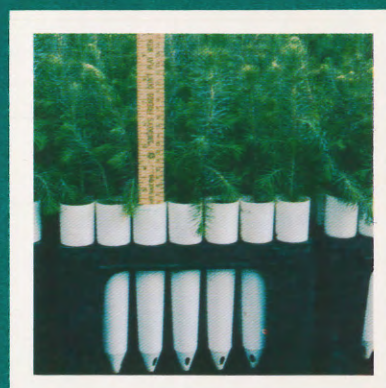
The Container Tree Nursery Manual • Volume One

Nursery Planning, Development, and Management



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The Container Tree Nursery Manual

Volume One
Nursery Planning, Development, and Management

Chapter 3
Nursery Design and Site Layout

Contents

1.3.1 Introduction

Once the nursery site has been selected, the next step in developing a container facility is to consider how much environmental modification will be needed to produce a crop of high-quality seedlings within the given time constraints. To accomplish this objective, let's look at the nursery environment and discuss how growers can culturally modify it.

1.3.1.1 The propagation environment

The conditions in a container nursery have been radically altered from the natural environment, and a term is needed to describe the wide range of possible nursery facilities. We like the term **propagation environment** because it is comprehensive without being limited to a particular type of structure or production system. A propagation environment contains two separate but related parts: the atmospheric component and the edaphic component.

Atmospheric factors. The main factors of the atmospheric environment are light, temperature, humidity, and carbon dioxide (fig. 1.3.1). The atmospheric factors are strongly affected by the geographic location and type of nursery facility and so must be carefully considered during nursery site selection and construction of propagation structures. The climate at the nursery site will determine what type of propagation environment will be needed. If the ambient environment is mild and time is not a major limitation, then container seedlings can be successfully raised in an open growing compound or a low-cost propagation structure. On the other hand, if the climate is severe and crops must be produced in a short time frame, then a fully controlled greenhouse will be necessary.

Edaphic factors. The two principal factors of the edaphic environment are water and mineral nutrients (fig. 1.3.1). In container nurseries, the edaphic factors are independent of nursery location and can be completely controlled by the type of container, growing medium, and cultural practices. (See volume two of this series for more discussion on containers and growing media.)

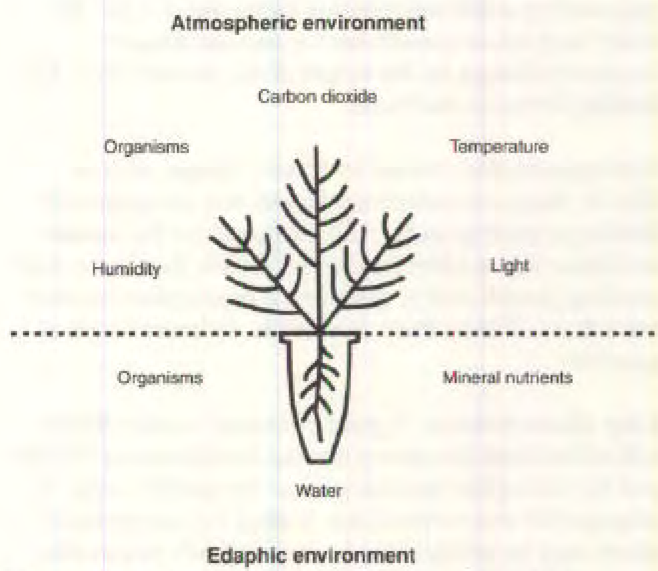


Figure 1.3.1—*Container seedlings are affected by "limiting" factors in the atmosphere and in the growing medium.*

Biotic factors. Both the atmospheric and edaphic components contain other organisms that can affect plant growth-either positively or negatively (fig. 1.3.1). One of the primary attractions of container nursery culture is that growers have more control over biological factors and can design propagation environments that exclude pests. In fact, in climates where weather conditions are otherwise ideal for plant growth, one of the most important design considerations is pest exclusion. Nurseries can also encourage beneficial microorganisms, for example, by inoculating the growing medium with mycorrhizal fungi. (The effect of pests on nursery design is discussed in section 1.3.4.1, and a detailed discussion of the biological component of the propagation environment is provided in volume five of this series.)

1.3.1.2 Limiting factors and nursery design

Container nursery developers can use the concept of limiting factors to determine which environmental conditions should be modified on their site. The **principle of limiting factors** states that, when a process is governed by several factors, its rate is limited by the factor that is closest to the minimum requirement (Odum 1971). Conceptually, the idea of limiting factors can be visualized with the wooden barrel analogy that Whitcomb (1988) used to explain mineral nutrient deficiencies. Plant growth is represented by the water in the barrel, which is constructed of wooden staves, each representing a different limiting factor (fig. 1.3.2). The water level (plant growth rate) at any one time or location is limited by the height of the shortest stave (the limiting factor) in the barrel.

If we expand this concept to nursery design, we can identify those environmental factors that are potentially limiting to plant growth. The challenge for the nursery developer lies in identifying those factors that could limit seedling growth and in designing a propagation environment that will keep them as close to optimum levels as possible.

Crop characteristics. A good container nursery design will reflect both the environmental conditions on the site and the biological requirements of the specific crop. A propagation environment that is ideal for one group of plants may be biologically or economically unsuitable for another. Most nurseries produce a number of different species, however, and so often different propagation environments must be designed to meet the needs of the various crops. On a practical basis, most nursery developers must compromise to obtain some sort of average environment in which they can grow the entire range of crop species.

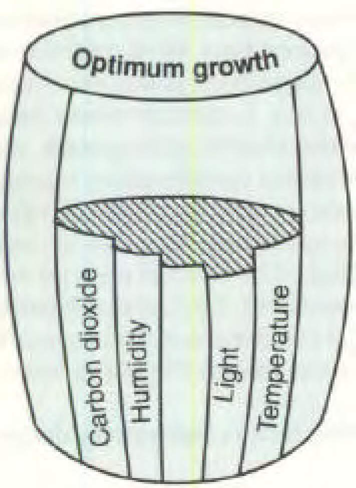


Figure 1.3.2—*Limiting factors can be visualized as the staves in a wooden barrel that control the rate of plant growth, represented by the level of water in the barrel (modified from Whitcomb 1988).*

Forest and conservation nursery crops can have radically different environmental requirements that developers must factor into the nursery design process. One characteristic that makes forest and conservation seedlings different from most other types of horticultural or ornamental nursery crops is that they are typically planted in relatively harsh environments without subsequent care. Because forest nursery stock must be properly hardened to withstand the stresses of outplanting, traditional propagation structures and growing regimes have had to be modified. These special types of propagation environments are discussed in section 1.3.2. Nursery developers can get an idea of the biological requirements of typical forest and conservation species by visiting other local nurseries or consulting the growing schedules in volume six of this series.

Local climate. Next, the nursery developer must determine the amount of environmental modification that will be necessary on the selected site. Container seedlings have been grown in a wide variety of different environments, from open growing compounds to sophisticated greenhouses. Of course, the costs of nursery development and operation increase with the extent that the environment must be modified. Although a sophisticated greenhouse can optimize all the environmental factors that limit growth (table 1.3.1), a simpler, less complicated propagation structure may be the most economical choice in many environments. The nursery that matches the biological requirements of the crop to environmental conditions of the site will also be the most economical, and so nursery developers should devote ample time to site analysis before the type of propagation environment is selected. (The specifics of site selection are discussed in chapter two of this volume.)

Table 1.3.1—*Potential to control limiting factors in different propagation environments*

Limiting factors	Type of propagation environment		
	Minimally controlled	Semicontrolled	Fully controlled
Atmospheric			
Temperature—high	No	Partially	Yes
Temperature—low	No	Yes	Yes
Humidity	No	Partially	Yes
Light—photoperiod	Yes	Yes	Yes
Light—photosynthesis	No	Yes	Yes
Light—quality	No	Yes	Yes
Carbon dioxide	No	Partially	Yes
Pests	No	Partially	Yes
Edaphic			
Water	Yes	Yes	Yes
Mineral nutrients	Yes	Yes	Yes
Pests	Yes	Yes	Yes

1.3.2 Types of Propagation Environments

Container nurseries can be categorized by the relative amount of environmental modification: fully controlled environments, semicontrolled environments, and minimally controlled environments.

1.3.2.1 Fully controlled environments

A fully controlled growing environment requires a propagation structure that contains all the environmental control equipment necessary to keep all potentially limiting factors at optimum levels (table 1.3.1).

Operationally, fully controlled propagation environments have many positive biological attributes (table 1.3.2). They are suitable for almost any type of climate and, due to the high degree of environmental control, the risk of losing a crop to severe weather is low. The favorable conditions permit crops to be grown year-round with a rotation of 3 to 9 months, making multiple crops a distinct possibility. However, fully controlled environments are the most expensive to build and operate, primarily due to high energy requirements.

Growth chambers. Growth chambers are the only propagation environments that completely control all factors that can potentially limit growth (table 1.3.1). The main advantage of growth chambers over greenhouses is that they artificially supply all aspects of light (intensity, duration, and quality). In addition, because they are completely insulated from the outside environment, growth chambers do not experience the radical temperature fluctuations that sometimes result from changes in solar input. Although they have been used for seed germination tests and experiments, only a few companies have developed growth chambers large enough for operational seedling production. Two were constructed underground in mines, but these proved to be economically unfeasible. Currently, the Iron Range Resources and Rehabilitation Board is operating a growth chamber in Chisholm, Minnesota, and propagating seedlings for mineland reclamation (fig. 1.3.3). Over the past 10 years, they have grown 44 different species of plants in two crops per year at competitive prices. Growth chambers are also used in micropropagation to start the plantlets before they are moved out to a standard propagation environment.

Table 1.3.2—*Operational considerations for selecting a propagation environment*

Factors	Type of environment: Minimally controlled	Semicontrolled	Fully controlled
Biological			
Ambient climate	Mild	Moderate	Any
Growing season	Summer	Spring to fall	Year-round
Cropping time	6–24 Months	3–12 Months	3–9 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

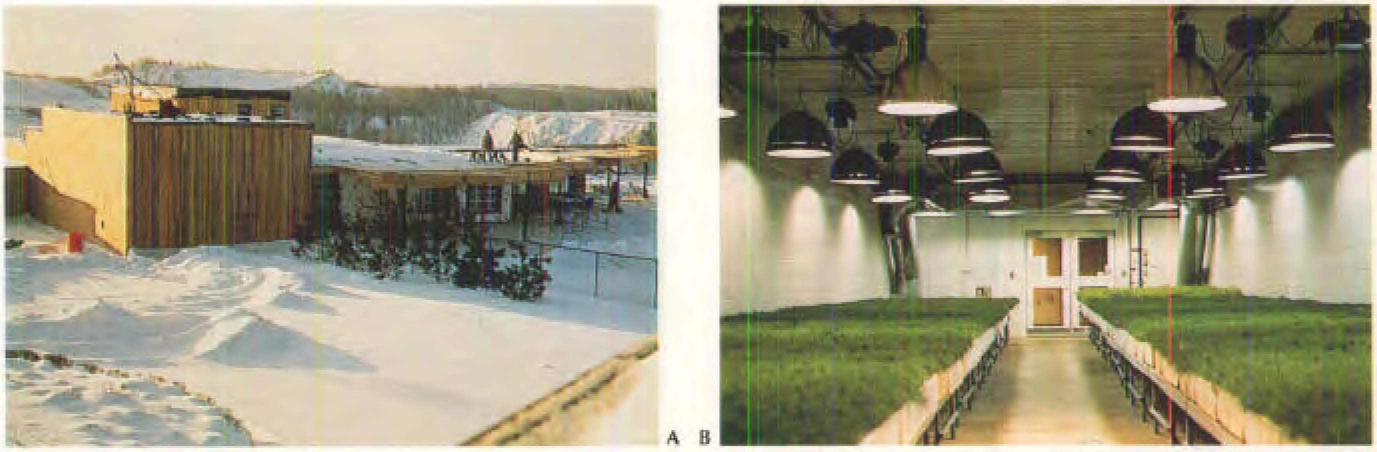


Figure 1.3.3—*Growth chambers can be built in any location* **(A)** *because they control all plant growth limiting factors* **(B)** *(courtesy of Daniel Jordan, Iron Range Resources and Rehabilitation Board).*

Greenhouses. Greenhouses are the traditional method of producing container plants, and they can be equipped to fully control the propagation environment (fig.1.3.4A). Greenhouses differ from growth chambers in that they use natural sunlight that is trapped inside the transparent structure and converted to heat (the "greenhouse effect"). The drawback of the transparent covering is that greenhouses are inherently poorly insulated and require both high-capacity heating and cooling equipment for good temperature control. Depending on whether the climate is arid or humid, the greenhouse environment may need humidification or dehumidification. Many forest and conservation species are sensitive to changes in daylength, and so photoperiodic lighting is often installed to prevent dormancy. Carbon dioxide generators can be used to promote faster growth rates. Irrigation systems with fertilizer injectors can supply optimum amounts of water and all essential mineral nutrients. Sophisticated environmental control equipment is used to balance all the various factors and keep them at optimal levels.

Figure 1.3.4—*Greenhouses are designed to capture sunlight and can be equipped to control all the factors that limit plant growth* **(A)**. *Because forest and conservation crops must be fully hardened, some growers remove the covering late in the growing season* **(B)**.

The traditional way of growing forest and conservation nursery crops was to start the seedlings in a greenhouse and then move them to a shadehouse for hardening. In fact, growers soon learned that the hardening phase was the most challenging and began to look at ways of modifying the crop schedule. Many began removing the greenhouse covering so that they could harden their crops in place without the additional labor and expense of moving the seedlings (fig. 1.3.413). Others began looking at structural modifications to the traditional fully controlled greenhouse.

1.3.2.2 Semicontrolled environments

This category includes a wide variety of growing structures that, as their name implies, are designed to control only certain aspects of the ambient environment (table 1.3.1). Crops can be propagated in semicontrolled structures in all but the most severe climates (table 1.3.2). Depending on the type of structure, crops can be grown from spring to fall with generally one crop produced per year; winter crops are not usually considered economical. Some types of semicontrolled structures, especially shadehouses and tunnels, are also used for hardening and intermittent seedling storage. From an economic standpoint, semicontrolled environments are cheaper to build and operate, although there is considerable variation between the different types of structures.

Shelterhouses. A modification of the traditional greenhouse, the original shelterhouse featured a permanent transparent roof with movable walls that can be rolled up or otherwise opened (Hahn 1982). This design permits considerable flexibility in environmental control. In the spring or in unusually cold weather at any time during the growing season, the sidewalls are kept lowered and heat turned on to maintain ideal temperatures. When ambient temperatures become favorable, the sides can be raised to permit natural ventilation (fig. 1.3.5A), eliminating the need for forced air cooling. Other than these structural modifications, shelterhouses can be outfitted with any or all of the standard greenhouse environmental control equipment to modify most limiting factors.

A

B

C

Figure 1.3.5—*Semicontrolled propagation structures are designed to allow easy and quick modification of the growing environment, from raising the sides* **(A)** *or adjusting the covering on the roof* **(B & C)** *(B & C, courtesy of Richard Vollebregt, Cravo Equipment Ltd.).*

Recently, computer technology and a variety of new shading materials have made many different types of semicontrolled propagation environments possible. An innovative new shelterhouse has been recently developed that features a retractable roof that can modify sunlight and crop temperature as weather conditions change (Vollebregt 1993). The roof material can be constructed of transparent fabric or shadecloth to produce a wide variety of light conditions within the propagation environment. Just like a shelterhouse, the transparent roof can be left closed early in the season and during cool weather and opened later to expose the crop to ambient conditions (fig. 1.3.5B&C). This feature makes retractable roof structures particularly valuable for forest and conservation seedlings because they can be gradually hardened to outside conditions yet still be protected from climatic extremes. Retractable roof propagation structures can also be designed with an inner shadecloth curtain to control light intensity and crop temperature. Responding to changes in ambient light intensity, the shade curtains can be computer controlled to open or close automatically in only 3 to 6 minutes. This allows the crops to receive more light early in the morning and late in the day and also throughout the day under partly cloudy conditions.

Hoop houses and tunnels. These low-profile metal bow-arch structures heat up rapidly in sunny weather, and thus are primarily used in cooler climates. Some nurseries have used larger structures (**high tunnels**) for propagation, starting the container seedlings in a greenhouse and then transferring them to the tunnels for finishing and overwintering (fig. 1.3.6A). High tunnels also can be equipped with portable heaters, so that seedlings can be germinated in place. During warm weather, the sides of the tunnels are normally rolled up to provide ventilation or are covered with shadecloth. In addition to solar or supplemental heat, tunnel seedlings receive only irrigation and fertilizer during the growing season. This minimal level of culture results in a relatively slow growth rate, and so the stock may remain in the structures for a second year. Smaller structures (low tunnels) are too short to accommodate motorized equipment and are used primarily to store stock overwinter (fig. 1.3.613, also see section 1.3.5.4).

Figure 1.3.6—*Hoop houses are low-cost structures that create semicontrolled environments for propagation* **(A)** *or overwinter storage* **(B)**.

Shadehouses. Traditionally, shadehouses (or **lathhouses**) were covered with snowfence or wooden slats, but several other types of shade coverings are now available in a variety of densities, materials, and colors (fig. 1.3.7A). Shadehouses are usually equipped with irrigation and fertilization systems but other limiting factors remain at ambient levels. Although traditionally used as hardening or holding areas, shadehouses are used by forest and conservation nurseries to propagate some species, and to finish crops in multiple-cropping regimes. In the latter case, seedlings or cuttings are started in a greenhouse and then moved to the shadehouse after they become established (fig. 1.3.713). In colder climates, shadehouses are also used for overwinter storage (see section 1.3.5.4).

Shadehouses have found considerable acceptance in the Tropics and the Subtropics, where sunlight can be too intense for young seedlings and torrential rains and wind can damage the crop. In these climates, a shadehouse with a permanent roof and open mesh sides (fig. 1.3.7C) will achieve the cultural objectives and also exclude insects and oth er pests from the growing area. The choice of shade material is important. White shadecloth helps keep the growing environment cool by reflecting sunlight, and knitted fabrics are superior to woven materials (George 1993).

A

B

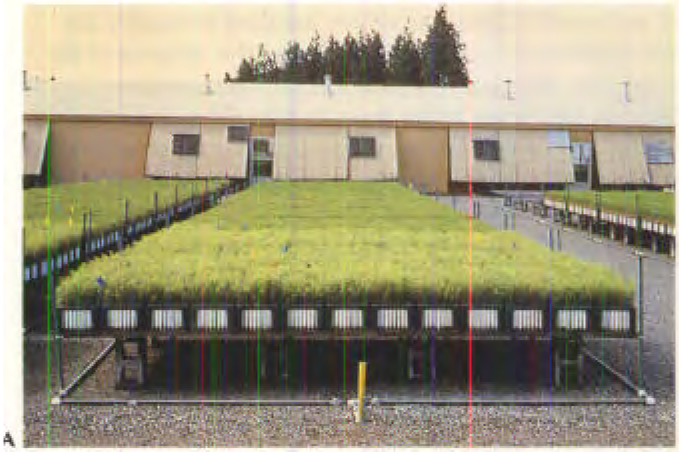
C

Figure 1.3.7—*Shadehouses are semicontrolled propagation structures that modify sunlight and can be used to either propagate* **(A)** *or harden crops* **(B)**. *They are particularly useful in tropical or semitropical climates* **(C)**. *(B, courtesy of Daniel Jordan, Iron Range Resources and Rehabilitation Board.)*

1.3.2.3 Minimally controlled environments (open growing compounds)

Open growing compounds were developed to produce an inexpensive container seedling that was well acclimated to the environment. The compounds are graded for good drainage and either covered with weed barrier fabric and gravel or paved with asphalt (fig. 1.3.8A). Although they offer little control of the ambient climate all are equipped with semipermanent irrigation lines that water and injected mineral nutrients can be applied (table 1.3.1). In cooler climates, some open growing compounds are equipped with photoperiodic lighting (fig. 1.3.813). Containers may be placed on benches, pallets, or directly on the ground, although the latter is not recommended because of poor air pruning of roots. The containers are arranged into elongated beds or bays, the dimensions of which are determined by the irrigation or seedling handling system. In some nurseries, seedlings are started in special germination chambers, but in other locations, germination takes place outside.

Although open growing compounds are the least expensive way to produce container stock, seedling growth rates are slow and, depending on the climate, it may take 1 to 2 years to produce a shippable seedling. Weather damage, such as a killing frost or torrential rain, is also a constant concern and so the risk of crop loss is the highest of all types of propagation environments (table 1.3.2). Cold injury to overwintered seedlings is a serious problem at nurseries at high latitudes or elevations.



A

B

Figure 1.3.8—*Open compounds offer minimal control of the propagation environment with irrigation systems that control water and mineral nutrition* **(A)**, *and some growers add photoperiod lights to extend daylength* **(B)**.

1.3.3 Selecting a Propagation Structure

A variety of different structures are used to modify the environment for growing plants, and the purpose of the following discussion is to introduce the container nursery developer to the basic terminology and concepts. For more detailed information on the engineering and operational aspects, the reader should consult standard greenhouse texts (Nelson 1991, Aldrich and Bartok 1989, Boodley 1981, and Hanan and others 1978). Horticultural supply firms also can provide information and advice on the best type of growing structure for a particular climate and application.

1.3.3.1 Functions and terminology

Greenhouses and other propagation structures come in many sizes and shapes (fig. 1.3.9). They can be simply classified by three factors: external form, internal support system, and whether they are free-standing or gutter-connected.

The external shape of a propagation structure is a reflection of its function-to capture the maximum amount of sunlight while protecting the crop from adverse climatic conditions. Many structures were designed to meet the unique conditions of a particular geographic region. In colder climates, for example, gothic structures are common because they shed snow more easily. Sawtooth designs are designed for good ventilation and so are best suited for warmer climates. New innovations also affect the design. The low cost of the new types of polyethylene coverings and the superior insulation capability have made **"double-poly"** quonset structures very attractive. On the other hand, propagation structures with internal columns are rarely used today because truss-frames are now available in wide spans.

The type of propagation structure also depends on the financial resources of the nursery developer and the availability of local material. The wooden rigid-frame structure is relatively inexpensive where wood is readily available and can be easily constructed by the developer. The design should also reflect future expansion plans. For example, the bow frame design is only used in gutter-connected applications, but a single structure could be constructed until further expansion can be financed (Bartok, 1993).

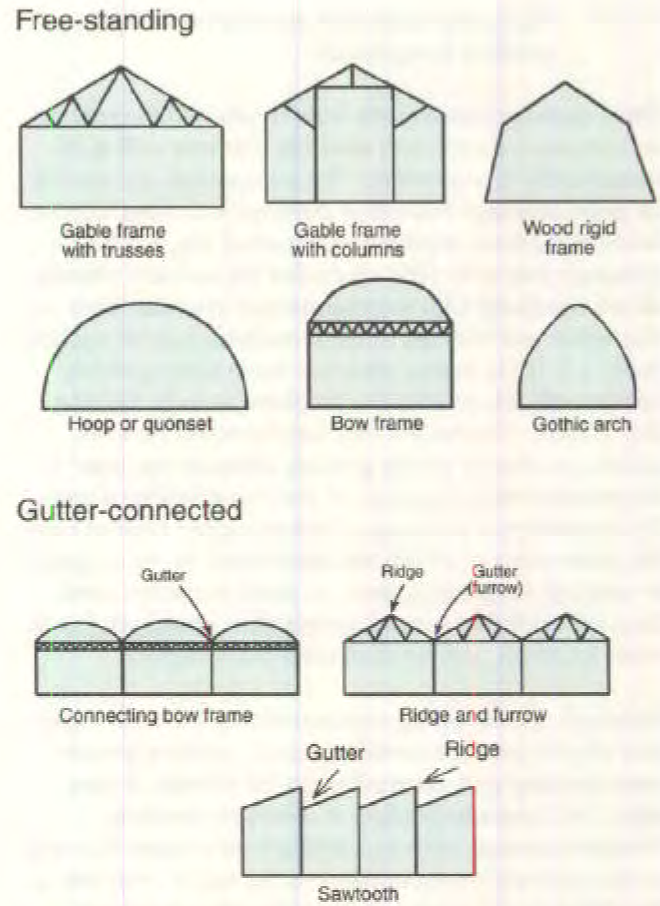


Figure 1.3.9—*Propagation structures come in a wide variety of shapes and sizes, and can be categorized as free-standing or gutter-connected (modified from Aldrich and Bartok 1989).*

Free-standing structures are ideal for new nurseries because they offer the most flexibility. Nursery developers can start with one or two structures and then add more later as business improves. Individual greenhouses are popular in forest and conservation nurseries because many different crops can be grown in separate environments. They also offer better access and shed snow more easily than multispan structures. On the other hand, gutter-connected propagation structures offer better space utilization, greater labor efficiency, and lower heating costs. For instance, one hectare of gutter-connected structures will use about 25% less heat than an equal area of free-standing structures (Bartok 1991 a). They are also most practical where land is limited or expensive.

As with all buildings, propagation structures must be constructed to support specific design loads.

1.3.3.2 Design loads

There are three types of design loads that are a reflection of the engineering characteristics of the structure itself and the local climate:

- Dead loads from the weight of the structure
- Live loads caused by building use
- Weather-related loads from wind and snow

In addition to the weight of the frame and covering, dead load calculations must include any equipment that is supported by the frame. Live loads include people working on the roof and hanging plants (Aldrich and Bartok 1989). Wind loads can be significant in many environments and snow loading is a serious consideration at higher latitudes and elevations. Information on outdoor design temperatures, wind speed, and expected average snow loads is available (Midwest Plan Service 1983). Container nursery developers should consult with an engineer or greenhouse supplier to obtain an estimate of design loads before beginning to plan a propagation structure.

In the following sections we will discuss the advantages and disadvantages of the different types of propagation structures, based on the following three functions:

- **Engineering-Safely** support the design loads
- **Biological-Capture** maximum sunlight, and protect the crop from adverse weather and pests
- **Operational-Allow** easy access and handling of seedlings and materials

1.3.3.3 Foundation and floors

The most important function of the foundation is to tie the structure to the ground because strong winds cause a lifting effect (Aldrich and Bartok 1989). A propagation structure must also have a strong foundation to counteract all the various loading forces, keep the environment clean and pest free, and provide a solid base for the container supports and the handling system.

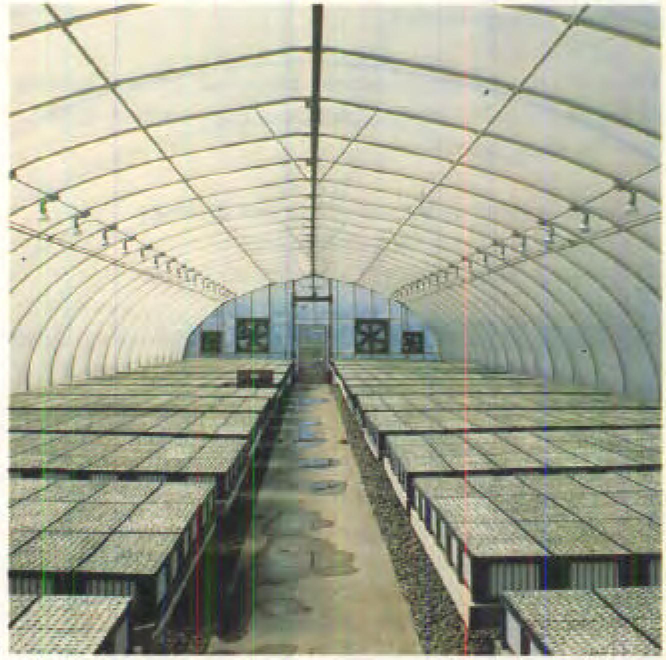
Construction materials. Foundations are made with poured concrete, whereas floors can be concrete, asphalt, or gravel covering a weed barrier fabric. The best foundation and floor for a propagation structure will be a compromise between the engineering, biological, and operational considerations and will most likely be determined by available funding. Solid concrete floors have many advantages, but concrete or asphalt traffic paths between the benches are a less expensive option (fig. 1.3.10). Bare soil or even soil covered with plastic tarp or weed barrier is never recommended in propagation areas.

Engineering considerations. Unlike other buildings, the foundations of most propagation structures are not continuous around the perimeter of the building. Instead, many structures have pier foundations consisting of a series of concrete footings poured below the frost line (Boodley 1981). The individual pier footings must be engineered to fit design loads and soil conditions, and their spacing corresponds to the distance between the primary frame supports (fig. 1.3.11 A). If primary frame members are spaced more than 1.2 m (4 ft) apart, a continuous masonry or poured concrete wall is often used (Aldrich and Bartok 1989).

Many designs use a curtain wall of concrete, cement blocks, composite panels of aluminum foam and vinyl, or wood around the perimeter of the structure to close the area between the piers (fig. 1.3.11 B). Although it does not provide any structural support, the curtain wall should extend below the ground line to exclude pests and should be insulated in cold climates (Boodley 1981). The floor of the propagation structure does not provide any structural support and so operational and biological considerations take priority.

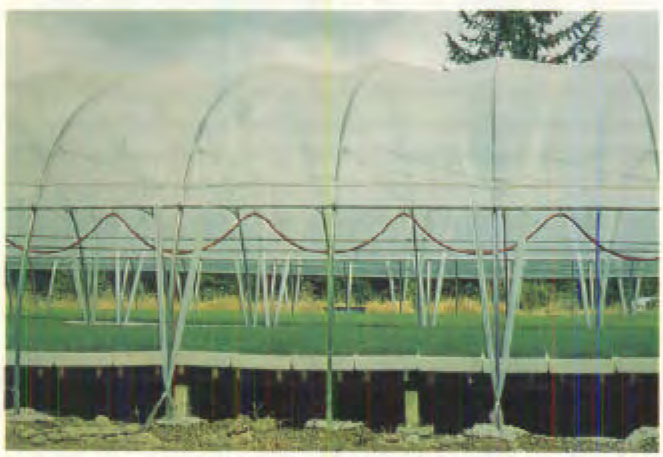
Biological considerations. A solid floor is essential in keeping the propagation area clean and free from pests. Moss and algae are always a problem in container nurseries, and insects and fungal pests breed on weeds growing in or around propagation structures. So, a floor surface that can be cleaned regularly is one of the basic tenets of a good pest management program. With the increasing concern about surface and groundwater pollution, a solid floor should be considered whenever possible because container nurseries will probably be required to catch and treat all irrigation runoff in the near future. It is much cheaper and easier to build floors during the initial construction than to have to retrofit the structure later.

A



B

Figure 1.3.10—*Solid floors help keep the propagation environment clean and allow the use of handling equipment* (A). *Other structures feature traffic paths down the center aisle* (B).



A

Figure 1.3.11—*The primary frame supports must be secured with concrete pier footings* (A), *which can be connected with a curtain wall around the perimeter of the structure* (B).

B

Operational considerations. Concrete floors are advantageous because they are strong, easy to clean, and light in color. If forklifts or other light vehicles will be used in the structure, then the concrete must be thick enough to support them safely-at least 10 cm (4 in). Asphalt is approximately 25% less expensive, but its dark color absorbs sunlight. This leads to overheating in hot climates and also causes the floor to become soft, which can limit vehicle access. Hardtopped traffic aisles that run between the benches are sometimes used, with the areas between the aisles covered with weed barrier fabric and large gravel.

1.3.3.4 Framing

The function of the frame is to provide support for the covering while causing minimal shading and heat loss, yet allowing for maximum ease of access and handling within the structure. The two basic types of frames are truss frame and quonset (fig. 1.3.12), and these can be further categorized by whether they have internal supports or a free span (table 1.3.3). In structures with internal supports, vertical columns carry the weight of the design loads (fig 1.3.13A), whereas free-span structures are engineered so that columns are unnecessary (fig. 1.3.13B&C). Internal columns are primarily used only for shadehouses and other low-cost structures because modern trusses can support spans of over 12 m (40 ft).

Figure 1.3.12—*The frame of propagation structures supports the covering, and the two basic types are the truss frame and the quonset (modified from Nelson 1991, Hummert 1993).*

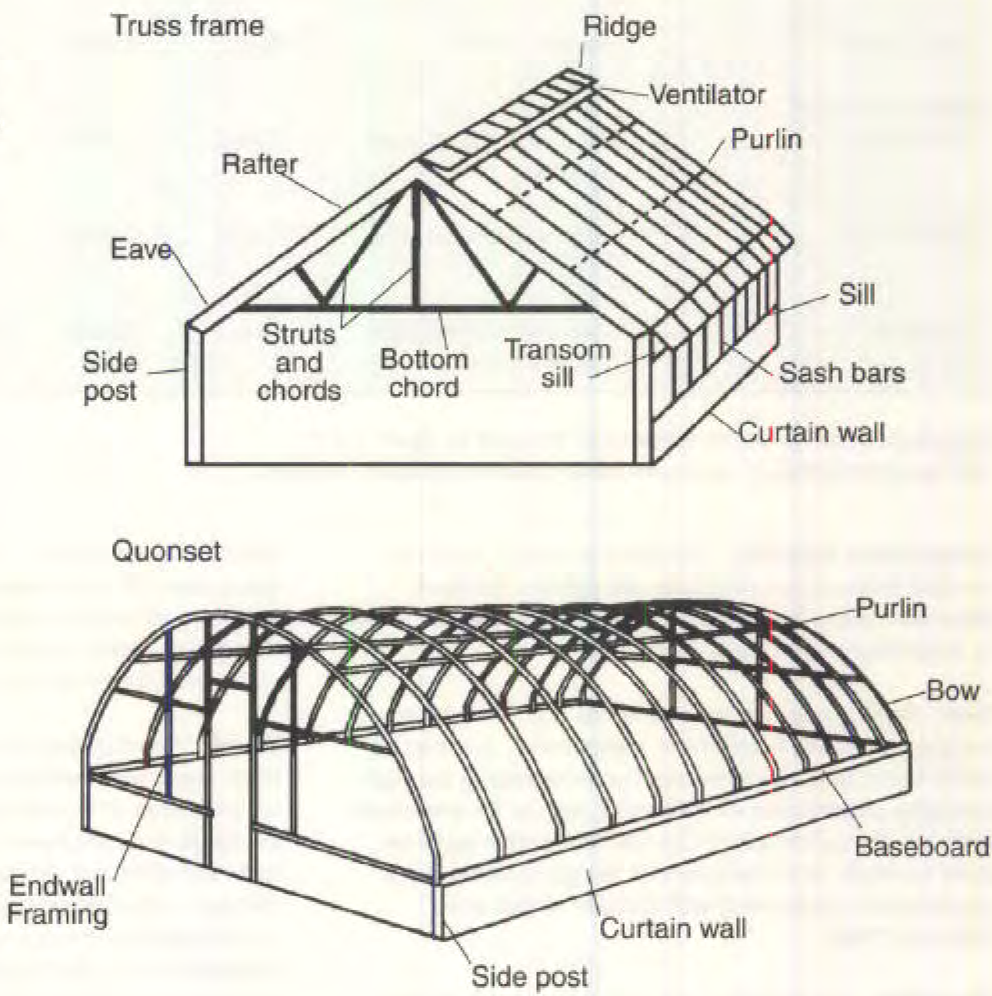


Table 1.3.3—*Characteristics of propagation structure frames and appropriate coverings*

Frame type	Framing material	Structural/operational characteristics: Support strength	Light transmission	Internal access	Suitable coverings: Rigid sheets	Plastic film
Free-span						
Gable frame with trusses	Treated wood Galvanized steel pipe	Good	Fair	Good	Yes	Yes
Gable frame with columns	Galvanized steel pipe	Good	Fair	Fair	Yes	Yes
Quonset	Galvanized steel pipe Aluminum extrusion	Fair Fair	Best Best	Good Good	Some Some	Yes Yes
Gothic arch	Treated wood laminate	Good	Good	Good	Yes	Yes
Rigid frame	Treated wood	Best	Good	Good	Yes	Yes
Gutter-connected*						
Bow frame	Galvanized steel pipe or tubing	Good	Good	Good	Yes	Yes
Gable frame	Galvanized steel pipe or tubing	Good	Good	Good	Yes	No
Sawtooth	Galvanized steel pipe Treated wood	Good	Good	Good	Yes	No

Diagrams of the structure frames can be seen in figure 1.3.9.
*All gutter-connected structures have columns between sections.

Construction materials. The three materials used for framing propagation structures are galvanized steel, aluminum alloy, and wooden timbers. Each material has its advantages and disadvantages.

Steel. Steel is popular because it has high strength-toweight properties, is relatively inexpensive, and can be easily fabricated. Because steel will corrode in the highhumidity propagation environment, it must be pretreated with hot-dip galvanizing. On-site fabrication must be done carefully to make sure that the galvanizing is not scratched or the framing will corrode at that point (Garzoli 1988).

Aluminum. Because they are not as strong, aluminum structural members are relatively larger than those of steel. Most of the aluminum used in propagation structures is extruded and must be manufactured to detailed specifications, which increases the cost. Galvanized steel bolts or screws used to secure aluminum framing will produce electrolysis and eventual corrosion (Langhans 1980), but this is not a problem with commercially available structures.

Wood. Wood frames are inexpensive and can be hand fabricated. Information on the engineering properties of various types of wood and their uses in structures is available (e.g., Midwest Plan Service 1983). Because high humidity and temperature favor decay and insect damage, redwood or cedar have traditionally been used in propagation structures, but the high cost of these materials has made them less attractive. Other types of wood must be treated with preservatives. Chemical treatments must not release vapors that could be phytotoxic to the crop or leach excessively, which could pollute runoff water. Preservatives such as chromated

Figure 1.3.13—*Simple propagation structures support the frame with regularly spaced rows of internal columns* **(A)**, *whereas sophisticated free-span structures are engineered to use trusses to increase the amount of propagation area between the columns* **(B)**. *Because they are relatively larger, wooden trusses* **(C)** *intercept more sunlight than metal ones.*

copper arsenate (CCA), ammoniacal copper arsenate (ACA), copper chromate acid, and chromated zinc chloride are very resistant to leaching and will not vaporize. Wood can be treated in three ways: pressure treatment, dipping, and painting. Pressure treatment is most effective and can increase the life of wood by 10 times (Langhans 1980). Glue-laminated arches are also sometimes used but they are relatively expensive.

Engineering considerations. Hoop or quonset frames have a lateral outward force induced at the ground level and therefore must be restrained by solid footings. The frame consists of hollow pipe bows and lateral purlins (fig. 1.3.12). Both galvanized steel and aluminum extrusion bows can be used, but the latter are considerably more expensive. Although a single layer of film plastic is sometimes used, double-layer plastic that is inflated with a small blower is much stronger and adds considerable strength to the structure. Wooden structures must be well constructed, not only to support their own weight but to withstand heavy wet snows in colder climates.

Biological considerations. Growing structures with trusses or other internal supports intercept sunlight and create internal shadows. Because they are relatively larger, wood trusses intercept more sunlight than metal ones (fig. 1.3.13C), although this can be lessened by painting them white to increase their reflectivity. Shading, which is much more of a problem during the late fall and winter when the angle of the sun is low, can be reduced by proper orientation (see section 1.3.6).

Operational considerations. Column-supported structures can cover wide spans, but the vertical columns create shadows and limit the use of large materials-handling equipment (fig. 1.3.13A). Some growing space is lost along the sides of quonset structures without high curtain walls because the angle of the roof restricts good air movement and access for workers.

1.3.3.5 Coverings

The function of the propagation structure covering is to capture sunlight while maintaining the desired temperature, humidity, and carbon dioxide levels for the species of plant being produced. The importance of the covering cannot be overemphasized because, during cold weather, it serves as the only barrier between an ideal propagation environment and disaster (Gray 1992). A wide variety of transparent materials have been used for covering propagation structures.

Construction materials. Glass has been used to cover conservatories since Greek times and was the only covering available until around 1950. In fact, the term "glazing," which is still sometimes used to refer to greenhouse coverings, is derived from the use of glass panels. During the past 40 years, a wide variety of different transparent plastics have been developed for covering propagation structures, including hard plastic panels and flexible plastic sheeting (Boodley 1981). Since 1979, plastic films have dominated the market and currently 80% of new greenhouses are constructed with double-polyethylene film (Reilly 1992). The type of structural framing must be considered when choosing a covering because some materials are more appropriate for some frames than others (table 1.3.3). Some structures, including greenhouses, typically have the same covering on the roof and sides. Shelterhouses, on the other hand, have one material on the roof and another flexible material on the sides, which can be rolled up (fig. 1.3.5A).

Plastic films or sheeting. Flexible, transparent films of polyethylene, polyester, polyvinyl fluoride, and polyvinyl chloride have been used to cover propagation structures. They are roughly the same in light transmittance, but vary in heat transmittance, durability, and cost (table 1.3.4). Although early trials used single sheets, growers quickly converted to double-layered coverings after the energy crisis of the early 1970's. Not only does the double layer provide better insulation, but the air inflation makes the covering much more resistant to wind damage. Today, double-layered plastic film is the standard of the industry.

Low-density polyethylene ("poly"). This polyethylene is the best known and most widely used plastic used to cover propagation structures in the United States. It is chemically inert, stays flexible at low temperatures, and is permeable to both oxygen and carbon dioxide. Sheets of 4- or 6-mil-thick (0.004- to 0.006-in) poly are typically, used, and a number of different brands are available in dimensions up to 80 by 150 ft. Agricultural or construction grade poly is not recommended because it has a useable life of only 9 months. Greenhouse grades of poly can last from 3 to 5 years, depending on weather conditions and application (table 1.3.4).

Table 1.3.4—*Engineering and operational considerations for different propagation structure coverings*

Covering material composition	Operational considerations: Advantages	Operational considerations: Disadvantages	Light (% PAR)	Heat (%)	Lifespan (yrs)	Cost ($/m²)	Cost ($/ft²)
Rigid panels							
Glass*	Excellent transmittance, resists weathering and abrasion	Low impact resistance, relatively expensive, heavy	88 75–80 91–94	3 <3 <3	>25 >25 >25	8.07–21.52 37.66–75.32 13.45–37.66	0.75–2.00 3.50–7.00 1.25–3.50
Fiberglass-reinforced polyester†	Low cost, strong, easy to install	Surface degrades easily, yellows with age, highly flammable	90 60–80	<3 —	10–15 7–12	9.15–13.45 53.80	0.85–1.25 5.00
Acrylic†	Excellent transmittance, resists weathering, easy to fabricate	Scratches easily, flammable	93 87	<5 <3	>20 >20	16.14–21.52 21.52–37.66	1.50–2.00 2.00–3.50
Polycarbonate†	High impact resistance, low flammability	Scratches easily, high expansion and contraction	91–94 83	<3 23	10–15 10–15	13.45–16.14 18.83–26.90	1.25–1.50 1.75–2.50
Polyvinyl chloride	Durable, low flammability, high impact strength	Low light transmittance, short lifespan, degrades under UV	84	<25	>10	10.76–13.45	1.00–1.25
Plastic films							
Polyethylene	Inexpensive, easy to install	Short life, low service temperatures, comes in many sizes	< 85	50	2–3	0.65–0.97	0.06–0.09
Weatherable polyester	Excellent transmittance, high service temperatures, durable	Limited sizes, low impact resistance, relatively expensive	85–88	30	7–10	5.38–10.76	0.50–1.00
Polyvinyl fluoride	Excellent transmittance, UV and impact resistant, very durable	Tears easily, relatively expensive, limited sizes	92	21	>10	4.30–5.38	0.40–0.50

* Glass values are for double-strength, insulated, and Solatex® panels, respectively.

† Fiberglass-reinforced polyester, acrylic, and polycarbonate values are for single-walled and double-walled panels, respectively.

Source: Aldrich and Bartok (1992), Nelson (1991).

Most propagation structures are covered with a double-layer of polyethylene sheeting inflated with a small fan, which increases its durability and can result in heat savings of 30 to 40% (fig. 1.3.14A). The outer layer should be 6 mil thick and the inner layer 4 mil thick (Boodley 1981). Single layers of poly sheeting have also been installed over fiberglass and other coverings to increase their insulation value (fig. 1.3.14B). Polyethylene film for nursery use comes in rolls and contains antioxidants and ultraviolet inhibitors to counteract the deleterious effect of sunlight and to extend its usable life. New products are continually being developed. One contains an infrared-blocking agent to stop heat loss, end another features a wetting agent to prevent condensation on the inner surface (Aldrich and Bartok 1989).

Other plastics. Although other types of plastic sheeting have been used as greenhouse coverings in research studies, none are as inexpensive or practical as polyethylene. Therefore, the following information is included for completeness only and **the following coverings are not recommended for operational use.**

Polyvinylfluoride (PVF) has the highest light transmission of all plastic films. It also has a long usable life because it is resistant to abrasion, tolerates a wide range of temperature, and is transparent to ultraviolet light (Boodley 1981). Rolls of PVF are narrow, however, and the film must be spliced together to cover most propagation structures (Nelson 1991). Polyvinylchloride (PVC) film is durable and retains heat better than polyethylene, but attracts dirt and dust, which lower its life as a covering. It also becomes brittle at low temperatures and soft on very warm days. Another drawback of PVC film is that it comes in very narrow rolls. Although more common in Japan and Scandinavia, ethylene vinyl acetate copolymers (EVA) films are not used in the United States because of their expense (Boodley 1981).

Rigid sheets. In addition to traditional glass, several types of rigid plastic sheets are used to cover propagation structures.

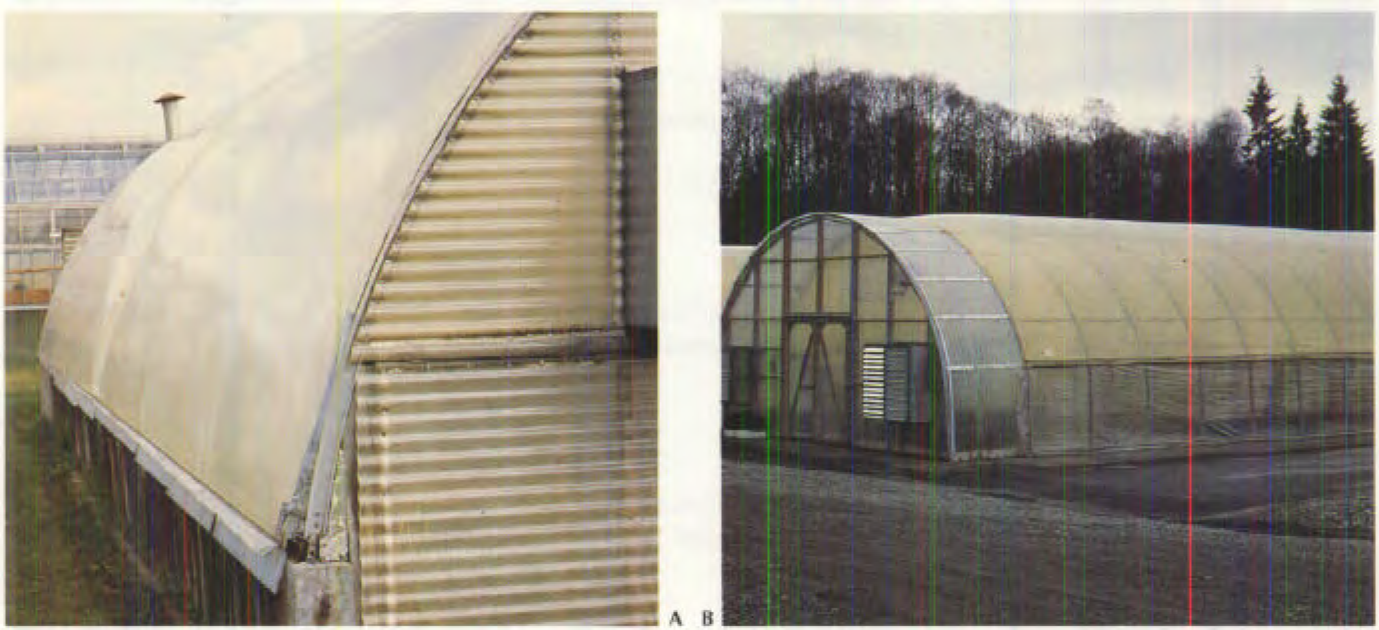


Figure 1.3.14—*Plastic ("poly") sheeting is the most inexpensive way to cover ("glaze") a propagation structure. Double-poly layers are air-inflated to provide a rigid covering* **(A)**, *or a single layer can be installed over other coverings to increase the insulation value* **(B)**.

Glass. Because of its high light transmittance and durability, glass has been a popular greenhouse covering for decades (fig. 1.3.15). Although several grades and weights of glass panels have been used for covering propagation structures, tempered glass such as Solatex® is recommended (table 1.3.4). Recent technological innovations have produced panels that are 0.9 to 1.8 m (3 to 6 ft) wide, which greatly reduces the number of supporting sash bars and caulking (Bartok 1993). Smaller panels may still be best where breakage due to hail or other causes is a problem (Boodley 1981). Glass is actually too transparent for some crops and so stippled panels that produce a more diffuse light are available. Double-layer Thermopane® glass is more expensive but reduces heat loss. Although sash bars were traditionally made of wood, extruded aluminum supports are becoming more popular because they require less maintenance and reflect more light.

Structured plastic panels. Fiberglass-reinforced polyester was the first type of rigid plastic panel used to cover propagation structures (table 1.3.4). Corrugated fiberglass panels contain strands of fiberglass, which scatter the light entering the structure, producing a diffuse light that is ideal for plant growth. Although inexpensive, the surface of fiberglass panels weathers relatively easily, and the ultraviolet rays in sunlight cause it to yellow with age (fig. 1.3.16A). Treating the surface of fiberglass panels with polyvinyl fluoride (Tedlar®) or sprayed-on coatings retards yellowing. One of the biggest drawbacks to fiberglass panels is that they are highly flammable and, although fire retardant brands are available, they are not suitable for nursery use (Nelson 1991). Although they still can be seen on many older structures, fiberglass panels are decreasing in popularity and are being replaced by newer types of corrugated polycarbonate sheets (fig. 1.3.16B).

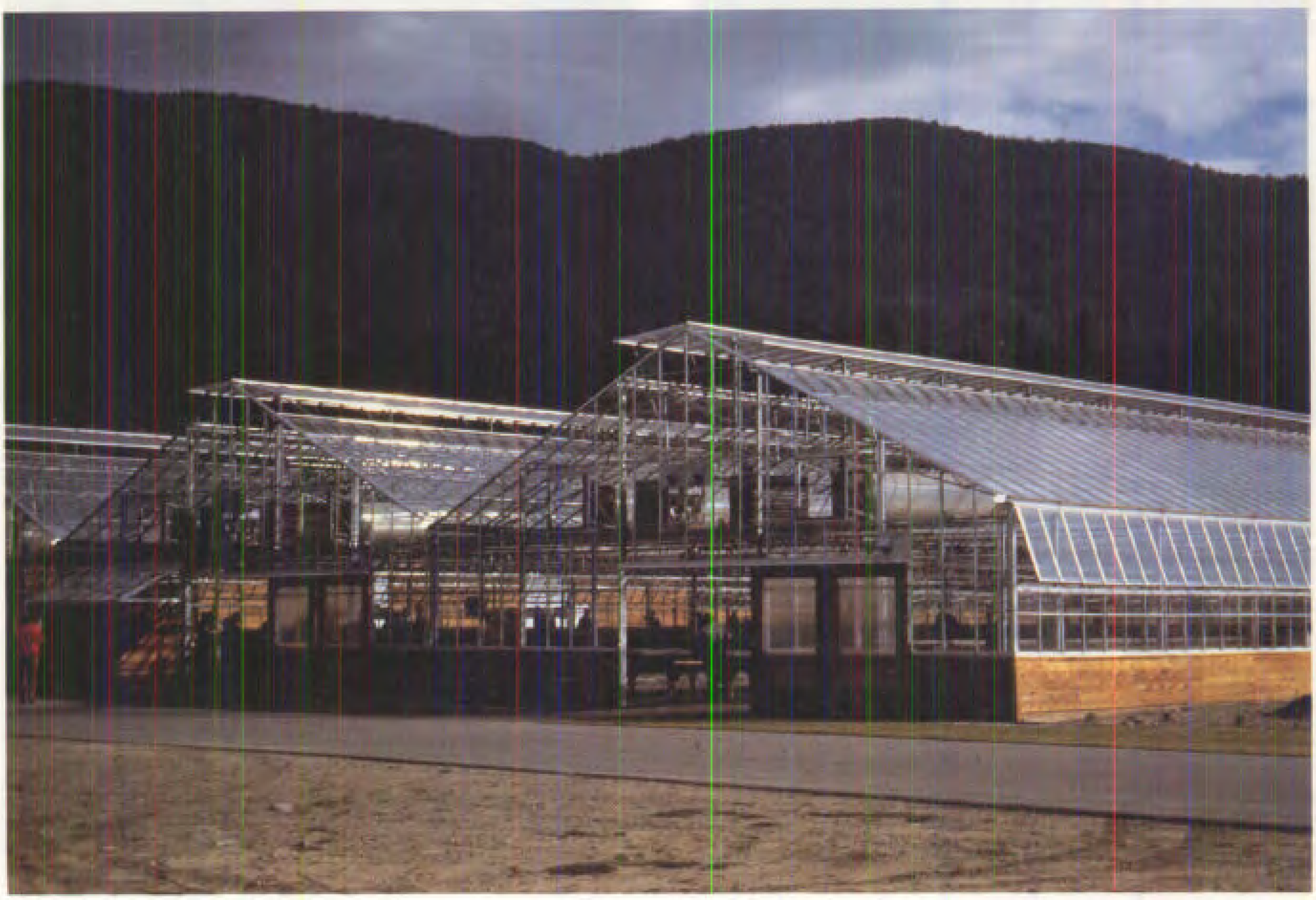


Figure 1.3.15—*Glass greenhouses have been traditionally popular because of their long life, and new production technology makes glass coverings even more practical.*

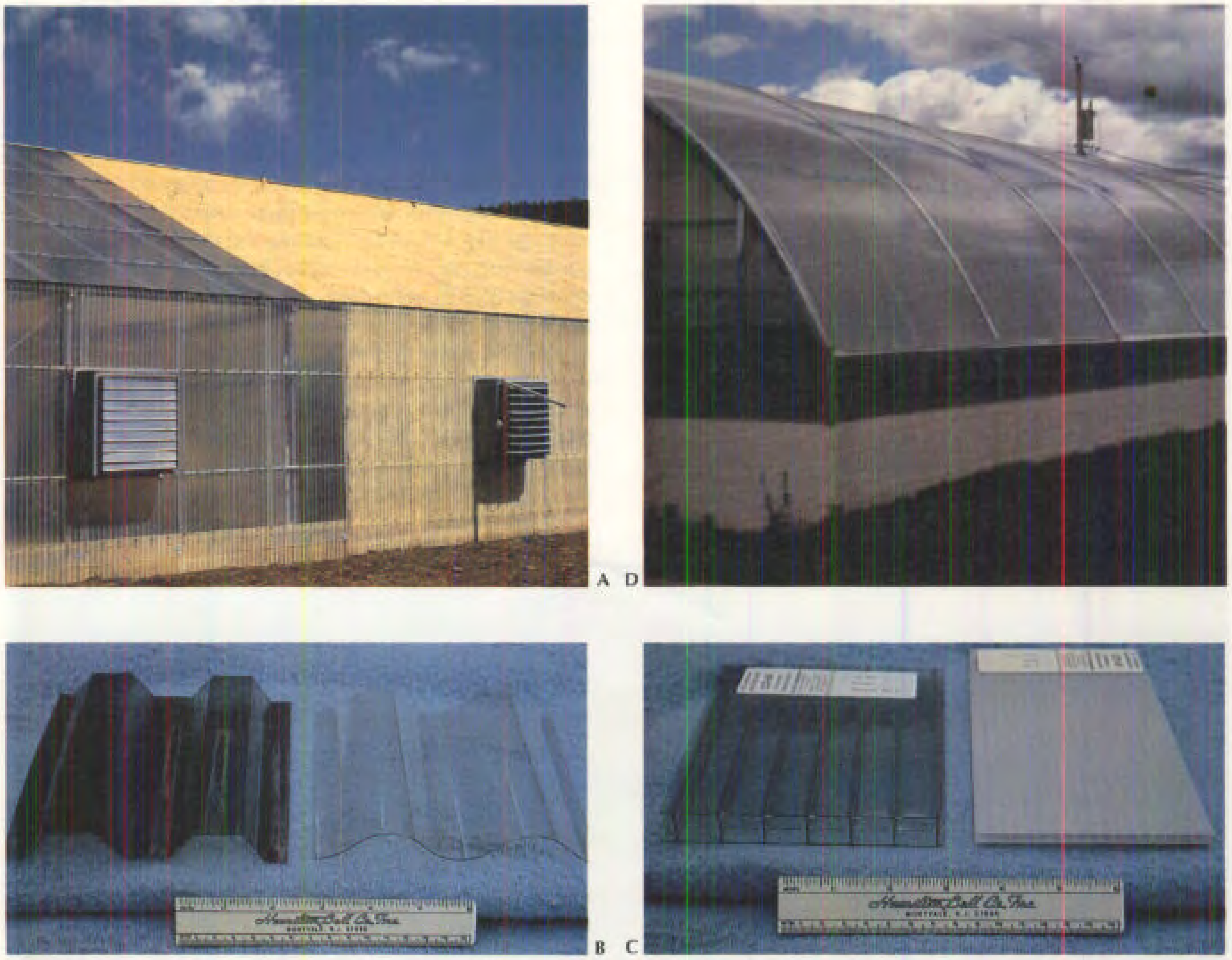


Figure 1.3.16—*One of the first types of rigid plastic panels was fiberglass-reinforced polyester but it tended to yellow with age* **(A)**. *Several new structured plastic panels are now available in single-layer corrugated* **(B)** *or double-layer flat sheets* **(C)**, *which are flexible enough to cover quonset structures* **(D)**. *(Samples in B&C courtsey of Co-Ex Coprporation, Rocky Hill, CT.)*

Structured panels of acrylic and polycarbonate have only been available for the last 10 to 15 years, and although relatively expensive, they are rapidly increasing in popularity (Nelson 1991). Acrylic and polycarbonate panels are lightweight and durable, and they have excellent light transmission properties (table 1.3.4). Structured plastic panels are available in both single layer corrugated sheets (fig. 1.3.1613) and chambered flat panels, which can be double or triple layered (fig. 1.3.16C). Recently, double-layer acrylic panels with increased insulation ratings have entered the market. Although initially used for covering the end walls on film plastic greenhouses, structured plastic panels are flexible enough to fully cover quonset propagation structures (fig. 1.3.16D). Like fiberglass, acrylic panels are flammable but polycarbonate panels are not (Boodley 1981).

Rigid polyvinyl chloride panels were introduced as an inexpensive substitute for fiberglass, but operational use showed that their life expectancy was only 2 to 5 years (table 1.3.4). They are not commonly used today, because like their film plastic counterparts, they discolored under ultraviolet light and became brittle (Nelson 1991).

Shade coverings. Many semicontrolled propagation structures feature coverings producing varying amounts of shade, such as wooden lath or shadecloth. Shadehouses can be constructed of narrow slats nailed individually on the frame but snowfence, a type of fencing made of lath connected with wire, is commonly used (fig. 1.3.17A). Commercial snowfence provides 55% shade and is constructed of wood that has been pressure-treated to resist decay. It is available in 1.2- or 1.8-m (4- or 6-ft) widths and should be installed so that the individual pickets are oriented north to south to adjust for movement of the sun (Hummert 1993). Shadehouses with lath on the sides are also effective in providing wind protection and excluding large animals.

Several types of shadecloth are commercially available and provide various percentages of shade (30 to 95%) depending on the closeness of the weave, the thickness, and the color of the fabric (fig. 1.3.17B&C). For forest and conservation species, 55% shadecloth is normally used, but 30% sheeting is popular in more cloudy climates. Installation and useable life of shadecloths depend on the type of material. Shadecloth only comes in standard lengths and widths and so has to be custom-fabricated to fit many structures. Shadecloth is available in several fabrics, each having different properties. Polypropylene is strong and durable and will shrink only 1 %. Saran shrinks about 3%, however, which means that it should be installed with a slight sag. Polyester is fire and mildew resistant. Lock-stitched polyethylene will not run or fray when cut or punctured and, being resistant to ultraviolet light, has a long operational life (Bartok 1990b).

Engineering considerations. A growing structure must be designed so that the covering is suitable for the frame. Although most frame types can be covered with rigid plastic sheets, plastic films are not recommended for structures with internal support columns (table 1.3.3). The covering must also be able to support the structural loads, especially in areas with significant winter snow accumulation (fig. 1.3.17D).

Rigid sheets require relatively more fasteners than plastic films and so the panels should be as large as possible. Plastic films must be tightly secured to the frame to avoid wind damage and, when double layers are inflated, to minimize air leakage. Wooden furring strips are an inexpensive option and can even be used to fasten double layers of plastic (fig. 1.3.18A). Several different fastening systems are commercially available. One features a quick snap-locking feature (fig. 1.3.1813) making replacement quick and easy, which is important when damaged films need to be replaced during cold or windy weather. Because the dimensions of plastic film change with temperature, sheets can be pulled taut when installed in cold weather, but 5 to 8 cm (2 to 3 in) of slack must be left when temperatures are near 27 °C (80 °F) to allow room for contraction.

Double-layer plastic **(double-poly)** sheets that are air inflated have many positive features compared to single-sheet applications. Poly tubes are now available so that the double covering can be applied in one step. In addition to their superior heat insulation value, double-poly coverings are considerably stronger than single layers of the same material. They also extend the life of the plastic because the tighter fit reduces wind abrasion against the frame. The thickness of the outer layer should be 0.152 mm (6 mils) to offer more resistance to mechanical damage, while the inside sheet can be only 0.102 mm (4 mils) thick. The ideal inflation height should be 1.25 to 10 cm (0.5 to 4 in) because internal air currents reduce the insulation value at greater heights (Nelson 1991). The layers are inflated with a simple squirrel-cage blower (fig. 1.3.18C) that can maintain 5.1 to 7.6 mm (0.2 to 0.3 in) of water static pressure; higher pressures of 13 mm (0.5 in) are necessary under high wind conditions. For a greenhouse measuring 8 x 29 m (26 x 96 ft), a blower (1 amp, 155 W) that can deliver 5.7 to 11.3 m^3/min (200 to 400 ft^3/min) of air at 1 mm (0.5 in) of static water pressure is sufficient. The inflation pressure is controlled by adjusting the size of the intake on the blower. Manometers are used to monitor inflation pressure and can be homemade or purchased commercially (Bartok 1990a).

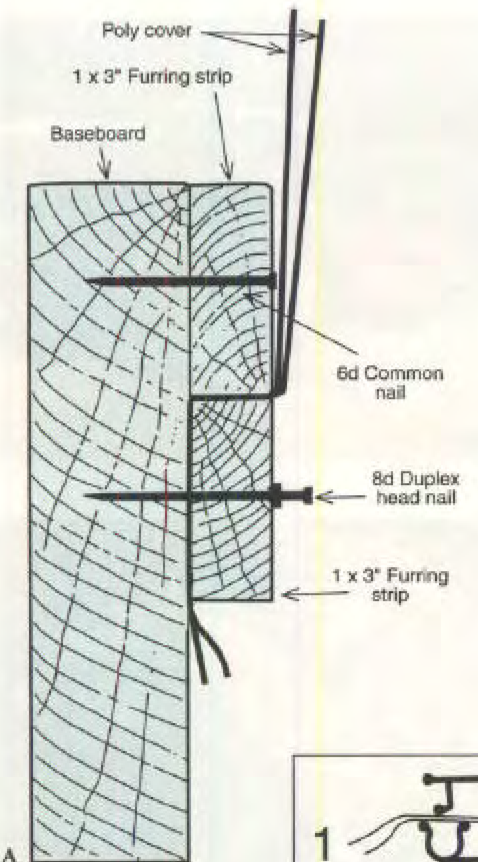
A

C

B

D

Figure 1.3.17—*Shadehouses are covered with lath* **(A)** *or shadecloth* **(B)**, *which is now available in colors* **(C)**. *Any type of growing structure must be designed to support structural loads, especially in snowy climates* **(D)**.



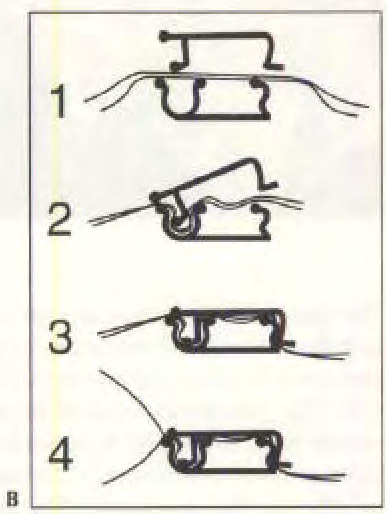


Figure 1.3.18—*Double layers of plastic sheeting can be attached to the framing with wooden furring strips* **(A)** *or specially designed fasteners* **(B)**, *and a fan* **(C)** *maintains the positive air pressure to keep them inflated. (A, modified from Bartok 1993; B, from Hummert 1993.)*

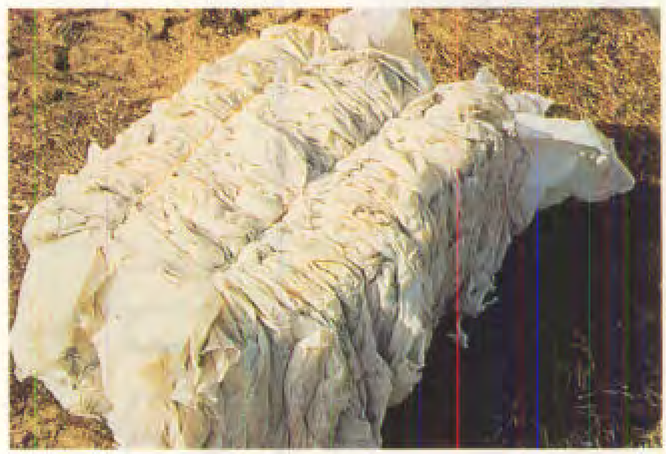
Biological considerations. The main biological consideration is light transmission, and all coverings allow a high percentage of photosynthetically active solar radiation to penetrate (table 1.3.4). These maximum light values may need to be moderated for some crops or at some stages during the growing season. Light quality is also affected by the type of covering, and some new colored plastics can affect the ratio of various wavelengths reaching the crop. Different colors of shadecloth are also available (fig. 1.3.17C).

Operational considerations. At higher latitudes and elevations, heat conservation becomes a major characteristic when selecting a covering. The heat transmittance values vary considerably for the major types of coverings (table 1.3.4), and nurseries in cold climates generally choose multiple layered coverings that provide the best insulation. Air-inflated double-poly structures can save about one-third of the heating cost (Bartok 1990a). Maintenance and replacement of coverings are also important factors. Rigid panels can last as long as 25 years or more, compared to only a few years for plastic films (table 1.3.4). Replacing plastic films can be impossible in windy conditions, but with good weather and experienced workers, most nurseries have mastered the process so that it is routine. Some nurseries use specially constructed scaffolds to make changing the covering both easier and safer (fig. 1.3.19A). Disposing of used poly coverings used to be a drawback, but recycling is becoming more of an option (Bartok 1992a). After removal, the used plastic sheets can be mechanically gathered into either rolls or bales (fig. 1.3.19B&C) that can be processed by plastic recyclers.

A

Figure 1.3.19—*Some nurseries use special scaffolds to make changing coverings easier and safer* **(A)** *and used plastic sheeting can now be recycled if it is rolled or baled* **(B & C)** *(B & C, from Bartok 1993.)*

B



C

All coverings collect dust and dirt over time and loose their light transmission capabilities, and so periodic: cleaning is necessary. For example, without cleaning, the light transmission of poly films was found to decrease 4 to 7% over a period of 18 months (Giacomelli and Roberts 1993). One of the drawbacks of double-poly houses is that they are so airtight that they restrict air exchange and are more difficult to cool and dehumidify. Condensation on the inside of the cover causes problems because it reduces light transmission and drips onto the crop. New plastic films with "anti-fog" properties can reduce this problem, however.

The life of shadecloth is several years if it is properly installed; it must be stretched tight and secured to prevent whipping and tearing in high winds (fig. 1.3.17B). Shadecloth should be furled or taken down in winter snow areas and is also more prone to wind damage when the weather is cold. Shadehouses made of lath can also be damaged by heavy snowfall (fig. 1.3.17D). In areas with heavy snowfalls-30 cm or 12 in of wet snow-lath on the roof should be in rolls (such as snowfencing) so that it can be rolled up and removed in winter. Even if lath on the roof of a shadehouse is removed, the shadehouse walls should be left up to protect the seedlings from high winds.

1.3.4 Designing a Propagation Environment

The next step in container nursery design is to determine how many different propagation environments are needed and how large each should be. If the seedlings are to be grown in an open compound, then the calculations are relatively easy. However, when structures must be built, there are many biological, economic, and political considerations that affect both external and internal design.

1.3.4.1 Biological considerations

Crop size and type. Based on the identified demand for seedlings or market survey, the nursery developer should have a good idea of which species and how many seedlings to grow per crop. The number of seedlings will define the total size of growing area that is required, and the biological requirements of the different species will determine what types of propagation environments will be needed. However, nursery developers should recognize that it may become necessary to increase production in the future or grow additional species that were not initially considered. Therefore, it is important to retain enough flexibility during nursery development to be able to respond to future business opportunities. It is possible to design a container nursery without specific production information, but persons entering the market on a speculative basis must decide on some seedling production estimates and crop species for planning purposes.

Need for different environments. If the desired crop can be grown on the same schedule and in a relatively similar environment, then large propagation structures are warranted (fig. 1.3.20A). Large structures are inherently less expensive to build and more cost effective to operate per unit area. Their irrigation and fertilization systems are simpler to design, and they cost less to heat because they have less perimeter area for heat loss. These design features have cultural as well as economic implications, because seedling growth is often poorer around the edges of the growing area, the "edge effect" Large propagation structures can be divided into separate environments with movable curtains or sliding doors (fig. 1.3.20B), although the environmental control systems must be designed accordingly.

A number of smaller propagation environments can provide the grower with some distinct advantages (fig. 1.3.20C). Smaller structures can be used to generate a range of environments to accommodate the requirements of a variety of species and also allow different growing schedules during the year. If the crop consists of species with radically different requirements, then the developer must divide them into biologically compatible groups. The number of these groups will determine the minimum number of propagation environments that will be needed, unless they can be grown at different times of the year in a multiple-cropping system. Having a number of smaller environments also gives the grower mare flexibility in propagating, handling, and delivering. From a nursery development standpoint, small environments are advantageous because they can be added sequentially over time without disrupting ongoing production. The risk of total crop failure is less because fewer seedlings will be lost if one structure fails, and the duplication of equipment provides backup in case of emergency.

Length of crop rotation. The crop rotation is the amount of time that it takes to propagate a crop within a given environment and grow it to the size and quality when seedlings can be either shipped or transplanted to another location (fig. 1.3.20D). Although there are variations with crop species, stock types, and local climate, nursery developers must calculate an average rotation for planning purposes. The average duration of each crop rotation and the number of rotations per year will determine the number and size of propagation environments that should be developed. Many forest and conservation species can be grown to shippable size in as little as 3 to 4 months under ideal conditions. The duration of typical crop rotations can be obtained from other nurseries in the local area, but often estimates must be made based on similar species. Typical crop rotations are discussed in volume six of this series and can be used for general planning purposes, although growth rates can vary significantly from nursery to nursery.

Multiple crops per season. Some nurseries are able to grow more than one crop per year in fully controlled greenhouses (fig. 1.3.20D). Other growers start their crops in a greenhouse or germination chamber and then move them to other growing structures, such as shadehouses or tunnels, or out into open compounds. Although most efficient from a spatial standpoint, multiple cropping requires considerable experience and skill. In some areas, the trend has been away from multiple greenhouse crops and towards nursery systems employing simpler propagation structures and cultural regimes. Whether multiple cropping is feasible depends on the inherent growth rate of the species and their desired size. The experience of other local growers is probably the best guide, although this can vary considerably with cultural and economic factors.

A

Figure 1.3.20—*A variety of different plants can be grown in the same area if their biological requirements are similar* **(A)***; if not, then the structure must be divided into separate environments* **(B)** *or smaller structures must be used* **(C)***. Multiple crops can be grown with careful planning and by moving plants between different propagation environments* **(D)***.*

B

C

Pest exclusion. One of the most attractive features of container nurseries is that they offer the grower the ability to effectively eliminate most pests from the propagation environment. The ability to exclude pests depends on the type of propagation environment. Even in open growing compounds, soil-related pests can be eliminated because the seedlings are grown in containers filled with artificial growing media. Reusable containers are sterilized between crops and the components used in artificial media are also sterile. A couple of new container design features are also helping reduce

Year One												
	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Crop #1	Greenhouse							Shadehouse				
Crop #2								Greenhouse				
Crop #3								Greenhouse				

Year Two												
	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Crop #1	Shadehouse			Shipping								
Crop #2		Shadehouse										
Crop #3		Shadehouse						Bareroot transplanting				

Year Three												
	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Crop #1												
Crop #2	Shadehouse			Shipping								
Crop #3												

D

pest problems. Styrofoam® block containers called Copperblocks® have cells that have been coated with copper carbonate. Although primarily used to chemically root prune seedlings, the copper compound is also an effective fungicide and keeps root pathogens from developing in the cells. The Ventblock® is another type of Styrofoam container that is designed with ventilation holes between the cells to encourage air movement and reduce humidity within the seedling canopy (fig. 1.3.21). Gray mold, caused by the fungus *Botrytis cinerea* (Pers.:Fr.), thrives in high-humidity environments, and operational trials with Ventblocks have shown them to significantly reduce gray mold infection of Douglas-fir seedlings (Peterson and Sutherland 1990).

Obviously, the opportunities for pest exclusion are much greater in enclosed propagation environments. In climates where ambient conditions are ideal for plant growth, one of the main purposes for building a propagation structure is to exclude nursery pests. Research has shown that 90% of the insects that infest container nursery crops enter propagation structures through vents or open doors. Thus, growers are beginning to install insect screens as one part of an integrated pest management (IPM) program. Screens of both stainless steel and woven synthetic fabric have been used to exclude insect pests, including thrips and whiteflies. Covering vents with fine-mesh screens significantly reduces airflow, however, which can lead to high temperature problems in naturally ventilated structures. Therefore, growers applying exclusion screens to existing structures will have to make adjustments to reduce solar heating, such as converting to higher static pressure fans or using shadecloth (Neat 1992).

Figure 1.3.21—*Many forest and conservation nurseries grow their crops in multi-cavity containers called blocks or trays.*

Special plastic film coverings can also help control fungal diseases. For example, researchers in Israel have developed a polyethylene film that screens out the ultraviolet wavelength of sunlight that is necessary for the germination of Botrytis spores (Lieberth 1991). In another trial, vinyl plastic film with infrared inhibitors reduced the relative humidity inside the greenhouse and resulted in better plant growth and lower incidence of gray mold and other fungal diseases (Vakalounakis 1992).
These new pest exclusion practices, as part of an IPM program, will reduce pesticide use and the potential of polluting surface water and groundwater.

1.3.4.2 Economic and political considerations

Construction costs. Construction costs vary considerably between different types of structures and are typically quoted per area of covered production space (table 1.3.5). Some growers prefer to erect their own structures whereas other, less-experienced nursery developers use the expertise of commercial contractors. Be sure to supply contractors with the same detailed set of specifications and conditions so that the bids will be comprehensive and comparable.

Make certain that you have included everything in your cost estimate. Many novice developers consider only the basic structure and forget about all the other associated costs of developing an operational nursery. For example, the price of a standard double-poly greenhouse may be quoted as $16.14/mz ($1.50/ftZ). However, this price does not include labor, environmental control equipment, electrical wiring, and plumbing which increase the cost to $58 to 84/ml ($5.40 to 7.86/ ft'). Finally, add the cost of purchasing and grading the land, constructing service buildings, drives and parking areas, and the cost can increase another 30 to 45% (Nelson 1901).

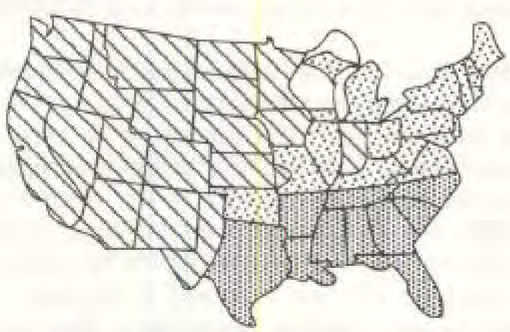
An economic analysis should also consider other associated operating expenses when comparing types of propagation structures. For example, difficulty in obtaining materials, a shortage of reliable labor, or just the inconvenience of maintaining and recovering a structure may make a rigid plastic covering more practical than plastic sheeting in the long run. Fuel savings are another major consideration in cold climates; heating costs can be as much as 30 to 40% less in a double-poly structure than in a structure with single glass panels (Nelson 1991). These types of specific costs can be difficult to obtain, however, and so new nursery developers will want to contact other local nurseries for estimates.

Local building codes and taxation policies. The selection of the best nursery design can also be affected by local building codes, taxation policies, and land use laws. Greenhouses and other propagation structures are subject to local building codes, which cover every aspect of design and construction to protect public safety and the environment. The building codes of most states have been adapted from model codes published by three different organizations (fig. 1.3.22). The Basic Building Code (BOCA) is used in the Northeast, the Uniform Building Code (ICBO) in the West, and the Standard Building Code (SBCCI) in the South. Local municipalities may adopt any of these codes or even modify them to suit local needs, and so nursery developers are urged to consult local authorities during the nursery design phase to make certain that they are aware of local requirements (Aldrich 1993).

Table 1.3.5—*Construction costs for different types of propagation structures*

Framing and foundation	Type of covering	Cost/m² (dollars)	Cost/ft² (dollars)
Greenhouses			
Galvanized steel truss frame with concrete foundation and floor	Tempered glass panels	118.36–153.33	11.00–14.25
Galvanized steel ridge and furrow frame with concrete piers and floor	Double-layer polyethylene	53.80– 83.39	5.00– 7.75
Galvanized steel pipe arch frame with concrete piers and floor	Polycarbonate sheets	59.18– 85.54	5.50– 7.95
Galvanized steel pipe arch frame with concrete piers and floor	Double-layer polyethylene	30.13– 45.73	2.80– 4.25
Shelterhouses			
Galvanized steel gable frame with concrete piers and asphalt floor	Fiberglass roof with insulated fabric sides	37.73– 75.32	3.50– 7.00
Shadehouses			
Galvanized steel quonset with concrete piers and gravel floor	Double-layer polyethylene with shadecloth sides	19.37– 26.90	1.80– 2.50
Site preparation		8.07– 10.76	0.75– 1.00

Source: Aldrich and Bartok (1992), Hummert (1993), Hahn (1992).



Basic Building Code (BOCA)
Building Officials & Code Administrators International, Inc.
Homewood, IL

Uniform Building Code (ICBO)
International Conference of Building Officials, Inc.
Whittier, CA

Standard Building Code (SBCCI)
Southern Building Code Congress International, Inc.
Birmingham, AL

Figure 1.3.22—*Nursery developers must be aware of local building codes, which generally are based on 3 regional codes (modified from Cyro Canada 1991).*

The method of appraising land and propagation structures can differ significantly between States and even within counties or cities. Some appraisal systems consider propagation structures covered with glass or structural plastic panels to be permanent structures, whereas those covered with polyethylene sheeting are considered to be temporary. In other locations, some types of temporary propagation structures are classed as "Agricultural Personal Property" and so are tax-exempt. So nursery developers should consult other growers in the area and tax consultants to determine local codes for appraising land and structures. Counties or other government taxing agencies maintain a current listing of property assessments and tax rates (Bartok 1991 b). The difference in annual taxes could be significant enough to favor one type of propagation structure over another.

Water pollution. Water quality is one of the most important ecopolitical issues at the present time, and new legislation is being enacted to regulate the chemical discharge from all agricultural activities. Chemical fertilizers and pesticides have contributed greatly to the increased seedling growth that can be realized in container nurseries, but they can also pollute surface and groundwater if they are allowed to leave the propagation environment. The principal agricultural pollutants of concern are pesticides and their degradates, as well as nitrates and phosphates. Pesticides and nitrates that have leached into the groundwater can pose a risk to human health in relatively low concentrations. Runoff of nitrates and phosphates leads to eutrophication of surface water bodies.

Container nurseries can contribute to point-source pollution when fertilizers or pesticides are injected into the irrigation system and then enter the water discharge leaving the nursery. Nurseries can also be accused of non-point-source pollution if water quality tests show groundwater to be contaminated with nitrates or pesticides (Landis and others 1992).

Water pollution restrictions will only become more stringent with time. Container nursery developers should incorporate water control features in their nursery design and layout so that they will have a no-discharge facility (fig. 1.3.23). The first design feature should be impermeable flooring in all propagation environments. In previous years, many container nurseries were designed with gravel floors so that irrigation runoff could just soak into the ground. Even those propagation structures with solid floors were graded so that runoff drained either into an adjacent ditch or pond. The next feature should be a nursery layout designed so that all irrigation runoff is collected into a pond where it can be either recycled or treated. Several ornamental nurseries in California and Oregon have pioneered irrigation recycling for container nurseries (Skimina 1992). Operational trials at the University of Idaho Forest Research Nursery have shown that water discharge can be effectively collected and treated on the nursery site with a constructed wetland (Dumroese and others 1992). Several closed-loop irrigation systems are also being developed that completely eliminate discharge from the propagation environment.

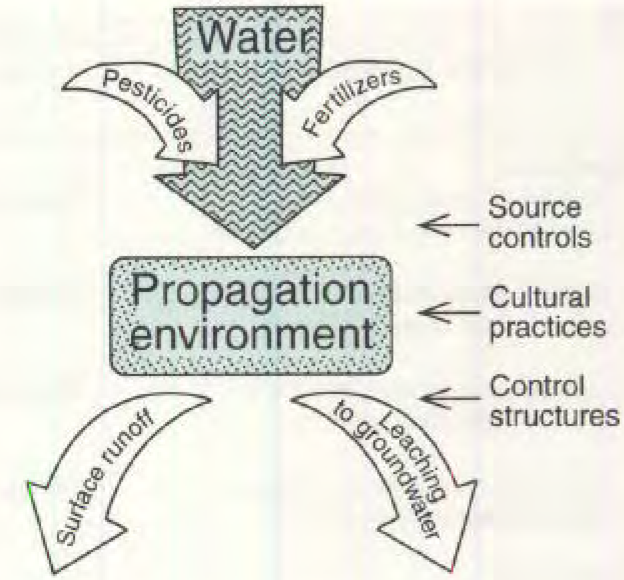


***Figure 1.3.23**—Controlling runoff of irrigation water to stop potential pollution of surface or groundwater is a relatively recent nursery design concern that will become even more important with time (Landis and others 1992).*

Many of these water pollution control features are relatively inexpensive when they are incorporated into the initial nursery design and layout, but can be significantly more costly if an existing facility must be retrofitted.

Reliability. A nursery that has been poorly designed can be disastrous, and some container nurseries have failed because the wrong type of facility was constructed (McDonald 1982). Even in a fully controlled propagation structure, equipment failure or severe weather can cause rapid, disastrous environmental changes. If the facility has not been properly matched to the environment, the grower will have to struggle to maintain suitable growing conditions. These design flaws will be reflected in poor-quality seedlings and higher-than-normal nursery operating costs.

Developers should visit other nurseries in their area to learn what types of facilities have been successful, and ask them what they would do differently if they could built their nurseries over again. A decision matrix approach can also be used to evaluate the many different factors that must be considered (see section 1.2.4).

1.3.4.3 Efficient spatial layout

Once the decision on the types and sizes of propagation environments has been made, then the internal space can be designed. **Production space** is defined as that area within the propagation environment that is covered with seedlings. Other areas such as aisles do not directly contribute to seedling production. Seedling costs are a direct reflection of **production space efficiency,** and so developers should carefully design the layout of their nursery facilities. Any space within the propagation environment that is not producing seedlings becomes part of the spatial overhead and increases unit costs.

Container dimensions. The most critical factor affecting production space efficiency is container size. A large variety of types and sizes of containers have been used to produce forest and conservation species and each has its advantages and disadvantages. (The criteria for selecting a container are discussed in detail in volume two of this series.)

The most important characteristic for layout design is the amount of production space that each container will occupy. Most containers used in forest and conservation nurseries are aggregates called blocks or trays (fig. 1.3.21), and their lengths and widths can be used to calculate surface area per unit. When growing different species or stock types, several different container sizes may be needed. If this is the case, some types of container such as Styrofoam blocks have the same outside dimensions for a range of different cell capacities (table 1.3.6). This allows growers to interchange container sizes without changing the layout of the production space and will also produce the best overall space efficiencies.

Type of container support and handling system. The decision to grow seedlings on benches, pallets, or other supports also affects the space efficiency within the propagation environment. One traditional container support system consists of permanent benches or tables with regularly spaced aisles to allow access to all parts of the production area. There are two standard configurations for permanent benches: longitudinal and peninsular (fig. 1.3.24). Although they are more space efficient, peninsular benches may be more restrictive for conveyors or other motorized handling systems. Movable or rolling benches are a relatively recent innovation that can greatly increase production space efficiency by 25% over fixed bench systems and can approach 90% overall space utilization (Langhans 1980).

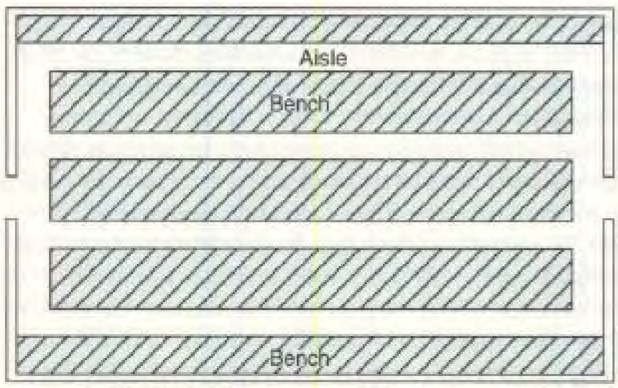
The type of container handling system will affect growing space estimates because it determines the number and dimensions of aisles and corridors within the propagation structure. For example, if a forklift and pallet system will be used, aisles and doors must be wide enough to accommodate them and provide adequate turning radius. (Specific information on container support and handling systems is provided in section 1.4.2 of this volume.)

Open growing compounds. Because they have no external structural limits, open growing compounds are the simplest to design. Open compounds are typically divided into sections or bays, the dimensions of which are determined by the coverage of the irrigation system and the need for worker's access. If fork lifts or other equipment will be used within the compounds, then additional aisle space must also be allowed (fig. 1.3.25).

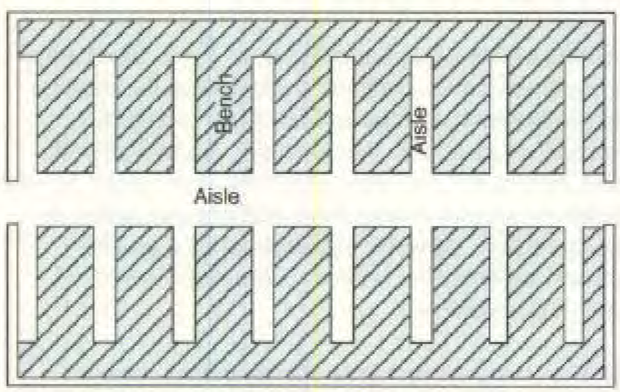
Table 1.3.6—*Containers that have the same outside dimensions for different cell capacities offer several advantages for crop planning and production space efficiency*

Styrofoam block containers				No. of cells per container	Total cells in greenhouse* (880 blocks)
Cell capacity		Outside dimensions			
cm^3	in^3	cm	inches		
41	2.5	36 x 60	14 x 24	240	211,200
66	4.0	36 x 60	14 x 24	160	140,800
106	6.5	36 x 60	14 x 24	112	98,560
336	20.5	36 x 60	14 x 24	45	39,600

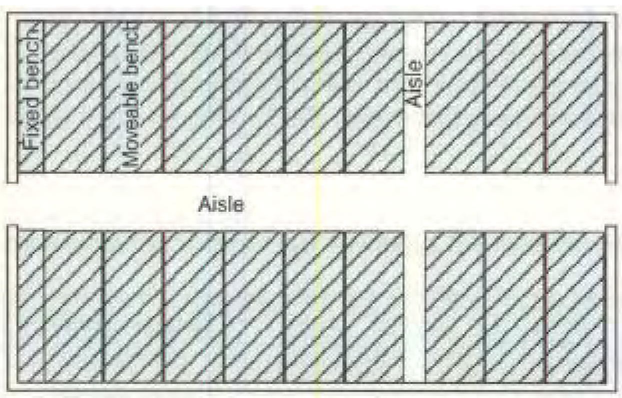
*See figure 1.3.26



Longitudinal bench layout – 59% space efficiency



Peninsula bench layout – 69% space efficiency



Movable bench layout – 81% space efficiency

Figure 1.3.24—*Space within a propagation environment is valuable, and so bench layout is a compromise between access and efficient utilization of the growing area. Permanent benches can be longitudinal or peninsular, and movable benches are becoming increasingly popular. (Modified from Aldrich and Bartok 1989.)*

Figure 1.3.25—*Seedlings in open growing compounds are grown on pallets or temporary benches.*

Propagation structures. Some special considerations are necessary in fully controlled greenhouses with heating and cooling systems. The main objective of any layout is to achieve maximum space utilization while allowing for reasonable access for workers and keeping seedlings a safe distance from heating and cooling equipment. Usually 30 to 60 cm (1 to 2 ft) of space between the greenhouse walls and the benches is provided to keep the plants away from hot or cold air flowing down the wall and to encourage good internal circulation. Areas near cooling pads and exhaust fans are often more subject to excessive drying, and so containers should be located about 1 m (3.3 ft) away.

Sample space calculations. Consider a greenhouse that is 9.3 m (30 feet) wide and 30 m (98 ft) long with heaters, fans, and cooling pads located on the end walls. The seedlings will be grown in Styrofoam block containers measuring 36 x 60 cm (14 x 24 in) and will be placed on wooden pallets, which can be handled with a pallet jack or forklift. A standard pallet measures 1.2 x 3.7 m (4 x 12 ft), and the containers could be oriented on the pallets either sideways or endways (fig. 1.3.26A). Placing them sideways will allow 3 rows of 6 blocks or 18 in all, whereas the endways orientation produces 2 rows of 10 blocks for a total of 20 per pallet—the most space-efficient option. Each pallet contains 4.44 m^2, of which the blocks occupy 4.32 m^2, for a space efficiency of 97%, which is a very good fit.

Because the greenhouse must be loaded from the ends, the pallets would have to be oriented sideways across the greenhouse (fig. 1.3.26B). This orientation would allow for a center aisle of 1 m (3.3 ft) and side aisles of

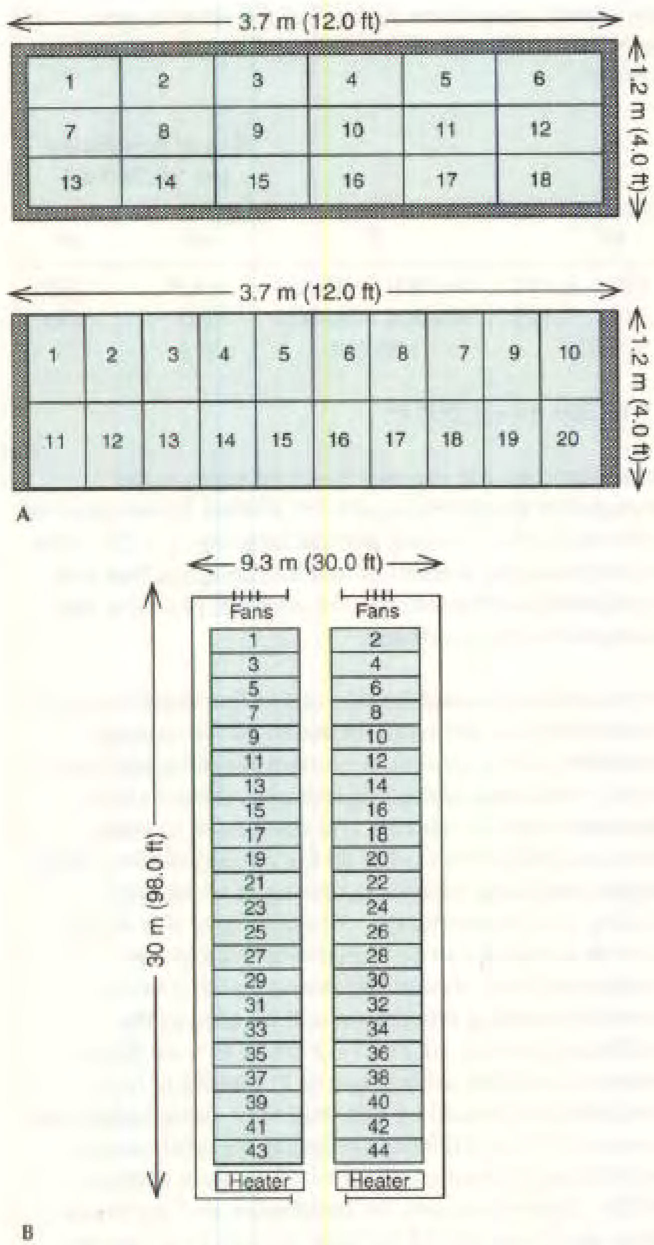


Figure 1.3.26—*Nurseries growing their crops on pallets design them to hold the maximum number of containers* **(A)**, *and the layout and orientation of the pallets in the propagation area must allow ample room for access and environmental control equipment* **(B)**.

approximately 0.5 m (1 .2 ft). Leaving 1.0 m (3.2 ft) on one end of the greenhouse for a buffer from the fans and 2.0 m (6.4 ft) on the other for the heaters results in 2 bays of 22 pallets each. Therefore, this layout would permit 44 pallets of 20 containers each or 880 containers in all, for an average space efficiency of 70%. Multiplying this by the pallet space efficiency (0.70 X 0.97) yields an overall greenhouse production space efficiency of 68%.

This same general procedure can be used for other container types and bench systems. The best spatial arrangement will be a compromise between access for workers and equipment and maximum production space. Note that more seedlings can be produced in the same greenhouse by substituting a smaller capacity container. Using the Styrofoam block with the largest cell capacity will produce 39,600 seedlings per crop, whereas using the smallest capacity container will yield 211,200 seedlings (table 1.3.6). Seedling size and quality would be significantly different between the two different types of containers, however, and some species will not tolerate higher growing densities.

1.3.4.4 The ideal nursery design

It should be obvious by now that there is not one "ideal" propagation structure for every application. The best choice will depend on many factors, and nursery developers should attempt to get as much information as possible before the final decision is made. Read the latest nursery trade journals to get the very latest technical information because that in books is usually several years old. Contact universities with horticulture or agriculture schools, horticultural supply firms, and other local growers to gain practical perspectives. Be wary of product claims or replacement guarantees, as most cover only the purchase price of the materials, not the labor for installation or the cost of a lost crop (Jozwik 1992).

In the final analysis, the container nursery developer must consider all aspects of a growing structure: engineering, biological, operational, and economic. These factors can be assigned **weights** based on relative importance and the decision-making procedure from section 1.2.4 can be used to make a final selection. Be certain to include political considerations, especially for government or company nurseries. One type of growing structure may be the most economically and biologically sound option, but it may not be the best alternative if the company or agency will not accept its appearance or the risk of crop loss associated with it.

1.3.5 Service Buildings

A nursery is more that just the propagation structure or growing compound. A successful nursery facility will also include a headhouse, storage buildings, and offices to support the work force and provide a handy source of tools, equipment, and supplies.

1.3.5.1 Headhouse

The main service building in support of a propagation house is referred to as a **headhouse,** which is an analogy to the critical function that it serves to the rest of the nursery facility. Depending on the sophistication and size of the nursery facility, the headhouse provides many services; it

- Shelters the environmental control equipment
- Provides materials and equipment storage
- Serves as a workroom during sowing or packing
- Provides a location for the office, restrooms, and lunch room
- Functions as a repair shop

Headhouses are an excellent place to locate the main electrical panel, environmental controls and computers, irrigation valves and switches, and the emergency alarm system. Because fertilizers and pesticides can be stored nearby, fertilizer injectors are often located in the headhouse. If pesticides must be stored in the headhouse, they should be stored in a separate room that is properly designed to minimize possible spills and contamination of the rest of the headhouse (see section 1.3.5.2)

Regardless of its functions, the headhouse should be located so that workers, supplies, and the crop can be moved quickly and efficiently. To maximize access and minimize shading, the headhouse is usually attached to the north side of a single unit or row of structures, or at the center of a range of structures (fig. 1.3.27). The size and internal layout of the headhouse depends on the types of activities, size, and storage requirements of each nursery. The proper size for a headhouse in a container nursery will vary considerably depending on many factors. Actually, headhouse size is not a fixed proportion of total production space, but the relative area decreases as the size of the nursery increases (Bartok 1992b):

Size of propagation structures		Size of headhouse per 10,760 m^2 of production space*	
m^2	ft^2	m^2	ft^2
930 – 3,717	10,000 – 40,000	13.9	150
3,717 – 7,435	40,000 – 80,000	9.3	100
>7,435	>80,000	7.0	75

* 10,760 m^2 = 1,000 ft^2

Some nurseries use inactive space or aisles in the propagation structures to perform all their labor-intensive activities, such as sowing and packing (fig. 1.3.28). This can decrease the amount of headhouse space that will be required but requires careful advance planning and an emphasis on cleanliness.

The headhouse should be laid out so that materials and people can flow efficiently between all the various operations with a minimum of extra handling and cross traffic. Work-area space requirements should allow adequate room for workers and equipment to work safely and efficiently during all the various nursery work periods: shipping, receiving, sowing, grading and packing, and maintenance. All equipment should be portable so that it can be stored when not in use. Headhouse floors should be concrete and, if heavy materials-handling equipment will be used in the headhouse, at least 10.2 to 15.2 cm (4 to 6 in) thick. Ceilings should be a minimum of 7.3 m (24 ft) high. Artificial lights should be fluorescent or metal halide and produce 215 lux (20 foot candles) at the work surface and 108 lux (10 foot candles) in office areas (Bartok 1992b). Doors between the headhouse and the propagation structures should be large enough to accommodate materials transport systems and equipment; Nelson (1991) recommends service doors that are 3 m wide by 2.7 m high (10 by 9 ft). A loading dock is also a good idea to facilitate unloading supplies and shipping seedlings (see section 1.3.6.2).

Several headhouse plans should be developed, and flow diagrams made for each phase of work. Then, the design that best meets all the various requirements can be selected.

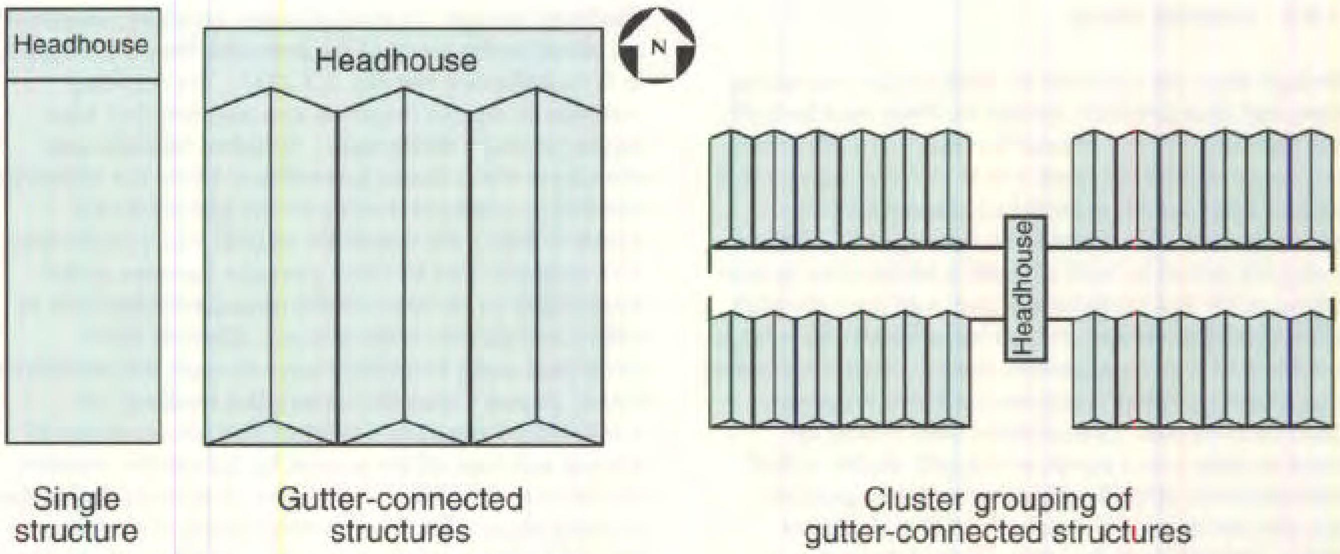


Figure 1.3.27—*The headhouse should be located close to the propagation structures but on the north side to eliminate shadows; in larger nurseries, the headhouse should be placed in a central location (modified from Boodley 1981)*

Figure 1.3.28—*Nurseries perform labor-intensive operations such as sowing and grading in the headhouse or, if conditions permit, in the aisles of the propagation structure.*

1.3.5.2 Pesticide storage

Although there are currently no Federal laws mandating where and how pesticide storage facilities must be built, others prohibit the use of land that may have previously been contaminated (Dwinell 1992). Several states in the Midwest have already established some minimum regulations and other states are following suit. Nursery developers would be well advised to incorporate certain features, such as a containment pad, into their site plan. Indoor pesticide storage and mixing areas should have a concrete pad with an approved coating. Larger nurseries using motorized spray equipment will require an enclosed outdoor pad. Containment pads should be sloped to drain into a sump, which will enable spilled pesticides to be diluted with water and then pumped back into the sprayer or into a disposal tank (Bartok 1992c). Other design specifics are contained in two excellent publications: *Designing Facilities for Pesticide and Fertilizer Containment* (Kammel and others 1991) and the *Proceedings from the National Symposium on Pesticide* and *Fertilizer Containment: Design and Management* (Midwest Plan Service 1992). Both can be purchased from the Natural Resources Management and Engineering Department at the University of Connecticut in Storrs.

1.3.5.3 Office space

Office space may seem to be a luxury when designing a container nursery, but it becomes very important once business begins. Accordingly, an office should be included in the nursery plans if at all possible. Larger nurseries design separate office buildings for clerical and managerial staff whereas, in smaller facilities, offices are usually located in the headhouse near the main entrance. Allow approximately 9.3 m^2 (100 ft^2) per person in the office area (Bartok 1992b). Because the amount of paperwork and recordkeeping increases exponentially with the size and sophistication of a nursery, office areas should be designed so that they can expand as the operation grows.

1.3.5.4 Seedling storage

Forest and conservation seedlings are a **perishable** commodity. Unlike many other products that can be held without a decrease in quality, nursery crops are living and therefore have a **limited shelf life.** Developers must give special consideration to the type and amount of storage space that will be required. There are two basic types of seedling storage: sheltered storage and refrigerated storage

Sheltered storage. In mild climates, container seedlings are stored in the propagation area until they are shipped to the outplanting site (fig. 1.3.29A). The seedlings continue to receive irrigation and are protected from drying winds by shelterbelts. At higher latitudes and elevations where freezing weather is likely, the container seedlings are placed directly on the ground for the winter to lessen the possibility of cold injury to the roots. This operation can be labor intensive because all the seedlings must be taken off the propagation benches or pallets and placed on the ground. Growers have developed some innovative ways to make this procedure easier. At one Canadian nursery, the seedlings are supported on specially-designed supports made out of fencing and kept off the ground by collapsible wooden spacers (fig. 1.3.29B). This allows air pruning during the growing season, but when winter comes, the tension on the end cables is released and the entire bay of seedlings drops to the ground. In very cold and windy locations, the bays of seedlings should be insulated around the perimeter.

Shadehouses have been used as a combination hardening and storage structure for many years. The typical shadehouse for overwinter storage had shading on both the roof and sides (fig. 1.3.17A) that protected seedlings from adverse weather, including high winds, intense rains, hail, and heavy snow. Shadehouse storage reduces seedling temperature below what it would be in direct sunlight by reducing sunlight by about 30 to 50%. This shade and the reduced wind speeds can significantly lower transpirational water losses during the growing season and also protect against the scorching caused by desiccation of foliage in cold weather when roots are cold or frozen. Fully enclosed shadehouses also protect seedlings from large animal pests such as deer and rabbits. This protection may actually increase the potential for small animal damage, however, because mice and other rodent populations can quickly increase when protected from their predators.

Shadehouse design will vary with nursery climate. In mild climates, a waterproof roof is desirable for overwinter storage of trees to prevent overwatering from rain and the leaching of nutrients from the containers. In areas that receive heavy wet snowfall, shadehouses for overwinter storage must be significantly stronger than temporary storage structures. Another option is to remove the shade covering during the winter to allow the snow to fall through and insulate the crop. Light dry snow will not damage the seedlings and actually serves as an excellent insulator.

Figure 1.3.29—*Seedlings can be stored in open growing compounds in mild climates* **(A)** *but must be supported off the ground whenever roots are actively growing* **(B)**. *Hoop houses covered with white plastic sheets are used for sheltered storage in high-latitude nurseries* **(C)** *but must have vents to allow cooling during sunny periods* **(D)**. *(C, from Regan 1993.)*

Hoop houses and tunnels are low-cost quonset structures that have been used to store forest and conservation seedlings in some high-latitude nurseries. After the growing season, the coverings are removed from the quonsets and the seedlings placed on the ground for overwinter storage. In other systems, the seedlings are grown in greenhouses and then moved to the hoop houses that are covered with white poly sheeting to relect sunlight, while providing protection from wind and precipitation (fig. 1.3.29C). Often, hoop houses are designed with side vents to allow air exchange during warm periods in the winter when inside temperature could become high enough to cause seedlings to break dormancy (fig. 1.3.29D).

The size of sheltered storage area that will be needed depends primarily on the type of propagation system, the number of crops produced per season, and the length of time that the seedlings will have to be stored. Nurseries that produce more than one crop per year will need to carefully analyze the necessary amount of storage space; experience has shown that a storage area of 2 to 3 times the propagation space is often required.

Refrigerated storage. Bareroot seedlings have been stored under refrigeration for many years, but this practice is relatively new for container nursery stock. When forest and conservation seedlings were first produced in containers, it was assumed that container seedlings could be planted all year and many nurseries shipped their stock to the outplanting site in the growth container. Then, several things happened that gradually changed how container stock was stored and shipped. First, shipping the seedlings in the container was found to be costly and cumbersome and many of the reusable containers came back to the nursery dirty and damaged (fig. 1.3.30A). Second, growers observed that container stock stored in sheltered storage broke dormancy very early, *especially in their root systems* (fig. 1.3.30B). This often occurred before the planting window on many sites, and operational trials revealed that nondormant container seedlings did not tolerate the stresses of handling very well. So, to minimize storage volume and maintain the seedlings in a fully dormant condition until the outplanting sites were ready, nurseries began extracting **(pulling)** the seedlings from their containers, grading them, and packing them for refrigerated storage.

There are two different types of refrigerated storage used in forest and conservation nurseries-cooler storage and freezer storage. They are distinguished by the temperatures at which they hold seedlings:

	In-box temperature
Cooler storage	1 to 2 °C (33 to 36 °F)
Freezer storage	-4 to -1 °C (25 to 30 °F)

A

B

Figure 1.3.30—*Many nurseries are converting from sheltered to refrigerated storage for both operational and biological reasons. Seedlings shipped in the container are often damaged during shipping and outplanting* **(A)** *and, in cold climates, the root systems of seedlings in sheltered storage freeze solid, which can lead to desiccation and dormancy problems—note the active white root tips (arrow) on this frozen plug* **(B)**.

Cooler storage is recommended when seedlings are going to be stored for less than 3 months and when seedling shipments occur throughout the storage period. When the storage period is going to be more than 3 months, many nurseries use freezer storage. This extends the allowable storage period because the lower temperatures suspend seedling metabolic activity and conserve stored carbohydrates. Freezer storage also significantly reduces the incidence of storage molds. Because freezing the seedlings turns all the free water in the storage container to ice, the development of pathogenic fungi is retarded. Storage pathogens, such as gray mold (Botrytis cinerea), can spread rapidly at temperatures slightly above freezing and ruin entire boxes of stored seedlings. (Refer to volume five of this series for more information on storage molds and other storage-elated problems.)

To retard desiccation and protect them during handling and storage, container seedlings are typically wrapped in plastic film or put into plastic bags. These bundles are then placed into waxed cardboard boxes that are often lined with another plastic bag (fig. 1.3.31A). The boxes are stored on pallet racks (fig. 1.3.31 B), which can be moved by forklift into the refrigerated storage units where they are stacked into bays (fig. 1.3.31C&D).

Basic concepts. Refrigeration is the process of removing heat from a substance until a desired storage temperature is reached and maintained (Hardenburg and others 1968). Nursery stock is typically cooled by the room cooling method, in which the boxes of seedlings are exposed to cold air moving at a velocity of 60 to 120 m/min (200 to 400 ft/min). The basic components of a refrigeration system are the vapor compression refrigerant, the compressor, the condenser, and the evaporator (fig. 1.3.32). The refrigerant is pumped through a pipe to the thermostatic expansion valve, where it is released evenly into the evaporator (A in fig. 1 .3.32), where it "boils" under the reduced pressure. Because evaporation is a cooling process, heat is absorbed by the evaporating refrigerant, cooling the air around the finned evaporator coils. Circulation fans blow air through the evaporator where it is cooled and then distributed throughout the storage area. The refrigerant, which is now a gas at low pressure and temperature, is returned to the compressor (B in fig. 1.3.32), where the pressure is increased. The hot compressed gas is then pumped to the condenser (C in fig. 1.3.32). Condensation is a heat-releasing process and so when air is blown across the condenser fins, heat is removed from the gas and it changes back into a high-pressure liquid (Bartsch and Blanpied 1990). The liquid is then stored in the receiver, ready to be sent back to the evaporator when cooling is required.

All vapor compression refrigerants are referred to by an "R" number. The refrigerants used in small refrigeration systems are halocarbons, also know as chlorofluorocarbons. Fully chlorinated refrigerants, such as R-11 and R12, have been implicated in the destruction of the earth's ozone layer and so are being phased out. Alternative refrigerants are being developed but will be much more expensive and will not be compatible with existing refrigeration systems. Recent legislation mandates that all halocarbon refrigerants be recovered and recycled. Therefore, new nursery refrigeration systems will need to be periodically serviced by portable recovery and recycling units that remove the moisture and any contaminants from the refrigerant so that it can be reused.

The amount of cooling needed to keep seedlings at the desired temperature is called the **refrigeration requirement** or box load and is expressed as tons of refrigeration or British thermal units (BTU). A ton of refrigeration absorbs 12,660 kJ\h (12,000 BTU/h). The refrigeration requirement should be based on peak refrigeration load, which depends on many factors such as the specific heat of the seedlings, the target temperature, heat leakage, and heat of seedling respiration (Hardenburg and others 1986). Obviously, this is a complicated process, and so nursery developers should contact a refrigeration specialist during this phase of the nursery design process.

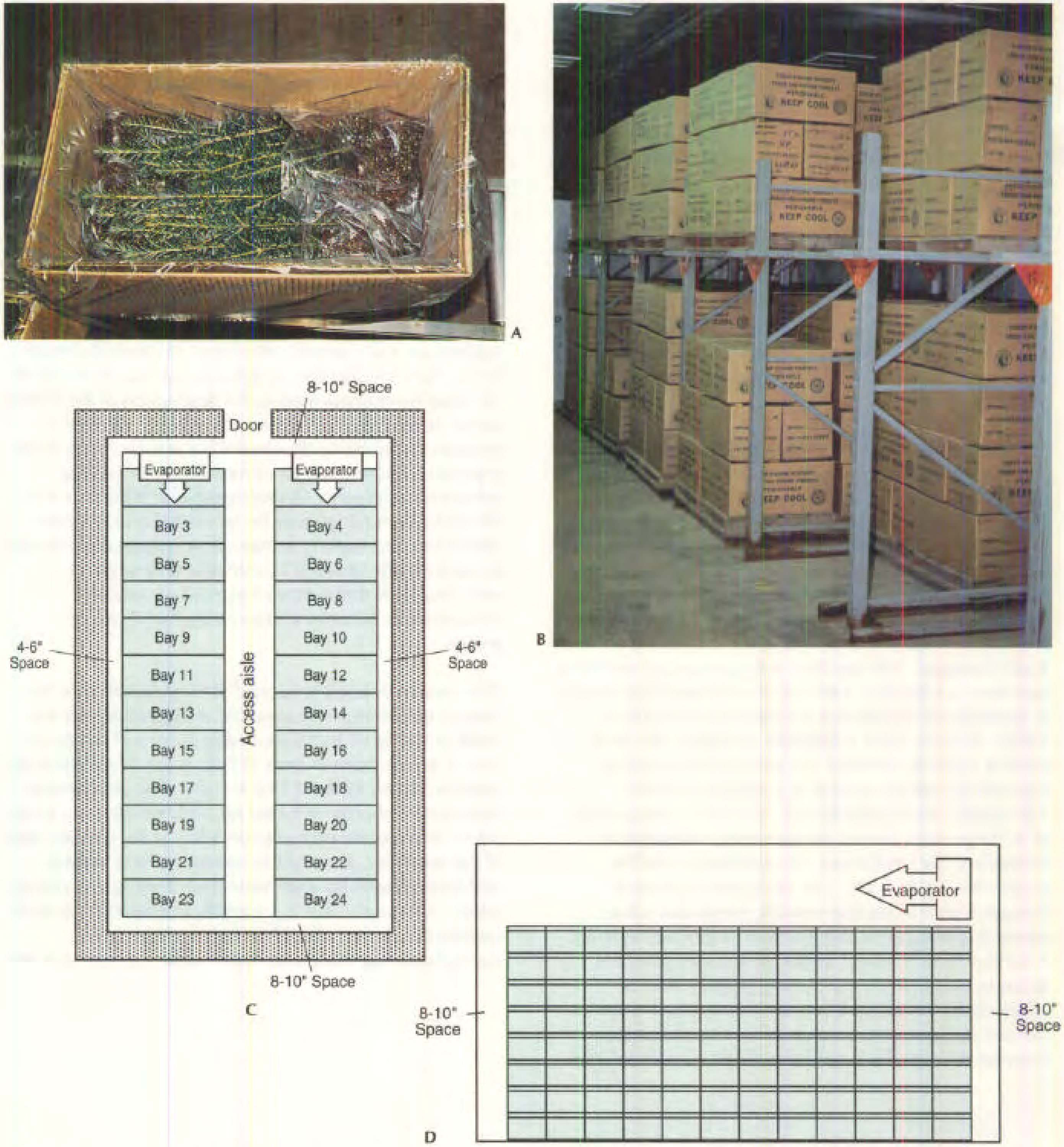


Figure 1.3.31—*Seedlings packaged for refrigerated storage are placed in cardboard boxes which are lined with plastic bags to retard moisture loss* **(A)** *and are then stored on pallet or rack systems in "bays" in the storage area* **(B & C)**. *The space must be designed to allow good air circulation from the refrigeration evaporator and around the perimeter* **(C & D)** *(C & D, modified from Bartsch and Blanpied 1990).*

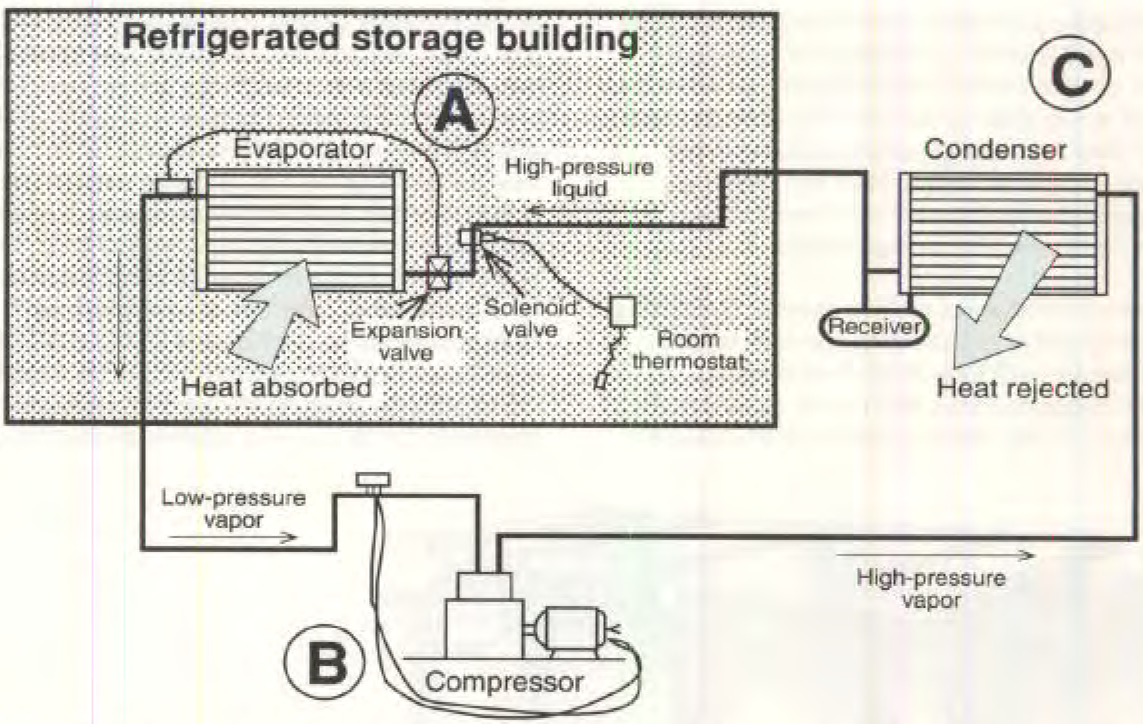


Figure 1.3.32—*The basic components of a refrigeration system include the evaporator* **(A)**, *the compressor* **(B)**, *and the condenser* **(C)** *(modified from Bartsch and Blanpied 1990).*

Designing refrigerated storage. The volume of storage required will depend on the total number of shippable seedlings, their size, the type of storage container, and the arrangement within the storage area. The first step is to determine how many seedlings will fit in a storage container. Nurseries growing several stock types may require different container sizes. Next, calculate how many seedlings will fit in a given volume of refrigerated storage (table 1.3.7). Dividing the total seedling production by the seedlings per cubic volume of storage will provide an estimate of the total volume of storage needed. The internal arrangement of the storage area varies greatly between nurseries, however. Nurseries that palletize their storage containers can stack them higher but need wider aisles for forklift access. Some nurseries store all their seedlings in bulk boxes and then assemble individual orders throughout the storage period, so that space is needed for temporary storage until the seedling orders are shipped and picked up.

Table 1.3.7—*The volume of refrigerated storage that will be needed for a specific number of seedlings varies inversely with their size*

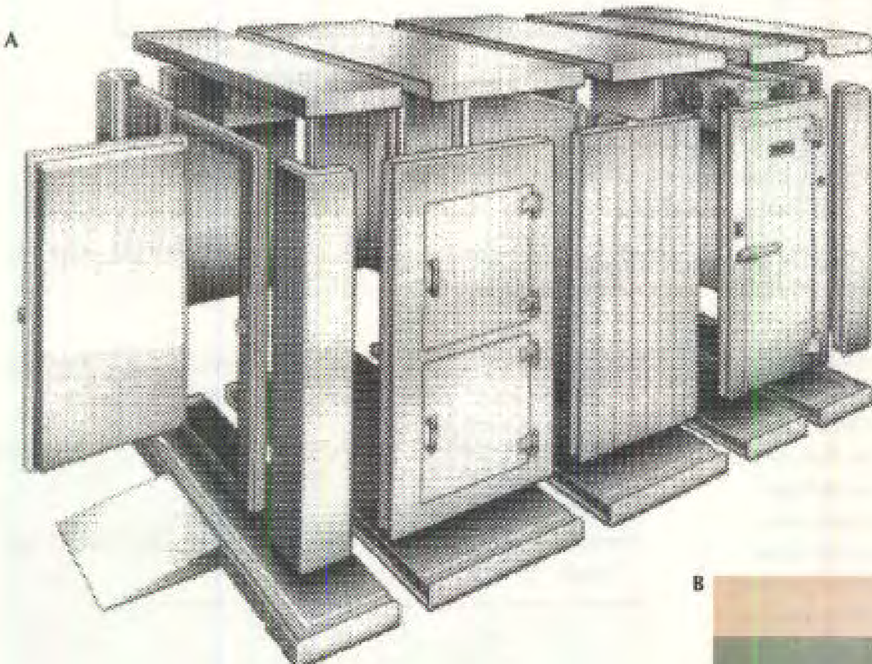
Styrofoam® container type	Container volume cm³	in³	Seedlings per storage box*	Boxes /m³	Seedlings /m³
2	41.0	2.5	750	15	11,250
4A	62.0	3.8	500	15	7,500
5	77.0	4.7	250	15	3,750
8	131.0	8.0	250	15	3,750
20	336.0	20.5	150	15	2,250

* Using a storage box of 26 x 53 x 46 cm = 0.063 m^3 (10.2 x 20.8 x 18.0 inches = 2.2 ft^3).

The final decision is whether to rent refrigerated storage space or to build your own. Nurseries in agricultural areas often are able to rent refrigerated storage when the facilities are not in their normal use. For example, apple processors often have storage space available in the spring when it could be used to store tree seedlings. Other nurseries rent refrigerated vans from trucking companies for the seedling storage season.

If you decide to build, there are two options: purchasing a prefabricated unit or constructing one from scratch. Several companies will help design and construct refrigerated storage buildings that can be expanded at a later date (fig. 1.3.33). Because desiccation is always a problem, cooler storage is often designed with humidity control to keep relative humidities near 100%. This is very important where seedlings will be stored in open bins but is not of critical importance when all stock is properly packaged. If freezer storage will be required, then the building must be designed with no internal water lines that could freeze and break. Considering the high value of stored seedlings, designing the refrigeration building with an alarm system and back-up compressor is recommended. The cost of a prefabricated freezer storage building can run around $176/ml ($5.00/ft3) without storage racks (Wenny 1993). (More detailed information on seedling storage structures and their operation can be found in volume seven of this series.)

A



B

Figure 1.3.33—*Refrigerated storage buildings are commercially available in prefabricated modular units that can be easily installed either inside existing structures* **(A)** *or as separate buildings* **(B)** *(courtesy of Bally Engineered Structures).*

1.3.5 Site Layout and Orientation

A container tree nursery should be laid out to maximize seedling growth while promoting maximum operational efficiency. Nursery developers should begin the layout process by sketching out the rough locations of the various nursery components (fig. 1.3.34). These sketches should be roughly to scale and done in pencil so that changes can easily be made. Several different computer programs are also available that make preliminary design work even simpler.

1.3.6.1 Locating propagation areas and orienting structures

The propagation environment is the heart of the nursery and so the entire facility should be arranged with respect to it. Container nurseries should always be laid out to maximize sunlight in the propagation areas. Open growing compounds should be situated to receive maximum sunlight while receiving protection from wind. They should not be located near large trees, buildings, or other obstructions that can cause shade during a significant portion of the day (see figure 1.2.1). As a general rule, a growing compound should be located at a distance at least 2.5 times the height of the nearest object to the south, east, and west (Walker and Duncan 1974).

Properly located shelterbelts can reduce adverse effects of wind. A well-designed wind barrier or a tree shelterbelt can significantly reduce heat losses of propagation structures, decrease the irrigation wind drift in shelter houses or open growing compounds, and provide protection from damaging storms (fig. 1.3.29A). The zone of protection varies with the height and location of the wind barrier. Tree shelterbelts should be located in the direction of the prevailing winds, and the growing area should be no closer than 4 to 6 times the height of a mature tree in the downwind direction. A mixture of evergreen and deciduous trees is best and the windbreak should be wider than the growing area to reduce wind turbulence around the ends. Tree species should be carefully selected to make certain that they will not harbor damaging insects or diseases. A fence windbreak approximately 3 to 3.6 m (10 to 12 ft) high can be constructed of lath snowfence or shadecloth that is 50 to 60% porous (not the same as percent shade) and supported by posts at 3-m (10-ft) spacing (Roberts and others 1989).

Because of the shading of framing and internal environmental control equipment, the orientation of propagation structures requires special consideration. Orientation refers to the compass direction along the main ridgeline of the structure. Because of the low solar angle and short days, solar orientation is most important in nurseries growing winter crops at high latitudes. During midwinter, container nurseries in northern climates receive only about one-third of the sunlight that they would in the summer (Roberts and others 1989). The proper orientation is different for free-standing and gutter-connected propagation structures.

Because more internal shadows will be created when the winter sun has to penetrate the end walls, the ridgeline of free-standing propagation structures should be oriented east to west at latitudes greater than 38° (fig. 1.3.35). At lower latitudes the orientation is less critical although a north-to-south solar orientation is preferred. Gutter-connected structures at all latitudes should be oriented north to south in order to minimize the shading that is caused by the adjacent structures (Nelson 1991). Solar orientation should also take local climate and topography into account. At locations where the mornings tend to be more cloudy than the afternoons, the ridgeline should be canted slightly more to the northwest. If, for example, a hill blocked solar access in the mornings, the ridgeline of the propagation structure should be canted more in the northwest-to-southeast direction (Husby 1973). Access corridors that connect a series of growing structures should also be on the north side.

The direction of the prevailing wind is also an important factor to consider when laying out a container nursery because wind increases heat loss in the winter and cooling efficiency in the summer. If winter crops will be regularly grown, then the structures should be oriented so that the end walls, which have the least surface area and can be insulated easily, are facing the prevailing wind direction. In like manner, the structure should be oriented with the vents windward and the exhaust fans leeward for maximum ventilation (Boodley 1981).

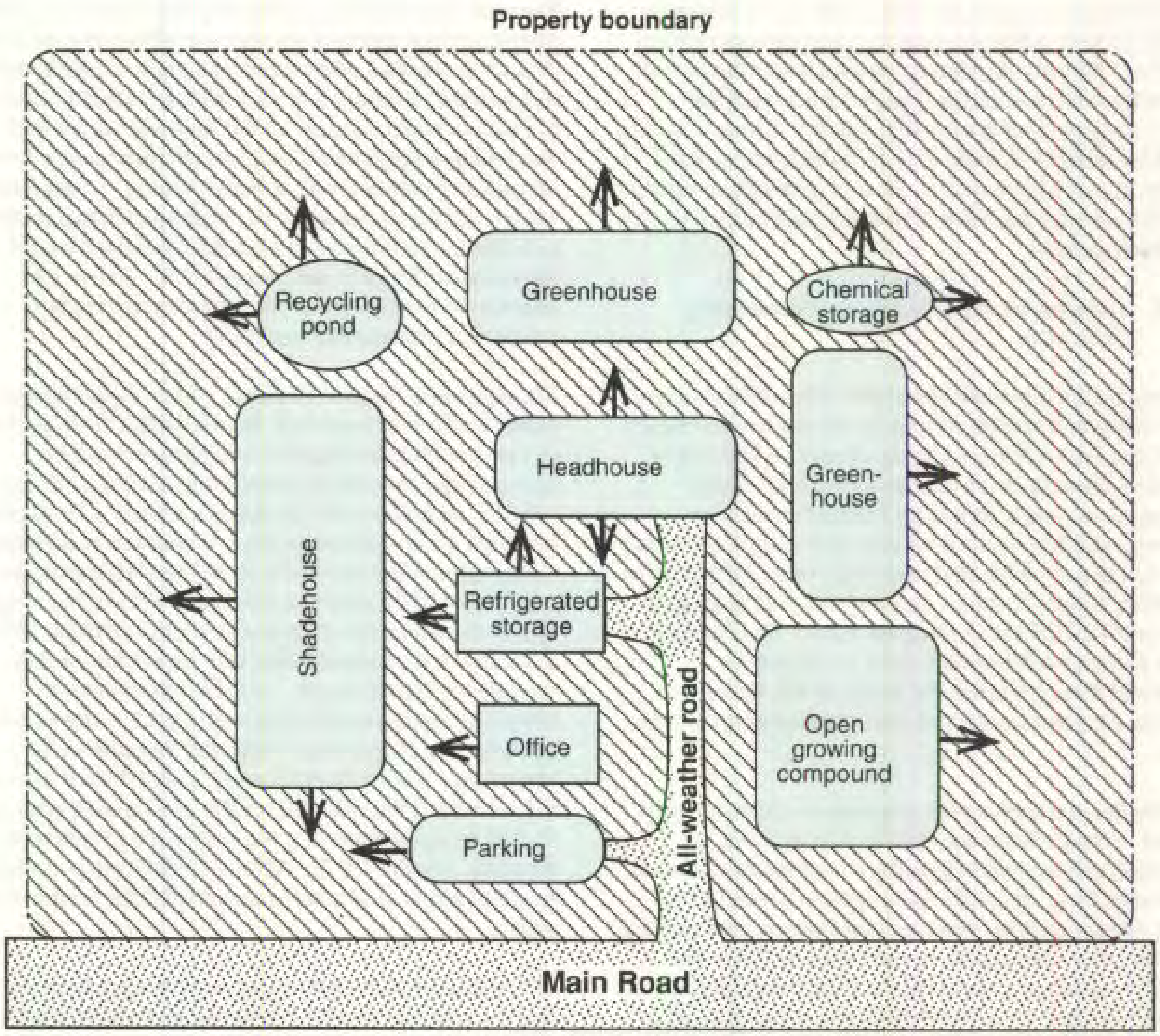


Figure 1.3.34—*Nursery developers should make a rough sketch of their nursery site to show the relative location of the various facilities and must also allow adequate room for future expansion (modified from Appleton 1986).*

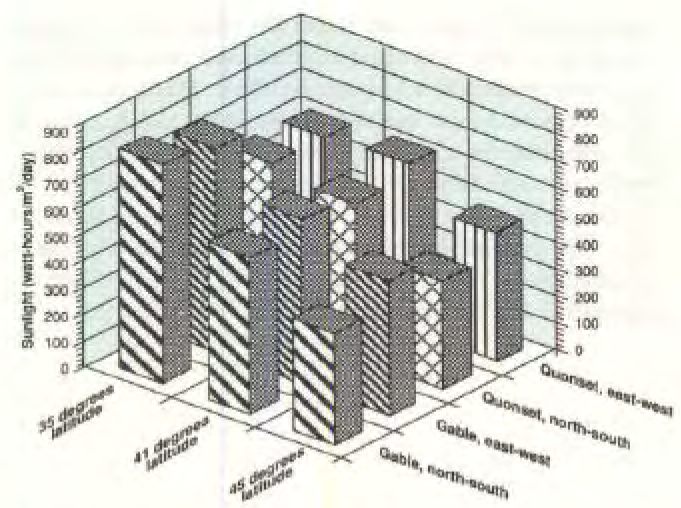


Figure 1.3.35—*Propagation structures must be oriented to capture maximum sunlight and minimize shading. Proper orientation varies with type of structure and at different latitudes because of the changing seasonal solar angle (modified from Bartok 1991c).*

At high latitudes or elevations where snow accumulation can become a problem, the distance between propagation structures must be wide enough to allow for snow removal. Snow slides off the roofs of structures and can accumulate to considerable depths between the buildings, where it may remain for weeks or months. Allow enough room between structures so that bucket tractors or other equipment can remove the accumulated snow and take it to another location.

1.3.6.2 Planning for easy access and materials flow

The entire site layout should be integrated so that the flow of workers, supplies, and seedlings is efficient both within and into and out of the nursery. The best design will depend on the type of container handling system. Nurseries that handle everything by hand or conveyors will want the distances between buildings to be as short as possible. If forklifts and other motorized equipment will be used, however, more space will be required for turning and maneuvering. Use the nursery layout sketch (fig. 1.3.34) to construct flow diagrams for each phase of work (Appleton 1986). Sketching the material flow throughout the nursery will help identify the most efficient layout. Inexperienced developers should contact existing nurseries and observe both the positive and negative aspects.

The headhouse needs to be readily accessible to the growing structures to permit easy flow of workers, materials, and seedlings (fig. 1.3.36). In larger facilities, a covered access corridor is recommended for safe all-weather access to the propagation areas and storage facilities. Loading docks should be considered if economically feasible because they will greatly aid in receiving materials and shipping seedlings. Generally, a loading dock in the headhouse is most convenient although some nurseries ship their seedlings directly out of storage. Most loading docks are 3.6 m (12 ft) wide and 1.2 m (4 ft) high to accommodate large trailers, although the actual size depends on what types of trucks will be used. All-weather roads should be at least 7.9 m (26 ft) wide and should be able to support in excess of 18,144 kg (40,000 lbs). Docks must be designed for good drainage and, in climates where ice accumulates during the winter, should be either located on the sunny side of the buildings or covered (fig. 1.3.37). A well-designed loading dock will also have good lighting, weather seals, and a system to remove exhaust fumes (Aldrich and Bartok 1989).

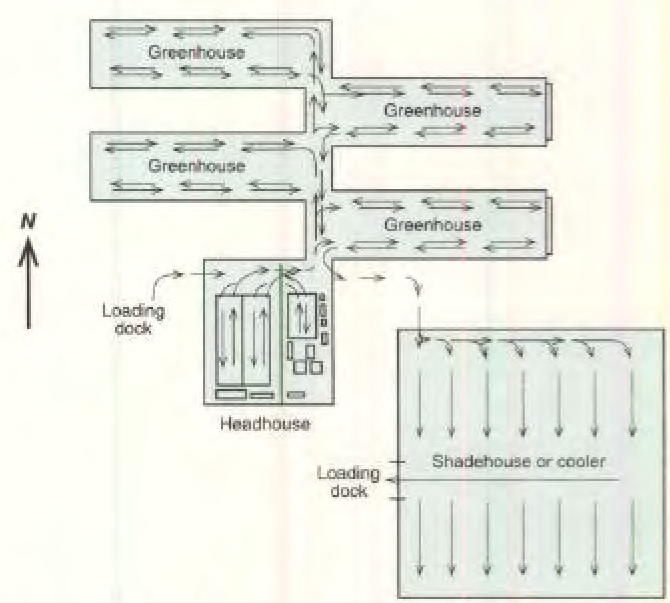


Figure 1.3.36—*Container nurseries must be laid out to facilitate the safe and easy flow of people, materials, and seedlings between the various facilities (modified from Husby 1973).*

Figure 1.3.37—*Loading docks allow easy unloading of supplies and increase the speed and safety of loading of seedlings into trucks, even during inclement weather.*

A good nursery layout will make the most of the selected site and will take both current needs and the possibilities for future expansion into consideration. Many nursery developers make the mistake of designing a layout that is only adequate for current needs. Make certain that the headhouse and other critical facilities are centrally located so that they will be accessible to future expansion. The proposed direction of expansion can also be included in the site layout sketches (fig. 1.3.34). (See section 1.2.2.4 for more discussion of this subject.)

1.3.6 Summary

The challenge to the nursery manager is to design a container facility that will modify the environmental conditions on the selected site so that a crop of high-quality seedlings can be grown within the given time constraints. To do this, it is necessary to evaluate which potentially growth-limiting environmental factors must be controlled and estimate the required costs. A well-designed nursery facility will produce the best propagation environment for the particular crop at the least cost.

A variety of different propagation structures has been used for growing forest and conservation crops, but the primary functions are to capture the maximum amount of sunlight, protect the crop from adverse climatic conditions, and allow easy access and handling of seedlings and materials. The type of structure will vary with the financial resources of the nursery developer and the availability of local material. The decision on how many different propagation environments are needed and how large each should be will depend on factors that are unique to each nursery. Seedling costs are a direct reflection of production space efficiency and so developers should carefully design their propagation environments. Any space that is not producing seedlings becomes part of the spatial overhead and increases unit costs.

A successful nursery facility will also include a headhouse, storage buildings, and offices to support the work force and provide a handy source of tools, equipment, and supplies. A container tree nursery will be laid out to maximize seedling production while offering optimum operational efficiency. A good nursery layout will make the most of the selected site and will take both current needs and the possibilities for future expansion into consideration. There is no one "ideal" container nursery. The best design will depend on many factors: engineering, biological, operational, economic, and (in the case of government nurseries) political considerations. These site factors can be assigned relative importance "weights," giving the developer an objective selection method that produces a numerical result.

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