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# Propagation Environments

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Many environmental factors influence growth and production of nursery plants. The primary processes affected by environmental factors are photosynthesis and transpiration. Photosynthesis is the means by 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 5.1). 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 water loss is called transpiration. To maximize the photosynthesis necessary for plant growth, growers must reduce the factors that limit photosynthesis or increase the factors that promote photosynthesis.

Photosynthesis, and therefore growth, can be limited by factors associated with the growing medium, other organisms, or the atmosphere (figure 5.2). Limiting factors related to growing media include water and mineral nutrients and are discussed in detail in Chapter 6, Growing Media, Chapter 11, Water Quality and Irrigation, and Chapter 12, Plant Nutrition and Fertilization. Photosynthesis can be limited by the absence of beneficial organisms or by the presence of harmful organisms; these instances are discussed in Chapter 13, Beneficial Microorganisms, and Chapter 14, Problem Prevention and Holistic Pest Management. Atmospheric factors that affect photosynthesis include light, temperature, relative humidity, and carbon dioxide levels. Propagation structures, or environments, are any area that is modified to encourage the growth of nursery plants by controlling these atmospheric factors during all phases of growth in the nursery. Understanding different types of propagation structures and how they work is critical whether designing a new nursery facility or modifying an existing one.

Tropical nursery facilities differ not only in their complexity but also in their biological and economical aspects. Propagation environments can be as simple as a garden plot where water and fertilizer are applied, or as complex as high-tech greenhouses that also modify all atmospheric factors. Although modifying atmospheric factors can also influence the growing media and occurrence of other organisms, our focus in this chapter is primarily on modifying atmospheric factors (light, temperature, and relative humidity) through a variety of propagation environments.

**Facing Page:** *Propagation environments modify atmospheric factors such as light and temperature. In this nursery, removable palm thatch provides shade for young seedlings but allows full sun to reach maturing plants. Photo by Thomas D. Landis.*

## Matching Propagation Environments to the Site

The best possible propagation environment is designed for a specific nursery site (Landis 1994). Whether building a new nursery or modifying an existing one, it is critical to analyze the limiting factors on the site. The value of such an analysis can be clearly demonstrated on the Big Island of Hawai‘i. One of the Hawai‘i Volcanoes National Park Service nurseries is located near sea level where the most limiting site factors are intense sunlight and seasonal high winds. This situation requires a strong structure to withstand wind loads and a shadecloth to minimize heat buildup. Moving up slope to the town of Volcano at 3,700 ft (1,130 m), the climate is milder year round than at the coast and the limiting factors are low sunlight with heavy rains, so a structure with a clear covering to maximize light transmission while protecting the crop from heavy rains would be ideal. Moving to an even higher elevation (7,000 ft [2130 m]), the limiting factor at Hakalau National Wildlife Refuge nursery is cold, with nighttime temperatures that can dip to freezing any time of the year. Thus, it is necessary to have an enclosed structure to protect the crops. 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 Stocktypes

Tropical nurseries grow an increasing diversity of native plant species. Often, these diverse 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 should be designed with various propagation environments in which plants of similar requirements and growth stages can be grown. For example, a controlled environment such as a greenhouse or other sheltered area can provide ideal conditions for germinating seeds and establishing young seedlings in containers. After young seedlings are established, they could be moved to a shadehouse or open compound to continue their growth. During hardening, the crops can be acclimated to the ambient environment in the same shadehouse or open compound.

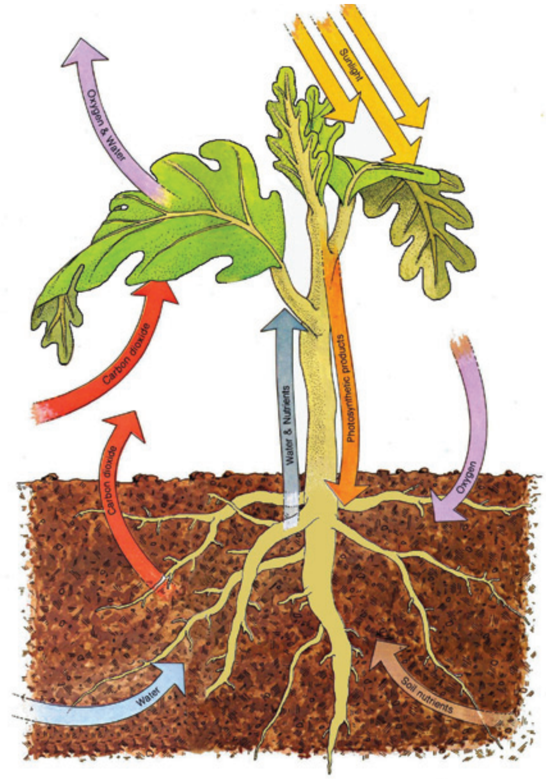


***Figure 5.1***—*Two important processes occur in the leaves of green plants. In photosynthesis, sunlight triggers a chemical reaction in which water from the soil and carbon dioxide from the air are converted to sugars and oxygen, which are released back to the atmosphere. During the process, water vapor is lost from the leaves in a process known as transpiration. Illustration from Dumroese and others (2008).*

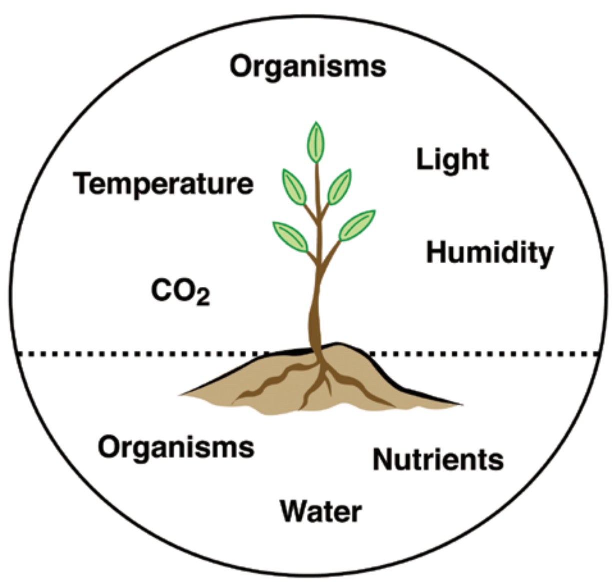


***Figure 5.2***—*It is useful to think of the nursery environment in terms of factors that might be limiting to plant growth. Limiting factors in the soil include water and mineral nutrients whereas, temperature, light, carbon dioxide, and humidity can be limiting factors in the atmosphere. Other organisms can either be beneficial or detrimental. Illustration from Dumroese and others 2008.*

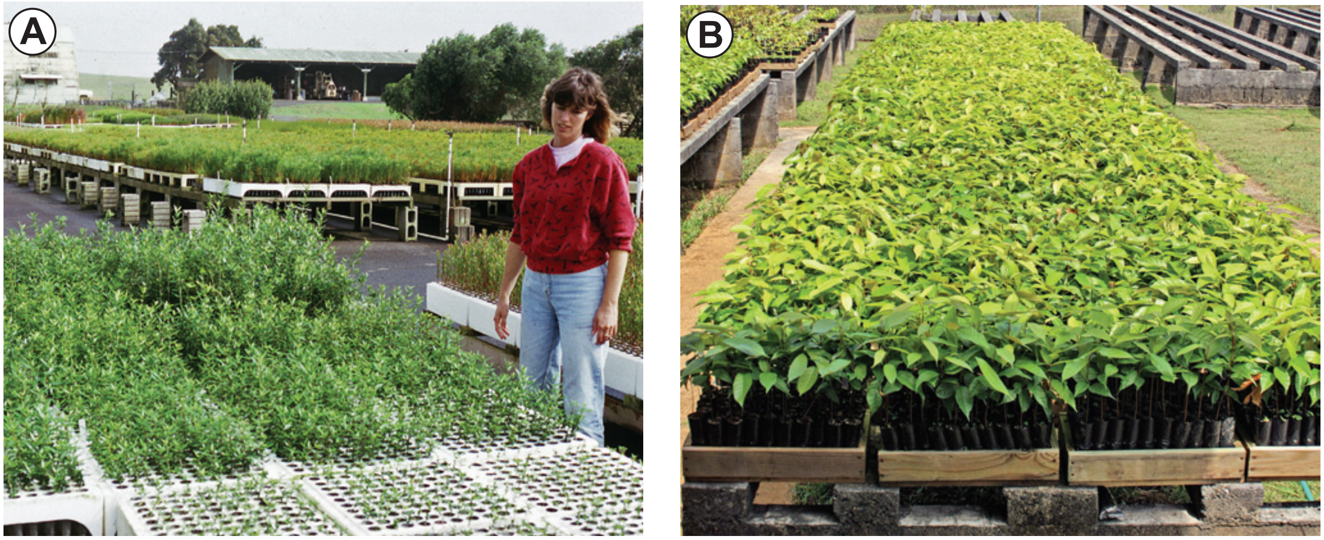


*Figure 5.3—Open compounds, like Waimea State Tree Nursery on the Big Island of Hawai'i, are common in tropical climates and often used for hardening crops grown in greenhouses or other structures (A). Open compounds often have irrigation and are fenced as seen at this Republic of Palau Forestry Department nursery (B). Photo A by Thomas D. Landis, and photo B by Tara Luna.*

## Minimally Controlled Propagation 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 is usually nothing more than an irrigation system and a surrounding fence.

### Open Growing Compounds

Open growing compounds are popular in tropical climates (figure 5.3). Nurseries use open compounds for plant propagation and for areas to expose crops previously grown inside structures to ambient conditions during hardening. Plants can be grown on elevated platforms, benches, or pallets to improve air pruning of the roots, or directly on a layer of gravel (to provide drainage) that is covered with landscape fabric (to control weeds). Irrigation is provided by 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 needs to be fenced to minimize animal damage, and, in windy areas, a shelterbelt of trees around the compound can protect from desiccation and improve irrigation coverage.

#### *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. They can also be used to provide specific habitats for certain wetland plants, such as for mangroves adapted to saline coastal habitats. Wetland ponds can be aboveground reservoirs, such as children's 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 5.4). These simple propagation environments use growing media amended with controlled-release fertilizer and require only periodic flood irrigation. Some islands, like Hawai'i and American Samoa, have freshwater wetland species that can be grown as container plants with freshwater flood irrigation.

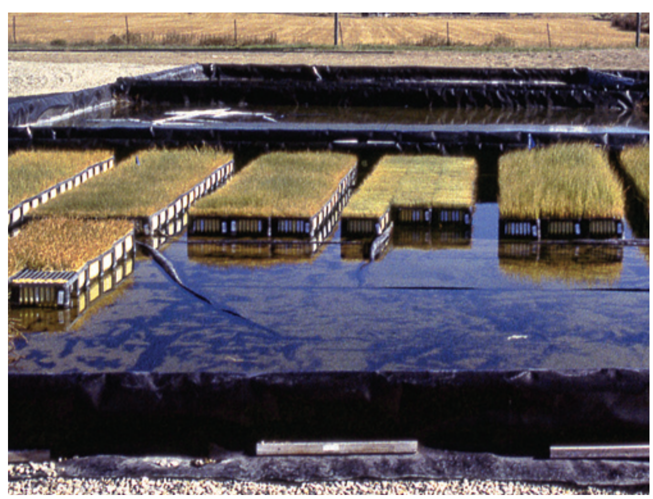

*Figure 5.4—Wetland ponds can be constructed in the outdoor nursery for growing wetland species. On a smaller scale, plastic tubs can be used instead. Photo by Thomas D. Landis.*

## Semicontrolled Propagation Environments

Another 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. As their name suggests, they have no heating source except for the sun. Cold frames are the most inexpensive propagation structure and are easy to build and maintain. Because conditions inside can stay relatively warm and moist, cold frames can be used for seed germination or rooting cuttings. They can also be used to protect seedlings and cuttings from heavy rains and wind.


*Figure 5.5—Cold frames are an inexpensive alternative to a greenhouse. Cold frames should be placed in a sheltered location for additional protection (A). Coverings may be removed (B) or held open to manage humidity and heat levels (C). Photos by Tara Luna.*

The ideal location for a cold frame is an area with a slight slope to ensure good drainage. A sheltered spot against the wall of a building or greenhouse provides additional protection (figures 5.5A). Some nurseries sink the floor of the cold 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 mahogany 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 needs to be built so that it is weather-tight and so the top can be opened partially or fully to allow for various levels of ventilation, watering, and the easy removal of plants (figure 5.5B, 5.5C). The cover must be able, however, to be attached securely to the frame to resist wind gusts. 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 can be labor-intensive because they need to be opened and closed daily to manage temperature and humidity levels. A thermometer that can be conveniently read without opening the cover is mandatory. In a cold frame, plants grow best at 65 to 85 °F (18 to 29 °C). If air temperature goes above 85 °F (29 °C), the top must be opened to allow ventilation. In the tropics, cold frames usually need to have shadecloth suspended above them to help moderate temperatures.

### Hoop Houses and Polyethylene Tunnels

Hoop houses and polyethylene ("poly") tunnels are versatile, inexpensive propagation environments. They are usually constructed of semicircular frames of polyvinyl chloride (PVC) or metal pipe covered with a single layer of heavy polyethylene and are typically quite long (figure 5.6). Some hoop houses have end walls made of solid material such as water-resistant plywood. The cover on hoop houses is changed or removed during the growing season to provide a different growing environment, eliminating the need to move the crop from one structure to another. In general, during the rainy season, a clear plastic

*Figure 5.6*—*Hoop houses can be used for a variety of propagation environments by changing or removing the coverings. Photo by Douglass F. Jacobs.*

cover is used during seed germination and seedling establishment. The plastic cover protects the young germinants and seedlings from heavy rains and can be pulled back as needed to provide adequate ventilation. As the dry season approaches and the seedlings are established, the plastic cover can be 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.

### Shadehouses

Shadehouses are the most permanent of semicontrolled propagation environments and serve several uses. In the tropics, shadehouses are commonly used to propagate plants under conditions of intense sunlight (figure 5.7A). Less permanent shadehouses consist of a metal pipe frame covered with shadecloth and allow for rapid take down when tropical storms threaten. When used for growing, shadehouses can be equipped with sprinkler irrigation and fertilizer injectors (figure 5.7B). When the shade is installed on the sides of the structure, shadehouses are very effective at protecting crops from wind and therefore help to reduce transpiration. Shadehouses can also be built with local materials (figure 5.7C).

## Fully Controlled Propagation Environments

Fully controlled environments are propagation structures in which all or most of the limiting environmental factors are controlled. Examples include growth chambers (high-cost option used almost exclusively for research) and greenhouses. Tropical nurseries with large forestry and restoration programs often make use of greenhouses. Fully controlled environments have the advantage of year-round production in nearly any climate. In addition, most crops can be grown faster and have more uniform quality than those grown in propagation environments with less control. These benefits must be weighed against the higher costs of construction and operation. The more complicated a structure is, the more problems that can develop. This concept is particularly true in the remote locations of many tropical nurseries, where electrical power outages can be common and it is difficult, time-consuming, and expensive to obtain specialized parts and repair services. Some good references that provide more detail about greenhouse design include Aldrich and Bartok (1989), Bartok (2000), and Landis and others (1994).


*Figure 5.7*—*Shadehouses are semicontrolled environments that are used for protecting plants from intense sunlight, rain, or wind (A). They can be constructed of wood frames with lath or metal frames with shadecloth and are equipped with irrigation systems that can also apply liquid fertilizer (B). In addition, shade can be created with locally available materials (C). Photos by Tara Luna.*

## Greenhouse Engineering Considerations

All greenhouses are transparent structures that allow natural sunlight to be converted into heat (figure 5.8A). At the same time, greenhouses are poorly insulated and require specialized cooling and ventilation systems to regulate temperatures. Keeping a greenhouse cool during sunny days requires carefully engineered ventilation systems. It is important to understand that greenhouse construction requires specialized skills (figures 5.8B, 5.8C). In developed areas, greenhouses may be regulated by municipal building codes and zoning, which is another good reason to work with a professional contractor before buying and constructing a greenhouse.

### *Design Loads*

The load on a greenhouse includes dead loads (the weight of the structure), live loads (caused by building use), and weather-related loads (wind). Live loads include people working on the structure and the weight of equipment, such as irrigation systems, fans, lighting systems, and even hanging plants.

### *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 landscape cloth, but the ground beneath the floor must drain water freely to prevent standing water and safety issues. Nursery crops require frequent irrigation and, depending on the irrigation system, much of this water may end up on the floor. Drain tiles might be needed to ensure that the greenhouse floor will not become a swamp. 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 many places. 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; these ponds or wetlands can sometimes be used for other purposes, such as growing wetland plants 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.

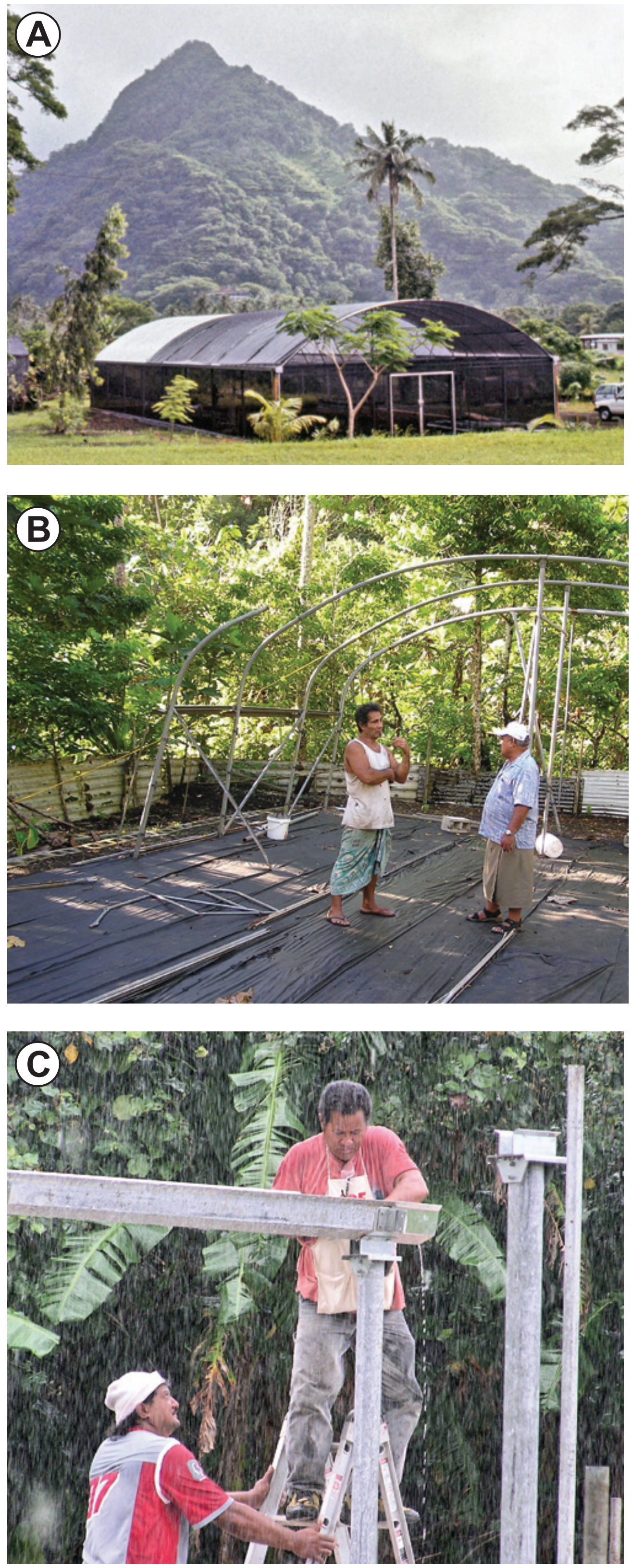


***Figure 5.8****—Greenhouses, like this one in American Samoa, are the most sophisticated propagation environments (A). Workers with specialized skills are needed from the initial surveying (B) to the final construction (C). Photo A by Thomas D. Landis, and photos B and C by Ronald Overton.*

### *Framing Materials*

Ideal framing supports the greenhouse 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 (figure 5.9).

Polyethylene tarps are relatively cheap but require replacement every 2 to 4 years depending on the grade of plastic. Double layers of polyethylene sheeting that are inflated with a fan are stronger and provide better insulation longer than a single layer. 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, polyethylene greenhouses require good ventilation to prevent condensation.

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.

These panels are the most common greenhouse coverings, and a more detailed description of costs and engineering and operational considerations is available in Landis and others (1994).

## Controlling Greenhouse Temperatures

One of the most challenging aspects of a greenhouse is controlling temperature. Sunlight is converted into heat that can become lethal to plants. A sophisticated control system that can maintain a designated temperature through a series of heating and cooling stages is a necessary and wise investment to minimize energy costs. Vents and fans are used to keep air moving inside the greenhouse and exhaust heat from the structure. In dry, windy environments, wet walls use the power of evaporation to cool incoming air. Growers can also use short bursts of their irrigation system for cooling. Automatic sensing instruments are available that can be connected with cooling equipment to trigger a cooling cycle for the greenhouse. Mechanical thermostats provide the best and most economical form of temperature control and can be used to activate motorized vents and fans within a greenhouse.

***Figure 5.9****—Greenhouses are covered with transparent coverings such as plastic sheeting or hard plastic panels to maximize the amount of sunlight reaching the crop. Photo by Brian F. Daley.*

# Specialized Rooting Propagation Environments

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 5.10A), 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 polyethylene coverings that, in addition to maintaining high humidity, keep the area warm. If the chambers are outside, the covering further protects cuttings from rain and drying winds. For more information on rooting cuttings, see Chapter 10, Vegetative Propagation.

## Enclosed Rooting Chambers

Because it is easy to construct and very economical, a simple enclosed rooting chamber is essentially the same

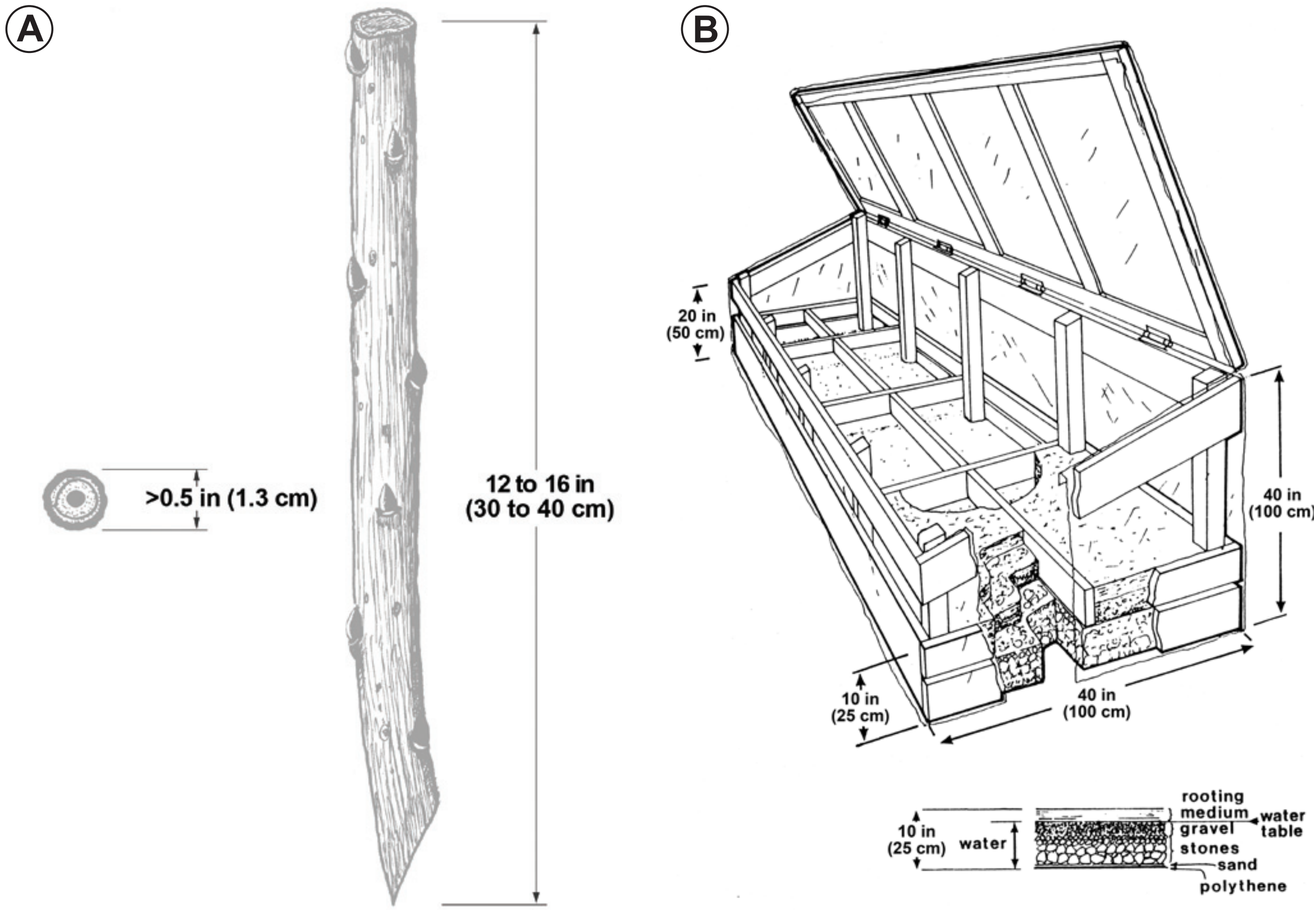


***Figure 5.10**—Rooting cuttings require a specialized propagation environment because cuttings lack a root system (A). The "poly propagator" is the most simple and inexpensive rooting chamber (B). Illustrations by R.H.F. Wilson from Longman 1993.*

as the cold frame discussed earlier. They are commonly used in tropical nurseries throughout the world because they do not require electricity. Enclosed rooting chambers rely on manual operation so they require diligent daily inspection to regulate humidity and air temperatures, and the rooting medium must be watered as needed. They typically have shadecloth suspended above them 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 polyethylene plastic sheeting and is a simple and inexpensive design (figure 5.10B).

## Intermittent-Mist Rooting Systems

These rooting propagation environments are either enclosed or open. Rooting cuttings is much easier in these environments because intermittent-mist rooting chambers have a high degree of environmental control (figure 5.11A). Clock timers (figure 5.11B) control the timing and duration of misting from specialized nozzles (figure 5.11C). Frequent misting maintains high humidity that reduces water loss from the cuttings, and evaporation of the small droplets moderates air and leaf temperature.

Mist systems require high water pressure that is supplied through PVC pipes. Mist timing is controlled by two time clocks that open and close a magnetic solenoid valve in the water line linked 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 needs to be installed in the water line after a gate valve.

Because of the proximity of water and electricity, all employees need to 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 coverings. The high humidity encourages the growth of algae and mosses, so the mist propagation system needs to be cleaned regularly. Mist systems require water that is low in dissolved salts; "hard" water may result in whitish deposits that can plug mist nozzles. See Chapter 11, Water Quality and Irrigation, for more information.

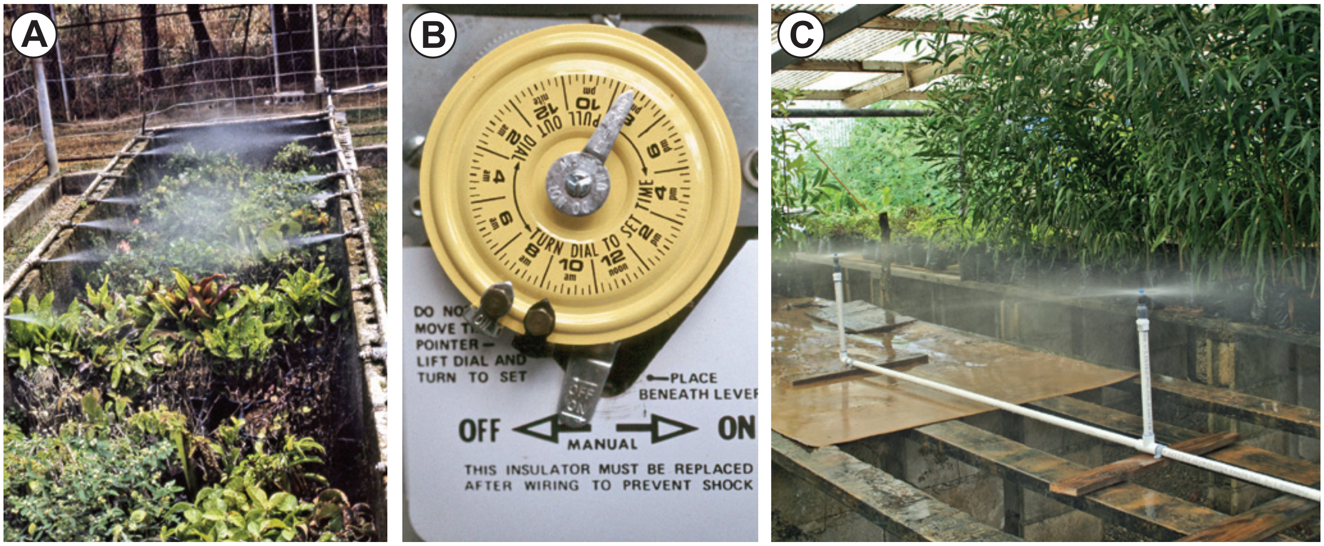


***Figure 5.11****—Intermittent-mist systems are easily controlled environments (A). Programmable timers control the timing and duration (B) of specialized mist nozzles (C), which keep humidity levels high, reduce transpiration, and provide cooling. Photos A and C by Tara Luna, and photo B by Thomas D. Landis.*

## Modifying Light and Temperature in Propagation Environments

As mentioned earlier, light is necessary for photosynthesis, which provides energy for plant growth. For light-loving species, more light results in more growth (figure 5.12A), but greenhouse light levels are often too intense to grow some species of tropical plants (table 5.1). As a result, growers apply shadecloths to lessen light intensity and the resultant heat (figures 5.12B, 5.12C). Shadecloths are rated by the amount of shade they produce, ranging from 30 to 80 percent. Black has been the traditional color because it is relatively inexpensive, but now shadecloth comes in white, green, and reflective metal. Because black absorbs sunlight and converts it into heat that can be conducted into the propagation structure (figure 5.12D), black shadecloth should never be installed directly on the covering of any propagation structure, but instead needs to be suspended above it to facilitate air movement. Although more expensive than black shadecloth, white or aluminized shade fabrics are better for tropical environments and will do a much better job of cooling the propagation environment while still keeping light levels high. 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.

***Table 5.1****—Shade requirements of a variety of tropical plant species.*

| Scientific name | Light requirement |
|---|---|
| *Acacia* species | Sun |
| *Pandanus* species | Sun |
| *Scaevola* species | Sun |
| *Bobea* species | Partial shade |
| *Bonamia menziesii* | Partial shade |
| *Pritchardia* species | Partial shade |
| *Cyathea, Cibotium* species | Shade |
| *Cyrtandra* species | Shade |
| *Elaeocarpus bifidus* | Shade |

### Monitoring Temperatures

Thermometers that record the maximum and minimum temperatures during the day are simple and economical instruments (figure 5.13A) that can help growers monitor subtle microclimates within any propagation environment. New devices, such as self-contained, programmable temperature sensors, are revolutionizing the ways in which temperature can be monitored in nurseries (figures 5.13B, 5.13C). 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 temperatures under

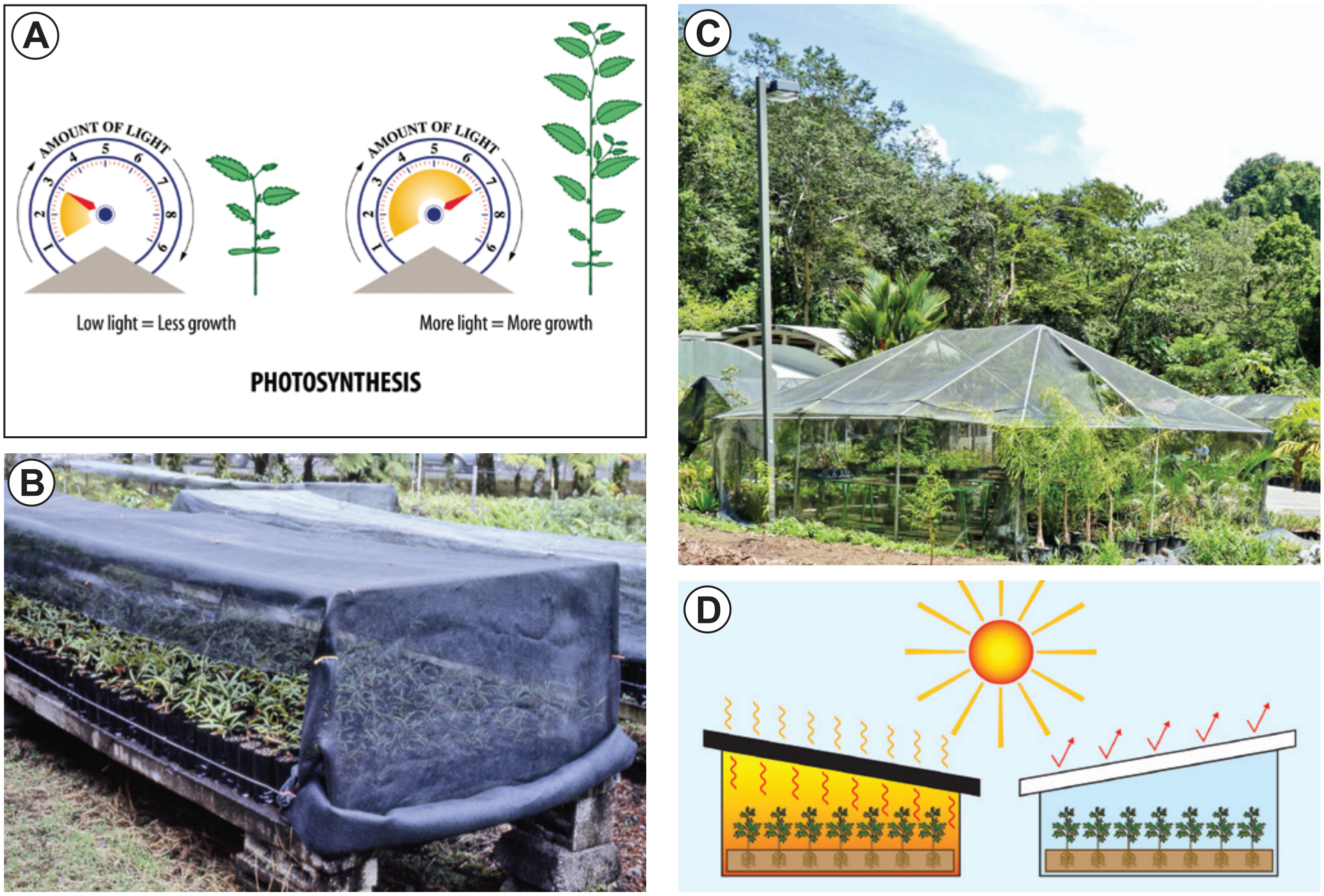


***Figure 5.12**—Sunlight provides the energy necessary for plant growth (A) but is converted to heat inside propagation structures. Shadecloth reduces light intensity and cools the environment in small enclosures (B) and larger shadehouses (C). Compared with white or reflective shadecloth, black shadecloth can absorb heat and radiate it into the propagation environment (D). Illustration A from Dumroese and others (2008), photo B by Tara Luna, photo C by Brian F. Daley, and illustration D by Jim Marin.*

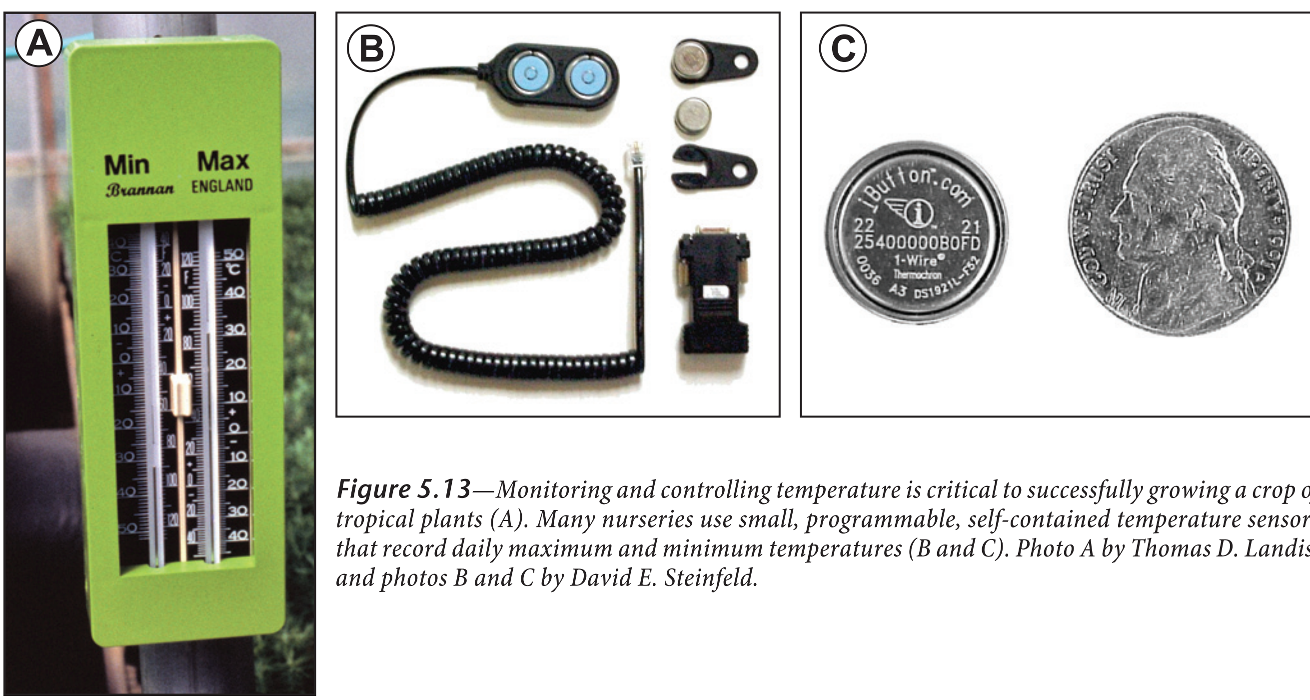


***Figure 5.13**—Monitoring and controlling temperature is critical to successfully growing a crop of tropical plants (A). Many nurseries use small, programmable, self-contained temperature sensors that record daily maximum and minimum temperatures (B and C). Photo A by Thomas D. Landis, and photos B and C by David E. Steinfeld.*

most nursery conditions. The data recorded on the sensors must be downloaded to a computer and can then be easily placed into a spreadsheet. The small size of the sensor can also be a drawback; it is easy to misplace. Attach a strip of colorful flagging to indicate where the sensors are located and write any necessary information on the flagging with a permanent marker.

## Equipment Maintenance

Even if you purchase the most reliable "automatic" environmental control equipment, it must be monitored and maintained. The hot and humid tropical nursery environment is particularly hard on equipment, and especially so in coastal areas where equipment may also be exposed to salt. Regular maintenance ensures longevity, reduces costly repairs, and may help avoid disasters.

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. Equipment records should be included in the nursery's daily logbook. See Chapter 4, Crop Planning: Propagation Protocols, Schedules, and Records, and Chapter 19, Nursery Management, for more details. These log books will be 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 and a handy supply of hardware items such as washers, screws, and bolts. 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 and easy to find.

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