conducted into the propagation structure, black shadecloth should never be installed directly on the covering (figure 4.13C) but instead should be suspended above it to facilitate air movement. White shadecloth absorbs much less heat than black, and other colors absorb intermediate amounts of heat. New aluminized fabrics do a great job of reflecting incoming sunlight (figure 4.13D). Applying a series of shadecloths, each with a lesser amount of shade, over a period of time is a good way to gradually harden nursery stock and prepare it for outside conditions.

Supplemental Lighting

Another way that sunlight affects plants is the relative length of day and night, which is known as "photoperiod." Some native plants, especially those from high latitudes or high elevations, are very sensitive to daylength, a process controlled by the plant pigment phytochrome. When days are long, shoot growth occurs, but, when daylength drops below a critical level, shoot growth stops (figure 4.14A). Native plants

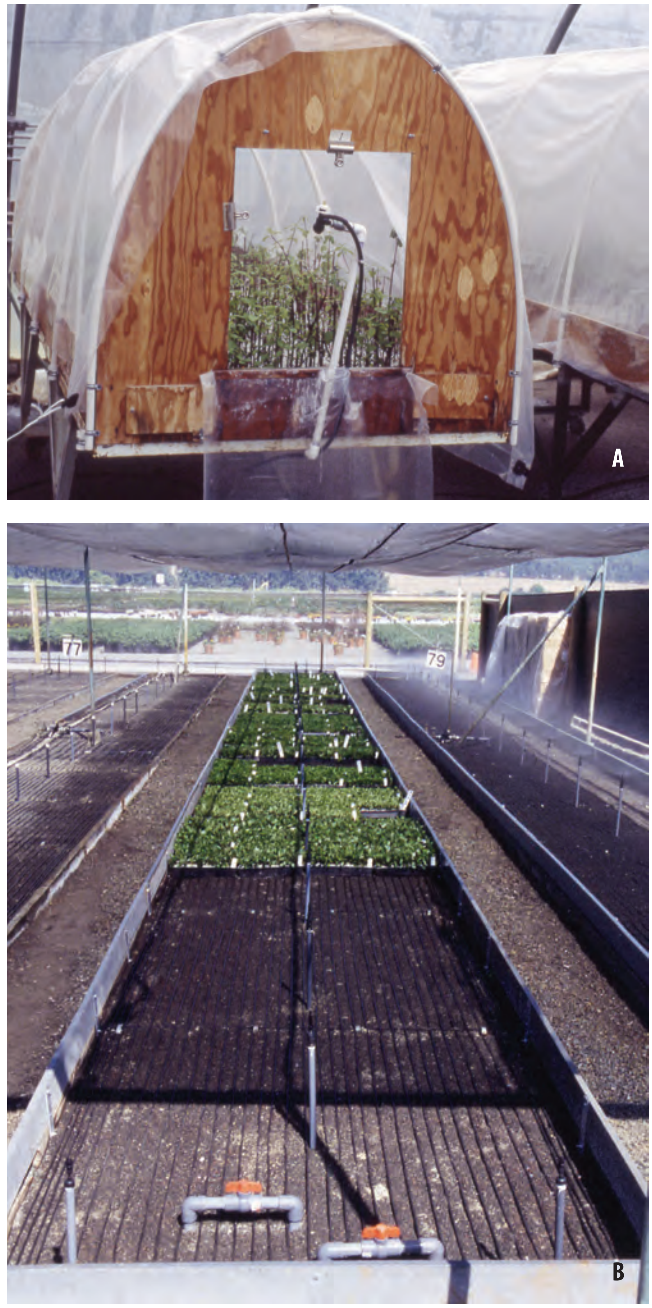
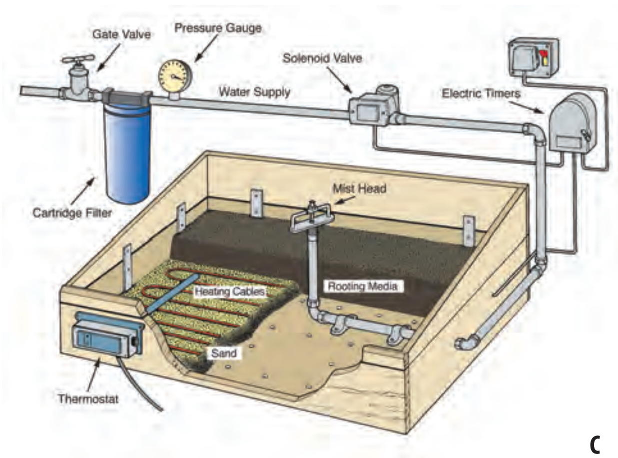


Figure 4.12—*(A) Intermittent-mist systems can be either enclosed or (B) in outdoor growing compounds. (C) Their environments can be easily controlled. (D) Programmable clock timers control the timing and duration of (E) specialized mist nozzles, which (F) keeps humidity levels high, reduces transpiration, and provides cooling. (G) Heating cables or mats under the growing medium keep rooting medium temperatures high.*
Photos A, B, D-G by Thomas D. Landis, C byTara Luna.


Gate Valve
Pressure Gauge
Solenoid Valve
Water Supply
Electric Timers
Cartridge Filter
Mist Head
Rooting Media
Heating Cables
Sand
Thermostat

C


PULL OUT DIAL
TURN DIAL TO SET TIME
DO NO
MOVE TI
POINTER —
LIFT DIAL AND
TURN TO SET
PLACE
BENEATH LEVER
OFF
MANUAL
ON
THIS INSULATOR MUST BE REPLACED
AFTER WIRING TO PREVENT SHOCK

D

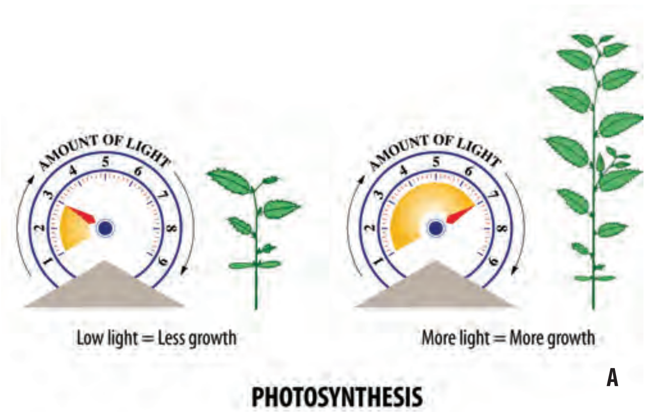
E

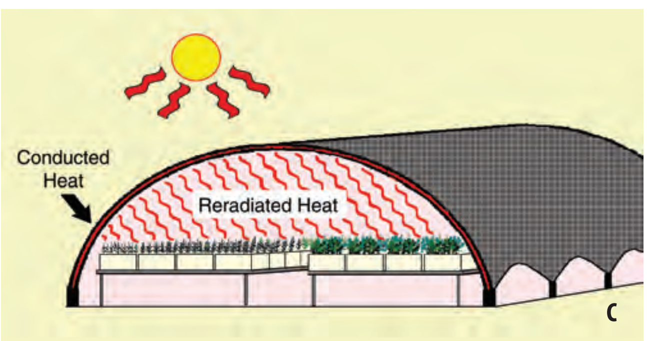
F

G

Table 4.2—Shade requirements of a variety of native plant species

Scientific Name	Common Name	Shade Requirement		
		Sun	Shade	Either
Artemisia tridentata	Big sagebrush	X		
Carex aquatilis	Water sedge	X		
Prunus virginiana	Chokecherry	X		
Dryopteris filis-mas	Male fern		X	
Chimaphila umbellata	Pipsissewa		X	
Gymnocarpium dryopteris	Oakfern		X	
Ceanothus sanguineum	Redstem ceanothus			X
Rubus parviflorus	Thimbleberry			X
Pteridium aquilinum	Bracken fern			X





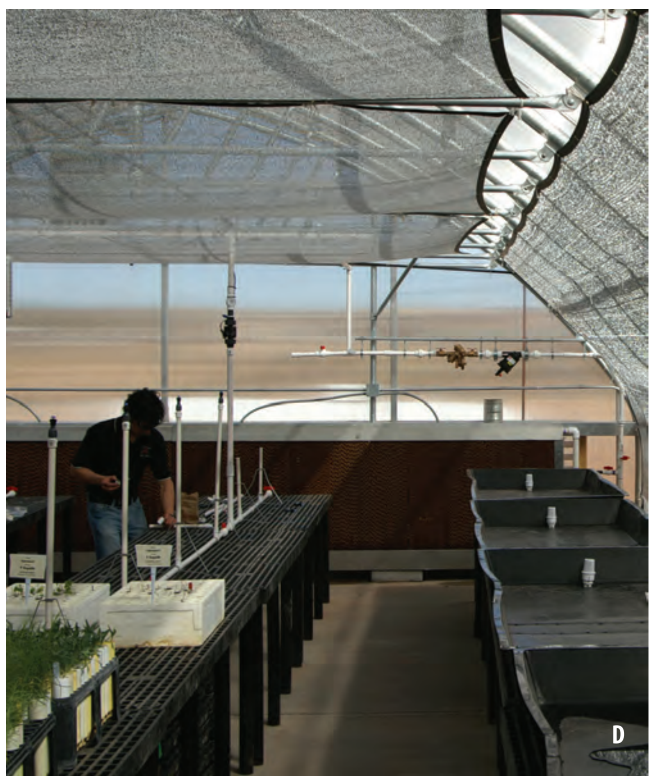
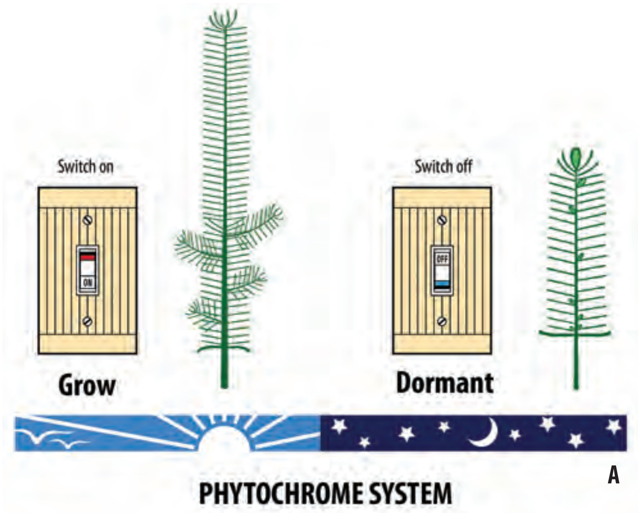


Figure 4.13—*(A) Sunlight provides the energy necessary for plant growth but is converted to heat inside propagation structures. (B) By reducing light intensity, shadecloth cools the environment. (C) Black shadecloth absorbs heat that is radiated back into the propagation environment, but (D) new aluminized shadecloth diffuses light without generating heat.* Photos by Thomas D. Landis, illustrations by Jim Marin.



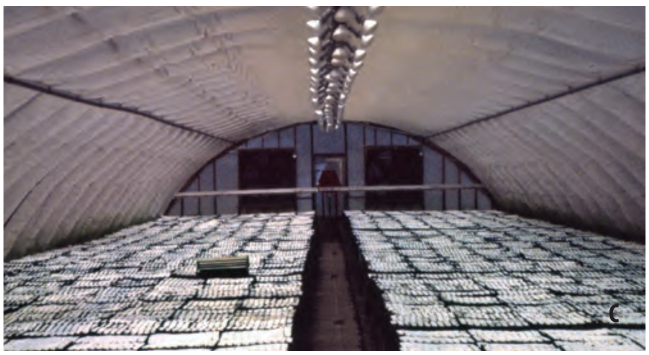


Figure 4.14—*(A) The relative length of day compared to night affects plant growth like a switch; long days stimulate growth, but short days cause dormancy. (B) Native plants from northern climates or high elevations are particularly sensitive to daylength and will quickly set a dormant bud under short day conditions. (C) Nurseries use photoperiod lights to artificially keep days long and their crops in an active state of shoot growth.* Photos by Thomas D. Landis, illustration by Jim Marin.

from northerly latitudes or high elevations are particularly sensitive to daylength and will "set bud" (stop shoot growth) quickly when days begin to shorten (figure 4.14B). This process is genetically controlled and protects plants against early fall frosts.

Container nurseries use photoperiod lights to extend daylength to force continued shoot growth (figure 4.14C). The lights are turned on as soon as seeds germinate and are shut off when height growth is adequate and the hardening phase begins. Several different lighting systems are used in nurseries; for more details see Landis and others (1992).

Modifying Temperature

One of the most challenging aspects of nursery management is controlling temperature in propagation structures. Temperature directly affects chemical reactions involved in plant metabolism and also affects rates of transpiration. As just discussed, sunlight is converted into heat, but this can be managed with shadecloth. Control units (figure 4.15A) automatically operate cooling and heating systems within greenhouses. Vents and fans are used to keep air moving inside the greenhouse (figure 4.15B) and exhaust heat from the structure (figure 4.15C). In dry environments, wet walls use the power of evaporation to cool incoming air (figure 4.15D). Growers can also use short bursts of their irrigation system for cooling (figure 4.15E).

Heating greenhouses is much easier than cooling them. During cold weather, heaters keep the propagation environment at the ideal temperature for growth (figure 4.16A). Rising fuel costs are becoming more of a concern and nurseries are adjusting their growing schedules and using other management strategies to reduce fuel costs. Many growers start their crops in heated greenhouses and then move them outside as soon as the danger of frost has passed (figure 4.16B)

Temperature Monitoring and Control Systems

Fortunately, temperature is very easy to measure and should be monitored at all times during the growth of the crop. Automatic sensing instruments are available that can be connected with cooling and heating equipment to trigger a cooling or heating cycle for

Figure 4.15—*(A) Fully controlled greenhouses contain heating and cooling systems and sophisticated controllers. (B) Greenhouses heat up quickly during sunny weather and must be designed for cooling with interior circulation fans and (C) exhaust fans and vents. (D) In dry climates, fans pull air through wet walls, where it is cooled by evaporation. (E) A quick application of irrigation water can also be used to cool crops.* Photo A by Jeremy R. Pinto, B-E by Thomas D. Landis.

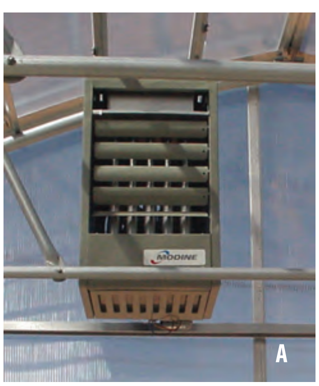


Figure 4.16—*(A) The heat from greenhouse heaters is circulated through the growing area. (B) Rising fuel costs are causing many nurseries to start their crops in a heated greenhouse and then move them to an open compound like this one at the Confederated Tribes of the Colville Reservation Nursery in Washington State.* Photo A by Thomas D. Landis, B by R. Kasten Dumroese.

Figure 4.17—*(A) Monitoring and controlling temperature is critical to successfully growing a crop of native plants, and monitoring equipment is inexpensive. Many nurseries use thermometers that record daily maximum and minimum temperatures and (B and C) small, programmable, self-contained temperature sensors.* Photo A by Thomas D. Landis, B and C by David Steinfeld.

the greenhouse. Mechanical thermostats consist of a temperature sensor and switch that can be used to activate motorized vents, fans, and unit heaters within a greenhouse. Thermostats provide the best and most economical form of temperature control. Sophisticated control systems that can maintain a designated temperature through a series of heating and cooling stages is a very necessary and wise investment, considering current fuel costs.

Thermometers that record the maximum and minimum temperatures during the day are simple and economical instruments (figure 4.17A) that can help growers monitor subtle microclimates within the propagation environment. For example, the south side of the greenhouse is usually warmer than the north side or areas closest to the vents or cooling system. Thus, you could plan your greenhouse space by placing species that require slightly cooler temperatures for germination and growth on the north side of the greenhouse and use the south side of the greenhouse for species that prefer warmer temperatures. New devices, such as self-contained, programmable temperature sensors, are revolutionizing the ways in which temperature can be monitored in nurseries (figures 4.17B and C). Many of these sensors are small enough to be placed within a container or storage box and can record temperatures (between -40 and +185 °F [-40 and 85°C]) for more than 10 years. Because these single-chip recording devices can be submersed in water and are resistant to dirt and impact, they can be used to monitor most temperatures encountered in the nursery. The data recorded on the sensors must be downloaded to a computer and can then be easily placed into a computer spreadsheet. The small size of the sensor can also be a drawback; they are easy to misplace. Attach a strip of colorful flagging to indicate where they are located and write any necessary information on the flagging with a permanent marker.

EQUIPMENT MAINTENANCE

Even if you purchase the best "automatic" environmental control equipment, it must be monitored and maintained. The hot and humid nursery environment is particularly hard on equipment; regular maintenance ensures longevity, reduces costly repairs, and may help avoid disasters. When selecting equipment, it is helpful to consult with other nurseries in your area that are growing similar species.

Routine maintenance of all greenhouse and nursery operation equipment should be a top priority. Someone who is mechanically inclined should be given the responsibility for equipment maintenance. Write everything down. The best place to do this is in a daily log book. See Chapter 3, *Crop Planning and Developing Propagation Protocols,* and Chapter 16, *Nursery Management,* for more details. These log books can be filed away by year and will prove invaluable when solving problems, budgeting, and developing maintenance plans. A system of "promise cards" specifies when servicing needs to be done and can be incorporated into the nursery computer system. Keep a supply of spare parts on hand, especially parts that may not be readily available or may take a long time to receive. It is a good idea to have a spare cooling fan motor on standby. A handy supply of hardware items such as washers, screws, and bolts is also good idea. Familiarize all employees on the operation of all equipment so that problems can be detected early. The instruction manuals for all equipment need to be kept on hand.

SUMMARY

A propagation environment must be carefully designed and constructed to modify the limiting factors on the nursery site. Each site is unique and there is no ideal type of nursery structure. Crop size, species, length of crop rotation, and the number of crops grown per year are important design considerations. The need for different propagation environments for different species and at different growth stages should also be considered. If only a few species with similar growing requirements are to be grown, then a large single growing structure is feasible. If the plan is to grow many different species with very different growth require- ments, then a variety of propagation structures will be needed. Having several smaller propagation structures provides more flexibility; these structures can be added over time. Propagation structures are modified based on the location and prevailing environmental conditions at the nursery and for the species that are being grown. In fully controlled greenhouses, temperature and humidity are usually provided by automatic heating, cooling, and ventilation equipment. Automatic control systems are a necessary investment in greenhouses. The diversity of species grown in native plant nurseries requires the provision of ambient conditions during the different phases of growth, including germination and establishment, rapid growth, and hardening. Thus, most native plant nurseries have a variety of propagation structures to meet these needs. With careful planning, these structures can be used for a variety of purposes throughout the year.

LITERATURE CITED

Aldrich, R.A.; Bartok, J.W., Jr. 1989. Greenhouse engineering. NRAES-33. Ithaca, NY: Cornell University, Northeast Regional Agricultural Engineering Service. 203 p.

Bartok, J.W., Jr. 2000. Greenhouse for homeowners and gardeners. NRAES-137. Ithaca, NY: Cornell University, Northeast Regional Agricultural Engineering Service. 200 p.

Landis, T.D. 1994. Using "limiting factors" to design and manage propagation environments. The International Plant Propagators' Society, Combined Proceedings 43: 213-218.

Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. 1992. The container tree nursery manual: volume 3, atmospheric environment. Agriculture Handbook 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 145 p.

Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. 1994. The container tree nursery manual: volume 1, nursery planning, development, and management. Agriculture Handbook 674. Washington, DC: U.S. Department of Agriculture, Forest Service. 188 p.

Tripp, K.E.; Stomp, A.M. 1998. Horticultural applications of *Agrobacterium rhizogenes* ("hairy-root") enhanced rooting of difficult-to-root woody plants. The International Plant Propagators' Society, Combined Proceedings 47: 527-535.

ADDITIONAL READING

Clements, S.E.; Dominy, S.W.J. 1990. Costs of growing containerized seedlings using different schedules at Kingsclear, New Brunswick. Northern Journal of Applied Forestry 7(2): 73-76.

APPENDIX 4.A. PLANTS MENTIONED IN THIS CHAPTER

big sagebrush, *Artemisia tridentata*
bracken fern, *Pteridium aquilinum*
chokecherry, *Prunus virginiana*
longleaf pine, *Pinus palustris*
male fern, *Dryopteris filix-mas*
oakfern, *Gymnocarpium dryopteris*
pipsissewa, *Chimaphila umbellata*
redstem ceanothus, *Ceanothus sanguineus*
rushes, *Juncus* species
sedges, *Carex* species
thimbleberry, *Rubus parviflorus*
water sedge, *Carex aquatilis*