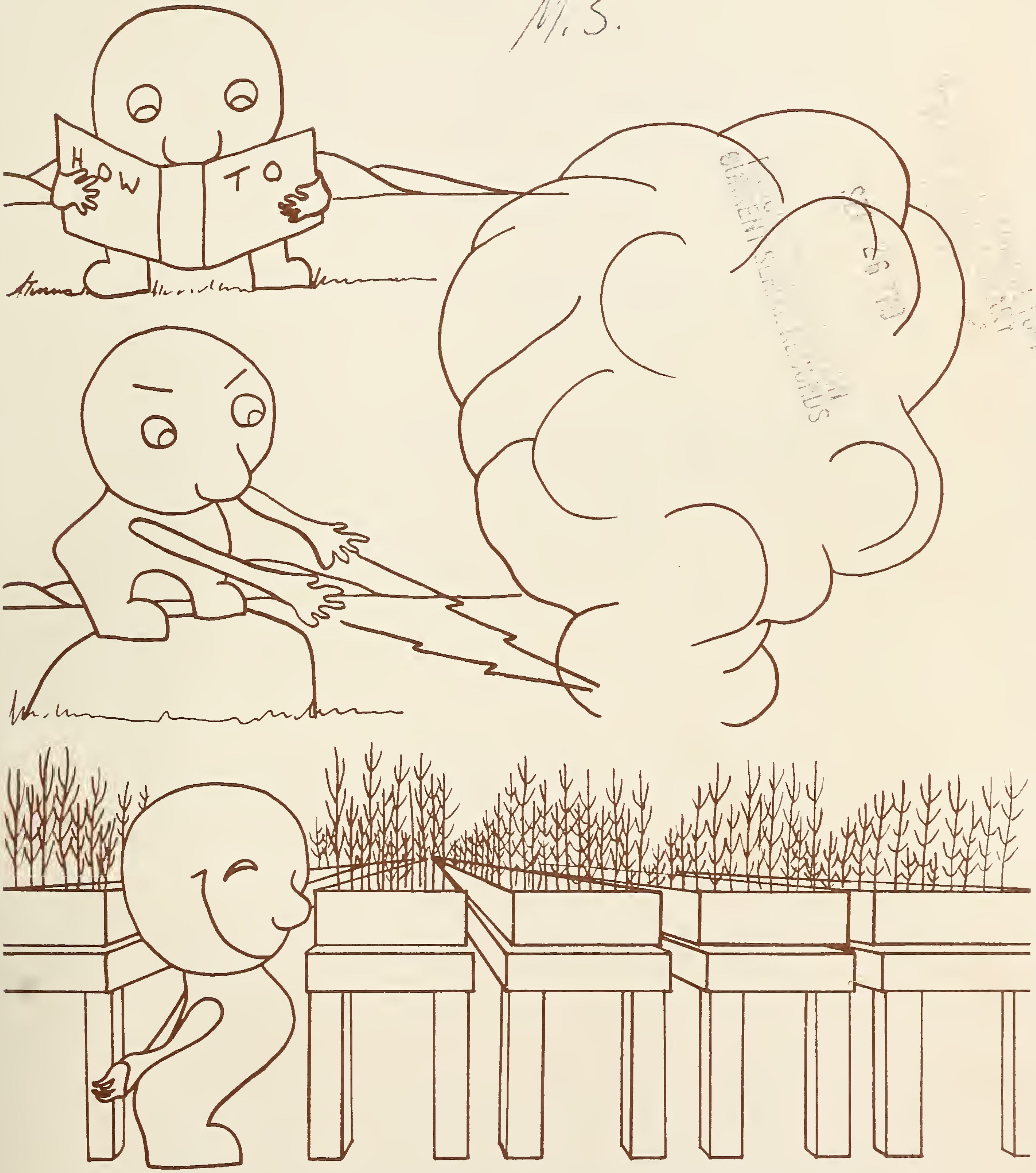
How to Grow Tree Seedlings in Containers in Greenhouses

Richard W. Tinus and Stephen E. McDonald



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Abstract

This guide to development and operation of a greenhouse nursery for container grown forest tree seedlings will help managers decide if a nursery should be built and gives criteria for selecting site, building design and layout, hardware, controls, container, and growing medium. It discusses environmental factors that can be controlled, optimum conditions for growth, and how to achieve them. Growing schedules, greenhouse cultural practices, nursery management, and troubleshooting problems are also discussed.

General Technical Report RM-60

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How to Grow Tree Seedlings in Containers in Greenhouses

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Forword and Acknowledgments

A comprehensive manual on containerized tree seedling nurseries and the methods of growing trees in containers has been needed for some time. This manual, begun in June 1975, is presented for use in the field with the understanding that its immediate need will outweigh its flaws. We have consulted with administrators and nurserymen many times in the last few years. This manual attempts to answer the questions that have been asked most often. It is intended to be most useful to beginners, but we hope experienced practitioners will also find it useful.

Many people have contributed to this manual. We have relied heavily on publications and our personal interactions with authorities on the subject. We especially thank the following reviewers for their suggestions and constructive criticisms:

James Arnott	Peyton Owston
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James Lott	Frank Ter Bush

Cover drawing is by Arline Tinus.

We plan to revise the manual in a few years. We hope the readers will advise us of inconsistencies or of new findings in their investigations or experience by contacting us at the Rocky Mountain Forest and Range Experiment Station (USDA Forest Service, Bottineau, N. Dak. 58318) or State and Private Forestry, Rocky Mountain Region, USDA Forest Service, Box 25127, Lakewood, Colo. 80225).

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How to Grow Tree Seedlings in Containers in Greenhouses

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SECTION 1.—INTRODUCTION

1.1 Orientation of the Manual

This manual is designed to provide the user with two types of information:

1. A general reference for greenhouse nursery development (sections 2 through 9) with advice on greenhouse development, economics, hardware, and containers. The general advice in the earlier sections should be helpful in making decisions about greenhouse nursery development.
2. A specific reference for growing containerized forest tree seedlings (sections 10 through 21). Explicit directions are provided concerning environmental conditions for optimum growth, nutrition, mechanics, pest control, and troubleshooting. These sections should be most useful to nurserymen.

The manual focuses on greenhouse development and tree growing in the western United States, particularly the interior West, where many new greenhouse nurseries are being started and a great variety of problems are encountered. Much of the information also applies to greenhouse nursery systems anywhere.

This manual is intended to answer most of the questions asked by novices and to help them avoid blunders. It is not an operating manual for any particular nursery, but, by using the principles and guidelines included, a nurseryman can assemble his own (Goodwin 1975, Matthews 1971).

The suggestions and directions in this manual should be used with judgment and discretion. Nothing is as valuable as a nurseryman's personal observation and deduction based on his own experience in his own location.

Throughout this manual, trade names are used only for specificity, brevity, and the convenience of the reader. No endorsement to the exclusion of equally suitable products is implied or intended.

Parts of this manual discuss the use of pesticides. Because of rapid changes in registration and labeling, the reader should check to be sure his proposed use is legal. Remember that pesticides can be harmful to humans, domestic animals, desirable plants, and fish or other wildlife if they are not handled or applied properly. Use all pesticides selectively and carefully, following the directions on the container. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

1.2 Information Confidence Levels

This manual is intended to provide the nurseryman with as much information as possible, but the quality of information about seedling biology varies considerably. The following grading system is used throughout to help the reader decide how much confidence to place in the information:

Level A—This information has been developed in controlled experiments of adequate size and thoroughly tested in production greenhouse situations. It is thought to be complete and accurate.

Level B—This information has been developed in small scale experiments or results from accumulated experience in production greenhouses. It is believed to be valid, but is subject to further testing.

Level C—This information is based on observation, and frequently from isolated cases. It is offered in the view that some knowledge is better than none.

SECTION 2.—DETERMINING PLANTING STOCK NEEDS

There are logical, sequential steps that should be taken before making a final decision to build a tree nursery. Several important facts should be determined at the outset:

1. What species and sizes of trees are wanted?
2. When and where will such trees be planted?
3. How many trees of each species and size will be needed?
4. How long will these needs persist, and how will they change over time?

With these facts determined, the potential nursery developer can analyze the planting stock alternatives available. (Note: Throughout this manual, the acronym "CTS" is used to abbreviate the term "containerized tree seedling.")

SECTION 3.—ALTERNATIVE PLANTING STOCK SOURCES

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3.1 Should You Grow Your Own Trees?

Growing your own trees, either in a bare-root (conventional) or CTS facility requires a concerted effort. Much time must be devoted to the project, especially at the outset. Capital investment will be required. In return, there will be good control over the operation and source of planting stock.

There are a number of advantages to not growing your own trees. Some of these are the converse of the advantages noted above. Time and capital would be freed for other opportunities. Also, buying planting stock from others passes many of the worries of producing seedlings to the producer.

There are some advantages to procuring some trees from outside sources and growing the rest. Growing only part of the program planting needs affords some security of supply and provides the technical capability needed to produce full program needs, if outside sources are cut off. Growing part of a program's tree needs will also allow good control of production of critical species, or plant materials of unusual value or for special purposes.

3.2 Is a Bare-Root or Container Nursery Wanted?

When a decision is made to start a nursery, should it be a bare-root or container facility? Both types have advantages and disadvantages. In bare-root nurseries, seedlings are grown in exposed seedbeds under specialized farming practices, removed from the soil, and shipped to the planting site with roots bare (fig. 3-1). The principal characteristics of bare-root nurseries are:

1. The trees are grown in soil. Consequently the soil must be suitable for tree-growing (Wilde 1958). Such soil is often difficult to find in a convenient location, and is often expensive.
2. Large amounts of high-quality irrigation water are required (Stoeckler and Jones 1957).
3. Seedlings are exposed to the adverse weather.
4. Much high-quality land is involved along with farm equipment, special nursery implements, an extensive irrigation system, and expensive support buildings.
5. The operation is sensitive to the economies of scale. Once the operation is begun, it is important to function at near capacity levels to keep unit production costs to a minimum.
6. Rate of seedling growth and time of dormancy break are largely controlled by the climate.
7. Little energy is required, compared to greenhouse operations.
8. Seedlings can be compactly packaged and shipped. However, they are perishable and must be kept moist and cool.
9. Natural buffering in the outdoor environment allows seedlings to tolerate mistakes in culture and timing better than in greenhouse nurseries.

The term "containerized tree seedling nursery" refers to those nurseries where the tree seedlings are grown in a medium placed in a container (fig. 3-2). The containers usually are specially designed for this purpose. They can be placed in the open, where the climate is mild, but in more rigorous climates are placed in a greenhouse or under shade fabric where the growing environment is controlled. In this manual, the term "container nursery" usually means "a controlled-environment greenhouse nursery where tree seedlings are cultured in specialized containers" (Tinus 1974a). Container nurseries have a number of common characteristics:

1. They can be constructed on land with low agricultural value (i.e., in many places unsuited to bare root seedling production).
2. While high water quality is an asset in CTS nurseries, it is not as crucial as for a bare-root nursery. Relatively small quantities are required, and quality can be upgraded by filtration and/or addition of chemicals.
3. Greenhouse-grown trees are not exposed to adverse weather, so, production is more reliable.
4. A container facility is less sensitive to the economies of scale than a bare-root nursery. Each greenhouse unit tends to support its own costs, and the nursery is a multiple of such units tailored to demand. No large workforce of diversified skills is required, and most equipment necessary for operation is used all of the time.
5. Container nurseries can use large amounts of energy. This energy is consumed in increasing the speed and reliability of production.

Figure 3-1.—Typical bare root conifer seedlings.

6. Containerized seedlings are bulky to package and ship. However, they are usually less perishable than bare-root seedlings.
7. The controlled environment in a greenhouse increases ability to control diseases and insects, but incidence and rate of spread may be much higher.
8. Container trees can be produced faster than bare-root trees (Stein 1974).

Under some circumstances, a facility combining bare-root and container nursery features might be appropriate. An example might be a nursery site suitable for growing broad-leaved, but not conifer, seedlings. In another case, where the amount of arable land at nursery is insufficient to meet increasing demands by bare-root production, a container facility can be added to supplement production. Perhaps trees from high-value, genetically superior

Figure 3-2.—Typical container-grown conifer seedlings.

seed would be raised in a greenhouse where they are protected from the weather, while lesser value stock is reared in outdoor seedbeds. Another case for a combined facility could relate to planting site requirements. Some sites may require containerized seedlings for adequate survival, while on others, bare-root seedlings are most cost effective. Some argument for a combined operation can be made simply on the basis of providing a flexible response to varying production demands, such as rearing container trees to quickly replace a stand destroyed by wildfire.

There are many circumstances where a combination of bare-root and container facilities can be highly complementary, especially where a bare-root facility already exists. Generally, bare-root facilities are most practical for large-scale operations, where providing many seedlings will result in low unit production costs. However, a bare-root nursery must also be on a favorable site, with a reasonably long growing season, to be economical. Container nurseries, however, can produce trees at about the same cost as in small and medium scale bare-root facilities.

3.3 Choosing Between Alternatives

First, is container stock needed for adequate field survival in plantations? If so, the decision is to use a container facility. However, if costs per surviving tree are similar using bare-root or containerized trees, the decision is still open.

Second, is there a suitable bare-root nursery site in the vicinity? Both biological and economic factors (land costs) should be considered. If no such site exists, the decision against a bare-root facility is made.

If both options are still open, the next step is to determine whether the desired production capability can be generated with the available capital. If one option was dropped earlier and insufficient capital is available to develop the desired production level in the other option, the option can be modified to a simpler version (which may be biologically riskier), the level of production reduced, or more capital sought.

Fixed-cost/variable-cost interactions between container and bare-root operations differ as volume of production increases. Projection of production levels, coupled with capital investment and production costs of each option, should indicate the optimum type of operation at different production volumes. A combined container/bare-root operation may be indicated.

Energy source is a key factor in greenhouse operations and should significantly influence the choice between a container or bare-root facility. Fossil fuels are dwindling, becoming more expensive, and in some cases, are interruptable (Besemer 1977, Pimentel 1975, McDonald 1977a). Alternative energy sources, such as waste heat from electrical generating facilities, may be readily available and are adequate for greenhouse heating (Jensen 1977a). Warmer climates cut heating needs. Cheap and reliable energy for greenhouse heating could radically revise an economic analysis of container production. Sole reliance on expensive sources of energy (electricity, propane, oil) reduces the attractiveness of the greenhouse option option.

Finally, consider availability of the technical expertise required. No formal training programs for tree nurserymen are available. However, horticultural departments of various universities train people in greenhouse and ornamental nursery management. As a result, expertise for container nursery operations may be more readily available than corresponding expertise in bare-root nursery operations.

The authors have deliberately kept these discussions of nursery alternatives brief; before a final decision between CTS and bare-root facilities is made, the reader should consult sections 4 and 5.

SECTION 4.—GREENHOUSE DEVELOPMENT

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4.1 Requisites for Greenhouse Development

Greenhouse Nursery development cannot succeed without (1) managerial commitment, (2) money, (3) a location, and (4) labor.

4.11 Managerial Commitment and Money

These two items could be considered synonymous. They are the highest priority requirement for development of a CTS growing operation. Sound preliminary estimates of planting stock needs, investment requirements, and production costs for nursery development will help secure managerial commitment. Initial facility development may be a trial installation for training personnel, demonstrating the techniques, and reassuring management about project feasibility. It also can be a full-blown nursery development, planned as such from the beginning. The rate of development usually is controlled by availability of capital as much as by managerial commitment. Whatever the level, a continuing managerial commitment is necessary to the successful development of an operational CTS nursery.

Greenhouse nursery projects should be carefully planned so the right equipment is purchased and to assure that all capital is invested wisely. Such planning will maximize the likelihood of success, and will reflect well on managers associated with the development.

A word of warning, one of the major pitfalls in CTS nursery development comes from a preoccupation with mechanical and engineering aspects of the work to the detriment of sound economic and biological reasoning. Often the key seasonal operations in a nursery are brief, high volume, high employment, frantic periods of work. In between these periods, the normal level of work involves a relatively few skilled and semiskilled people. The demands on supervisory personnel and the trauma generated during peak work periods can easily make over-mechanization appear plausible, when it is not. The manager and planner must keep in mind that a task lasting a brief time may be accomplished efficiently by intensive application of labor. If the job is continuous or relatively long-lasting, mechanization becomes more feasible. Each case should be judged separately, but the differences between short-run and long-run economics should always be a major consideration in nursery development. To avoid such pitfalls developers of a container nursery should constantly ask these questions:

1. Is this item of hardware required to meet the biological needs of the seedlings?
2. If not, is it wise to buy it to save on labor, maintenance, or other costs?

Answering these two questions, based on the biological needs of the trees and the economics of nursery enterprise, can save thousands of dollars.

4.12 Location

Location is important in CTS nursery development. Room is needed not only for present but also future development. The site should be reasonably level. The character of the soil is not important beyond its bearing strength and suitability for foundations and traffic.

4.13 Site Requirements

The location site **must** have:

1. Energy sources to provide light and heat.
2. Water of adequate quality and quantity.
3. Sufficient available labor.

4.14 Energy

Greenhouse operations often require large amounts of energy. Consequently, the amount and type of energy needed and its availability at the site are key site selection factors. Analysis of the energy aspects of greenhouse location should consider the following factors.

Quantity of energy needed.—Some assessment of energy needs of the proposed greenhouse facility is needed at the outset. This requires an estimate of greenhouse area, construction (heat loss potential), location (weather, elevation), the amount and intensity of artificial light to be used, temperatures to be maintained and their duration, and type of heat source and equipment to be used. In most instances, one or more of these factors, such as location, is assumed before such calculations are made.

Energy source.—Traditionally, greenhouses have been heated with convenient fossil fuels. Presently, such fuels are becoming increasingly expensive, and in some cases, the supply unreliable (McDonald 1977a, Pimentel 1975). Therefore, the choice of energy source is no longer so clear.

1. Fossil Fuels.—Natural gas is the most popular fuel for greenhouse heating (McElroy 1975). It is still reasonably priced, but trends indicate it will be uneconomical for greenhouse use soon (Wiegand 1976).

   Coal and oil are not scarce now, but oil is increasingly expensive and may not be available on short notice. Use of coal as a direct fuel source may require expensive antipollution equipment to make its use environmentally acceptable. Price of liquified petroleum gas (LP) likewise has risen, nearly prohibiting its use for greenhouse heating except as a backup or supplemental heat source (Steinhart 1974).

   Natural gas, LP gas, coal, oil, and electricity can all be transported to the greenhouse site. However, natural gas and electricity are not stored at the site. Interruptions in gas and electrical service can be catastrophic. Interruptions in gas service have been rare, but a back-up energy source for gas or electricity should be considered.
2. Electricity.—Some experts predict electricity will be the energy source for the future for greenhouse heating because it is presently becoming more competitive in price and supply with fossil fuels (Duncan 1975). It is an engineering advantage to place a greenhouse entirely on a single energy source.
3. Solar energy.—Technology is developing rapidly for use of solar energy to heat air or water (Jensen 1976). For climates with enough cloud-free days, this is a viable alternative heat source. However, even the best solar heating units usually will not supply 100% of a structure's heating needs. Prolonged cloudy weather can exhaust stored heat reserves. As a result, solar-heated structures require a full capability back-up heat source. They also require a higher initial capital investment than fossil-fueled units. The big advantage of such systems is that the capitalized "fuel" costs never increase. A careful economic analysis of local feasibility of solar energy use is needed. Solar energy application can be surprisingly economical at high latitudes where the equipment is used for long periods, despite the cold weather.
4. Geothermal energy.—The internal heat of the earth can be tapped where there are natural sources of hot water or steam or by digging wells to inject water into hot rock to heat the water. The hot water or steam is then passed through heat exchangers in the greenhouse. There are many oppportunities for using the geothermal resources to heat greenhouses in the western United States (White and Williams 1975). The technology for using naturally occurring sources of hot water and steam is relatively simple, if the water is of usable quality, quantity, and reliability. The water must not be so saturated with dissolved salts that resultant deposits will clog plumbing. The tech-

nology for developing geothermal wells exists, but can be quite expensive, unless circumstances are very favorable (McDonald et al. 1976).

5. Waste heat.—Greenhouses can be heated by waste hot gases or liquids (usually water) that are products of high temperature or energy generating processes (White 1976). Waste fluids other than relatively pure water can be passed through heat exchangers that circulate warmed air or water to greenhouses. Relatively pure hot water can be piped directly to greenhouses. At present, this heat source is probably the most reliable, low cost, and technically feasible energy alternative to direct fossil fuel heating. Nuclear and fossil-fueled steam turbine electrical generating plants are the richest potential sources of such industrial process heat. Numerous manufacturing processes also develop hot gases and liquids from which the greenhouse industry could draw surplus heat. Pulp and paper mills are excellent examples. Canadians have reported direct use of exhaust gases to heat greenhouses (Green et al. 1977).
6. Biogas conversion.—Inflammable gases (methane) can be generated by the fermentation of plant and animal wastes. Conversion equipment is commercially available. The science is better developed in some foreign countries than in the U.S., but our large western feedlots provide unparalleled opportunities for greenhouse heating using this source. With current technology, one cow can provide waste products sufficient to generate enough methane to heat about 250 square feet of greenhouse space in a moderate western U.S. climate.[1] Based on these figures, a 100-cow feedlot operated all year could generate enough biogas to heat a greenhouse complex growing 2 million tree seedlings per year in 8-cubic-inch containers. Since waste disposal at such feedlots is a constant, costly problem, cooperation of the feedlot owners is very likely.
7. Mine-mouth or deep-mine heat.—Many mines are constantly ventilated to provide fresh, cool air to the miners. The air removed is hot and moist. This potential heat source is being tested for greenhouse use in eastern coal regions with excellent prospects for success (Walker et al. 1976, Buxton et al. 1976). There is also a precedent for growing tree seedlings under artificial light deep in a hardrock mine at the Bunker Hill Mining Co., Kellogg, Idaho.

[1]*Personal communication with Lloyd Vic, president, Industrial Systems Engineering, Inc., Albuquerque, N. Mex.*

Possible use of non-traditional energy sources.—The potential use of energy sources other than fossil fuels should be a consideration in greenhouse site selection. However, because the technology for utilization of these various types of energy is in different stages of development, and because traditional fuels are still relatively inexpensive, small-scale production of the components for alternative energy systems is often not economical. The Department of Energy (D.O.E.) conducts programs dealing with research and development of such energy sources. For more information contact the D.O.E. Technical Information Center, P.O. Box 62, Oak Ridge, Tenn. 37830.

Heating system design.—Long range planning is especially important in design of greenhouse fuel and heating systems (Love 1975). Most greenhouses in the United States use central heating systems in which the heat of fuel combustion is transferred to water and distributed as steam or hot water (Nelson 1973). These systems are generally more fuel efficient than combustion systems which directly heat the air (Newland 1974).

A few years ago, coal was the accepted fuel. The use of coal decreased because of the increase in its cost per BTU value, delivery problems, mechanical handling problems, clean-up requirements, and discharge of unburned residues into the air. With the rising prices and supply problems of petroleum and natural gas, some return to coal by greenhouse operators probably can be anticipated.

Recently, unit heaters for directly heating the air in greenhouses have gained popularity. Their problem had been poor heat distribution in the greenhouse. This has largely been solved by placing a perforated polyethylene tube on the front of the heater which conveys the warm air the length of the greenhouse, dispersing the heat through the perforations (Walker and Duncan 1975) (figs. 4-1 and 4-2). Popularity of this system comes from its low cost and ease of installation, built-in redundancy (where two or more units are used) and ease of servicing. Such units are usually gas fired.

The type of system (boiler or unit heater) selected depends on economic factors (cost of hardware, ease of installation and maintenance, scale of operation, fuel utilization effectiveness, type and cost of fuel used) and personal preferences. Greenhouse firms selling such structures are experienced at making such recommendations based upon local conditions.

Energy source selection.—Reliable, reasonably priced energy is absolutely vital to CTS nursery development. The price of natural gas in the western United States has risen 200% between 1973 and 1976 (Wiegand 1976). The supply of natural gas for nondomestic uses has been interrupted in recent winters. The medium to long-term prospects for natural gas and fuel oil cost and availability for greenhouse heating is unclear, but two things appear certain:

1. Cost of oil and gas will increase.
2. Availability of natural gas will become less dependable.

Therefore, when oil or gas fuels are used, it may be wise to calculate a short-term benefit large enough to offset the risk attributable to uncertain fuel costs and supply. Ways to do this are:

1. Raise prices of trees produced so the capital expenditure to develop the greenhouse can be rapidly amortized.
2. Build greenhouses that are inexpensive and that have a relatively short projected structural life.
3. Combine these two actions.

Use of a coal-fired boiler to heat a greenhouse complex should assure the nurseryman of a more reliable heat source. Such boilers cost more to purchase and maintain than similar oil or gas-fired models. Also, coal units may require pollution control devices.

The alternatives to fossil fuels can hold a number of advantages. If a long-term arrangement, which stabilizes heating costs, can be found (solar heating, waste heat leasing, etc.), future fuel price increases and/or interruptions might be avoided. Also, such arrangements may provide a constantly improving economic position as fossil fuel costs rise.

The economics of energy source planning for greenhouses are complex and depend largely on the scale of the operation and the perspective of the developer. Modest developments with short-term goals and rapid amortization of capital argue for use of traditional fuels at present. Large developments with long-term capitalization of substantial investments may be better served by using some alternative, nontraditional heat source.

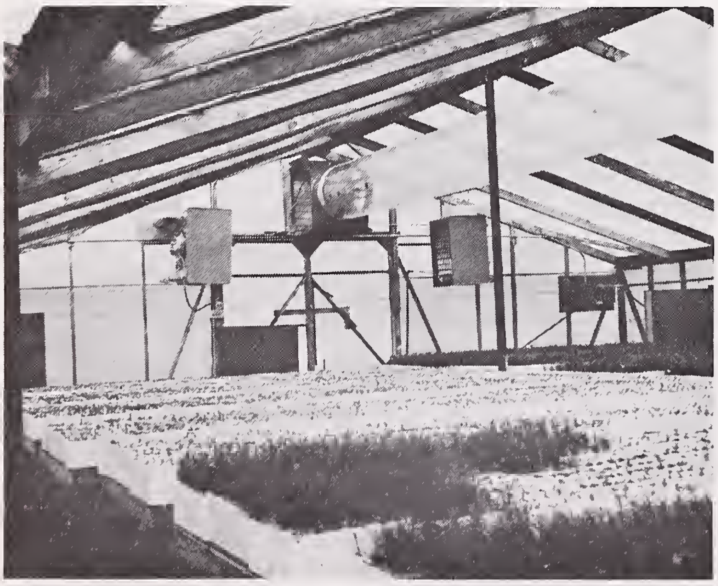


Figure 4-1.—A perforated plastic tube system used for air circulation, heat distribution, and first stages of ventilation.

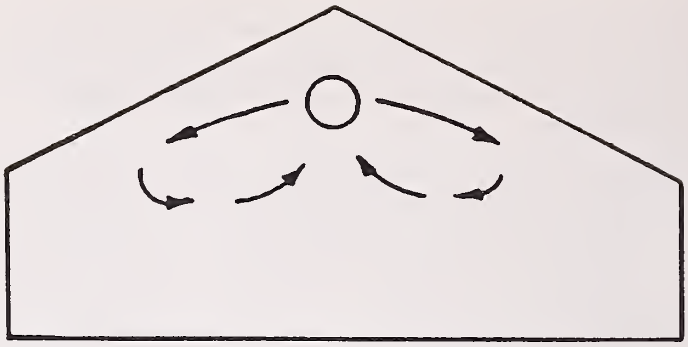


Figure 4-2.—Overhead perforated polyethylene tube.

4.15 Water

The quantity of water required for a container nursery is modest compared to a bare-root nursery. Still, some idea of the amount that will be required is needed for site selection. Approximately 0.4-0.5 gallons per hour per square foot (16-20 $l/hr/m^2$) of greenhouse area is needed to water 8-inch (20-cm) deep tree seedling containers. This rate of application is great enough to avoid having the foliage wet long enough to unduly encourage fungal development. A change in this rate for different depths of containers should be proportional to the difference in the depth. If a 12-inch (30-cm) deep container is used, the rate would be increased to 0.75 gallons ($12 \div 8 \times 0.5$) per square foot per hour (30 $l/hr/m^2$). About the same watering capability is required for shadehouse. Rates of use also have to be calculated for the rest of the complex: domestic needs, landscaping needs, cooling water. However, these are normal components of civil engineering calculations and are available from engineering sources. The total flow rate estimate for the installation need not assume that the whole system will be used at the same time. Watering in greenhouses, shadehouses, and lawns can easily be staggered, and the total flow rate requirements of the installation correspondingly reduced (and money saved in installation costs).

Estimates of total annual water needs are often required of prospective water users seeking water rights. In drier climates, for 8-inch (20-cm) deep containers in a greenhouse operated all year, about 100 gallons per square foot (4,070 l/m^2) of greenhouse space will be needed. In more humid climates only about 30-40 gallons per square foot will be needed.[2] Again, a change in container depth will result in a proportional change in the water requirements. Reduction in the time the greenhouse is occupied will result in a directly proportional reduc-

[2]*Personal communication with Phillip Hahn, Forestry Research Manager, Georgia Pacific Corp., Eugene, Oreg.*

tion in water need. Trees in a shadehouse will require equivalent amounts of water for the months the shadehouse is used. An example of calculations to arrive at the necessary figures for water demand follows:

Given:

1. Other nursery water needs—40 gallons (150 l) per minute at 40 pounds per square inch (2.8 kg/cm^2)
2. 5,000 square feet (464 m^2) greenhouse
3. 7,500 square feet (695 m^2) shadehouse
4. Two crops per year in greenhouse
   (3 months for one in 6-inch (15-cm) deep containers)
   (9 months for the second in 10-inch (25-cm) deep containers)
   (6 months for first crop in shadehouse)
5. Shadehouse water is never on at same time as greenhouse water.
6. Eight-inch (20-cm) deep containers need 100 gallons per square foot per year (4,070 $l/m^2/yr$)
7. Eight-inch (20-cm) deep containers need 0.5 gallon per hour per square foot (20 $l/m^2/hr$)

Calculation of water rate needs.—The shadehouse and greenhouse will not be operated at the same time, but have different areas with different containers. Therefore, it must be determined which unit requires the **greater** flow of water.

Greenhouse:

(1) (0.5 gallons per hour per square foot) × (10-inch deep containers) ÷ (8-inch containers) =
(2) (0.5 gallons per hour per square foot) × (1.25) = 0.625 gallons per hour per square foot
(3) (0.625 gallons per hour per square foot) × (5,000 square feet) = 3,125 gallons per hour (11,800 l/hr)

Shadehouse: (10-inch-deep containers will never be in the shadehouse.)

(1) (0.5 gallons per hour per square foot) × 6-inch containers) ÷ (8-inch deep containers)
(2) (0.5 gallons per hour per square foot) × (.75) = 0.375 gallons per hour per square foot.
(3) (0.375 gallons per hour per square foot) × (7,500 square feet) = 2,812 gallons per hour (10,630 l/hr)

The water flow rate needed for the greenhouse is greater with 10-inch (25-cm) containers than the shadehouse with 6-inch (15-cm) deep containers, even though the shadehouse is larger. The total volume per minute demand for the facility is estimated by converting the maximum gallons per hour for the greenhouse into gallons (or liters) per minute and adding the gallons per minute requirement for the rest of the facility (given, from engineer's estimate):

(3,125 gallons per hour) ÷ (60 minutes) = 52 gallons per minute + 40 gallons per minute = 92 gallons per minute or approximately 100 gallons per minute (378 l/min.)

Facilities projected beyond the current development should also be calculated into the rate and total annual needs. Normally, no two greenhouses would be using water at the same time, unless there are many greenhouses.

Total annual water needs calculations.—The greenhouse will be used all year, while the shadehouse is used 6 months a year. Assume fall is rainy. Therefore, 4 months of irrigation is needed at this location. The other uses are estimated by engineers to be 1,000,000 gallons per year (3,800,000 l/yr).

Therefore:

Total annual greenhouse needs:

100 gallons per square foot per year for 8-inch-deep containers

(1) (100 gallons per square foot per year) × (3 months ÷ 12 months) × (6-inch-deep containers ÷ 8-inch-deep containers) =
(2) (100 gallons per square foot per year) × (0.25) × (0.75) = 18.75 gallons per square foot per year.
(3) (100 gallons per square foot per year) × (9 months ÷ 12 months) (10-inch-deep containers ÷ 8-inch-deep containers) =
(4) (100 gallons per square foot per year) × (0.75) × (1.25) = 93.75 gallons per square foot per year.
(5) Adding (2) plus (4) = 18.75 + 93.75 = 112.5 gallons per square foot per year.
(6) (112.5 gallons per square foot per year) × (5,000 square feet) = 562,500 gallons per year (2,126,000 l/year) for the greenhouse.

Total annual shadehouse needs:

(1) (100 gallons per square foot per year) × (4 months) ÷ (12 months) × (6-inch-deep containers) ÷ (8-inch-deep containers) =
(2) (100 gallons per square foot per year) × (0.33) × (0.75) = 24.75 gallons per square foot per year.
(3) (24.75 gallons per square foot per year) × 7,500 square feet) = 185,625 gallons per year for the shadehouse.

Total greenhouse and shadehouse needs are 562,500 + 185,625 = 748,125 gallons per year (2,828,000 l/yr) or about 1 million gallons per year; with the 1 million gallons estimated for other uses, a minimum of 2,000,000 gallons (7,560,000 l) per year would be needed.

Water quality.—Quality of the water at a proposed greenhouse location is an important consideration in the site selection process. The source of the water to be used often has a definite effect on the water quality. Generally, sources fall into one of five categories:

Municipal water (water from wells or surface sources that has been treated to be potable).
Well water.
Irrigation system water; piped, but not potable.
Surface water from ponds, streams, or lakes.
Sewage effluent water.

Water quality is measured by the nature and amount of suspended and dissolved impurities. Suspended matter is material in the water that would eventually settle out, such as sand, silt, organic particles, etc. Inorganic ions and organic compounds dissolved in the water do not settle out. Suspended material can wear, abrade, and block nursery equipment and hardware. Municipal water usually has been filtered to remove particulate matter. This is not always true, however, and should be checked. Depending on the aquifer, well water may contain sand or silt. Sand can be filtered, but complete silt removal is much more difficult. Both sand and silt are abrasive and can quickly wear out water pumps, fertilizer injectors, and some types of sprinkler heads. Surface water sources, in addition to possibly having sand or silt, often will have suspended organic matter such as leaves, insects, seeds, spores, algae, etc. Pathogenic nematodes and fungi could be a problem, especially if the water includes runoff from agricultural land.[3] One way to improve the quality of such water is to create a settling pond that can be treated with chemicals.

The nature of the dissolved matter in a water source is of great importance. Water tests normally made by state health departments usually list the chemical properties of particular water solutions under several headings:

1. Concentration of various ions present in the water.—The list of ions on a standard water test is not all inclusive. Some are known plant nutrients, and some are not. The ionic concentrations may be expressed as milligrams per liter (mg/1) or parts per million (ppm), which, for our purposes, are equivalent.
2. pH.—This is a measure of the relative alkalinity or acidity of the water, and is familiar to most nurserymen.
3. Total dissolved solids.—This figure is the summation of all ions in the solution. It is sometimes called the "total dissolved salts," and is related to the osmotic pressure imposed by the soil water solution. If the salt concentration of the soil water solution around a tree's roots is too high, the tree will not be able to extract water from the soil. Of course serious growth inhibition comes long before this extreme point is reached. "Total Dissolved Solids" information helps determine suitability of the water for use as irrigation water in a greenhouse.
4. Total alkalinity.—This figure expresses the amount of some compound (often $CaCO_3$) equivalent to the amount of alkalinity in a water solution.
5. Total hardness ($CaCO_3$).—This is the total of all divalent ions in the water that would cause a precipitate when combined with sodium palmitate (soap). These ions are usually calcium and magnesium, but also include other heavy metallic ions. The figure is of little use to nurserymen as are the general terms "hardness" and "softness" when related to water quality.
6. Conductivity.—This is another measure of total dissolved ions in the water expressed as ease of passage of electrical current through the solution. The figure is usually expressed as millimhos per square centimeter (mmhos/cm^2), read from an electrical conductivity meter. The higher the reading, the higher the salt concentration in the solution.

[3]*Personal communication with Dr. Glenn Peterson, Project Leader, Rocky Mountain Forest and Range Experiment Station, Lincoln, Neb.*

Preliminary evaluations of water quality.—During the first visit to a proposed site, some basic observations will give the investigator important clues to the water quality. The amount of deposits of carbonates on sprinklers, faucets, sinks, etc., is a good indicator of the amount of calcium and magnesium bicarbonates dissolved in the water supply. Another indication is that the water will taste heavy and flat. For a third test, note the effort and amount of soap required to work up a "lather" and how long the suds, if any, persist on the surface of the water. If little soap or effort is required for a lather and suds persist on the water's surface there is little calcium or magnesium in the water. The presence of "scum" on the water can indicate calcium or magnesium bicarbonates. If the soap is difficult to rinse off, there may be considerable sodium in the water.

If the water tastes salty, sodium chloride is probably present. This should alert the developer to potential problems with the osmotic limit for dissolved solids or chloride toxicity.

Brown or orange-brown stains where water has run repeatedly usually indicate iron in the water. This probably has no serious negative implications, but the water could stain the greenhouse cover eventually.

A sulphur or "rotten egg" taste or smell indicates the presence of sulphides in the water.

When water containing bicarbonates is heated or evaporated, carbonates are deposited. This is generally not a problem, since it is recommended that all water used in irrigation be acidified (section 13). Acid solutions keep the calcium and magnesium bicarbonates in solution and alleviate most carbonate deposition. However, the concentration of bicarbonates can have serious consequences when unacidified water containing these ions is used for boiler system water or on cooling pads. When supplied with water test data, heating and cooling system engineers can determine if water will have to be treated for these uses.

Indications of high concentrations of calcium or magnesium bicarbonates or iron sulphates should not seriously affect greenhouse nursery site selection unless another equal or better site is available. However, any indication of relatively large quantities of sodium chloride, or heavy metals in the water should cause serious concern.

Evaluating a chemical water test.—If the site looks promising, a chemical water test should be made. Chemical components of water at a single location can vary from season to season, especially with surface water sources. Similarly, the chemical nature of well water can vary considerably in a locality. Conclusions drawn from a single sample or from water from a well adjacent to the planned development, should be considered tentative and rechecked at different times of the year. The actual water applied to the crop should be tested if possible. Routine water chemical analyses do not indicate concentrations of heavy metal ions such as lead, chromium, cadmium and mercury. However, even low concentrations of these ions in water can be toxic to plants. Presence of heavy metal ions in the water source is possible if:

1. There is a history of heavy metal contamination of water in the area.
2. The aquifer the water is coming from is one which bears metal ores.
3. The water is effluent from a sewage treatment plant.

If any of these statements are true, the water should be checked for heavy metal ions and the results analyzed by specialists who can relate the concentrations to tree growth.

Other toxic substances may be found under these conditions:

1. Water draining from swamps or bogs may contain chemical plant growth inhibitors leached from decaying plants. Some plants manufacture inhibitors to reduce competition with other vegetation—black walnut is the common example. When such plants decay in swamps and bogs, these inhibitors can be dissolved in the water.
2. Water from geothermal sites frequently contains sulphide or sulphite ions which are harmful to plant growth.
3. Surface water sources can be contaminated with complex organic compounds used in manufacturing or pest control. Possible sources of such contaminants should be examined before the greenhouse site is selected.

Below are water quality guidelines to use when choosing CTS greenhouse sites. These approximations are for preliminary site evaluation only.

1. Ion toxicity.—Nearly any ion required by plants, and many not demonstrated to be required, can be toxic to plants when supplied in excess. Table 4-1 lists nutrient ion concentrations that are suitable for plant growth and levels that should not be exceeded in the water supply (Hoagland and Arnon 1938). (Hoagland's solution may not provide optimum nutrition for trees but is useful for lack of a better guideline. This solution generally provides an osmotic tension of about 1.5 bars).
2. Dissolved solids.—The growth of most trees is retarded when the salt content of the soil solution exceeds a rather low value (Ayers 1977). Harmful effects of high salt concentration are attributable to effects of certain ions on plant metabolism when they are present in high concentrations and to reduce water absorption because of the high external osmotic

Table 4-1.—Composition (ppm) of Hoagland's solution and maximum ion concentrations allowable in a water source. Maximum concentrations listed may be too high for some species.

Element	Hoagland's solution	Maximum concentration
Nitrogen	210	500
Phosphorus	31	150
Potassium	240	500
Calcium	170	600
Magnesium	48	150
Sulfur	64	500
Iron	4	40
Chlorine	4	40
Manganese	0.5	5
Boron	0.5	5
Zinc	0.05	0.5
Copper	0.02	0.5
Molybdenum	0.01	0.5

pressure. Because the medium in which trees are reared is kept near field capacity (0.3 bars), there is little reason to worry about salt accumulation in the medium, particularly if the conductivity of the leachate from the containers is monitored as recommended in section 13. However, high salt concentrations especially sodium chloride, in irrigation water may damage the tree seedlings or seriously narrow the margin of safety between good tree growth and the osmotic limit. Conifers appear to be unusually susceptible to damage from excess dissolved salts in water (Baxter 1943, Kramer and Kozlowski 1960).

What salt concentrations are reasonable? Comparing the Total Dissolved Solids figure or electrical conductivity (one measure of total dissolved solids) (Section 6.56) from a water test from the proposed source water and the proportions of sodium and potassium ions to calcium and magnesium ions from the same test (Table 4-2), will estimate the desirability of the water (Black 1957, Sutcliffe 1962, Levitt 1972, Richards 1954).

3. "Total alkalinity."—Usually given as $CaCO_3$ equivalent, this figure can be used to calculate the amount of acid necessary to "buffer" the water to a slightly acid condition. Since relatively little water is used for irrigation in greenhouses, this calculation is not important at the preliminary site selection stage, although it is very important in calculation of nutrient solution compositions (section 13) after the water source and site are fixed. For site selection purposes, water giving total alkalinity figures in excess of 600 mg/l $CaCO_3$ should be avoided.

4.16 Labor Supply

A sufficient supply of labor must be available for the size of operation to be installed and that contemplated for the future. The work force needs to be relatively stable, semi-skilled, and capable of rapid expansion for shipping trees or loading greenhouses. The number of employees required depends on the size and complexity of the operation. An average of one laborer for each 120,000 trees and at least one technical supervisor for each 3,000,000 trees may be used as a rule of thumb.[4] Other large consumers of labor in the area should be known, so that areas can be avoided where seasonal pursuits (fruit harvest, etc.) may "dry-up" the labor supply when the workers are needed most.

4.17 Desirable Site Features

Sections 4.13, 4.14, 4.15, and 4.16 dealt with greenhouse location features that are "musts" (energy, water, and labor supply). This section deals with site attributes that are desirable, but not required.

Favorable climate.—A good greenhouse site should have a warm, dry, sunny climate without temperature extremes, located at as low an elevation as possible. These site characteristics will lessen structural and energy requirements for a greenhouse. Usually, the choice is a compromise between different mixes of characteristics. Climatic and latitudinal features of a site will affect both the fixed costs and variable costs of greenhouse operation. For instance a less expensive structure with smaller fans, heater, etc., would reflect the influence of a mild climate. This, in turn, means a lower amortization rate to carry over the life of the facility as part of the unit production price. Variable costs in the form of fuel and electricity will be less, if the greenhouse is placed at a sunny, mild, low elevation site.

Certain locations should be avoided. Valley bottoms and toes of slopes are cold because of cold air drainage. Frost pockets form where downslope air drainage tends to accumulate. Impingement angle of sunlight should also be considered. Amount of sunlight is often a limiting factor in greenhouse operations in central and northern states (Duncan 1975). In such areas, greenhouses should have an open southern exposure. Obstructions that interfere with light on its way to the greenhouse must be avoided. As a general rule, the greenhouse should be located at least 2.5 times the height of the object away from it in either the east, west, or south direction (A.S.H.R.A.E. 1965).

[4] *Personal communication with Robert Smith, Nursery Manager, Crown-Zellerbach Corp., Aurora, Oreg.*

Table 4-2.—Desirability of water supply as a function of conductivity or total dissolved solids and Na to Mg + Ca ratio (Richards 1954).

Ratio Na/(Mg + Ca)	Good		Usable but not desirable		Not acceptable	
	(ppm)	(mmhos)	(ppm)	(mmhos)	(ppm)	(mmhos)
<1:2	<400	900	1500	3000	2000 +	4000
>2:1	<200	250	500	700	600 +	800

Sheltered area.—The greenhouse should be placed where it is sheltered from the wind. Although maximum sunlight should be the first consideration, placing a greenhouse in a sheltered area reduces wind-induced heat losses (Duncan 1975). Pick an area with relatively low air velocities (check weather records) if possible.

Physiography.—The physiography of a greenhouse site should be reasonably level and well drained. The site should be more than large enough to allow for future expansion.

Closeness to market.—The greenhouse should be as close as possible to the market for its production to minimize transportation costs.

Supply and maintenance.—Supply and maintenance services should be available nearby. Proximity to these services will save money time and time again.

Living quarters.—A good greenhouse site will allow a person responsible for its operation to live nearby. If there is not a town nearby, it may be necessary to provide a dwelling on the site. The intent is to prevent vandalism and, more importantly, to correct greenhouse mechanical failures promptly. However, providing a dwelling on site is expensive, and a more desirable arrangement is for the employee to live off the nursery site but nearby.

4.18 Site Evaluation

Site selection can involve interacting factors of different degrees of importance. Sometimes one or a few factors are so important that the site selection is easy. At other times, the mix and relative weights of selection factors are so complex that selection is very difficult. In complex situations site alternatives can be arrayed opposite positive site attributes (McDonald 1976). The site attributes or elements can be weighted according to their relative importance in relation to economics, energy, personnel, finances, distance to market, politics, and other factors.

Table 4-3 in an example of such an analysis. The elements listed are not all inclusive, and each analysis will probably have different elements with different weights. Each element is rated for each alternative location on a scale from 1 to 10. The alternative rating for each element is then multiplied by the "weight" of the element. This element weight indicates relative importance of the elements, on a scale of 1 to 10. The products of element weight and alternative rating (importance) are totaled. If the alternative ranks and element weights truly reflect the advantages and importance, the alternative with the highest numerical value should be the most advantageous. This matrix is a simplified version of the type suggested in the Kepner-Tregoe decision-making procedure (Kepner and Tregoe 1965).

4.2 Economics of CTS Nursery Development

4.21 Economic Data

The first step toward entering the CTS greenhouse business is an economic feasibility study. Such studies normally examine both marketing and production. However, problems arise when this approach is taken with tree seedling production facilities. The production portion of the study can be quantified easily, but the marketing portion will often suffer from unsufficient data about market size and strength. If the only buyer is the company or agency developing the facility, the market is easily analyzed. For other situations, data on market size and the prices are hard to obtain. Without data on market size and prices, the optimum scale of facility development, product mix, and product pricing can only be guessed.

There is little published information about how containerized tree seedlings perform compared to bare-root seedlings (Owston and Stein 1974). Data are fragmentary, and results are hard to generalize. Although a number of large companies are accumulating data now for specific areas, good information for the variety of site conditions in the West may take years.[2] This makes sound analyses of market potentials for containerized seedlings difficult. The higher cost of containerized seedlings may be justified only if the cost per established tree relative to bare-root seedlings is favorable.

The technology of container seedling production, container shape and size, transport, and handling and planting in the field, is still rapidly evolving (Owston and Stein 1974), so, cost and field performance data quickly become obsolete.

The container planting system is new and glamorous compared to traditional nursery methods. Its advocates tend to be zealous about both real and unproven advantages of the system. In most cases, specific data do not exist to prove or disprove many claims about it. With a few notable exceptions,[5] much of the available data is biased and difficult to use for objective feasibility studies.

There are good reasons for the lack of market information. The product has not been fully evaluated. Its value to the buyer is difficult to assess. Pricing must be competitive with other producers,

[5]*Personal communication with James Arnott, Forestry Officer, Canadian Forestry Service, Pac. For. Res. Centre, Victoria, B.C.*

Table 4-3.—Site selection matrix.

Elements (rate 1-10, 5 average)	Element weight	Site alternatives: A		B		C		D		Contract		Combination of one or more	
		Rank	Prod.	Rank	Prod.	Rank	Prod.	Rank	Prod.	Rank	Prod.	Rank	Prod.
Advantage of assoc. w/ existing unit—Administration	6	8	48	3	18	10	60	2	12	8	48	5	30
Advantage of site now being available	10	10	100	7	70	8	80	0	0	7	70	5	50
Advantage of utilities on site	7	10	70	8	56	10	70	0	0	8	56	5	35
Advantages of closeness to market—Short term	6	10	60	4	24	4	24	5	30	5	30	5	30
Advantages of knowing fuel available now	10	7	70	6	60	7	70	7	70	8	80	5	50
Advantages of not having to build a headhouse	4	10	40	0	0	10	40	0	0	7	28	5	20
Advantages of being on economic-sized unit (economy of scale)	9	7	63	5	45	10	90	5	45	7	63	0	0
Advantages of control of quality	5	10	50	5	25	5	25	5	25	7	35	2	10
Advantages of full use of output	3	10	30	7	21	10	30	7	21	10	30	3	9
Advantages of nursery experience at site	2	7	14	0	0	10	20	0	0	7	14	5	10
Quality of greenhouse site— (heat reg.) (labor) (material & supp.)	6	3	18	3	18	6	36	8	48	8	48	5	30
Benefit to state forestry (and other agencies)	1	2	2	10	10	5	5	5	5	3	3	5	5
Benefit of economy of scale	1	10	10	0	0	0	0	5	5	0	0	2	2
Time to execute (time constraint)	5	10	50	5	25	10	50	3	15	5	25	2	10
PRODUCT TOTAL			643		372		600		276		530		291
Relative desirability			1		4		2		6		3		5

and there is some undefined demand for containerized tree seedlings, but it still appears to be a buyer's market.

4.22 Development Tactics—Alternatives

Limited development for evaluation.—This is a safe course, one that many have followed. The economic risk is low, because the amount invested is limited. The twin goals of (1) acquiring the technical capability to produce seedlings and (2) finding out how they perform in the field can be satisfied. Later decisions to expand or abandon the effort can be based on the added data obtained. The major drawback to this approach is that the economic benefits of a large scale operation are lost. Unit production costs will be high. This is true of most pilot projects and should be expected.

Lack of other sources and immediate need.—One of the advantages of container seedling facilities is that they can be developed rapidly just about anywhere. If an accelerated planting program is initiated, an agency or company can produce container seedlings rapidly without the time lag and huge initial expenditures required for bare-root nursery development. This is one reason companies in the Pacific Northwest recently developed container facilities.

Flexibility and reliability.—The intent here is to develop a limited container seedling production facility in conjunction with a bare-root nursery. Such a complementary arrangement has a number of advantages.

1. Rapid production of seedlings in the greenhouse can fill gaps in the overall program created by crop or seed failures in bare-root production (Stein and Owston 1977).
2. A greenhouse provides highly controlled propagation and culture where seed values are high or assured plant production is crucial.
3. Nursery labor force and other facilities can be used by both bare-root and container programs with resulting economies.

4.23 Feasibility Study

The procedure for conducting a feasibility study outlined below is based on work by Love (1975). Several basic questions need to be answered at the outset:

1. What species of trees in what size containers will be produced?
2. Where will these trees be planted, and what price would purchasers be willing to pay?
3. How much will it cost to produce the seedlings?
4. How many trees are needed?
5. What are the climatic and environmental constraints?
6. What are the management, land, labor, and capital requirements, and can these resources be secured?
7. What risk factors are involved (can the product be reliably produced, will it be accepted, can the investment be recovered in a reasonable time)?

4.24 Market Evaluation

Organizations contemplating creation of an internal CTS operation can do so without assessing demand, even though such an evaluation may be wise. Those planning production for others must evaluate markets to lessen investment risks. The market may be difficult to assess, but crude estimates are better than none, because overestimation can lead to serious consequences.

Potential market.—All potential customers should be contacted and information on the type and quantity of seedlings desired should be collected. The largest potential buyers should affect location of the facility, because CTS transport costs can be high (Colby and Lewis 1973). Separate clusters of demand may argue for smaller separate facilities.

Time of marketing.—Containerized seedlings may permit extension of the planting season (Stein and Owston 1977, and Mann 1977). Containerized trees, properly hardened, can be shipped any time of year. Depending on the nature of the planting sites and the volume to be planted, this can affect the market greatly.

Grade and quality of seedlings.—Only very high quality seedlings should be produced, because the cost of each tree is substantial. In addition, high transport costs preclude shipment of poor quality trees.

Species and container sizes.—Requiring a variety of species and containers increases the complexity of operation, which affects cost.

Transportation.—Containerized tree seedlings will be transported to a number of dispersed points in the forest. Since they are bulky and transport costs are high, the nursery should be centrally located to minimize haul distances. Estimated size of orders can also influence nursery location and mode of transport. Transport cost estimates may indicate more than one nursery, closer to the planting sites, to be the best solution.

Competition.—Commercial greenhouse operators are in competition with other greenhouses and bare-root nurseries. This may or may not be true of public or company operations, but, if the proposed operation will be in competition with other nurseries, the effect of this competition must be carefully gauged.

Price.—Some effort should be made to evaluate the price the market will bear and the price trends. These estimates should then be compared to estimated production costs and size of the proposed installation.

4.25 Production Cost Estimation

Product cost estimates are vital. For CTS production, the information regarding production costs is fragmentary; costs are different for each case. Location, climate, size of operation, type and number of crops, and the type of fuel and facilities used all have major impacts on cost of production. In the greenhouse vegetable industry, overhead or "fixed" costs account for approximately one-third of greenhouse production costs (Love 1975). Overhead costs have been increasing rapidly as building material, equipment, and interest rates have increased. But overhead, as a percentage of total cost, has been declining. Direct or variable costs have been increasing faster than overhead costs (Love 1975).

Overhead costs.—Overhead costs in government operations can be expected to be the same as for private industry. Even though there is no charge for capital, overhead assessments, and wage level constraints make up the difference. Indirect costs consist primarily of administrative costs and depreciation of facilities. The capital investment for the greenhouse, associated structures, and equipment may be high. As a result, depreciation per thousand plantable trees can be high (Colby and Lewis 1973).

Direct costs.—Labor, fuel, container, and delivery costs (or marketing costs) are the major direct or variable costs. All have risen sharply in recent years, especially fuel costs. Other direct costs such as water, fertilizer, pesticides, etc., are relatively minor.

1. Labor.—For tomatoes labor requirements for greenhouse production are more than twice that for normal field production (Love 1975). CTS culture is certainly not as labor intensive as greenhouse tomato culture, but may be more intensive than bare-root tree culture. The authors find that labor usually accounts for about 25% of the price of containerized tree seedlings.

   Some claim the bare-root nursery system is more labor intensive than the CTS system (Colby and Lewis 1973). This disagreement will not be finally settled until better data are published, but some digression here to clarify the argument seems worthwhile. CTS prices vary from less than bare-root prices to up to three or four times more, depending on a number of variables. If CTS stock costs of $120 per thousand (M) are assumed, then estimated labor cost would be $30. If bare-root seedlings are priced at $60 per M (for 2-year-old trees), about one-third of this price is usually fixed costs ($20). The remainder ($40) is made up largely of labor for culturing and lifting and packing, perhaps as much as $30 per M or more. Then, in this example, the labor cost for bare-root seedlings is 50% of the price. From this gross comparison, which is the authors' estimate for the western U.S., it can be seen that bare-root nursery production is more labor intensive than container operations, because labor costs make up a higher proportion of the product cost. Containerized tree seedlings probably require just as much or more labor per thousand trees as is required for bare-root stock. Although the percentage of the CTS price attributable to labor is lower than for bare-root stock, the total price usually is higher. The above is often not readily apparent, because most CTS operations are small compared to bare root nurseries. There are exceptions to this generalization, however. Arnott, for instance, has indicated that western hemlock seedlings, produced in the Pacific Northwest, are considerably less expensive when produced in containers.[5]
2. Fuel costs.—Fuel costs vary considerably with type of fuel used, climate, and facility. Fuel and other utilities account for about 25% of the cost of rearing CTS in the interior west, but may be as little as 5% in the Pacific Northwest or Southeast.[2] The increasing prices and questionable availability of some traditional greenhouse fuels makes selection of heating system type and fuel important in CTS nursery economic feasibility studies (section 4.14).
3. Seedling containers.—Containers and growing medium comprise the third major category of direct costs associated with CTS production. Containers come in a myriad of sizes and forms. The types available are discussed in section 9.2. Costs of these containers vary considerably, depending primarily on their size and construction, and whether they are recycled. Most containers must be filled with some kind of growing medium. Cost of the mix depends on its ingredients and the current market price of these materials. As a rule of

thumb, the cost of container and potting mix will be roughly 25% of the price of the tree.

4. Delivery (or marketing) costs.—Delivery costs include packaging materials and transportation. Packaging methods are not standardized. Transportation costs vary with the volume and weight of the product and distance from the production facility to the delivery point. The importance of the facility placement in relation to the delivery sites has already been discussed in section 4.17. Transport costs will usually be less than 10% of the product price for containerized tree seedlings.

4.26 Feasibility Assessment

When development tactics, market evaluation, product nature and quantity, and tentative location have been resolved, the feasibility of the project should readily be apparent. The work is in the collection of the data to compare, not the comparison. If cost of producing and delivering the CTS product does not provide a reasonable price, given the other factors in the situation, the enterprise is not economically feasible. For government or a private timber company the answer may indicate if it is wise to develop a facility or to procure trees from other sources. If such sources do not exist, a feasibility study may not be necessary, but is still recommended. Such a study forces consideration of as many aspects of the situation as possible and starts the development from a firm foundation of knowledge.

4.3 Development of Greenhouse Facilities

4.31 General Discussion

One of the most confusing aspects of developing a CTS facility is selection of a design. Alternative designs and equipment are well summarized by Ekblad (1973) and, in briefer form, by Newland (1974). Both explore the relative advantages of different greenhouse component options. The list of references compiled by Ekblad (1973) is a good place to look for further sources of information. Husby (1973) gives an excellent procedure for choosing the design of a greenhouse system for growing forest tree seedlings.

4.32 The Systems Approach

To assure that all considerations and requirements are drawn into the selection, a relatively simple systems analysis approach is warranted. It should be employed when there are too many factors and interrelationships to integrate without a systematic procedure. Bias and misconception can be minimized at the same time. Ekblad (1974) is probably the best reference available on the subject. In it he outlines a system design process:

"There is a temptation to look for a standard greenhouse system that is the optimum for growing containerized seedlings. Unfortunately, no single best system exists. Each species of plant has its own environmental requirement, each location has its own external environment and each manager has his own goals and cost constraints. Therefore, it would be surprising if a loblolly greenhouse in Georgia was exactly like a spruce greenhouse in Washington. What the manager needs is a total system that matches his requirements as closely as possible.

"Figure 4-3 illustrates the relationship of the greenhouse system to various requirements. Performance includes maximum and minimum inside temperatures, quantity of nutrient, quantity and quality of light, relative humidity, airflow and composition and others. Reliability includes avoidance of catastrophic failures, warning systems, and redundancy in controls. Under packaging and operability we define requirements for mixing soils, filling containers, seeding, thinning, transplanting, watering, fertilizing and preparing seedlings for transport to the planting site. Maintainability can be a tradeoff with reliability, the more reliable the systems the less maintenance required. All of these requirements are subject to cost limitations. Initial cost is important but annual fixed costs for depreciation, rent, insurance and taxes must be considered. Estimates of

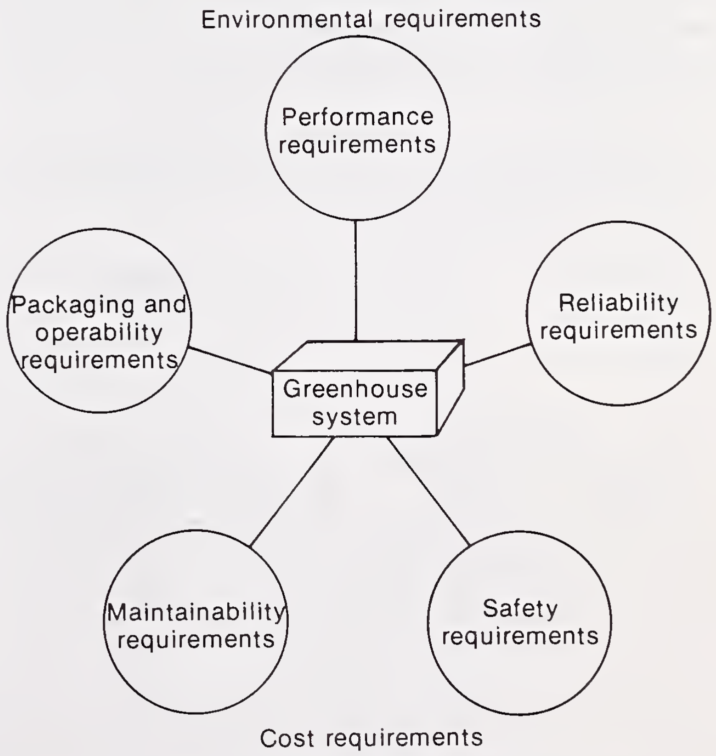


Figure 4-3.—A framework of system design (Ekblad 1974).

operating costs for fuel, electricity, fertilizer, growing media, containers and labor should be made. The manager may want to consider other less tangible costs such as cost inflexibility, possible changing land values, or energy shortages. Once a location is selected many of the environmental factors become fixed; maximum summer temperatures, minimum winter temperatures, snow loads, windspeeds, degree days, solar angle, daylight hours, solar energy, etc. If there is an option of locations this should be considered as a method of changing environmental requirements. In figure 4-4 we have a model of the systems engineering process. The process begins on the left with information. In this case it may be from a manager who wants yearly production of a number of seedlings, of a certain size and species and in a certain biological condition at a specified time within cost limits. The next step is to establish the requirements that will meet these goals. After detailed requirements are established we can look for solutions. This may be existing commercial equipment and components or it may require new designs. Concurrently, we begin technical analysis and testing, if required, to determine whether the proposed designs meet the criteria which has been established.

"I have been told that there is only one independent consulting engineer in the United States who specialized in greenhouse design. Unfortunately, there is no single book that covers all phases of analysis and designs in detail. However, there are many technical publications on greenhouse design, particularly from the American Society of Agricultural Engineers. Manufacturers and their representatives willingly supply information. Assistance is also available from engineers in state and federal government.

"The next step is evaluation and decisionmaking. The decision may be to propose new solutions and modify certain requirements.

"In summary, the system design process should be an orderly, step by step process. In the case of a greenhouse system it is especially important that the team include an engineer and a biological expert and that each be willing to continuously evaluate and change their solutions and requirements to meet the original goals."

4.33 Biological Considerations

The most important weight should be given to those requirements that provide environmental control for growing the species of tree seedlings wanted. In some instances, only a rudimentary greenhouse may be required, in others, a fully-controlled one is necessary. In each case, the biological requirements of the seedlings must be satisfied at the location specified. Several companies on the West Coast have developed semicontrolled or uncontrolled facilities for containerized seedling rearing. They are taking advantage of the mild, Pacific maritime climate, an option not available in most western states. They trade climatic risk and slower seedling growth, for lower initial capital investment. Where this has been done with a sound evaluation and understanding of risks involved, it has been successful.

4.34 Size

The size of the projected greenhouse development is determined by the size and number of trees to be reared and how long each crop will be in the house. Often, more than one crop is grown per year in a greenhouse. This can occur under several circumstances.

1. The trees reach the required size in less than 6 months, making it possible to rear two or more crops a year.
2. One crop of large trees, taking perhaps 8 months to grow, is followed by another crop that can be grown in 4 months.

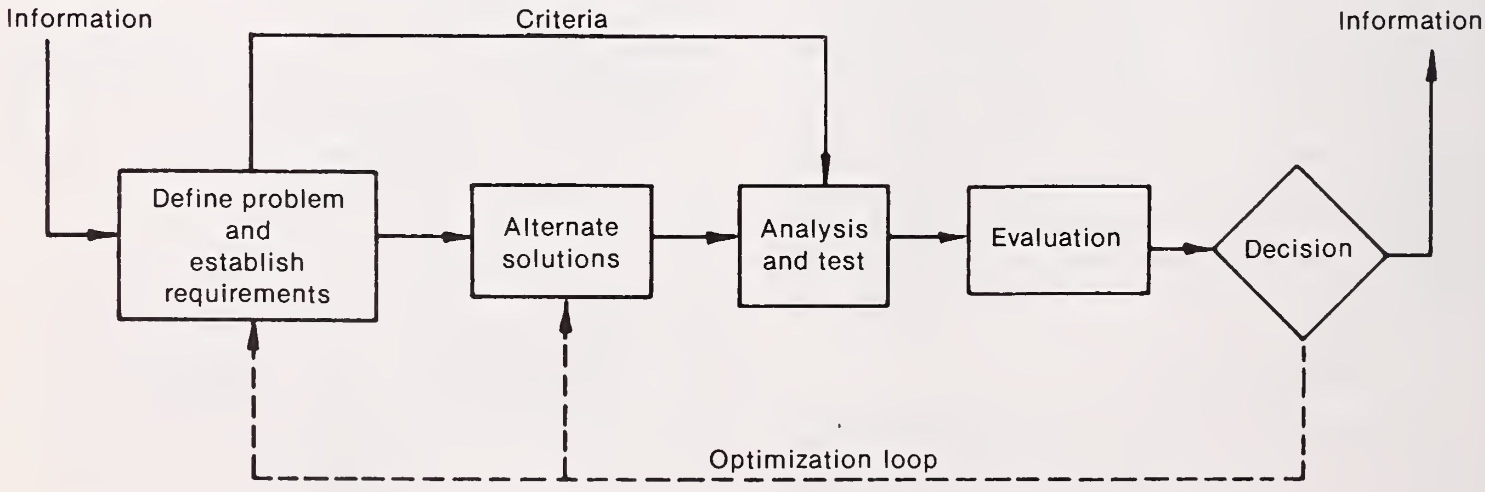


Figure 4-4.—Model of the system-design process (Ekblad 1974).

3. For one of two crops grown in the greenhouse, it serves only as a starting facility. The started crop is transferred to another growing site, such as a shadehouse, for continued growth. The second crop is then started and grown in the greenhouse.
4. The greenhouse serves only as a starting facility. Crops are started and then transferred elsewhere for growth to full size (finishing).

In other cases, only one crop may be grown per year in some greenhouses. This is true if the species grown is slow-growing, the container size is large, or it is biologically or economically advantageous. It can occur where the crop is ready in less than a year, but trees are left in the greenhouse for protection from winter temperatures, excessive rainfall, or for dormant season storage. The time the seedlings are in the greenhouse, and the resultant area of greenhouse space required, depends a great deal on the climate of the site selected. Options for utilization of the greenhouse space are more numerous in mild climates. In very cold climates, fuel costs may be so high only summer operation of the greenhouse is economical. The space required depends on:

1. The number of seedlings to be grown per year.
2. The percentage of seedling survival in the greenhouse.
3. The number of crops to be grown per year.
4. The numbers of months of operation per year.
5. The net usable bench space planned per house.
6. The type of container used.

The ability to grow a CTS crop of a certain species and size in a given time is discussed in Section 15. A procedure to convert this into a seasonal cycle and then calculate the actual greenhouse space needed is covered in section 5.3. Size of other buildings, etc. is discussed in section 7. In the initial planning phases of a project, detailed information is not needed to estimate size of a development and its cost. Final design efforts will take care of details once the decision is made to go ahead.

4.35 Summary

The demand for CTS planting stock, either real or projected, must be the starting point. Product demand, integrated with the biological requirements of the species selected and the climate at the proposed site, provide parameters for greenhouse design and scale. Several design alternatives will probably be viable. The one finally selected will depend on factors such as available capital, perspective, etc., but the overriding consideration is that the design selected must be capable of controlling the growing environment to successfully meet the biological requirements of the species.

SECTION 5.—GREENHOUSE FACILITIES

SECTION 5.—GREENHOUSE FACILITIES

The first step toward selecting the components for a greenhouse facility is to consider how much modification of the natural environment is required to produce the required size of seedling in the time allowed. Biological requirements in general and specific requirements for many species are presented in later sections, and the reader should consider these before making a final selection of hardware. Later sections also tell why various greenhouse components are needed and how necessary they are.

This section briefly explains common greenhouse designs and lists the advantages and disadvantages of the materials currently available for their construction, but gives little operational and biological detail. Information on why components are needed and how necessary they are is covered in later sections.

How to orient the greenhouse and locate it properly with respect to obstacles that cast shadows is explained in detail. The procedure for determining number and size of greenhouses and bench layout within each is presented using specific examples.

A brief cogent primer which provides a rational basis for design, selection of equipment, and operation of practical and efficient greenhouse climate control systems has been published by Augsberger et al. (1975).

5.1 Greenhouse Framework and Covering

A wide variety of greenhouse structures and covering materials are available. The traditional glass greenhouse is only one of several options available. Several plastics are suitable for greenhouse coverings, and structures have been designed to be compatible with the physical properties of plastic.

5.11 Structures

In a commercial greenhouse, the structure is intended to provide support for the covering material and suspend certain auxiliary equipment. The structure should cause a minimum of shading during daylight hours.

Supporting structures for commercial greenhouses can be grouped into four categories: rigid frame, truss support, column support, and air supported. Four common rigid frame structures are shown in figure 5-1. They can be covered with either flexible or rigid plastic; the frames are usually spaced on 4-foot centers. These frames have a lateral outward force induced at the ground level. Therefore they must be restrained by foundations, footings, or pipes.

Originally, a single layer of film plastic was used as a covering, but double layer plastic has been so successful that it is now used almost exclusively. The double layer film is separated by air pressure from a small centrifugal blower. Commercial models have continuous clips that hold the plastic in place. This provides a very tight, well insulated house and overcomes the tendency to tear and flap in the wind.

Usually, the end walls are covered with a rigid plastic, regardless of whether the top is film or rigid. This facilitates framing around doors and other openings. Recovering is also simplified if rigid plastic is used over the first section that has cutouts for heaters, etc.

Examples of truss and column supported structures are shown in figure 5-2. These structures were widely used for glass houses. Some have been adapted to plastic covering. They can be used to cover wide spans, but they tend to create shading or restrict movement because of interior supports.

Almost any of the freestanding structures shown in figures 5-1 and 5-2 can be adapted to connected units as shown in figure 5-3. This arrangement reduces heat losses and uses less land. However, the units also shade each other on short winter days because of the low sun angle, allow diseases to spread more quickly, and are more susceptible to breakage from snow load.

A summary of several types of frames is given in table 5-1.

Miscellaneous construction tips.—Paint wooden structures white to increase reflectance. In snow areas have roof of at least 5/6 pitch to slip snow from a plastic house. Allow enough space between houses for accumulation of the snow that falls from the roof. Never treat greenhouse wood with pentachlorophenol or creosote, as the fumes may kill plants; use copper salts and paint. Concrete foundations may be used but are not necessary. Consider protection from rodents and birds.

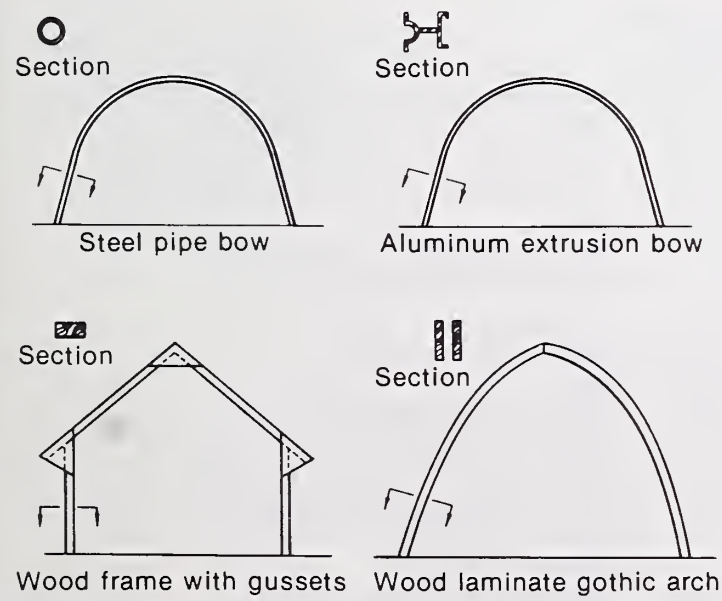


Figure 5-1.—Freestanding rigid frame structures (Ekblad 1973).

5.12 Covering

There are basically three types of covering material for greenhouses. These are glass, rigid plastic, and plastic film. There are several factors to consider in selecting a type of covering material:

(1) Solar energy transmitting properties (table 5-2)
(2) Heat transfer properties (table 5-2)
(3) Weatherability
(4) Susceptibility to vandalism
(5) Support structure required
(6) Ease of construction
(7) Condensation of water
(8) Cost (Table 5-3)

Duncan (1972) summarized the general characteristics and performance data of the more widely used materials.

Polyethylene (regular and UV stabilized).—

1. Lowest cost covering, but must be replaced periodically.
2. Widely available, although some manufacturers report recently they have stopped production of this product for greenhouse use. Be cautious about buying any product of unknown quality for greenhouse use.
3. Relatively short life in the sun: regular—9 to 11 months, UV stabilized—14 to 30 months.
4. Splits easily at the folds. Use unfolded or lay-flat rolls for maximum life.
5. Transmits approximately 85-88% of the sun's light.
6. Transmits all wavelengths of action spectra required for plant growth.
7. Transmits the wavelengths of thermal radiation which allows the house to cool more rapidly at night.
8. The strength of the new 4- and 6-mil (100- or 150-μm) film is one to two times that of the 1/8-inch (3-mm) standard glass.
9. Permits double layer covering, which results in 35-40% reduction of heat loss, reduced condensation, and only 8-10% reduction in light due to the second (clean) layer.
10. Provides a tighter house with less air leakage, which causes somewhat higher inside humidity.
11. Most useful for low cost temporary or seasonal coverings.
12. Polyethylene film reinforced with synthetic fibers is also available at a cost four to five times that of regular film, but generally this material is not used for greenhouses.
13. Double layer covering on top side of structure with centrifugal fan developing pressure between the two layers is a way to reduce labor and installation costs. Life equal or better than that of conventional installation methods.

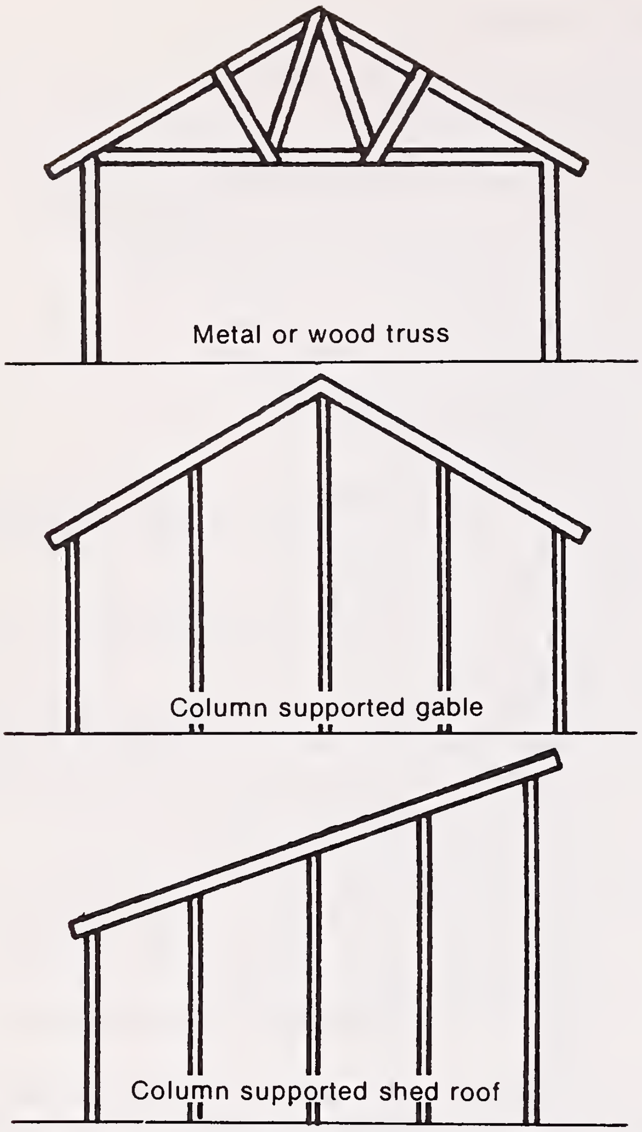


Figure 5-2.—Freestanding column supported or truss frames (Ekblad 1973).

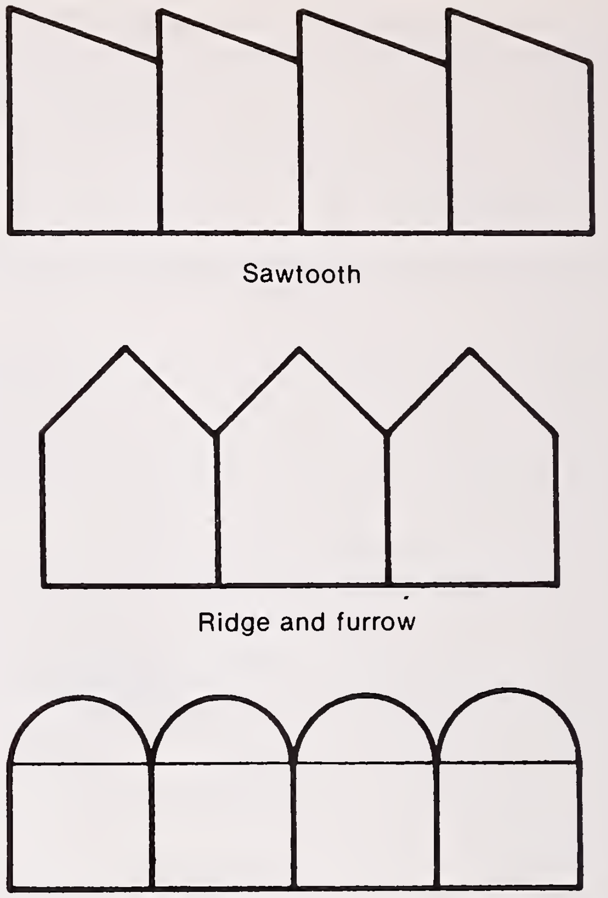


Figure 5-3.—Connected versions of freestanding frames (Ekblad 1973).

Table 5-1. Greenhouse frame.

	Covering				
Frame	**Glass**	**Film plastic**	**Rigid plastic**	**Commercially available**	**Comments**
Steel pipe bow		X	X	Yes	widely used for film plastics, minimizes shading, inexpensive.
Aluminum extrusion bow		X	X	Yes	deluxe version of steel pipe bow.
Wood frame with gussets		X	X	No	easily fabricated, considerable shading, plans available.
Wood laminate gothic arch		X	X	Yes	very lightweight, uses very little wood, plans available.
Metal or wood truss	X	X	X	Yes	widely used for glass houses, considerable shading when wood is used, suitable for wide spans.
Column supported gable	X		X	Yes	widely used for glass houses, restricts movement, suitable for very wide spans.
Column supported shed roof	X		X	No	simple construction, frequently used in connected houses.

Table 5-2.—Sunlight transmittance and radiant heat loss protection of common covering materials (Hanson 1963, Duncan and Walker 1970, Cathey 1961).

Material	Percent transmittance (0.4-0.7 μm)	Percent radiant heat loss protection
Window glass (94 mil)	89	93
Polyethylene film (no condensation)	73	26
Fiberglass (15% acrylic modified tedlar coated)	90	99

Vinyls.—

1. UV stabilized forms are more resistant to sunlight than polyethylene and last 2 to 5 years.
2. Cost is 3-10 times that of polyethylene, depending on thickness.
3. Made in narrow widths (5 to 7 feet). Must be heat-seamed together by manufacturer for wider widths.
4. Soft and pliable material.
5. The material tends to be electrostatic, which causes it to collect dust and dirt. This necessitates regular cleaning.

Polyvinylfluoride.—

1. The Tedlar® film has proven to have excellent weatherability, but is too costly to compete with other films as a covering. It is being used as a surface coating which is molecularly bonded to fiberglass panels to improve their weatherability.

Polyvinylchloride (PVC).—

1. Transparent to solar radiation, but the unprotected polymer darkens during weathering by the influence of UV rays. Most of the materials have not been suitable for more than 2 to 4 years as a greenhouse covering and, therefore, are no longer advised for greenhouse use.

Plexiglass®—

1. An acrylic plastic that has been available for many years but has not been widely used as a greenhouse covering because of high cost, except for special climatic or conservatory type facilities.
2. It is much more resistant to impact than glass.
3. Transmits approximately 90-92% of available sunlight and is available in UV-transmitting and UV-absorbing types.
4. Has long life and weathering resistance compared to glass.
5. Softer than glass; it is easily scratched and is sensitive to some solvents.
6. Costs appreciably more than glass and other possible covering materials.
7. Flexible enough to be used as curved panels in glasshouses.
8. Strong enough to resist snow and ice loads near gutters of connected houses.
9. Expands and contracts greatly with temperature changes and should not be directly nailed or screwed down but held under a cover strip with soft mastic sealer to allow movement.

Fiberglass reinforced rigid plastics (FRP).—

1. Many brands of the polyester resin reinforced with fiberglass are available in flat and corrugated forms. Corrugated form adds strength.
2. Made in weights from 4 to 8 ounces per square foot (1.2-2.4 kg/m²), widths up to 51½ inches (131 cm) (48-inch (122-cm) coverage), and lengths precut up to 30 feet (9 m) or more on special order. Use minimum numbers of joints and laps to reduce chances of dust and dirt accumulation between panels and also air or water leakage. Use proper clear sealer on laps for tightness.

Table 5-3.—Comparison of greenhouse covering costs (1972 Dollars) (Duncan and Walker 1972).

Material	Initial cost ¢/ft²	Installation labor cost ¢/ft²	Years expected life	Maintenance cost, aver. per year	Cost per year per ft²
Poly (4, 6 mil)	1-1½¢	1½-2¢	1	—	2½-3½¢
Poly UV (4, 6 mil)	2-2½¢	1½-2¢	2	—	2-2½¢
Fiberglass, 15% acrylic modified					
(4 oz.)	20-25¢	1½-2¢	8-10	1½¢	3-3½¢
(5, 6 oz.)	30-35¢	1½-2¢	12-15	1½¢	2¼-2½¢
Tedlar Coated, (5, 6 oz.)	40-55¢	1½-2¢	15-20	½¢	2½-3¢
Glass	50¢	2-3¢	30 +	1-1½¢	2-3¢

3. Cost ranges from 20 to 30 cents per square foot ($2.15-3.20/m^2) for 4- to 5-ounce (1.2-1.5 kg/m^2) panels, 30 to 35 cents ($3.20-3.75/m^2) for 6-ounce (2.4-kg/m^2) panels, and 45 to 55 cents for Tedlar coated panels. Culls (Grade B) and assorted lengths are sometimes as low as 15 cents per square foot, but be cautious of the quality of these products.
4. Two to four times more resistant to impact and lateral loading than glass. Crazing (not shattering) usually results from impact, but this crazing has no harmful effect unless the panel surface is cracked or broken.
5. The polyester of the panels burns freely and rapidly; entire houses have burned in approximately 10 minutes. Flame retardants and good weatherability have not been successfully combined. Insurance on fiberglass is not easily obtained.
6. Clear or frosted panels of greenhouse-quality material transmit approximately 78-90% of available light when new. Non-greenhouse formulations, especially colored panels, should be avoided.
7. Panels with 15% acrylic additive have proven more durable than straight polyester formulations.
8. Acrylic modified polyester panels need cleaning at least annually, and generally resurfacing with an acrylic liquid sealer every 4 to 5 years to restore weathered surfaces to near-new transmission and surface condition (except Tedlar coated). The durability of the sealer coat is questionable and is under study.
9. Some manufacturers' guarantees are rather nebulous. Until accurate evaluation procedures and quality standards are established, judge a product more on its performance and company reputation than by the guarantee.
10. Proper attachment to the structure and sealing and fastening of lapped joints are essential for resistance to wind forces. (Use fasteners every 8 to 12 inches (20-30 cm) on ends and sides, or follow manufacturer's specifications.)

Regular Glass.—

1. Single strength and small panels are not used much on newer designs and constructions. Replacement of panes in existing houses should be with double-strength glass for more resistance to breakage.

Tempered Glass.—

1. Two or three times stronger than regular glass.
2. Frosted or "hammered" types available for better light.
3. Larger pane sizes permit fewer structural members; hence, less shadows.
4. Requires special structural members and glazing methods to give water and airtight construction.

Figures 5-4 and 5-5 give spectral transmission curves for several covering materials. Some of the materials have a very high transmittance in the infrared. This causes greenhouses covered with high transmitting materials (e.g., polyethylene) to cool very rapidly at night. Table 5-4 gives the thermal transmittance for several typical materials.

Table 5-4.—The mean thermal radiation transmittance of selected materials (Walker and Slack 1970).

Material	Transmittance percent
Glass 3/32 inch thick	4.4
Polyethylene 4.70 mil	70.8
Polyester 5 mil (mylar)	16.2
Polyvinyl chloride	12.0
Resin bonded fiberglass	1.0

In summary, the best greenhouse structure and covering is one which fits the goals and constraints of the developer. The cost or structural features should not be the only consideration in selection. The greenhouse is an engineered system with interactive components. For example, a structure with high heat losses will require greater heating capability and more fuel. Consultation with agricultural engineers, the local greenhouse industry, and the local greenhouse supply industry can guide the developer

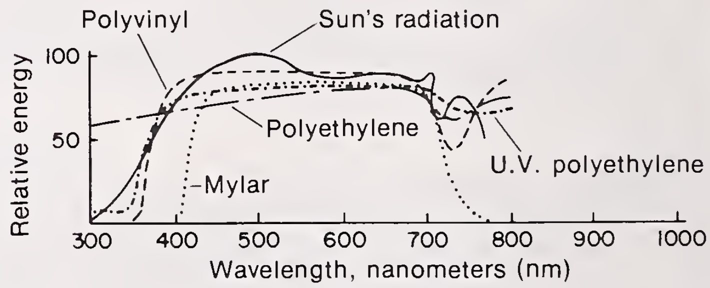


Figure 5-4.—Spectral transmittance of selected film greenhouse coverings (Walker and Slack 1970).

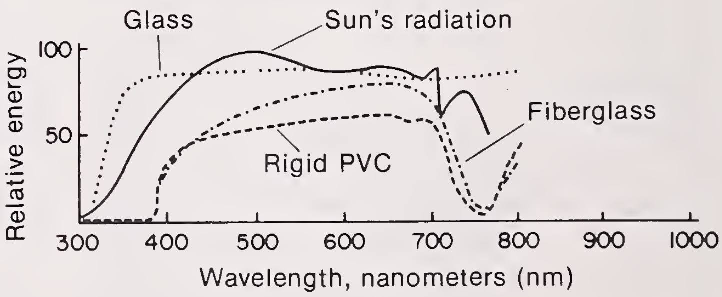


Figure 5-5.—Spectral transmittance of selected rigid greenhouse covering materials (Walker and Slack 1970).

around many pitfalls. Contact the state agricultural extension service, or state university engineering or horticulture department for advice.

5.2 Layout and Orientation

5.21 General Discussion

The general layout of a CTS nursery should permit maximum production efficiency. This is the second axiom of CTS operation development, especially in large operations. (The first axiom is provision for a biologically sound growing environment). Hoenke (1974) lists basic steps to accomplish this goal.

Select container handling system.—If this is speculative because of lack of experience, the system should be as flexible as possible so it can accept a variety of types and sizes of containers and pallets, etc. The planner should decide if the system is to accommodate a forklift or other rolling stock for moving trees.

Determine greenhouse size.—This depends on species to be grown, containers to be used, and dates of shipment to be targeted, as well as economics and availability. A greater number of small houses can provide the grower with more product and delivery flexibility than a few large ones. It also means more equipment, more duplication and redundancy, more exterior wall area to heat, etc., which increases fixed and variable costs. Therefore, a good balance between the efficiencies of larger houses and the flexibilities of smaller houses is needed.

Plan access to the greenhouse.—Quick and easy access should be provided to all greenhouses. The spacing between houses and/or width of roads should permit access to the greenhouses by the largest equipment that will be used, allow room for snow removal, and allow adequate room for free exhaust and intake of air. Road surfaces should be smooth and firm enough for all-weather use to aid container handling and provide a sanitary surface around the greenhouses. The work center or headhouse needs to be readily accessible to the greenhouses and should be designed to provide all the necessary functions of shipping, receiving, potting, and seeding (section 7.1).

Integrate flow of materials.—The whole design should integrate all systems so that the flow of materials is constant and smooth for maximum efficiency. Several floor plans should be made and analyzed with flow diagrams made for each phase of work (fig. 5-6).

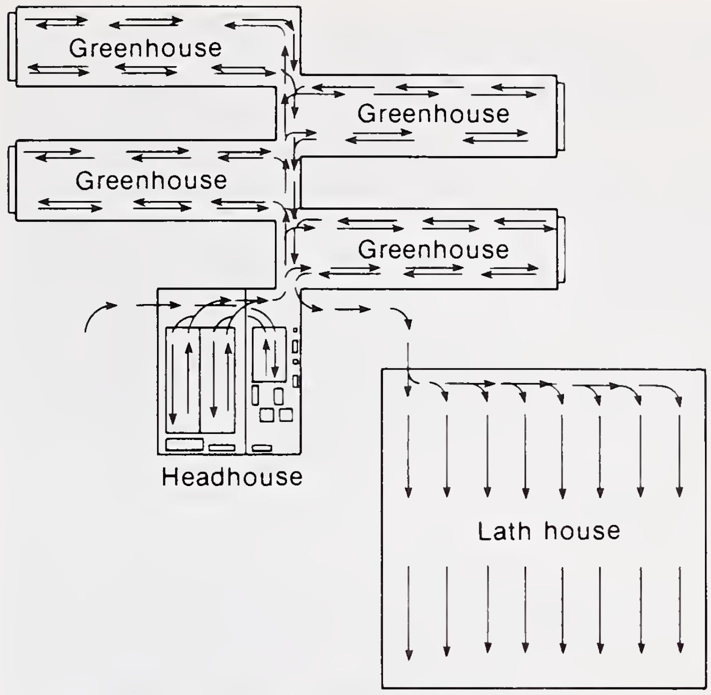


Figure 5-6.—Pallet movement diagram (Husby 1973).

Planning for growth from a pilot or trial project to a large production nursery is often a difficult development problem. Under these circumstances, the planner must foresee future expansion. Short-sighted development of trial projects with no thought of future expansion can make later expansion expensive and difficult.

5.22 Ridgeline Orientation

Maximum light transmission is needed when days are short and the sun remains low in the sky. Sun angle calculations, therefore, should use figures for the growing period when the sun is lowest in the sky. The orientation of the long axis (ridgeline) should be perpendicular to the direction from which most solar radiation comes in the winter. Bozeman, Mont. will be used as an example. During December, the solar energy arriving at the greenhouse is only sufficient to be effective between about 9 a.m. and 3 p.m. During this time, the sun altitude varies from 10.7° at 9 a.m. to 22.3° at noon, as measured from the horizontal (fig. 5-7). The bearing angle varies between 41.5° east of south to 41.5° west of south (Husby 1973). This indicates that an east-west ridgeline orientation is necessary.

At Bozeman, during December, the mornings tend to be more cloudy than the afternoons (Husby 1973). To take advantage of this phenomena, a slight cant of the ridgeline to the northwest would be required.

This calculation could be modified for the same location if, for instance, a mountain blocked the sunrise until 60° south of east and at 20° elevation at 10:30 a.m. Under these circumstances, the ridgeline would be canted more to the northwest-southeast line to capture the maximum amount of energy available from the daylight in December.

At lower latitudes, where the sun is higher in the sky in the winter or crops are not actively growing in midwinter, this orientation of the ridgeline will not be so important. Often, greenhouses are constructed with the ridgeline on a north-south line when the south endwall is transparent (except possibly for exhaust fans) and cooling pads are placed at the north wall. This orientation is usually satisfactory for tree growth, especially when coverings, such as plastic film or fiberglass, are used that diffuse the light and eliminate most shadows.

5.23 Shadows

Shadows from adjacent greenhouses.—Where several greenhouses are to be placed in a parallel arrangement, avoid having one greenhouse shading the next one. Such shading can be eliminated by simply providing a large allowance of space between greenhouses. A more realistic approach, because of high real estate costs, is to minimize the space required between greenhouses. This can be done by making a couple of assumptions and a few calculations. The information needed is:

1. The height of the greenhouse structures from the ground to the top of the ridge of the roof.
2. The angle of the sun from the ground at the time of day at the time of year for which the calculations are made.

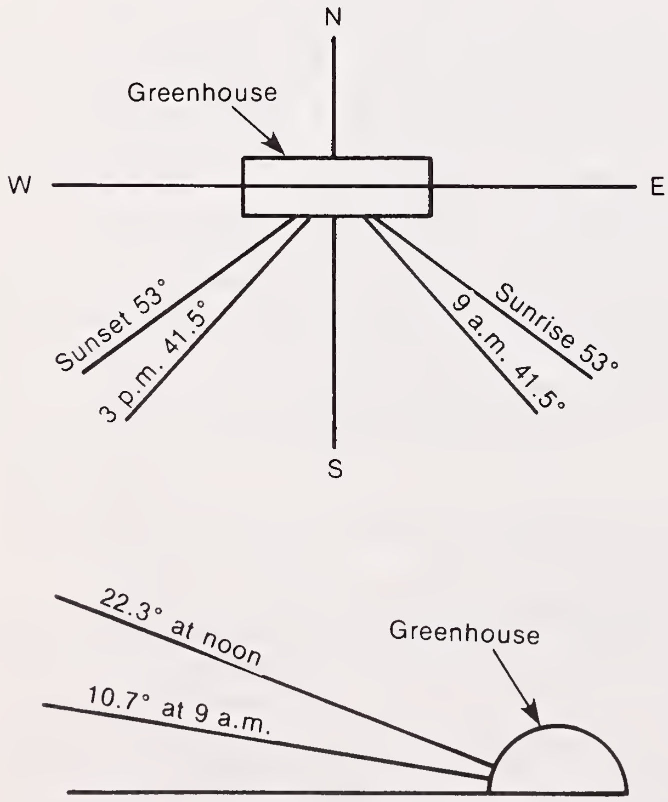
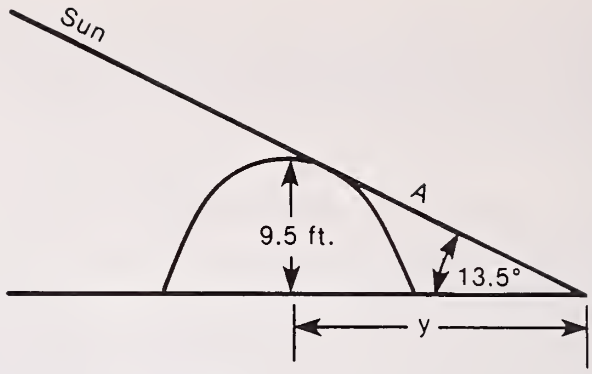


Figure 5-7.—Sun altitude and bearing angle at Bozeman, Mont., in December (Husby 1973).



$$y = \frac{9.5}{\text{Tan } 13.5°}$$

$$y = \frac{9.5}{0.24}$$

$$y = 39.6 \text{ ft.}$$

Figure 5-8.—Calculation of greenhouse shadow over the ridgeline (line A) (Husby 1973).

3. The angle of the orientation of the long (lengthwise) axis of the greenhouse with respect to true north.

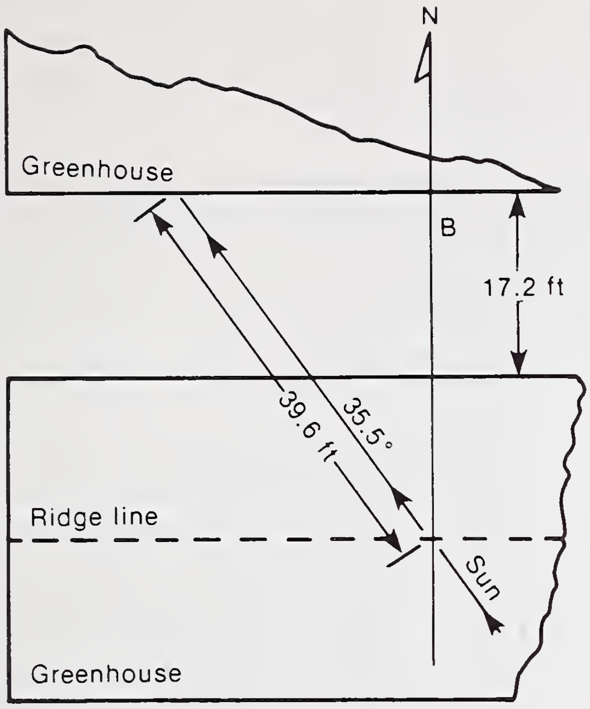
Use the method shown in figure 5-8 to calculate the length of shadow along the line of sun angle over the ridgeline of the greenhouse (Husby 1973). Next, find the length of the shadow perpendicular to the ridgeline in December (fig.5-9).

Note that in this example the ridgeline is east and west, but it may not be in many cases. Also, no compensation is made for ground slope in any direction.

Headhouse and corridor shadows.—In the design and layout of the greenhouse complex, attention should be given to minimizing the shadows cast onto the greenhouses by supporting buildings or structures. This can be done by placing opaque structures, such as cooling pads or headhouses, on the north side of the greenhouses. Cooling pad systems along the sides of the greenhouses (cross-flow cooling) should be kept short enough to be below crop height in the house.

Where a corridor is necessary with greenhouses branching off from either side of it, some shadows cannot be avoided. However, the effect can be minimized by constructing the corridor of transparent or translucent materials.

In summary, structure shadows can be compensated for by a thorough greenhouse planner. The planner should also note the surrounding trees that could cast shadows on the greenhouses. The probability that someone might construct a large building on adjacent property that would shade the greenhouses should also be considered. This is a problem of "solar right-of-way" which is important for greenhouses and solar-energized buildings.



$z = 39.6 \cos 35.5°$
$z = 39.6 \times 0.814$
$z = 32.2$ ft

Minimum space, m
$m = 32.2 - 15$
$m = 17.2$ ft

Figure 5-9.—Calculation of greenhouse shadow perpendicular to the ridgeline (Husby 1973).

5.3 Number and Sizes of Greenhouses Needed

5.31 Starting Information and Assumptions

The following must be known or assumed to complete these calculations.

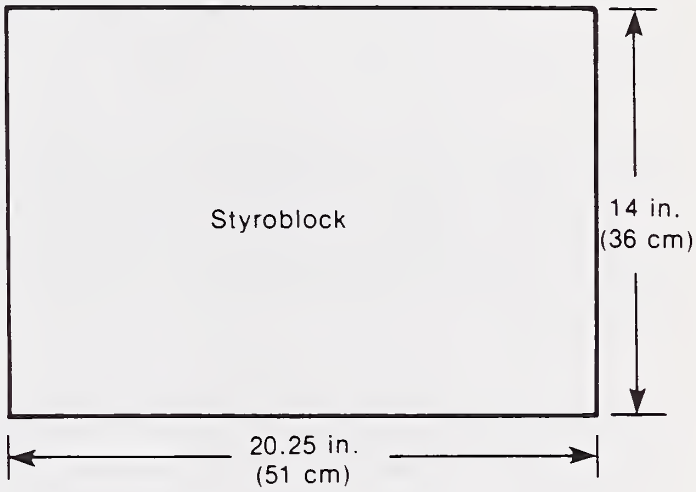
1. How many trees are to be produced per crop?
2. How many different growing environments will be required to produce the crop (i.e., how many different tree species requiring separate environments)?
3. What containers are to be used?
4. Will these containers be placed on pallets, benches, or other systems?
5. What are the minimum aisle widths? This ties into the proposed system of moving the containers.
6. What are the target dates for seedling shipment?
7. How long will it take for the species to be grown to fill the containers adequately and to reach shippable size?

If these items are known, then the greenhouse space required, the different environments necessary, and the number and size of greenhouses needed can be calculated. The greater the number of species to be grown and the greater number of container types and sizes to be employed, or shipment dates needed, the more complicated the procedure will be.

If some assumptions are made at the outset as to size and type of house, the calculations are greatly simplified. Following is an example from Ekblad (1973), where a size of greenhouse is assumed and a container type is selected. The result is a straightforward calculation. Assume that space must be provided for 1 million trees per crop. Houses are available commercially 30 feet (9.3 m) wide and 96 feet (30 m) long. Trees are to be grown in styrofoam containers. The styroblocks are to be placed on pallets, which can be rolled into and out of the greenhouse on permanent tracks. Dimensions of an available styroblock container are given in figure 5-10.

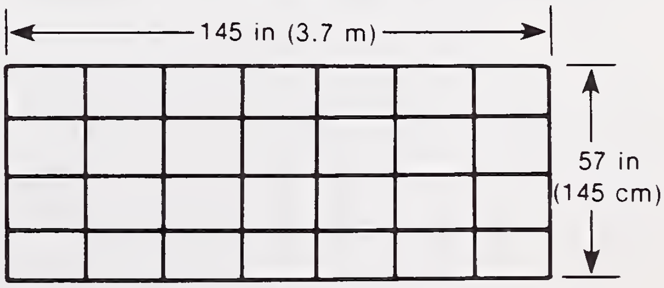
A convenient size of pallet is considered to be about 12 by 4 feet (3.7 × 1.2 m).

Consider the styroblock layout in figure 5-11. This means pallet dimensions must be 4 feet 9 inches by 12 feet 1 inch, which allows 3 feet of aisle with 1½ feet



192 holes per block
Holes - 16 x 12

Figure 5-10.—Dimensions of an available styroblock (Husby 1973).



Pallet dimensions - 4 ft 9 in x 12 ft 1 in
(1.47 x 3.74 m)

4 x 14 in = 56 in
7 x 20.25 in = 141.75"
Allow 1/4 in. space (6 mm)
between each block

Figure 5.11.—One possible layout of styroblocks on a large pallet (Husby 1973).

of space at each wall. Allowing 2 feet between pallet and cooling pad provides 94 feet of growing area, with 20 pallets along one side with 40 per house. Number trees = 40 × 28 × 192 = 215,000 trees per house. Trees per crop = 4 × 215,000 = 860,000 trees per crop (no blank cavities).

Consider an alternate styroblock layout (fig. 5-12). This results in a pallet 5 feet 1½ inches by 13 feet 1 inch, which allows a 2-foot (60-cm) aisle with 1 foot (30 cm) of space at each wall, and 3.5 feet (1.1 m) between pallet and cooling pad. There would be 18 pallets along one side, with 36 per house. Number of trees = 228,000 per house. Number of trees per crop = 910,000. The difference in width between these two layouts is small. Therefore, the 13 by 5 foot (40 by 1.6 m) pallet appears to be the better choice. Using the larger pallets can produce 100,000 more trees per year.

However, if very few specifications have been placed on the nature of the projected operation, the calculations become very complex. Usually, the developer will have some of the information necessary to do the calculations; values for other items must be assumed. Following is a discussion of each question in more detail.

How many trees are to be produced per crop?—If the initial goal is pilot testing the container systems or testing the market, the scale of production will probably be small.These calculations are then greatly simplified. Some level of production must be targeted at the outset.

How many different growing environments will be required to produce the desired crop(s)?—See sections 10 and 12 for information on the biology of different tree species and their compatibility in the greenhouse. Other considerations are the duration of the rearing period and the target date(s) for seedling delivery. The major tree species to be grown and when they are needed is usually known.

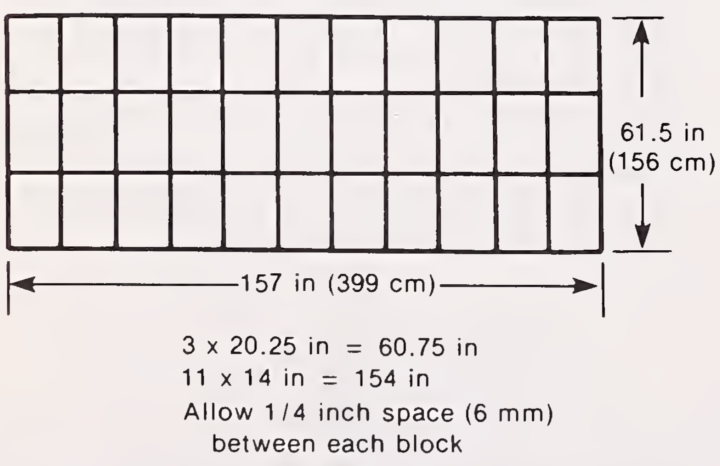


Figure 5-12.—An alternate styroblock layout (Husby 1973).

The duration of the rearing period for each tree species is estimated, based on the experience of others, then refined by the nurseryman's own experience (section 15).

What containers are to be used?—A large variety of types and sizes of containers are available (section 9.2). Each type has its advantages and disadvantages. The greenhouse developer should select container types and sizes he wants to field test or sell. This selection should be based on the best local knowledge concerning:

1. The minimum size that will produce good seedling survival for each species, and
2. The type of container that will work best given local transport and planting methods. In a new development, a variety of types and sizes will probably be desirable, with fewer used after the trial period. It is easier to select one or two types and sizes to use for most of the greenhouse space, and limit trials of other types and sizes to small numbers. The greater the number of container sizes and styles employed, the more complicated space calculations are. Often, a single style is chosen to simplify calculations, although several types will be employed.

What kind of greenhouse benches will be used?—Will the containers be placed on pallets, benches, or some other support system? Such systems are discussed in detail in section 7.4. The handling system will affect greenhouse space estimates. The problem is fitting the containers on the support/handling units. Sometimes greenhouses are built without regard to container size or bench configuration. Benches and containers are then fitted in a haphazard way following construction. This is not a recommended practice. The support system should be selected before construction.

What are the minimums for aisle widths and other spacing?—This must be a part of the support-handling system plans. Aisles and doors must be wide enough to accommodate a forklift or a pallet system if these are to be used. Aisles are also needed for inspection and thinning operations and to allow air circulation. Some systems have fixed benches with a few narrow aisles and a moving platform which can carry workers over the trees for thinning, etc. Sometimes the benches slide or can be moved to create a walking space, but elsewhere there is a solid array of trees. The most common system is benches or tables to hold the containers with a center aisle of medium width and permanent, narrow, lateral aisles between benches. This last system is probably the cheapest to install, but sacrifices some greenhouse room to lateral aisles that otherwise could be used for production.

Usually, 1 or 2 feet (30-60 cm) of space between the greenhouse wall and the benches is provided. The reasons for this are (1) to keep the plants away from hot or cold air flow immediately adjacent to the exterior wall, and (2) to allow free air circulation, up and down, along the exterior wall to minimize air stagnation.

The containers are usually placed no closer to cooling fans and pads than 2 feet (60 cm) and are usually at least 4 to 5 feet (120-150 cm) away. This avoids undue chilling of the closest plants. Similarly, plants are usually kept at least 2 feet (60 cm) away from exhaust fans and, preferably, 4 to 5 feet (120-150 cm) away. Areas immediately adjacent to exhaust fans are subject to accelerated air velocities which dry the trees excessively. These floor space losses can often be retrieved by using air plenum chambers to dissipate velocity or encourage total laminar air flow within the house. However, cost of such designs must be measured against the greenhouse space lost.

What are the target dates for seedling shipment?—If medium-sized trees are wanted in about equal numbers in the fall and spring, it may be feasible to operate a single house year round with no "down" or inoperative period. However, large trees may require 10 months growth with the greenhouse inoperative for 2 months (one crop per year). Another example would be delivery of large trees in the spring and smaller or faster growing ones in the fall. Under such conditions, a crop can be reared in the house from midwinter to spring, then transferred to a shadehouse for further growth and overwintering before planting. After that crop is removed to the shadehouse, another crop is started in the late spring in the greenhouse and grown until early winter. This way the greenhouse space is used to the maximum extent. Consequently, the interaction between delivery target date, species, and container will greatly affect needed greenhouse space. These production tactics need to be determined before space calculations are made.

How long will it take the desired species to reach the size wanted?—Some information is available from research and from operating nurseries for many tree species. In other instances, guesses must be made based on growth of related species. Projected growth rates for some species are given in section 10. Each greenhouse environment is slightly different no matter how closely it is controlled. Consequently, the same trees can grow at slightly different rates in different houses, even if controlled environment settings are the same.

5.32 Space Calculation Example

Consider the following hypothetical situation (table 5-5). The trees will be grown on benches 30 inches (76 cm) high, 3, 4, or 5 feet wide and in 4-foot-long modules. There will be 18-inch (45-cm) thinning aisles between benches and a center aisle in each at least 5 feet (1.5 m) wide.

It is expected it will take species A 10 months to reach adequate size, species B 7 months, and species C four months.

Bench space necessary.—Following are the calculations, by species:

1. Species A.—Spencer-Lemaire 30 cubic inch (492 cm³) Rootrainer® containers come four cavities to a "book" and 10 books fill the company's wire rack (see section 9.2 for discussion of container types). So, 40 cavities fit in a rack that is 11¼ by 18½ inches (29 × 47 cm) outside dimensions. Allowing an extra ¼-inch (6-mm) spacing on each side of the rack produces dimensions of 11½ by 18¾ inches (29 × 48 cm) and provides 5.39 square inches (35 cm²) per cavity or 1.497 square feet per 40 cavities, or 3.743 square feet per 100 cavities. If a 91% success rate is assumed, about 110,000 cavities will be needed, or 1,100 times 3,743 square feet = 4,118 square feet (382 m²) of usable bench space will be required. (Note: percent success rates are selected for ease of calculation. Normally they derive from experience.)
2. Species B.—Leach Super Cells® fit in trays with 200 cells per tray. Trays are 12 inches (30 cm) wide and 24 inches (61 cm) long. Allowing ¼-inch spacing on each side of the tray provides a

Table 5-5.—Hypothetical variables for calculating space requirements based on given production goals (M = 1,000).

Number	Species	Size	Container[1]	Season to plant
100M	A	large	30 cubic inch (410 cm³) Spencer-Lemaire	Fall (October)
200M	B	medium	Ray Leach Fir	Spring (May)
350M	C	medium	Styroblock 4	Spring (June)

[1]*Trade names are used only for specificity and brevity, and do not imply any endorsement by USDA to the exclusion of equally suitable products.*

bench density of 97 cavities per square foot (1,045)/m²). If a 91% growing success rate is assumed, about 220,000 cavities will have to be employed to produce 200,000 trees. Therefore, 220,000 ÷ 97 = 2,268 square feet (210 m²) of usable bench space will be needed.

3. Species C.—The Styroblock® 4 (3.94-cubic inch (65 cm³) cavity volume, gross) measures 13-7/8 by 23¼ inches (35 × 59 cm) and has 160 cavities. Allowing ¼-inch (6-mm) spacing on each side of the block brings dimensions to 14-1/8 by 23½ inches and produces a bench density of 69.41 cavities per square foot (748/m²) bench space. Assuming a 90% growing success rate, 350,000 cavities will have to be sown to produce 315,000 trees. So, 350,000 ÷ 69.41 = 5,042 square feet (468 m²) of usable bench space needed.

Number of greenhouses needed.—Greenhouse type and size are often selected before bench space needs are really known. When this is done the layout is simplified. For this example, the selection of the greenhouse size has not been made, because the species and delivery time compatibility must be considered. Let us say the growing environment required for species A is not compatible with the other species (section 10) and at least 10 months are needed for growth. From the above calculations, more than 4,100 square feet (370 m²) of greenhouse bench space are needed.

The case is more complicated for species C (5,042 square feet (468 m²) of space needed, delivery in June, 4 months to grow in the house) and species B (2,268 square feet (210 m²) of bench space needed, delivery in May, 7 months to grow). Since the total growing time is less than 12 months, there is a chance two crops may somehow be produced in the same greenhouse, even though both crops are to be shipped in the spring. This possibility can easily be investigated. While the months are available in the year to grow both crops (11 needed, 12 available), the common delivery date means one crop has to be grown and wait until shipment time while the other crop is grown. Feasibility of this can be tested by constructing growing "scenarios" diagrammatically using a circle to represent a yearly cycle (fig. 5-13).

Next the projected delivery dates for the crops are located. The growing periods for one crop and then the other can be plotted around this "clock face." There are two possibilities.

First, suppose we raise species C as a winter crop and species B as a summer crop. Figure 5-13 shows that species C can be grown from mid- or late December to the May delivery time. Species B can be grown from mid-May to mid-December and then moved to a shadehouse for overwintering and shipment from the shadehouse the following June.

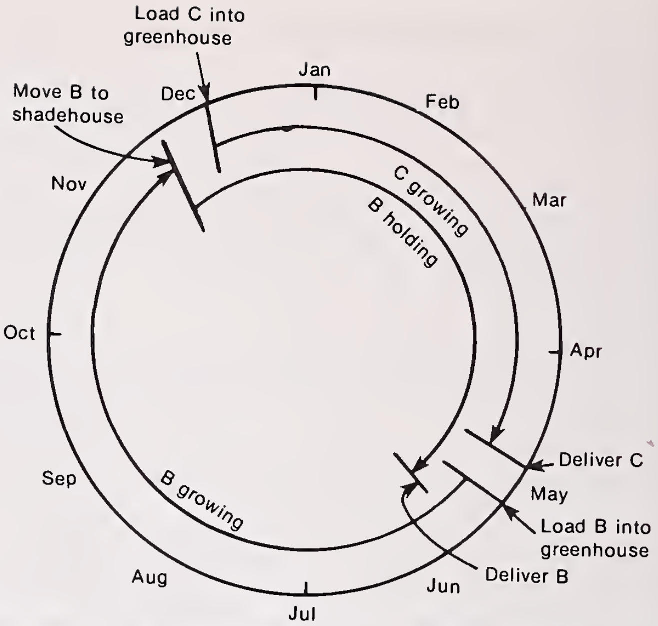


Figure 5-13.—Alternative 1. Grow species C as a winter crop and species B as a summer crop.

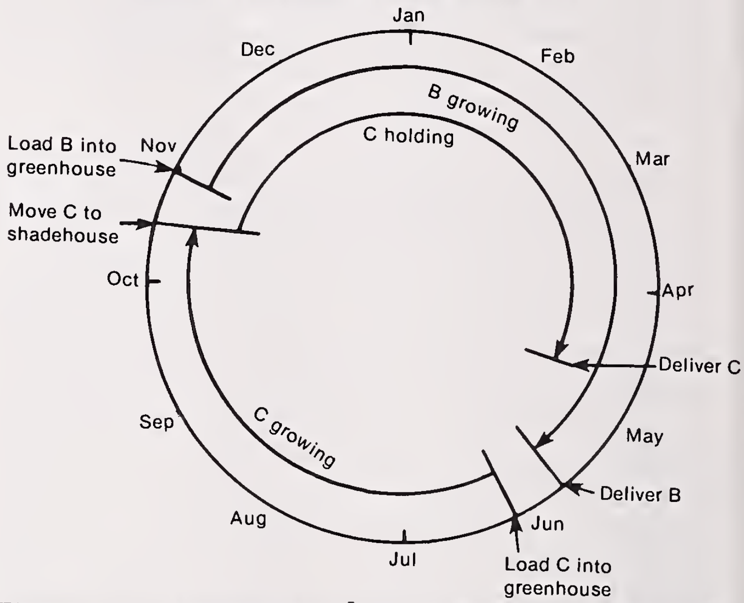


Figure 5-14.—Alternative 2. Grow species C as a summer crop and species B as a winter crop.

Holding species B overwinter in a shadehouse appears to be feasible, if this crop can be moved to the shadehouse after it has been hardened in the greenhouse.

Suppose, instead, species B is grown as the winter crop. Figure 5-14 shows that species C can be grown from early June to October, then moved to the shadehouse to overwinter. Species B would be loaded into the greenhouse about November 1, grown to June 1 and then shipped. Seven months are available to grow species B. Holding species C overwinter in a shadehouse is feasible and would be easier to execute than alternative 1. Also, species C goes into the shadehouse in October, which is biologically easier and safer. The same greenhouse facility can be used for growing both species B and C, so, alternative 2 appears to be the growing scheme to elect. At this point, note that the culture of species C will require about 5,042 square feet (468 m²) of greenhouse bench area, and species B will require about 2,268 square feet (210 m^2). This means, under alternative 2, the greenhouse will be more than half empty for seven months. This is important, since these months are high heating cost winter months. It is possible that provision can be made to heat only the producing half of the house when growing species B until business increases.

Before the decision is made to build one greenhouse for species A and one for species B and C crops, note the similarity of bench space requirements for species A and C (4,118 square feet (382 m^2) versus 5,042 square feet (468 m^2). If there is a way to grow both species in the same greenhouse, a number of other alternatives may open up, so, some investigation is warranted.

Species A and C can be grown in the same house, by growing species A from October to June in the greenhouse, then putting the trees into a shadehouse for the summer and delivering them in October. This means species A would grow in the greenhouse as long as 9 months and in the shadehouse for 4 months. Species C would be grown in the greenhouse from June to October and then be in the shadehouse until the following May when it is delivered. This plan would mean the greenhouse would be operated at capacity in the summer and that another house would be required for species B. The second house for species B could be smaller if two crops per year were grown, an advantage over alternative 2. However, this assumes that species A can finish its development in the shadehouse during the summer. It is reasonable to expect this, but the resultant trees may not be what is desired morphologically.

Assumptions about how well the trees will grow in the shadehouses are tenuous without experience, and can lead to variations in stock quality and added labor. If the production goals are definite and knowledge of how the trees would respond in a shadehouse is limited, it is safer to plan on two greenhouses of adequate size. Shadehouse growing could be tested later, and perhaps open the way for expanded production with the existing houses.

Remember that the milder the climate, the more the greenhouse may be used as a starting facility, and the greater the amount of growth that can be expected in the shadehouse. Most climates are somewhere between two extremes: one where the climate is so mild no greenhouse is needed for adapted plants to grow all year under shadehouse conditions; the other where a short growing season means all "accelerated" growth must be made in a greenhouse. This manual is oriented to average north temperate conditions. Plans for greenhouse utilization outside these conditions should take into account the difference from these average conditions.

In summary, alternative 2 is the selection with one house for species A and another house for species B and C. Two houses with approximately 5,000 square feet (464 m^2) of bench area each are needed. Since the area needed in each house is roughly the same, two very similar houses can be built. Similar houses offer these benefits:

1. Ease of maintenance
2. Fewer spare parts to stock, and interchangeability of parts.
3. Often the unit price will be a little lower when two are bought instead of one.
4. More visual harmony in the installation.
5. Greater ease of construction.

The structural types of greenhouses were discussed in section 5.1. Only dimensions will be discussed here.

5.33 Calculation of Dimensions and Interior Arrangement

It was assumed that the benches would be 3, 4, or 5 feet wide, in 4-foot (1.2-m) long modules. The center aisle is to be at least 5 feet (1.5 m) wide, and thinning aisles at least 18 inches (46 cm) wide. It is advantageous to have the same interior arrangement in each house. The planned container dimensions (including spaces between them for air circulation) are:

Species A: 11½ by 18¾ inches (29 × 48 cm)
Species B: 12¼ by 24¼ inches (31 × 62 cm)
Species C: 14-1/8 by 23½ inches (36 × 60 cm)

Assume that the parameters for greenhouse bench and aisle spacing are set by the container handling system to be used, the benches to be used, the house type, and the preferences of the developer.

Following are sample calculations for the two greenhouses, giving the containers and spacing requirements:

Species A.—A greenhouse with more than 4,118 square feet (382 m^2) of usable bench area is needed. Container dimensions are 18¾ by 11½ inches (48 × 29 cm). A 5-foot (1.5-m) bench width is chosen at the outset, first, because it is commercially available. Second, with aisles on each side, the bench center can be reached for thinning excess trees. Thirty inches (76 cm) is as far as anyone should be required to reach for thinning or weeding. If the reach is further, there is too much back strain, and the work rate cannot be maintained). Third, there is no advantage of using narrow benches (smaller units) in this instance.The question then becomes how to orient the containers on a bench 5 feet (1.5 m) wide and of length, yet to be determined, to best utilize the bench width and come up with a greenhouse width which includes bench, aisle, and wall clearance. Greenhouse width should also be of common commercial dimensions and economic size. To do this, the container width and length are multiplied to reach a total width of about 5 feet (1.5 m) to see how they fit in that dimension:

With the long dimension placed laterally:

18.75 inches × 3 = 56.25 inches
60 inches − 56.25 inches = 3.75 inches unused bench width
3.75 inches ÷ 2 = 1.875 inches (5 cm) unused width on each side of bench with containers centered.

With the short dimension placed laterally:

11.5 inches × 5 = 57.5 inches
60 inches − 57.7 = 2.5 inches unused bench width
2.5 inches ÷ 2 = 1.25 inches (3 cm) unused width on each side of bench.

There is slightly less wasted space when the short dimension is placed laterally. The best width of the green house can be analyzed the same way while allowing for aisle and wall spacing. The difference is that the limit of greenhouse width is not set, as it was for the bench width. This is overcome by calculating several greenhouse widths. The standard available widths can be found for the type of greenhouse structure desired. The number of containers making optimal bench length can then be fitted into these various widths for (1) best bench space utilization and for (2) best overall greenhouse length. The greenhouse length and width also affect heating and cooling design. The greenhouse manufacturer can advise as to the best range of dimensions.

In this calculation, we will assume the best greenhouse width is 50 feet (15 m). If the specified 5-foot (1.5-m) minimum aisle is deducted, with 18 inches (45 cm) between the benches and the wall on each side (total 36 inches or 3 feet) (90 cm) the net space available for benches is 42 feet (12.8 m). It was also specified the benches would be in 4-foot (1.2-m) modular lengths. With the aisle down the center of the greenhouse, there is 42 ÷ 2 = 21 feet (6.4 m) available for benches on each side of it. Since we are confined to 4-foot (1.2-m) modules, this becomes 4 × 5 = 20 feet (6 m) and the aisle becomes 5 + 2 = 7 feet (2.1 m) wide (or the spacing from the wall can be increased). The container orientation can then be fitted to the 20-foot or 240-inch bench length.

The short dimension (11.5 inches) will fit into 240 inches 21 times, with 1.5-inch overhang or 0.75 inch on each end.

11.5 inches × 21 inches = 241.5 inches
241.5 − 240 = 1.5
1.5 ÷ 2 = 0.75.

With three tiers (from the sample calculations in the first part of this section) of containers, 21 containers deep, there are 63 containers on a 5- × 20-foot (1.5- × 6-m) bench. The long dimension (18.75 inches) (47 cm) will fit into 20 feet (6 m) 13 times, with a 3.75-inch (10-cm) overhang or 1.875-inch (5-cm) overhand on each end of the bench:

18.75 inches × 13 = 243.75 inches
243.75 inches − 240 inches = 3.75 inches
3.75 ÷ 2 = 1.875.

With five tiers (from previous calculations) of containers 13 deep, there are 65 containers per 5- × 20-foot (1.5- × 6-m) bench. The choice of benches and container orientation is, therefore, (1) bench dimensions of 5 × 20 feet, and (2) containers 18.75 × 11.5 inches oriented on the benches with the long dimensions parallel to the bench length in five tiers of 13 containers or 65 containers per bench.

Now, 65 containers per bench becomes 130 containers per bench tier (on each side of the center aisle), and 130 containers cover 194.7 square feet (18.1 m^2) of bench space per bench tier (1.50 square feet (0.14 m^2) per container times 130). Previous calculations indicated a usable bench space need of 4,118 square feet (382 m^2) to rear the desired crop in this type of container, so, (4,118 ÷ 194.7) = 21.15 or 22 tiers of such benches are needed. This figure determines the minimum length of greenhouse required for species A.

It was stated that aisles between benches would be 18 inches (45 cm) wide, so, 22 tiers would require 22 × (5 + 1.5) = 143 feet (43 m) of greenhouse length with 5-foot benches. The first containers should be at least 4 feet from the cooling pads, and the last containers at the end of the house should be an equivalent distance from exhaust fans. A greenhouse about 150 feet (45 m) long will suffice, because 7,500 square feet (696 m^2) (150 × 50 feet) of space will be needed (with 22 tiers of benches 5 × 20 feet).

Species C.—A greenhouse with more than 5,042 square feet (468 m^2) of usable bench space is required. Container dimensions are 23½ × 14-1/8 inches (60 × 36 cm). A 5-foot (1.5-m) bench width is chosen for the same reasons indicated for species A. Calculations testing both orientations are then made to see how many containers can be placed on this bench width:

With the long dimension placed laterally:

23.5 inches × 2 = 47 inches
23.5 × 3 = 70.5 inches
70.5 − 47.250 = 23.25 inches (59 cm) unused bench width on each side of the bench with the containers centered.

With the short dimension placed laterally:

14.125 inches × 4 = 56.5 inches
70 − 56.5 = 13.5 inches unused bench width
13.5 inches ÷ 2 = 6.75 (17 cm) unused bench on each side with containers centered.

The short dimension (14-1/8 inches) should be oriented across the bench in tiers of four containers each to best utilize the bench width.

The best width of the greenhouse can be found by duplicating the calculations for species A. Again, the benches are in 4-foot-long (1.2-m) modules 5 feet (1.5 m) wide. As before, it is assumed the best design width, considering model availability, cooling factors, etc., is 50 feet (15 m). Therefore, the benches again will be 20 feet long on each side of the aisle.

Since the short axis of the container will parallel the 5-foot (1.5-m) dimension of the bench, the long axis (23.5 inches) must be fitted to the 20-foot length dimension:

23.5 inches × 10 = 235.0 inches
240 inches − 235.0 = 5.0 inches unused bench depth
5.0 inches ÷ 2 = 2.5 inches (6 cm) unused bench depth on each end of the tier.

The layout is then (1) bench dimensions of 5 × 20 feet (1.5 × 6 m), and (2) containers 14-1/8 × 23-1/2 inches (36 × 60 cm) on the benches oriented with the long dimension parallel the 20-foot axis and the short dimension parallel the 5-foot axis in four tiers of 10 containers or 40 containers per bench.

Forty containers per bench becomes 80 containers per bench tier (on both sides of the center aisle). Eighty containers (80 × 2.305 square feet) = 184.4 square feet of bench space per tier. Previous calculations indicated a usable bench space need of 5,042 square feet (468 m^2) for species C. So, (5,042 ÷ 184.4) = 27.34 meaning 28 tiers of such benches are needed. This figure determines the greenhouse length as follows:

Aisles between benches are to be 18 inches (45 cm) wide, so, 28 tiers would require 182 feet (55 m) of bench and aisle space (28 × (5 + 1.5) = 182 feet lengthwise down the greenhouse. If 4 feet (1.2 m) of space on each end is added between the benches and the cooling pads and fans, the greenhouse could be 190 feet (58 m) long.

Species B.—Because the area needed for species B is smaller than required for species C, and it will be grown in the same house, no calculations for it are needed.

This example illustrates how such calculations can be made. Other interior arrangements are feasible, but the sequence of steps and calculations would be similar. The greenhouse dimensions arrived at (50 × 150 and 50 × 190) are rather unusual. In some ways, three or four smaller units might be more flexible and desirable. However, large units are less redundant and may be cheaper per square foot of space. Much would depend on the type of structure to be used and the availability of different sizes. The developer should be prepared to change his preconceptions based on results of these calculations.

SECTION 6.—GREENHOUSE HARDWARE AND CONTROLS

SECTION 6.—GREENHOUSE HARDWARE AND CONTROLS

This section deals primarily with the equipment incorporated in a greenhouse structure that enables it to become functional. The section is designed only to acquaint the reader with the equipment and how it might relate to seedling culture, but no detailed examination is made.

6.1 Greenhouse Temperature Modification

6.11 General Discussion

Modification of the climate within a building to provide a uniform environment is a complex problem.

Figure 6-1 indicates the most important factors influencing a greenhouse temperature environment. Some problems unique to a greenhouse are: (1) very rapid heat buildup from solar radiation, (2) rapid cooling caused by lack of insulation, (3) high degree of internal cooling resulting from evapotranspiration, (4) undesirable shielding of sunlight by equipment, and (5) high humidity due to evapotranspiration.

These influences are countered by cooling and heating equipment. Engineering calculations based on climatic factors, environmental requirements for the crop, and structural factors determine the equipment needs and designs. A well established engineering and production industry supplies greenhouses and associated engineering services to purchasers. The industry will assist prospective developers with the details of greenhouse design, layout, and equipment. However, the buyer must beware. Before asking for help from a commercial firm, the developer must have some idea of what he needs and the quality he should expect. Otherwise, he may acquire equipment he does not need or that is poorly constructed.

There is considerable choice among components needed for greenhouse temperature modification and the way they can be arranged. An engineering firm can be hired to design the system, but this may be too expensive for the small developer, who more often makes his decisions on the basis of greenhouse manufacturers' or dealers' recommendations, and his own experience and knowledge. Visit other greenhouse installations, and talk to fellow nurserymen to get a measure of the reliability and competence of local greenhouse distributors. Try to deal with distributors who carry a full line of greenhouses and equipment to assure several choices of component combinations and prices. Ask what sizes are cheapest per square foot in each greenhouse type. Economics of design and frequency of sale of a given type or size often can affect prices drastically. Keep notes on all types of houses seen, comments by users, prices, etc.

The developer should also attempt to get a basic education in greenhouse physics and design calculation. A concise and cogent explanation of greenhouse thermodynamics, psychrometrics, and aerodynamics can be found in the "Greenhouse climate control handbook" from Acme Engineering (Augsburger et al. 1975). It explains how some greenhouse components are sized through the use of various mathematical formulas and rules of thumb. Other sources of information on equipment for heating and cooling greenhouses are A.S.H.R.A.E. handbooks and publications of the National Greenhouse Manufacturer's Association. Some understanding of the calculations for heating, cooling, and ventilating greenhouses can save the small developer much money. He can critically review greenhouse proposals provided by manufacturers from both a technical and a cost approach.

The design for heating and cooling a greenhouse is affected by what crops are to be grown at the site and in what season. A method for projecting crop growth through a seasonal rotation to optimize greenhouse space utilization is described in section 5.3. This projection can be used to relate greenhouse temperature requirements to the seasonal weather and to a projected growing schedule, as outlined in section 15. This schedule outlines the development of the crop at a given time and gives environmental conditions needed to maintain that development. Consequently, the nurseryman can supply the designer with environmental conditions to be maintained in the greenhouse for any time of year. These factors combined with capital investment and other constraints, will allow suitable design alternatives to be assembled for the developer's consideration.

The more specific the developer can be about crop requirements for the proposed operation, the better a greenhouse designer can tailor designs to needs. If the developer has only vague ideas of what he needs or wants in terms of greenhouse environment any given time of year, the designer must always plan to meet the most demanding situation. That may be more costly than necessary.

The designs of other greenhouse components (generators, nutrient injectors, benches, etc.) are best incorporated in the original design. However, these other components usually can be changed without upsetting the basic physics of the greenhouse. Therefore, the design and selection of these parts is not as critical as the design and selection of structure, covering, heating, cooling, and ventilation.

6.12 Cooling

A type of ventilating and cooling system which takes advantage of wind and convection is illustrated in figure 6-2. The degree of temperature control depends upon house configuration, wind speed, and temperature. Natural ventilation cooling is widely used in CTS nurseries in the cool climate of the Pacific Northwest.

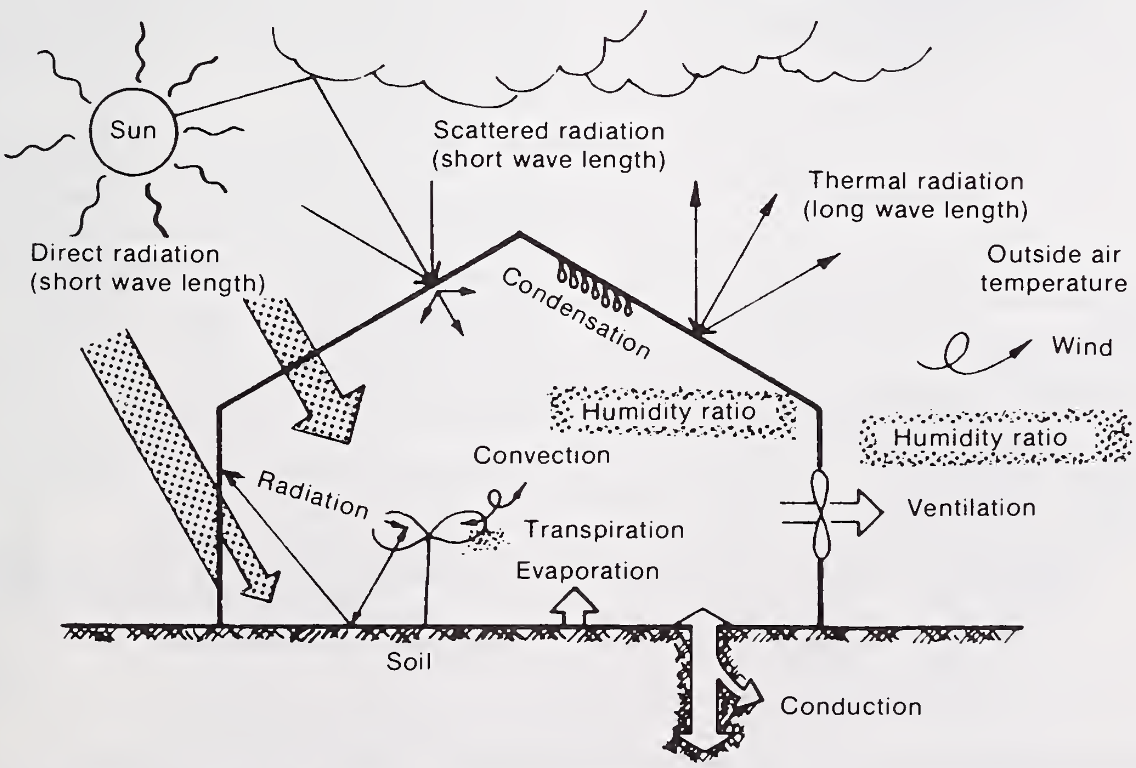


Figure 6-1.—Schematic representation of thermal environment of greenhouse (Ekblad 1973).

Exhaust fan cooling is similar in principle but provides positive control. The fans should be placed near plant level (figure 6-3) to minimize disturbance of hot air near the ceiling. These are usually sized by rule of thumb, based on air exchange rate. A widely used curve is presented in figure 6-4. Air exchange rates between three-fourths and one per minute are the most efficient. This curve is based on 50% of the incoming solar radiation being utilized for evapotranspiration. Generally, this system will maintain temperatures in a greenhouse 5° to 15° F (3-8° C) above outside dry bulb temperature.

Three types of evaporative cooling (figure 6-5) are used. The water spray may provide too much moisture and uses high pressure, and the small orifice nozzles are prone to plugging. The most popular is the fan and pad system. Pads may be of aspen excelsior, treated cardboard, or lava rock.

In addition to ventilating and evaporative cooling, various shading methods are used to reduce temperatures inside the greenhouse. Figure 6-6 illustrates some of the popular methods.

Synthetic fiber shade cloths may be stretched over the outside of a greenhouse to reduce greenhouse heating by the sun in summer. The degree of effectiveness depends on the opacity of the cloth. Shade cloths are available in grades providing shading range from 25% to 90%. An advantage of shade cloth is that solar radiation can be intercepted before it reaches the greenhouse. Studies in Arizona have shown this procedure to be an effective way to reduce greenhouse heating from solar insulation (Davis and Cole 1976). The same work revealed that placing shade cloth inside the greenhouse above the

Figure 6-2.—Natural ventilation (Ekblad 1973).

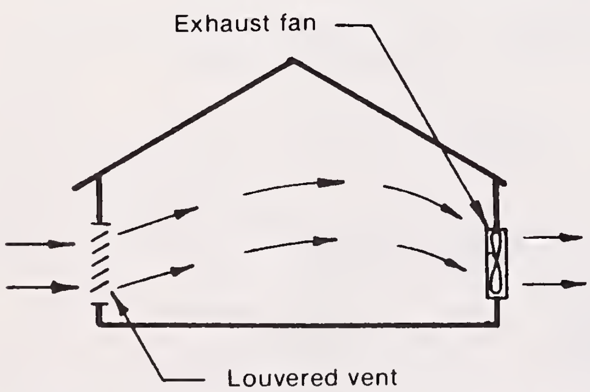


Figure 6-3.—Exhaust fan cooling (Ekblad 1973).

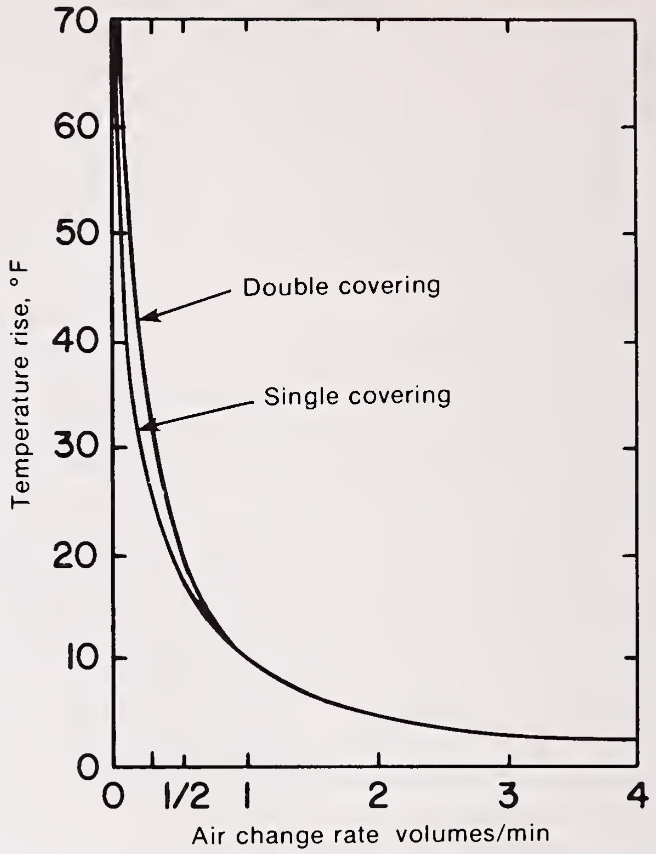


Figure 6-4.—Influence of air-exchange rate on temperature rise in single or double plastic-covered greenhouses (Ekblad 1973).

crop effectively raised greenhouse temperatures, although light intensities on the crop were reduced. Shade cloth inside the greenhouse may also interfere with proper ventilation.

A method used in California is to replace the plastic film with cheesecloth during the summer. This not only provides shading but increases ventilation. This is most practical when the plastic film is replaced annually.

In many parts of the country, it is common practice to paint the outside of the greenhouse in the summer to reduce the heat trapped in the structure and reduce the cooling load. Special greenhouse "shading compounds" are available which provide a translucent coating. Light or heavy coats can be applied depending on how much shade is desired. The paint usually weathers away, and many are designed to peel off with the first hard frost.

The advantages of such coatings are:

1. They are easy to apply.
2. Multiple coats can give different light intensities even in different parts of the same house.
3. They are economical.

The disadvantages are:

1. They are hard to apply evenly enough to

avoid variations in greenhouse light intensities.
2. Loss of paint due to rainfall may take place more rapidly than desired.
3. Collection of dirt on the paint may cause variations or increase in opacity of the greenhouse that are not wanted.
4. Light intensity cannot be conveniently increased once paint is applied.

Running water over the outside of the greenhouse can reduce internal temperatures, and can be done temporarily with a sprinkler in emergency situations. To be used over the long term, engineered systems would require soft water and filters, and possibly cause maintenance problems. Collection of water circulated between the layers of a double wall polyethylene covered house is one way to collect solar energy (Whitcomb 1976).

6.13 Heating

A common system of heating greenhouses is steam or hot water radiation using either plain or finned tubing around the house walls. A typical temperature

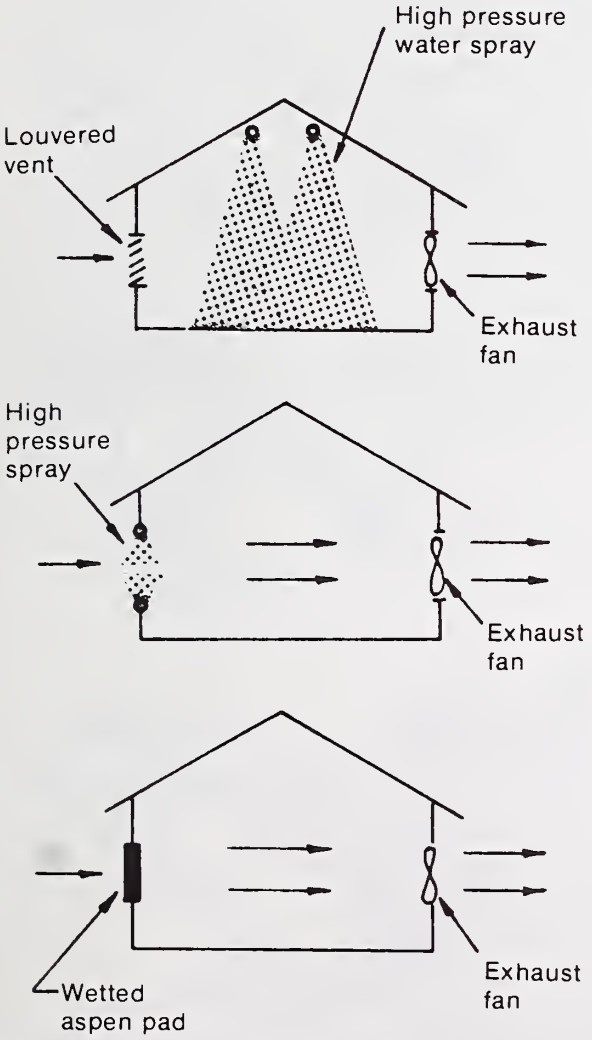


Figure 6-5.—Three types of evaporative coolers for greenhouses (Ekblad 1973).

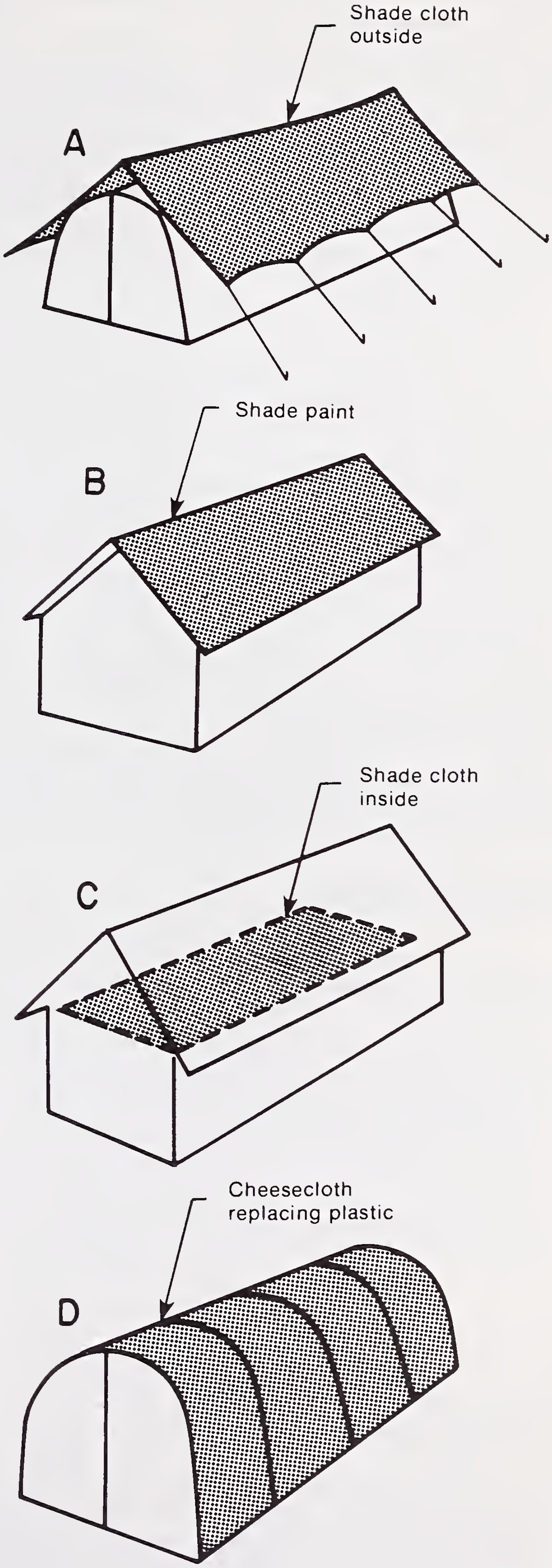


Figure 6-6.—Various methods of providing shade (Ekblad 1973).

distribution created by such a perimeter heating system is shown in figure 6-7.

This distribution can be improved by providing one-third of the total radiation uniformly across the house, either above or below the benches. An overhead circulating fan, referred to as a turbulator, is sometimes used to improve circulation. Figure 6-8 illustrates the airflow pattern expected by the manufacturer of this fan. The radiation tube heating method lends itself to large installations with a central heating plant.

Many new greenhouses, especially plastic covered ones, are heated with unit heaters. Some configurations are shown in figure 6-9. The most satisfactory are the two which incorporate an air distribution system in the form of a polytube. The polytube is a large polyethylene tube which is closed on one end and distributes air from many small holes in its side. These tubes may be used in multiple units, depending upon the size of the greenhouse. In severe climates, the addition of a cold air pickup hood at floor level reduces temperature differentials. An additional benefit of the polytube system is that it can be used to circulate air when no heat is being added, and it can be used as a mixing chamber to temper cold outside air.

The University of Kentucky has prepared nomographs for calculating heat requirements for greenhouses and estimating annual heat costs for greenhouses (Zimmerman et al. 1969).

6.14 Winter Ventilation

During hot weather, large quantities of air move through the greenhouse, either naturally or from fans, to provide cooling and ventilation. During winter, special attention must be given to ventilation to provide uniform heat, prevent high humidity, and provide gentle air movement around the plants.

In small greenhouses, ventilation and circulation may be provided by overhead fans and vents, windows, or doors. In the past several years, systems have been developed that give better results and are especially suitable for automatic controls. The major

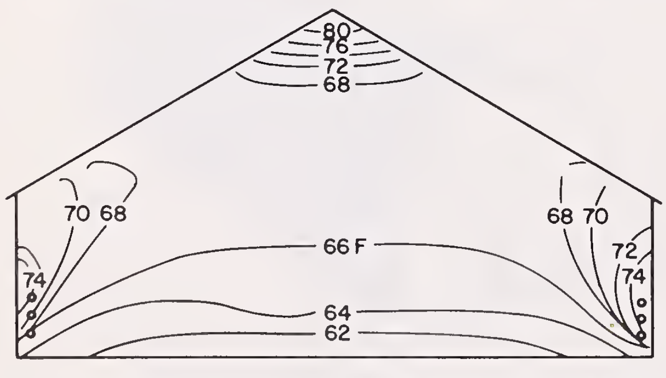


Figure 6-7.—Temperature profiles in a greenhouse heated with radiation piping along the sidewalls (Ekblad 1973).

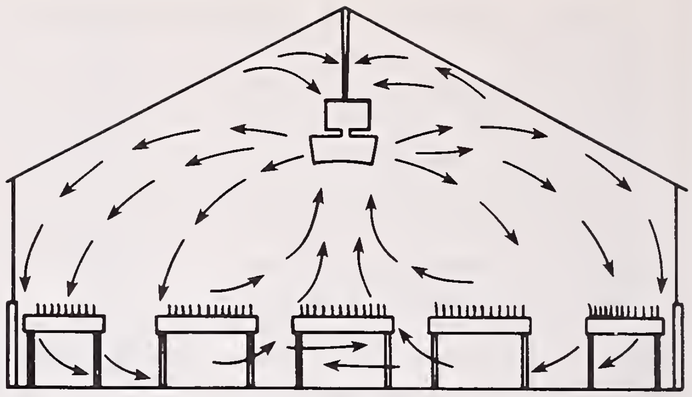


Figure 6-8.—Turbulator airflow pattern (Ekblad 1973).

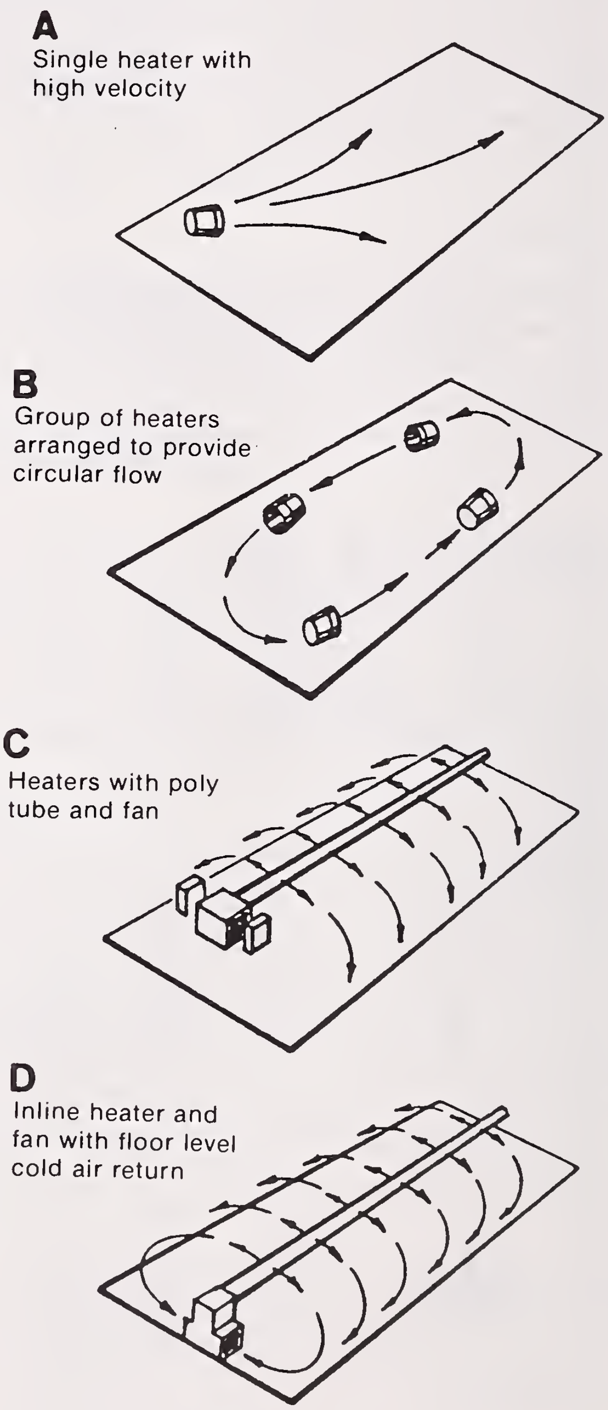


Figure 6-9.—Arrangement of unit heaters for greenhouses (Ekblad 1973).

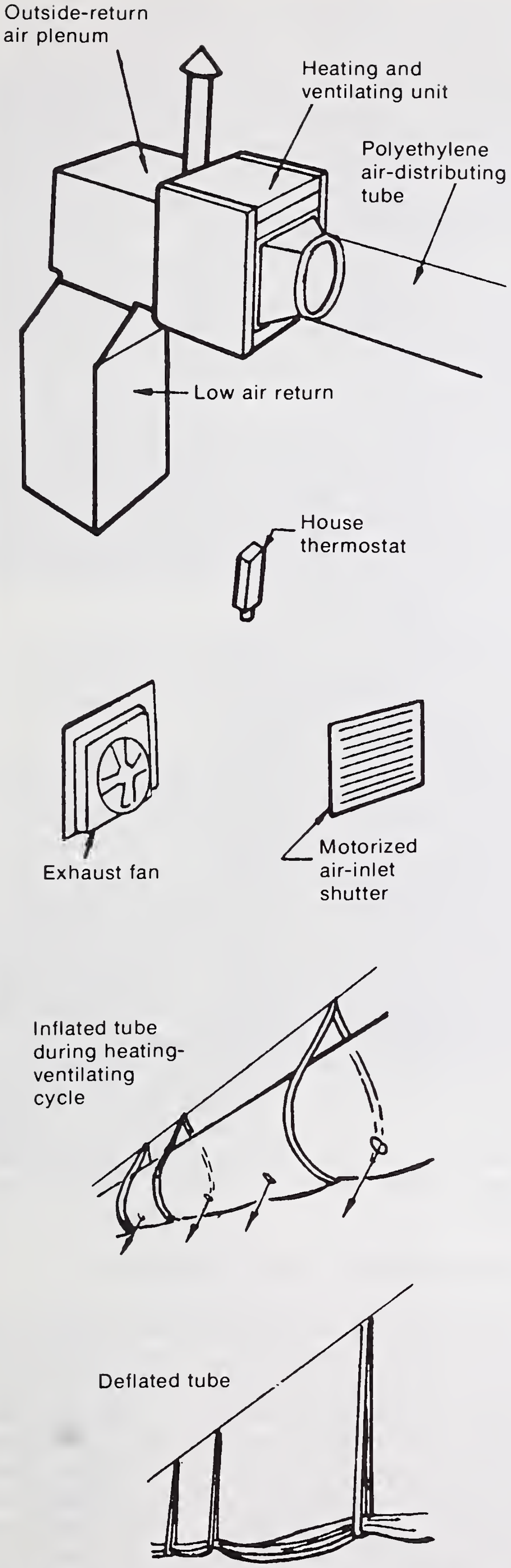


Figure 6-10.—Components of a winter ventilation system (Ekblad 1973).

components of a typical system are shown in figure 6-10.

The air circulation fan at the entrance to the polytube is allowed to operate continuously. The outside air inlet is operated to add outside air as needed for temperature and humidity control. The exhaust fan, which may be a part of the summer cooling system, is used in conjunction with the air inlet. Several types of cycles are shown in figure 6-11.

Several companies sell packaged or specially designed control systems that can include fan and pad cooling as well as winter ventilation (fig. 6-12).

6.15 Energy Conservation for Greenhouses

The increasing cost and scarcity of traditional fuels for heating greenhouses have prompted a very active research and development effort by government and industry to reduce the energy requirements of greenhouse operations. Some authorities believe far greater heat savings are necessary, if the commercial greenhouse industry is to continue as a viable segment of the agricultural economy (White et al. 1977). Some of the more basic energy conservation hardware and construction techniques such as thermal blankets and double-walled plastic or acrylic sheeting are already commercially available. The greenhouse developer should make sure to use the latest energy saving design and equipment that is economically justified in any new greenhouses.

However, potential greenhouse energy savings are not necessarily confined to equipment. White (1977) lists the following ways to save energy:

1. Select sheltered sites that are not in frost pockets (section 4.13).
2. Manage the greenhouse to maximize space utilization and solar energy capture:
   a. Minimize overhead piping and frameworks.
   b. Use effective windbreaks to reduce conductive heat loss.
   c. Keep covering material clean.
   d. Keep the greenhouse filled with plant material.
   e. Prevent shading of the greenhouse.
3. Modifications in cultural procedure can save energy:
   a. Lower plant growing temperatures.
   b. Plant earlier in the fall or later in the spring to take advantage of more natural heat from the sun.
   c. During coldest months, concentrate on plants that tolerate lower temperatures.
   d. Discontinue growing during coldest months.
4. Heat can be conserved:
   a. Install or convert to efficient boilers, burners, or heating elements.

b. Use efficient heat distribution systems. This includes insulating supply pipes, preventing steam or water leaks, and possibly skirting benches.
c. Use high quality controls that permit little temperature fluctuation and provide uniform heat patterns.
d. Seal and insulate the greenhouse. Use thermal blankets and perimeter insulation.
e. Where possible, use alternative energy sources such as solar, waste heat, or geothermal.

Care must be exercised to assure that equipment and structural changes made to save energy are economic. Also, it appears from recent research that a number of economical and effective energy conservation developments are forthcoming (Short 1977, Jensen 1977b, Hyde 1976, McDonald 1977a, Patch 1977, McDonald et al. 1976).

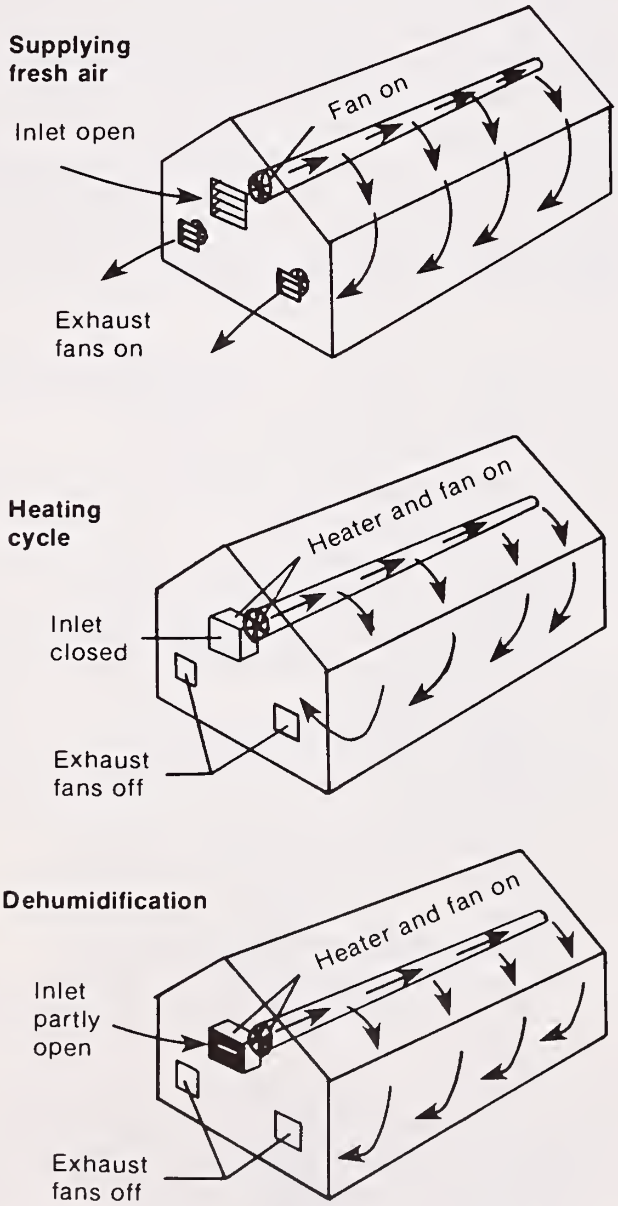


Figure 6-11.—Operation of a winter ventilation system (Ekblad 1973).

6.2 Greenhouse Lighting

The effects of light on CTS growth are discussed in section 12. Artificial light is provided to seedlings for two purposes: (1) to increase photosynthesis and (2) to prevent dormancy.

6.21 Lamps for Photosynthesis

To provide enough light to induce effective photosynthesis is quite expensive and probably impractical in most CTS nurseries, because 7-12 kilolux are required. Where it can be justified, the following lamps can be used:

The Xenon arc was one of the first high intensity sources used for photosynthesis. Its spectrum approximates sunlight, but it is very high in infrared. The light must be filtered through a water bath to make it suitable for plant growth. The arc also needs a flowing water jacket for cooling the bulb, which complicates the installation.

A quartz-iodine arc light also produces a very "white" light and makes very good building lighting for people, but produces a lot of radiation that a plant does not use efficiently.

Many fluorescent lights have a desirable spectrum in that their output peaks at 575-600 nm, and there is no output in the infrared. However, it is difficult to achieve intensities high enough to be effective, and the relatively large fixtures create a great deal of shade, which reduces the efficiency of sunlight use.

Incandescent light is also suitable for photosynthesis but is not very efficient, because such a large proportion of its output is in the infrared. It is generally used in conjunction with fluorescent lights to more nearly match the solar spectrum.

Probably the best source is the sodium arc. Its output peaks sharply at 590 nm. There is very little ultraviolet, and acceptable levels of infrared produced. It is an intense light, so, the fixtures can be spaced widely enough to avoid blocking much sunlight.

6.22 Lamps for Prevention of Dormancy

To prevent tree seedlings from becoming dormant prematurely, artificial lighting to prolong the photoperiod is often necessary. The biology of this phenomenon is discussed in section 12. Three methods are used to prevent dormancy induction: photoperiod extension, night break, and cyclic lighting. Photoperiod can be extended by continuous lighting 4 to 8 hours after sunset or before sunrise. Night break lighting employs 2- to 5-hour interruptions during the dark period. Cyclic lighting is brief interruptions of light repeated every 5 to 30 minutes throughout the dark period. This may require lighting only 2% to

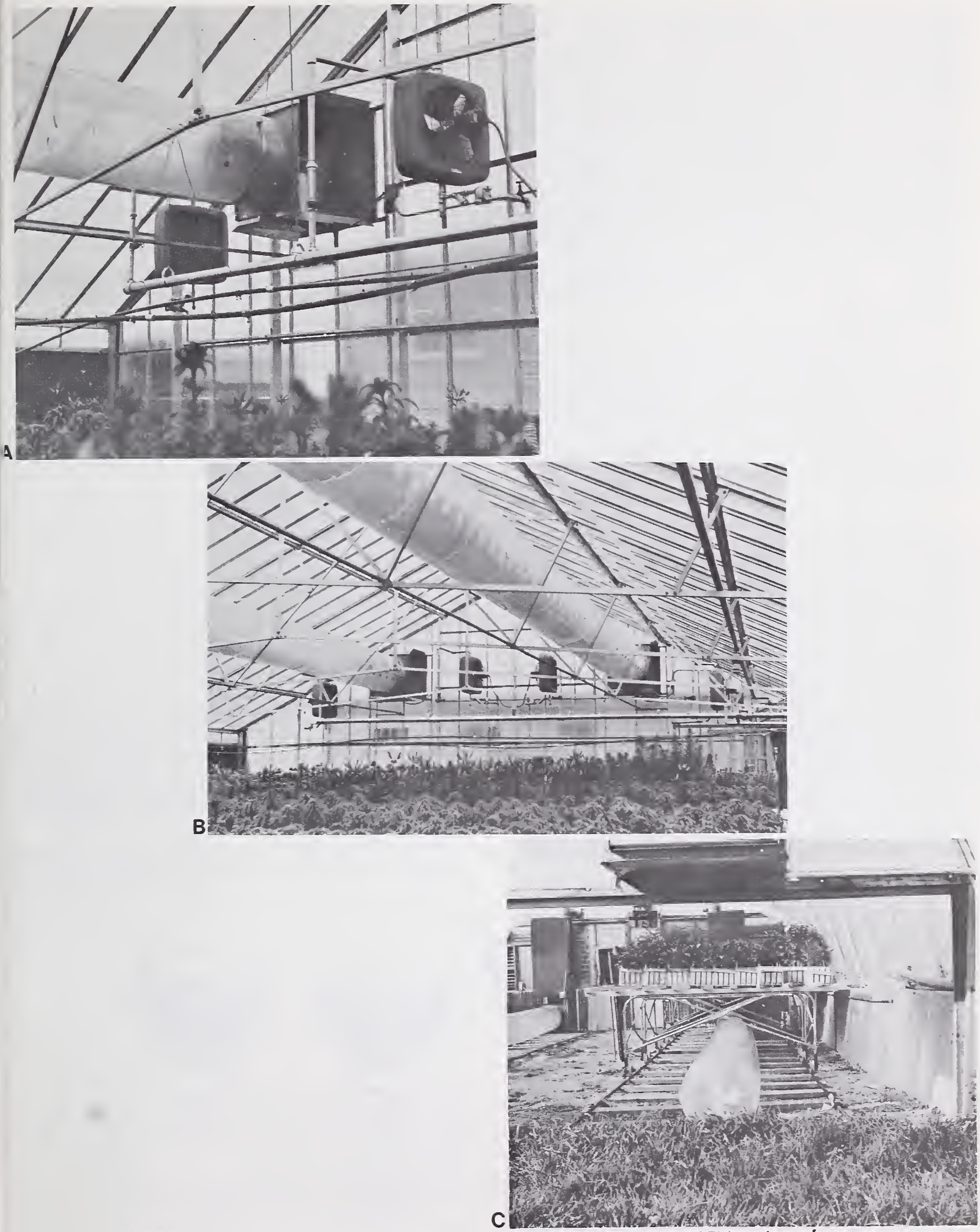


Figure 6-12.—Typical ventilating and heating system installed overhead (A and B) (courtesy of Acme Engineering and Manufacturing Corp.), or under benches (C).

10% of the time. Interrupting the dark period prevents cessation of stem elongation until adequate height growth is achieved. With southern genotypes, this practice may only be for "insurance" in summer. With northern genotypes, high elevation strains, or any time of the year other than early summer, photoperiod lengthening is essential. In fully controlled greenhouses, the interrupted dark cycle should always be employed during the height growth phase. The only cases where interrupted night might not be desirable are in the raising of ecotypes native to climates with long growing seasons. For instance, Owston[1] reports that coastal Douglas-fir and Western redcedar become tall and spindly under an interrupted night.

For interrupted night techniques to be fully effective, other factors in tree seedling's environment, such as temperature, humidity, water, and mineral nutrition, should be optimal. In CTS operations involving only control of watering and fertilization with little control of air temperature fluctuations, interrupted night is of less value.

Light intensity for phytochrome excitation need only be in the 40-foot-candle (430-lux) range.

Some of the factors to consider in selecting light source, intensity, and arrangement are: uniformity of light distribution, desired spectral energy distribution (SED), protection from humidity and water drops, light efficiency, initial cost, replacement cost, and minimum shading in daytime.

Three types of light sources are used: incandescent, fluorescent, and high-intensity discharge. The incandescent lamp consists of a heated filament enclosed in vacuum or surrounded by a gas such as nitrogen, argon, or halogen. The SED is basically dependent on the temperature of the filament, although the SED may be altered through the use of filters.

[1]*Personal communication with Dr. Peyton W. Owston, Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg., June 1978.*

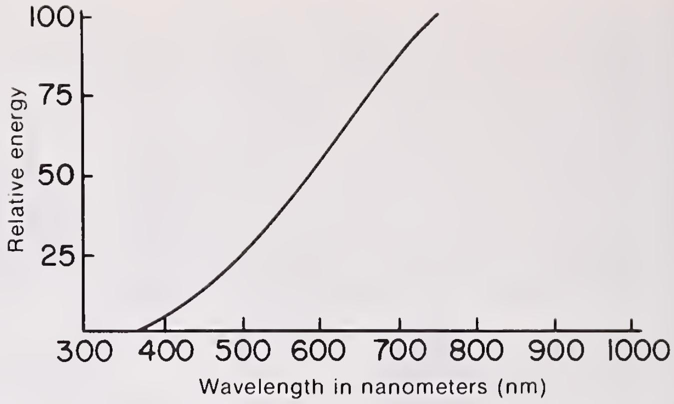


Figure 6-13.—Spectral energy distribution of a typical incandescent lamp (Bickford and Dunn 1972).

Incandescent lamps provide the desired spectral qualities, are cheap to install, and can be turned on and off without loss of bulb life. They are not as economical to operate as some other types of lamps, but their other characteristics (cost, spectral qualities) make them most advantageous. Figure 6-13 shows the SED of a typical incandescent lamp. Many types of incandescent lamps are available (fig. 6-14), and no ballasts are required. Some disadvantages are: low efficiency, point source of light (needs reflector), needs protection from water, and short life.

The standard incandescent bulb requires an external reflector to distribute light more uniformly. The reflector also provides protection from dripping water but casts unwanted shadows. Special types of the internal reflector (PAR and R) lamps are available with dichroic reflectors. They reflect the useful light forward and transmit infrared through the back of the reflector. The SED of a 150-watt PAR 38 lamp is shown in figure 6-15. Another special lamp that has been widely used in greenhouse applications is the pear-shaped, straight-necked lamp with internal reflector.

Most CTS greenhouse operators use incandescent lamps in a fixed arrangement as in figure 6-16. An

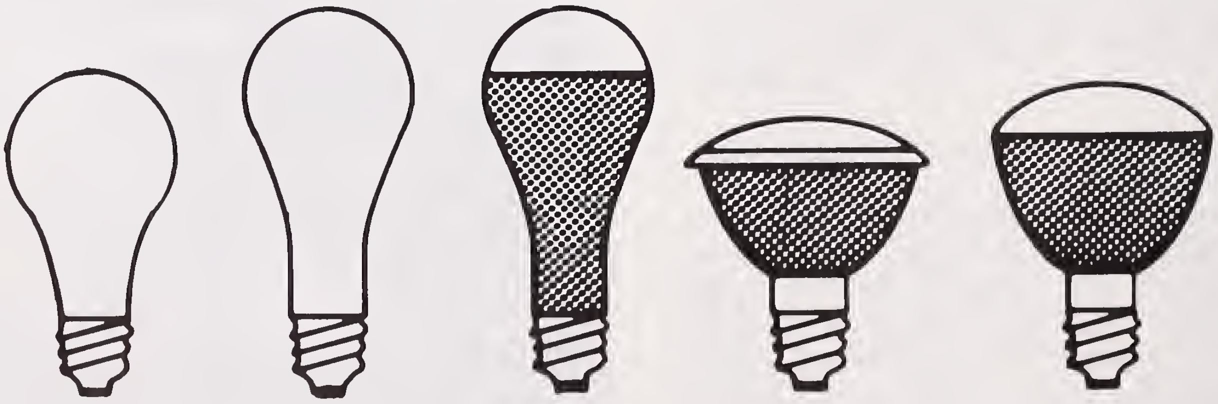


Figure 6-14.—Bulb shapes of incandescent lamps for photoperiod control (Ekblad 1973).

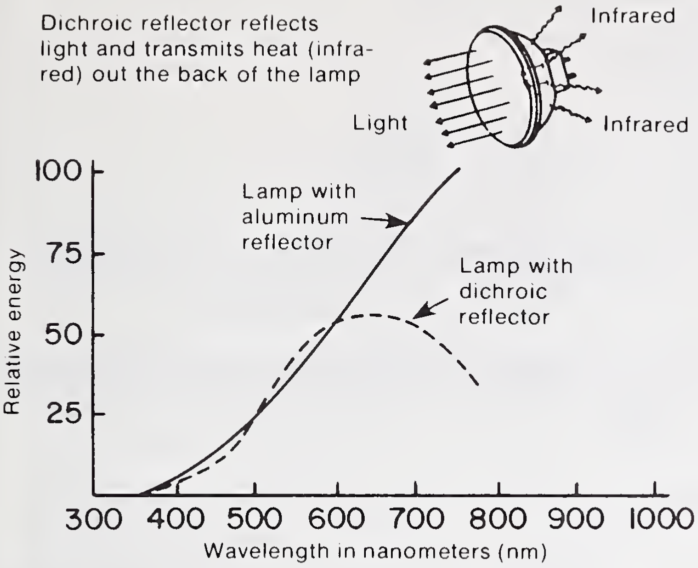


Figure 6-15.—Spectral energy distribution (SED) of a dichroic reflector compared to the same lamp with an aluminum reflector (Bickford and Dunn 1972).

electrical time clock switch turns the lamps on and off at prescribed intervals (see section 12 for interrupted night recommendations on frequency and intensity). Usually, in smaller greenhouses, all lights come on at once. In many larger installations, only part of the house comes on, then that part goes off, and another comes on. This sequencing reduces the total electrical demand and allows lighter duty service to be used.

The fluorescent lamp produces light by the action of radiation from a low pressure mercury arc on a phosphor coating of the inner surface of a glass tube. The fluorescent lamp requires a more complex electric circuit, including a somewhat bulky ballast, and lamp life is shortened if it is cycled on and off frequently. Fluorescent lamps are available with widely different SED's. Figure 6-17 shows the SED of one type of cool white fluorescent lamp. The sharp peaks are typical of most fluorescent lamps. A special fluorescent lamp for plants that produces more light in the 600-700 nm band is available. The initial installation cost of fluorescent lamps is twice that of incandescent, but they are four times as efficient in producing visible light and may last up to 12 times longer, provided they are not cycled on and off frequently. Also, the fluorescent is a line source of light which eliminates shadows as well as hot-spots directly beneath the lamp.

The objection that fluorescent lamps provide too much daytime shading can be reduced by special greenhouse fixtures that include remote ballasting and tandem arrangement of lamps. A special greenhouse lighting fixture is shown in figure 6-18. Waterproof fixtures with covered lamps are usually recommended for greenhouses.

High-intensity discharge (HID) lamps include mercury, metal-halide, and sodium lamps. Of these, only the metal-halide and sodium arc have been used for photoperiod lighting. The SED of the sodium and metal-halide are shown in figures 6-19 and 6-20, respectively. They are not suitable for cyclic lighting, because they require 5 minutes to start and cannot be conveniently used in short-duty cycles.

The important values are the energy available at or near 660 and 730 nm, not total visible light. Table 6-1 shows the energy output per watt in four bands for eight selected lamps. For photoperiod control, the two bands of interest are 600-700 and 700-800 nm.

6.23 Lamp Arrangement

There are three basic ways to arrange lamps.

Fixed array.—Lights may be installed overhead in a fixed array. Since those used for dormancy prevention only have to be on for a small fraction of the time, the electrical entrance need only be large enough to handle 1/15 of the lights at one time (section 6.53). (This could be 1/30 if species would

Figure 6-16.—Typical installations of incandescent lights to lengthen photoperiod (A) in a wide gabled greenhouse and (B) in a 27-foot (8-m) wide quonset.

never be grown that required light 6% of the time instead of 3%). A light source is needed that provides red light efficiently and can be turned on and off quickly and repeatedly. Most arc lights require lengthy warm up times and cannot be turned on rapidly. Fluorescent lights can be turned on and off rapidly, but this wears them out quickly. Incandescent lights are usually the best choice, because they provide satisfactory amounts of red light and can be repeatedly turned on and off without damage. When using incandescent lights, figure 86 watts per square meter of installed lighting, unless it is known in advance that the species to be grown respond adequately to less light. Lights should be 1.5-2.5 m above the seedlings. Use larger bulb sizes and fewer fixtures to minimize cost and maximize efficiency, consistent with keeping minimum light intensities above 400 lux. Arrangement of lamps for photosynethetic lighting must be a fixed array, wired to all be on at once, with lamps placed close enough together to provide the required intensity at seedling height.

Movable lights.—Another system is to leave the lights on continuously, but mount them on a moving boom. This way there is more choice of light sources, and a few intense sources can do the same job as a much larger fixed array. Probably the most efficient source would be the sodium arc (Arnott 1974, 1976). The only requirement would be that the boom make at least one round trip every 30 minutes. The moving boom system is a tempting choice for a greenhouse that is equipped with a moving boom watering system. In some installations, the lights and the water have been placed on the same boom.

This system has its own problems, however. If the boom should malfunction, the greenhouse would lose both its water and lights. It is best to keep as much of the electrical machinery out of the greenhouse as possible. A watering boom can be cable driven by a remote motor, but there is no way to avoid delivering electricity to a lighting boom. Nutrient solution is very corrosive to electrical machinery and fixtures, which must be carefully waterproofed and preferably kept out of contact with nutrient solutions.

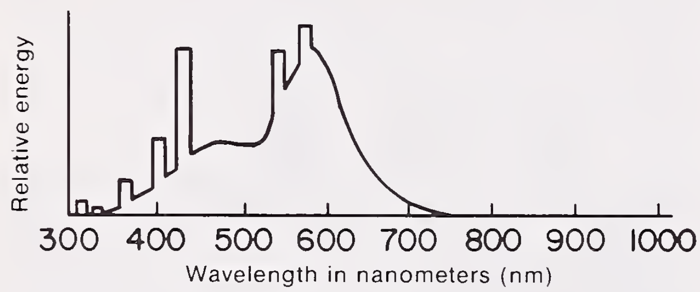


Figure 6-17.—Spectral energy distribution for a typical cool white fluorescent lamp (Bickford and Dunn 1972).

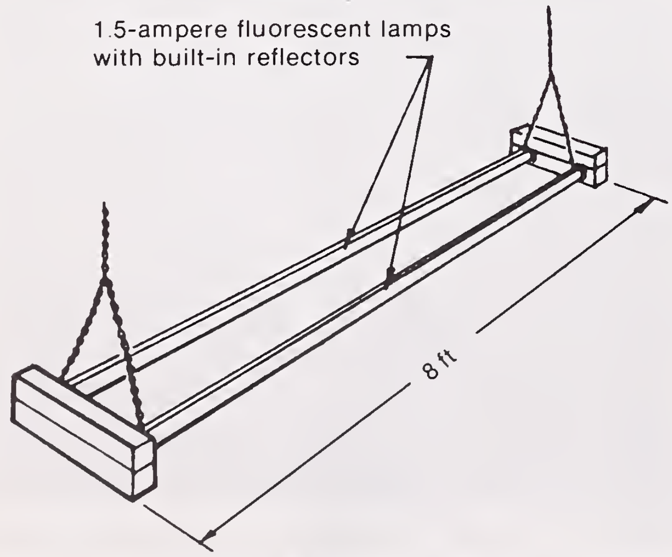


Figure 6-18.—Special greenhouse lighting fixture to minimize shading (Ekblad 1973).

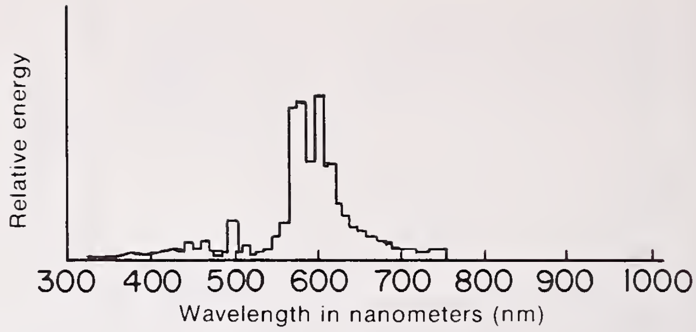


Figure 6-19.—Spectral energy distribution of 400-watt high-pressure sodium discharge lamp (Bickford and Dunn 1972).

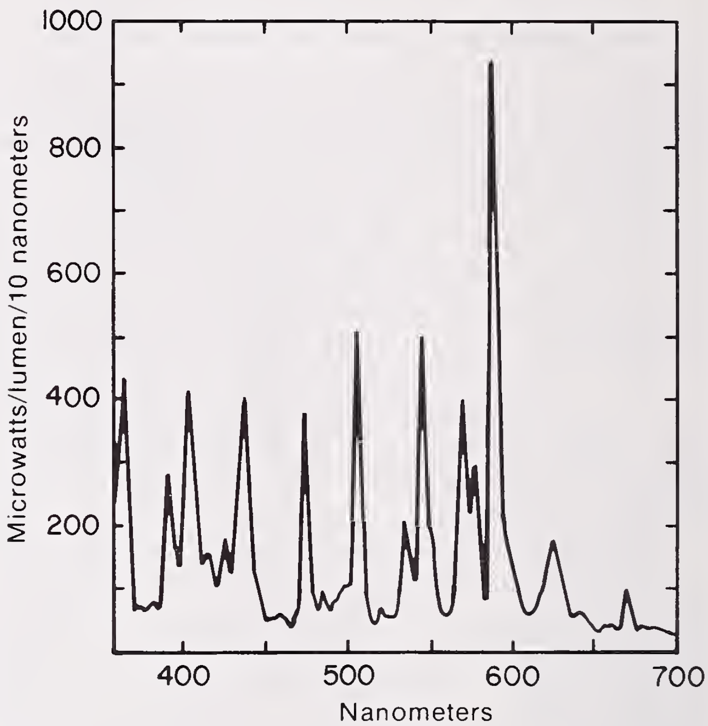


Figure 6-20.—Spectral energy distribution of a typical metal-halide lamp (Bickford and Dunn 1972).

Table 6-1.—Energy output of selected lamps (Ekblad 1973).

Lamp	Lamp watts	Total[2] watts	Lumens	Visible Output Milliwatts 400-500 (nm) watts	500-600 (nm) watts	600-700 (nm) watts	Visible total watts	Total IR far red 700-800 (nm) watts
Incandescent (100A)	100	100	1,750	0.8	2.2	3.9	6.9	4
Fluorescent CW 40 W (F 40CW)	40	50	3,200	2.7	4.5	2	9.2	—
Fluorescent Special Plant Lamp 40W	40	50	—	2.2	2	3.2	7.4	0.7
Fluorescent CW 1,500 MA (F 96T12/CW)	215	235	15,000	12.7	21.2	9.4	43	—
Fluorescent 1,500 MA Special Plant lamp	215	335	—	10.3	9.4	15	35	3.3
Fluorescent CW 1,500 + 100 W Incandescent	315	335	16,750	13.5	23.4	13.3	50	4
Mercury Phospher	400	425	20,000	11.6	28.4	18.3	58	—
Metal-Halide	400	425	31,000	26.2	50	12.1	88	[3]4
High-Pressure Sodium	400	425	42,000	10.3	55	39	105	[3]4

[1]*Typical values from manufacturer's data. IES handbook data and other publisher data.*
[2]*Includes ballast or auxiliary input.*
[3]*Estimated.*

Parabolic mirror.—Another possible way to achieve the same thing would be to use a fixed high-intensity source and move the light across the house with a rotating or oscillating parabolic mirror. At least two lights per house should be used to eliminate shadows and provide redundancy in case one fails. To the authors' knowledge this system has not been tried yet.

It is suggested that the greenhouse designer work closely with a plant expert most knowledgeable about the species to be grown. The size, location, and arrangement of luminaires can be selected using standard lighting calculations and tables given in the Illuminating Engineering Society Handbook (Ekblad 1973). When scaling from a growth chamber or small greenhouse to a large greenhouse, do not extrapolate by fixtures, lights, or watts per unit area. The edge effects of rectangular or small areas can introduce a large error. The requirements for each house should be calculated by an engineer based on spectral energy distribution required.

6.3 Carbon Dioxide Control

Carbon dioxide is the source of carbon for plants. During the night, plants respire and release CO_2. This may cause a rise in CO_2 concentration in the air to 400 parts per million (ppm) or more. However, as soon as the day begins and plants start using CO_2, the concentration drops to that of the outside air (about 325 ppm). If the house is closed during winter days with only two air changes per hour or less, the concentration often drops below 200 ppm and limits growth (Holley 1965). This situation is alleviated in the summer when air changes equivalent to one greenhouse volume per minute are required for ventilation. Good circulation of air is also helpful in making CO_2 available at the plant surface. An airflow rate of 100 feet per minute (30 m/min) has been found to be equivalent to 50% enrichment in CO_2. These are design factors that should be considered.

CO_2 may also be added artificially. Sources of CO_2 are: compressed CO_2 gas, dry ice, burning fuels, and soil organisms. Each of these sources has been used, but the most practical commercial method is to burn organic fuels.

Some factors to be considered in using burners for CO_2 production are: (1) the house must be closed, (2) considerable heat is added by the burner, (3) gases should be free of toxic byproducts, (4) CO_2 should not be added at night, (5) water is a combustion product, and (6) air for combustion must be provided.

Most commercial greenhouses use ventilation or evaporation for cooling. Both systems exhaust about one volume of greenhouse air per minute, making it impractical to add CO_2. Closed circuit cooling systems are very expensive. However, CO_2 can be added during the winter, when there is little ventilation. In the early morning and late afternoon, when cooling is not required, CO_2 may be added. Such additions are beneficial but not as efficient as midday treatments (Pettibone et al. 1970). Most plants are able to tolerate higher temperatures with increased CO_2.

The most critical plant toxicants associated with CO_2 enrichment and their maximum allowable values are as follows:

SO_2—0.2 ppm
C_2H_4—0.05 ppm
O_3—0.2 ppm
NO_2—20 ppm
NH_3—10 ppm
HCHO—0.7 ppm
CO—500 ppm

Certain compounds, such as carbon monoxide (CO) and ethylene (C_2H_4) are associated with incomplete combustion. Others are a result of contamination of the fuel, the most important of which are oxides of sulphur (Kretchman and Howlett 1970). The following fuels are suggested for CO_2 generation in tomato greenhouses because of their low sulfur content:

kerosene — 0.02% sulphur
propane — 10 grains sulphur per 100 cubic feet (230 mg/m^3)
natural gas — 3.5 grains sulphur per 100 cubic feet (80 mg/m^3) (Kretchman and Howlett 1970).

Complete combustion of natural gas and propane requires air and produces CO_2 and water in the following proportions by weight:

	Air required	CO_2 produced	H_2O produced
Natural gas (1.0)	17	2.7	2.3
propane (1.0)	16	3.0	1.6

Other hydrocarbons are similar (Sheldrake 1964).

Combustion produces from 8,000 to 10,000 Btu per pound (4,400-5,500 Kcal/kg) of fuel, depending upon fuels and burner efficiencies. Propane is the best fuel, because it has less variation in composition than other fuels. Fuels of low quality may produce too much sulphur dioxide, ethylene, or carbon monoxide. These combustion byproducts are harmful to people and plants. Kerosene generators should be avoided, because they are more expensive and more difficult to operate and maintain than gas burners.

Three commercial types of CO_2 generators are shown in figures 6-21, 6-22, and 6-23. Each burner comes with instructions for installation and operation. Calibration of burners (how much CO_2 to generate) depends on the leakage rate of air from the greenhouse when its ventilation system is not operating. Pounds of CO_2 required can be estimated by the following method.

Carbon dioxide occupies 8.72 cubic feet per pound at 60° F (10°C). Therefore, to estimate the pounds of CO_2 required:

$$\text{LB } CO_2/\text{hr} = \frac{\text{house volume (ft}^3)}{8.72} \times \frac{\text{concentration (ppm)}}{1{,}000{,}000} \times \frac{\text{air changes}}{\text{hr}}$$

or:

$$\text{kg } CO_2/\text{hr} = \frac{\text{house volume (m}^3)}{3.27} \times \frac{\text{concentration (ppm)}}{1{,}000{,}000} \times \frac{\text{air changes}}{\text{hr}}$$

Once the flow rate of CO_2 has been regulated for a particular house, a timer switch can be used to turn the generator on and off. The timer will have to be adjusted seasonally. Switches operated by a solar cell are also available. More complex systems that sense CO_2 levels and control the generator are available but are not generally used in commercial greenhouses because of cost and complexity. They are generally necessary for research purposes only. Since adding carbon dioxide to the air substantially increases growth rate and costs little, it is usually a good investment in fully controlled CTS greenhouses.

6.4 Watering and Fertilizing

Figures 6-24, 6-25, 6-26, 6-27, and 6-28 illustrate four types of commercial watering units. The main problem with the fixed overhead, rotating, oscillating, and spray stake sprinklers is lack of uniform coverage. A second problem is accumulation of moisture on nozzles or other parts of the system that drips on the foliage. A well designed fixed irrigation system minimizes these problems forever.

The overhead traveling boom sprinkler (fig. 6-28) has the most potential for uniform coverage. It is also the most expensive, approximately $1,500 per unit.

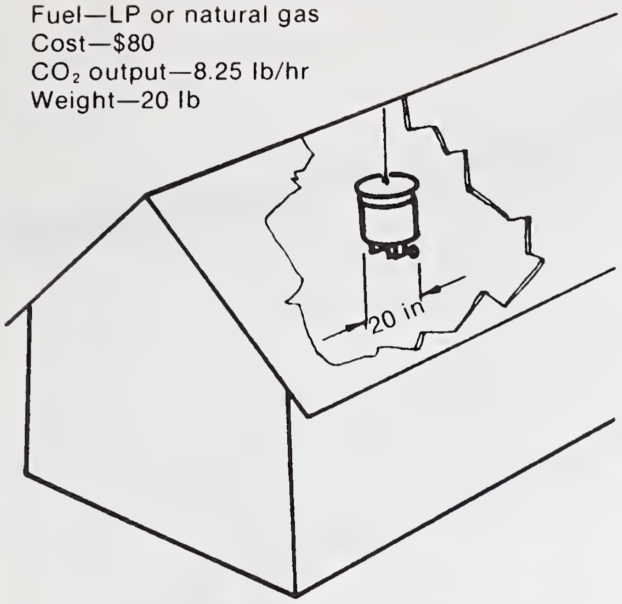


Figure 6-21.—Inside ceiling mounted gas CO_2 generator (Ekblad 1973).

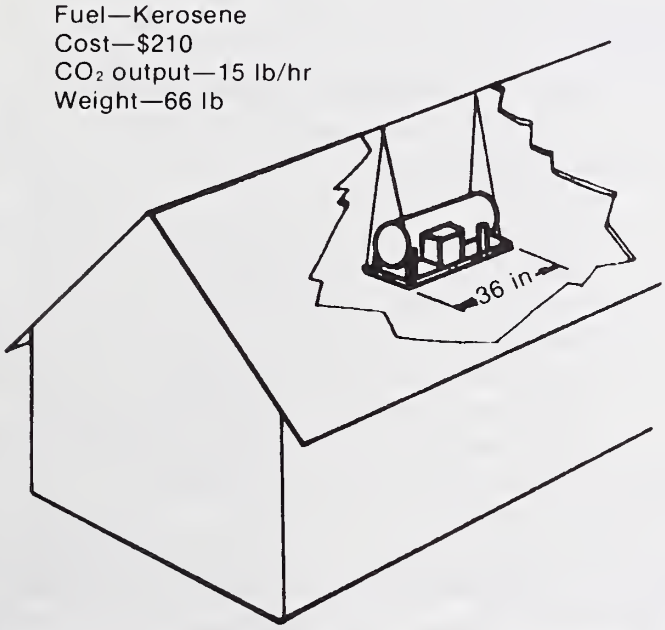


Figure 6-22.—Inside ceiling mounted kerosene CO_2 generator (Ekblad 1973).

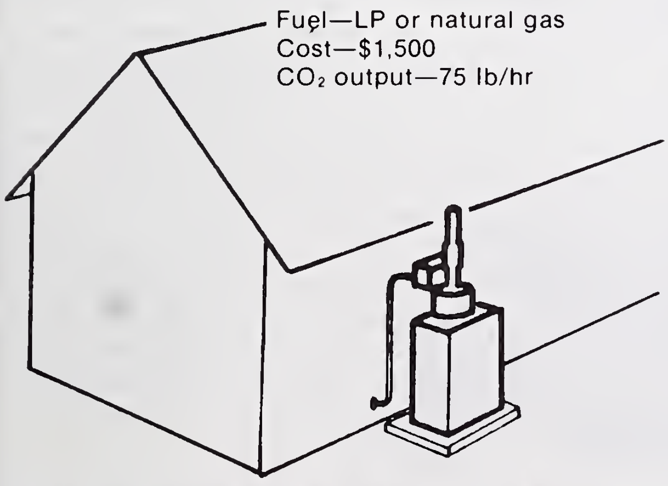


Figure 6-23.—Outside gas fired CO_2 generator (Ekblad 1973).

Distribution of water should be reasonably uniform. At each irrigation, especially when fertilizing, all containers are watered to full saturation. Because excess water flows through the containers, perfectly uniform application by the irrigation system is not necessary, but uniformity is desirable to shorten the irrigation period. The shorter the irrigation, the shorter time the foliage is wet, and the sooner greenhouse humidity drops from 100%, assuming adequate ventilation. This reduces the opportunity for fungal infection.

Droplet size generated by irrigation nozzles should be small enough to avoid damaging young seedlings or washing out pot mix, but large enough to allow a short irrigation period.

Fixed irrigation systems are common. They are frequently expensive to install, but mostly trouble-free in operation. Such systems are usually manually operated or operated with electric timers linked to electric solenoid valves. Usually, in large greenhouses, only part of the house, or one of several smaller greenhouses in a complex, is irrigated at a time. This sequencing of irrigation reduces water demand peaks and allows the use of smaller pipe in the water system. Most growers use fixed systems. In some cases, travelling boom sprinklers are used. These devices move back and forth over the benches of trees watering them each time they pass. Some of the advantages of the travelling boom are:

1. Properly operated, it will provide uniformity of application no fixed system can match.
2. The irrigation equipment is out of the way when not in use.

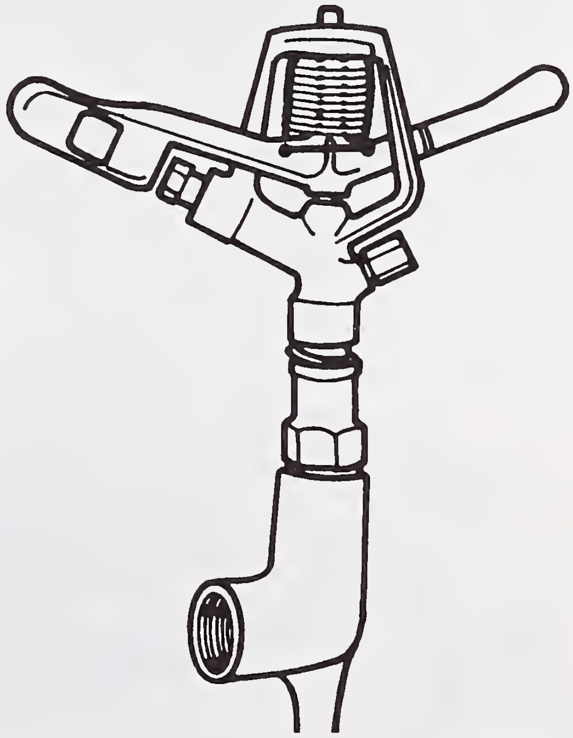


Figure 6-24.—Rotating sprinkler (Ekblad 1973).

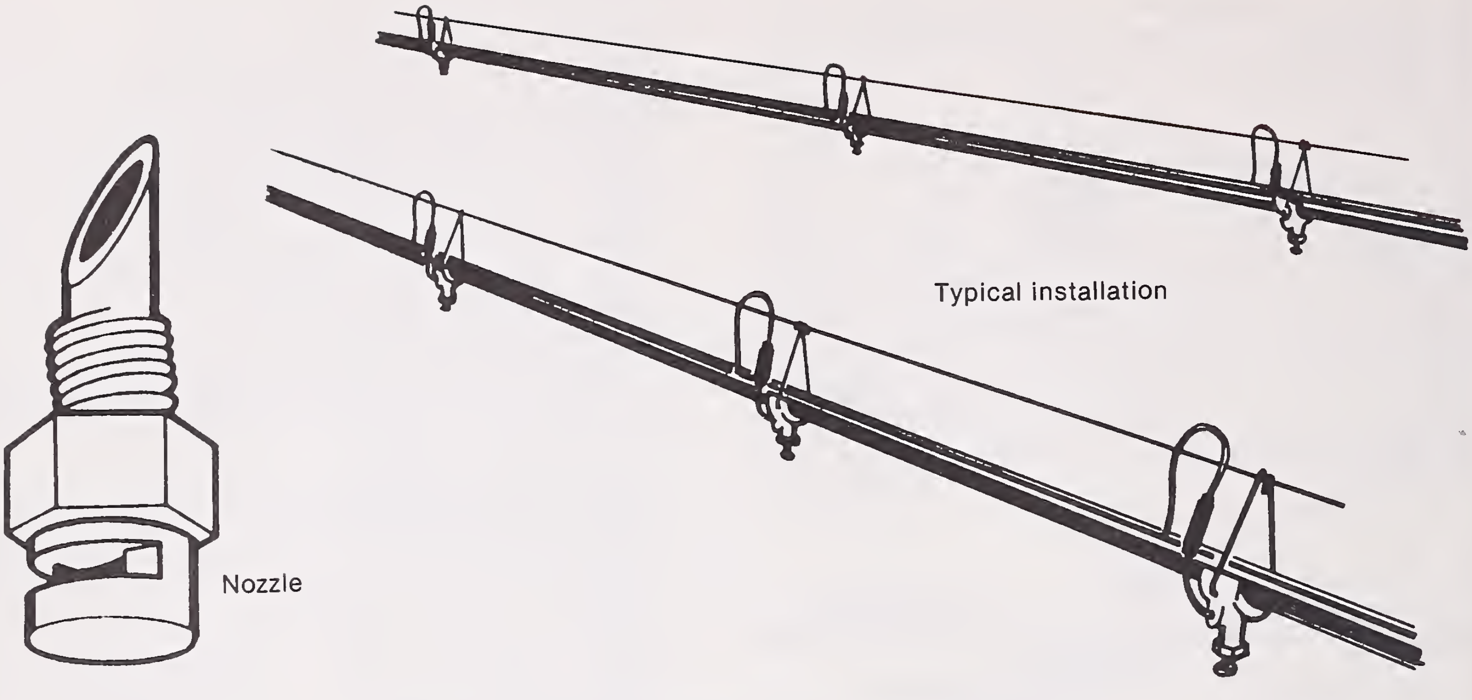


Figure 6-25.—Fixed overhead spray nozzle (Ekblad 1973).

3. Less initial investment in labor may be needed to install, but cost of the parts and material may be about the same as a fixed system. A moving boom also operates on a smaller water flow.

Some of the disadvantages are:

1. Any moving piece of equipment is prone to breakdown; travelling boom systems are often finicky and sometimes hard to operate.
2. The boom must be monitored while in operation in case of a malfunction.

Some fixed systems drip. When an improperly designed fixed overhead system is turned off, the residual water in the pipes will run out the lowest nozzles. Losses occur in trees below such drip points. There are several ways to counter this:

1. Design the system to irrigate with water supplied from below the benches or the sidewalls of the house. Of course the water supply line may then be in the way.
2. Draw the water from the top of the overhead pipe (fig. 6-25).
3. Quickly empty the overhead pipe of residual water by putting automatic drain valves in it at regular intervals or at each end.
4. If sprinkler heads must be hung from nipples connected vertically to the main line, keep the nipple length as short as possible.
5. Run a line or string from the nozzle down to the bench surface between containers.
6. A combination of the above.

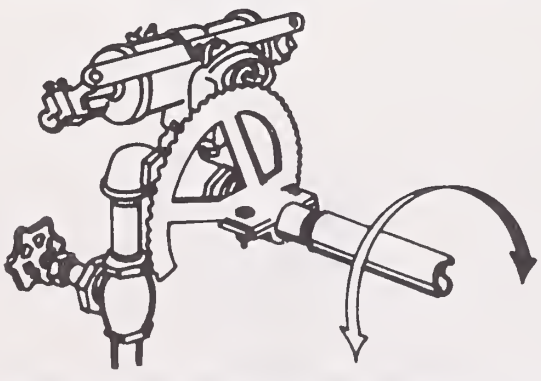


Figure 6-26.—Oscillating sprinkler (Ekblad 1973).

As mentioned in section 4.15, 0.4 to 0.5 gallons per hour per square foot (16-20 l/h/m²) of greenhouse space will saturate 8-inch (20-cm) deep containers rapidly enough to prevent foliage from being wet too long. This same guide can be used for choosing nozzle orifice size.

On the West Coast, where water sources are very pure and salt buildup in the container is not a problem, watering can be much lighter. Hahn[2] reports that 0.1 to 0.2 gallons delivered in 30 to 80 minutes is satisfactory. He also reports that, under high humidity conditions, the foliage never complete dries on large seedlings, even when watered only once a week. In this case, rapid watering is not important. Foliage rinsing is not necessary, because the foliage does not dry and there is little opportunity for salt burn. However, constantly wet foliage is the main cause of the Botrytis disease which is common in West Coast nurseries.

[2]Personal communication with Phillip Hahn, Georgia-Pacific Corp., Eugene, Oreg., June 1978.

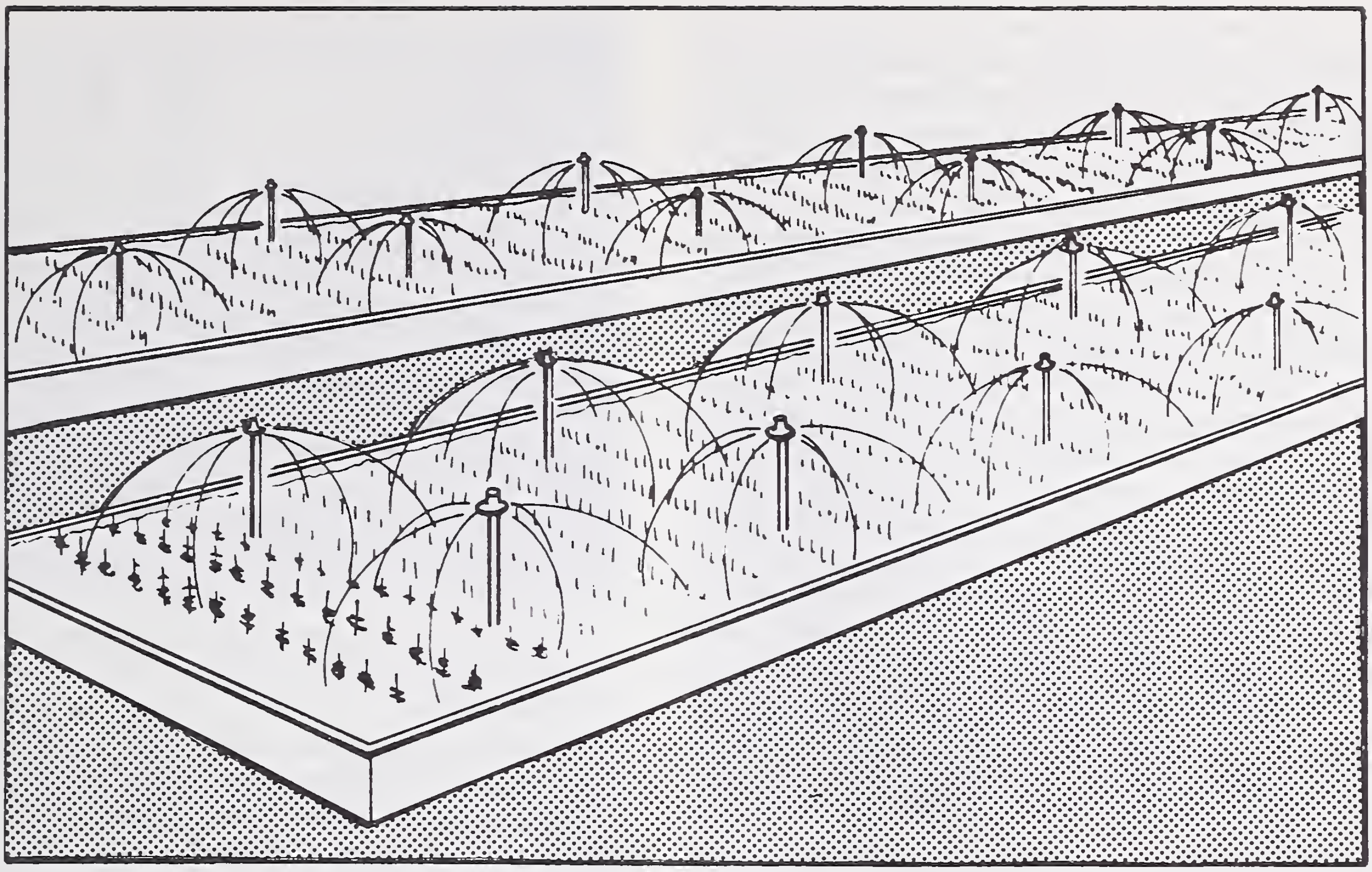


Figure 6-27.—Spray stake watering system (Ekblad 1973).

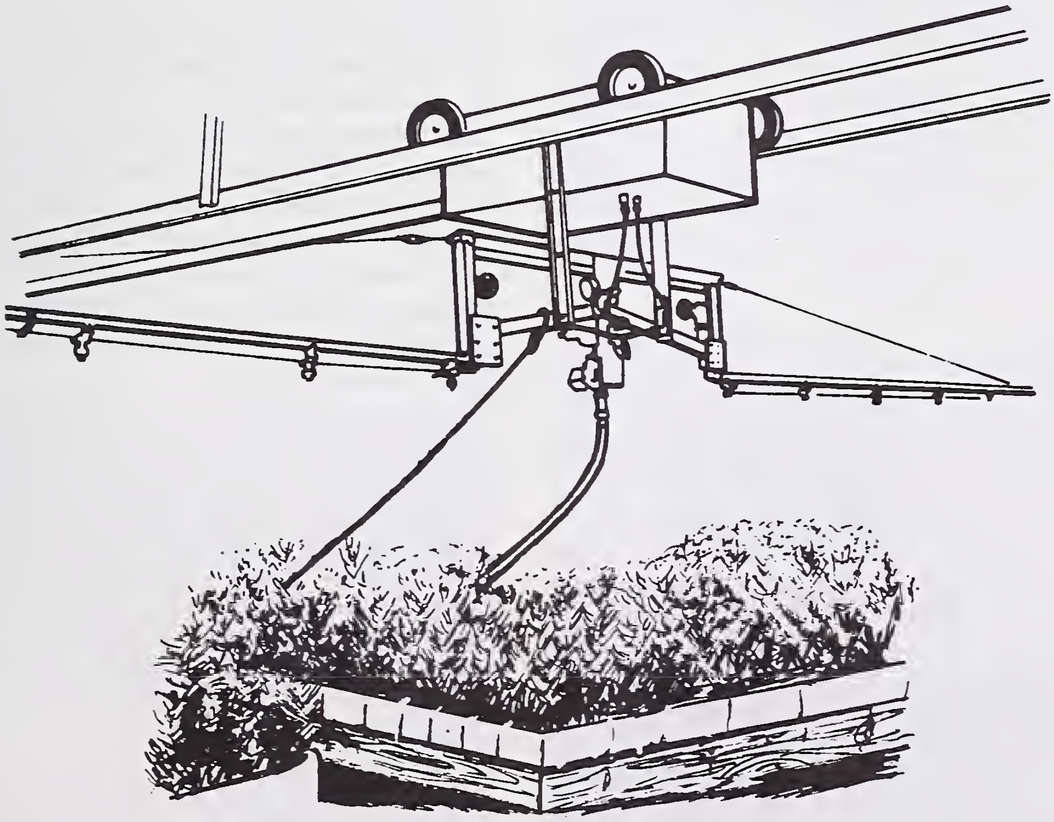


Figure 6-28.—Overhead traveling sprinkler (Creepy-crawler: Master Grower, Hatcher Sales Co.) (Ekblad 1973).

For CTS growing, irrigation water normally has to be adjusted to a slightly acid condition. This is done by acidifying the water before it enters the greenhouse irrigation system. At the same time, fertilizer solutions may be injected into the irrigation water. Such solutions corrode metal irrigation pipes, nozzles, and any other metal greenhouse hardware. This not only shortens the lifetime and increases maintenance on the system, but there is a possibility that the plants could receive toxic levels of copper or zinc. Therefore, any irrigation piping beyond the nutrient injectors should be plastic (PVC). Nozzles should be plastic or corrosion-resistant metal. If the irrigation solution is sprayed on the structural framework of the greenhouse, this framework should be aluminum, not galvanized steel. The irrigation system should be briefly flushed with plain water following a fertilizer application to wash the irrigation system, the greenhouse framework, and often the foliage. Trees should not be grown in spots where irrigation water chronically drips from the greenhouse frame. This will damage the trees and may cause localized zinc toxicity, if the frame is galvanized metal.

Nutrient injectors.—Several types of nutrient feeders are available commercially. The four basic types available for adding nutrients to the water are: suction, injection, electric, and ratio feeders. The suction feeder is attached to the suction side of the pump and an electrically timed solenoid allows chemicals to be added at a fixed rate. The injector feeder is operated by connecting a tube to the discharge of the pump, and the solution is introduced by pressure through a needle valve (fig. 6-29). The electrically driven feeder is an adjustable positive displacement pump. The motor is connected to the pressure switch of the pump and operates continuously when the switch is closed.

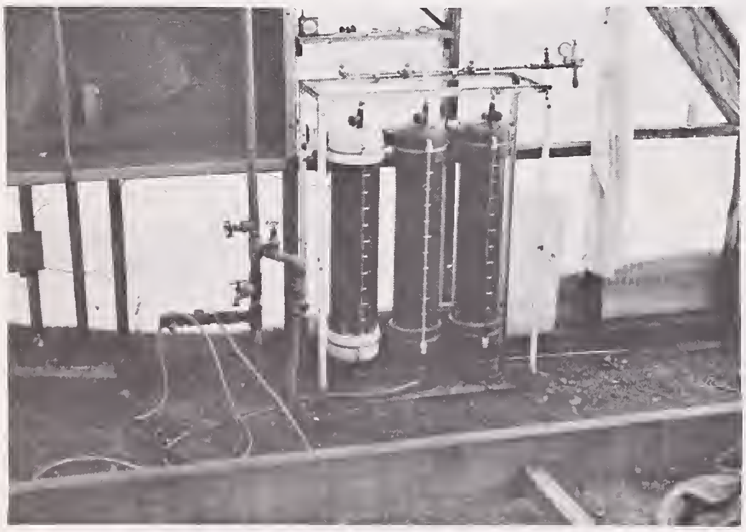


Figure 6-29.—Air pressure driven injection feeder.

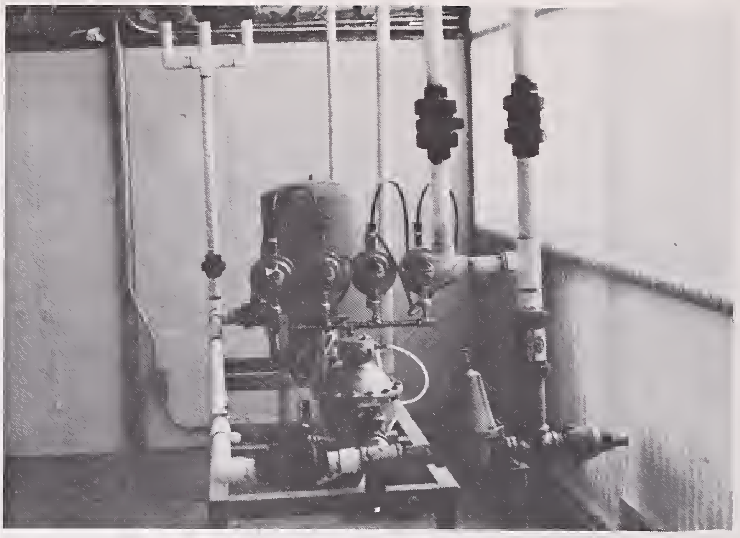


Figure 6-30.—Water driven proportional nutrient injector.

Proportional feeders are frequently used. These are positive displacement pumps operated by flowing water (fig. 6-30).

For CTS operations, the selected injection should be capable of injecting nutrient solutions into the greenhouse irrigation water at a proportion of about 200:1. Proportions of more than 400:1 will require the nutrient solution be so highly concentrated that chemicals will tend to precipitate out of solution. Proportions lower than 100:1 will require an unduly large tank of nutrient concentrate solution. The ratio must be accurate, but extreme accuracy is unnecessary except where the irrigation water must be acidified to alter its pH or when pesticides are added through the injector. In such instances, variations in injection rates are not desirable. Most injectors on the market, properly installed and calibrated, should be accurate enough. Water operated proportional feeders are probably the easiest to keep accurate, however. The injection rate of any injector should be monitored and adjusted as necessary to maintain reasonable accuracy. A simple effective monitoring method is to install a corrosion-resistant flow meter on the irrigation line and observe the rate of flow and the time it takes to inject a known amount of nutrient concentrate.

In some instances, two to four separate nutrient concentrate solutions must be prepared, because the chemicals in one are not compatible with those in another. These solutions can be injected either all at the same time with more than one injector or one after the other using one injector. The first procedure is preferable, because some of the first solution will leach out of the containers while the second is being applied.

If acidic nutrient concentrates are to be injected, injectors with plastic, rubber, or stainless steel parts should be used. Injectors constructed of brass should be avoided. Acids in the nutrient solution can

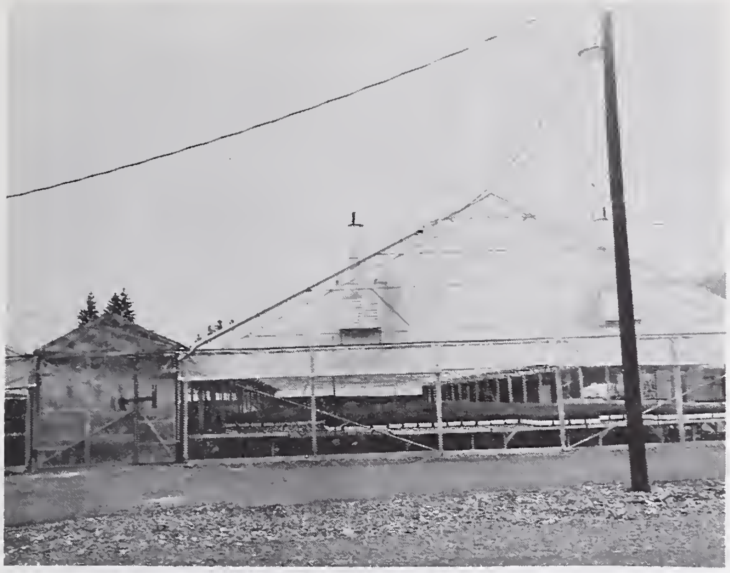


Figure 6-31.—A typical semicontrolled greenhouse.

corrode the brass causing excess copper and zinc ions in the irrigation water. The same applies to nozzle heads where water is to be acidified. Do not use galvanized iron or brass nozzles if possible.

Finally, if the injector is to ultimately serve more than one greenhouse, the plumbing should be of sufficient capacity to meet the demands. A work area for preparing the concentrates and storage area for the chemicals should be planned. If city water or other domestic water supply sources are used, local codes and general good practices will require a check valve or gravity break, to prevent any backflow.

6.5 Controls, Security, and Instrumentation

CTS operations can use greenhouses with fully controlled environments or in very mild climates, use no greenhouse at all (i.e. growing the trees in containers outside on a gravel or asphalt base). Between these extremes there are semicontrolled operations where trees are sheltered from rain to maintain control of irrigation and fertilizer regimes and mechanically protect seedlings (fig. 6-31). Some of these semicontrolled operations include provision for temporarily enclosing the structures and adding supplemental heat to protect plants from excessively low temperatures. Controls are usually simple—irrigation and fertilization control, protection from low temperature extremes by simple heaters and enclosures, and ventilation through roof vents using convection or, in some cases, gable-end fans. Operation of these controls may be manual or automatic.

Once a decision has been made to build a highly controlled green house, all controllable factors should be controlled for two reasons: (1) if a greenhouse is constructed, with all the associated expense and trouble, its capability should be utilized to the fullest extent economically practical, and (2) plant growth will be maximized when all factors needed for growth are optimized. The same applies even to semicontrolled houses, within the limits of the capability of the structure.

6.51 Temperature Controls

A greenhouse environmental control system not only includes the structure, but also automatic vents, fans, cooling systems, heaters, sensors, and controllers. All the machinery does not operate at once. The heaters warm the greenhouse, ventilators bring in fresh air, and the cooling pads cool incoming air, as needed. If all the equipment were on at once, it would be working at cross purposes. Consequently, the most efficient and economical way to keep the greenhouse environment at a preset optimum condition is to "stage" the temperature control equipment so that various components come on to meet the different levels of heating or cooling demand.

For example, suppose the air temperature in a greenhouse rises above optimum because of an increase in solar radiation. First a single exhaust fan is turned on. If the temperature continues to rise, the pump that wets the cooling pads is turned on. If the latter is the final stage of cooling, the temperature should begin to go down, provided the house was designed properly for the site conditions. As the temperature falls, the cooling pad water pump shuts off, then the fan.

The cooling system has passed through three "stages" from neutral (nothing running) to full cooling (stage 2) and back again, making a graduated response to a temperature change. The number of stages a greenhouse climate system can go through depends on the mechanical equipment and the sophistication of the control system linked to it. The amount, type, and size of the temperature control equipment (i.e. exhaust fans, ventilating fans, perforated tubes, heater, motorized shutters, turbulator fans, and cooling pad system) will vary from greenhouse to greenhouse, depending on how the house was engineered to meet requirements of the crop and site. The more sophisticated control systems can stage through a dozen or more steps from maximum heating to maximum cooling. Controllers operate by stages to:

1. Reduce equipment wear.
2. Save fuel and power.
3. Keep the greenhouse environment near optimum (less modulation).

6.52 Types of Controllers

Temperature control systems use one of two basic types of sensor.

Thermostatic control systems.—Greenhouse thermostats are electrical switches activated by expansion or contraction of an enclosed fluid caused by air temperature changes. Thus, a thermostat is a "go" or "no go" switch at any given temperature. Consequently, each thermostat can operate but one stage of a control system, and a number of thermostats are required to operate a staged system. If the neutral set point for the greenhouse is 70° F (21° C), the first stage cooling thermostat may be set at 72° F (22° C), and the second stage at 75° F (24° C). Some work in setting the individual thermostats is necessary to prevent the stages from "bucking," or acting at cross purposes with each other. The most commonly used greenhouse thermostat is a 120-volt, 15-ampere unit with a range of from 30° F (−1° C) to 100° F (38° C) and a 3° F differential (i.e. it can be set to an accuracy of about 1.5° F (0.8° C). These units are relatively inexpensive ($20-$25 each). A battery of these thermostats, one for each heating and cooling stage, is positioned near the center of the greenhouse where they are shielded from irrigation water and sunlight. However, their protective covering must allow free air circulation around the thermostat (fig. 6-32). The advantages of the thermostat control system are:

1. The system is 120 volts and can be wired and maintained with electrical hardware readily available in most hardware stores. Most electricians can readily understand, wire in, or service it, an advantage for greenhouses in rural areas.
2. The thermostats are cheap and easy to replace. Spares can be kept on hand.
3. The system depends on multiple, independent sensors. Each sensor and its stage of equipment is independent of the others. Mechanical failure of one sensor or system does not upset the other stages. If one stage does not work, the next stage will when the temperature reaches its set point.
4. All greenhouse machinery and controls can be the same voltage.

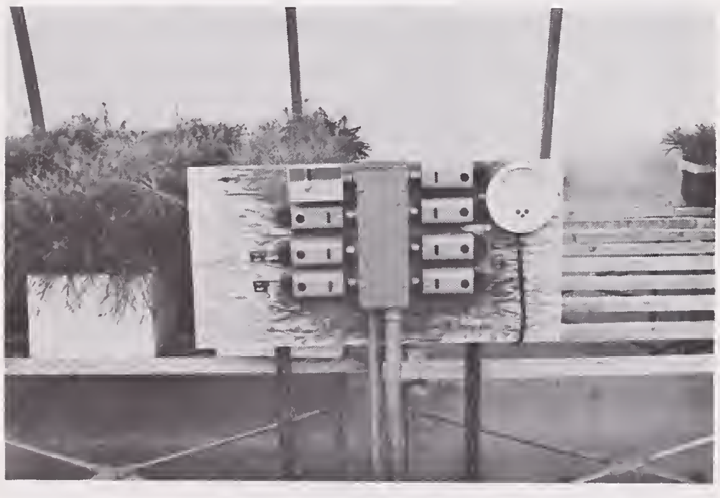


Figure 6-32.—Thermostat controls for a greenhouse, one for each stage of heating and cooling, and separate thermostats for day and night furnace settings.

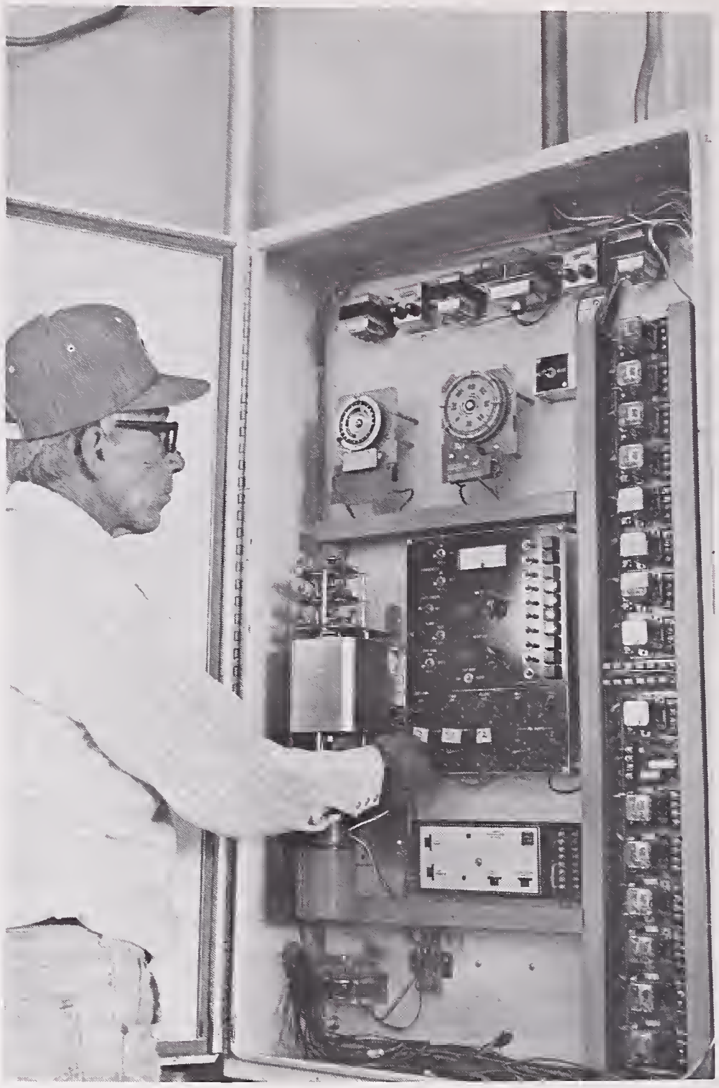


Figure 6-33.—Integrated heating and cooling control system with thermistor sensor. (Photo courtesy of Kansas Cooperative Extension Service.)

The disadvantages are:

1. Much of the modern greenhouse control equipment is 24 volts. Wiring for 120 volts is much heavier, and usually has to be in conduit in a greenhouse, and is much more hazardous in wet conditions.
2. The system described cannot be purchased as an assembled package, but must be designed and assembled piece by piece.

Thermistor control systems.—Thermistors are semiconductors that proportionately conduct more or less electrical current as they get warmer or colder. Since a thermistor senses changes in temperature over a range instead of at one point, only one is needed for temperature sensing in a greenhouse. The control panel actuates different heating or cooling stages at different preprogrammed temperatures (fig. 6-33). These systems can be purchased with few or many stages and numerous optional panels that will actuate accessory control equipment. The systems are usually designed for 24 volts. Manufacturers will tailor the system and accessories to the needs of the developer and will install and service it. These systems can be very expensive to purchase and maintain. The greenhouse developer should be sure to buy features he needs, but not more than he needs. Newer models have solid state controls which provide added reliability. The advantages of the thermistor temperature control systems are:

1. The systems are usually 24 volts, which are inexpensive to install and safe to use.
2. The systems can be tailored to and completely packaged for a given operation. Installation and maintenance can usually be purchased from the manufacturer.
3. Only one sensor unit is needed.
4. Special features are often built in or can be purchased as accessories. Examples are: day and night temperature setback, override switches, cooling water pump, shutoff during freezing weather, modulating vent or steam valve control, phase failure disconnects, decondensate cycles, and automatic CO_2 injection.
5. The sensitivity of thermistors can be adjusted.

Some of the disadvantages are:

1. Because of the complexity and unique nature of the equipment, many areas lack parts and maintenance service. With the exception of replacement of modular parts, a specialist is required for repair.
2. If the single sensor (thermistor) fails and another is not readily available, the entire system is out of order. This would also be true of some of the panel parts such as the sequencer (critical replacement parts should be kept on hand as recommended in section 21).
3. Since these systems can be purchased to provide very automatic operation, there is a tendency to check functioning less frequently than is prudent.
4. Two voltages are required in the greenhouse electrical system.

Choice of a system depends on the developer's needs, preferences, and available money. There are other types of proportional thermostats available which use bellows-operated potentiometers for proportional control of heating equipment such as steam valves, but they are not used in connection with modern temperature control panels.

6.53 Lighting Controls

Light to interrupt the dark period is usually controlled by time clocks. In a typical setup (fig. 6-34), a 24-hour time clock turns the lights on in the evening and off at dawn. This function can also be performed by a photocell which eliminates the need to reset the clock as the natural day length changes throughout the year. However, a photocell will gradually lose sensitivity, and should be cleaned periodically as dust accumulates. A 60-division timer with a cycle time from 6 to 60 minutes in series with the 24-hour clock or photocell is set to turn on the lights 1 minute out of 30, 12 seconds every 6 minutes, or anything in between. Some tree species may require more light than others, so, the clock could also be set to give light 1 part in 15 or 1 part in 10. Details are provided in section 12.

A smaller, cheaper electrical entrance can be used effectively, especially in large installations, if the lights are not all turned on at once (section 6.23). Because they are on only a small portion of the time, they can be divided into separate banks. One bank comes on and goes off, then the next and so on. This is controlled by a programmer or sequential cam timer which is in series with the other two time clocks.

In small greenhouses, these controls may operate on 110 volts and control the lights directly, but usually the timers operate relays which operate the lights. This intermittent lighting system works well with incandescent lights, but not with fluorescent or most arc lights (section 6.2). These lights must stay on continuously and are adapted for use on a moving boom, on which the only control needed is the 24-hour time clock or photocell.

All of the electrical controls will be safer and last longer if they are kept out of the greenhouse where they are continually exposed to high humidity and may be splashed with salty acidic nutrient solution.

Figure 6-34.—Typical controls for greenhouse lighting.

6.54 Humidity Controls

Proper relative humidity must be maintained in the greenhouse for optimum plant growth and disease control (section 11). Generally, most CTS greenhouses do not have mechanical devices specifically for humidity control. This feature is usually designed into the ventilating, heating, and cooling system.

The basic unit of control is the humidistat, which has a humidity sensor hooked to a single pole double throw switch. Thus, it can be wired to close on rise and dehumidify, or close on fall and humidify.

Dehumidification is the most common need in humid climates. It is most often accomplished by ventilation (i.e. the humidistat turns on an exhaust fan when the humidity rises above a certain level). If ventilation alone is not effective, a combination of heating and ventilation will be, even if the outside air is saturated.

Humidification is the most common need in dry climates and during cold weather when the heat is on. The humidistat may control the injection of steam or mist into the air circulation system, but there are other sources of humidity that are useful but not as easily adjusted on demand. The seedlings transpire, and humidity can be conserved by merely reducing exhaust ventilation. Doing so may not be practical, because ventilation is primarily for temperature control. Another conservation method is to use a double layer covering on the greenhouse. When a greenhouse has a single layer cover and the weather is cold, moisture will condense on the interior wall and roof surfaces. Much of this condensation will drip on the floor, drain away, and be lost from the greenhouse atmosphere. Evaporative cooling adds appreciable humidity to the air, but this must be regarded as a beneficial side effect of temperature control. Likewise, irrigation commonly brings the humidity to 100% for hours and even days at a time. Where humidification is needed, this is beneficial, but wet foliage is an invitation to disease, and some water supplies may leave harmful salt deposits if allowed to evaporate on the foliage. For these reasons irrigation for humidification should be done with care.

6.55 Security and Reliability

The subject here is not protection of the greenhouse installation from vandalism, although that is something the developer must also consider. The main concern is security and reliability of maintenance of the growing environment for the crop (i.e. the mechanical provisions to alert the nurseryman to mechanical failure, power interruptions, and other problems (section 21).

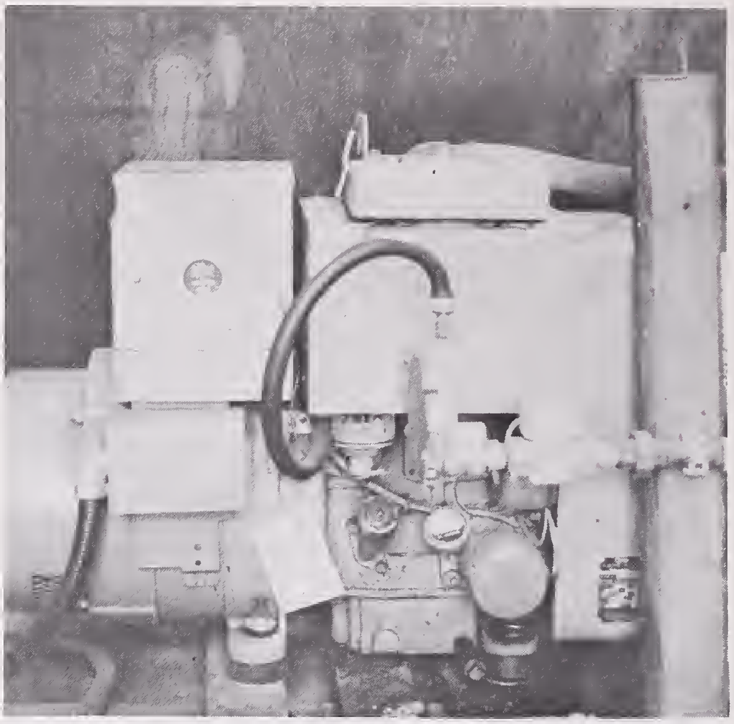


Figure 6-35.—An emergency generator big enough to run the essential heating and cooling is a good investment.

Probably the most common device is a thermostat which senses an abnormal change in greenhouse temperature and sets off an alarm. This can be a device that automatically dials a prescribed phone number and plays a prerecorded message. Some alarm systems can be programmed to sequentially ring several phone numbers in case the first is busy or does not answer. If a grower or his representative lives on the greenhouse site, a thermostat actuating a bell or horn in the residence may be adequate. More sophisticated alarm systems can detect and indicate particular mechanical failures. Some alarm systems can pinpoint the control system step that is malfunctioning, a valuable feature when a multistepped system is malfunctioning. Some can automatically start backup systems. Most are independent of the regular electrical power supply.

Common causes of temperature emergency are electrical power failure, loss of fuel supply to furnaces, or pilot light failure in the furances. Many modern greenhouses rely on furnaces requiring electricity for fuel ignition and heat distribution. Conversely, in hot climates, electricity is needed to run ventilating fans and cooling system water pumps. Therefore, every prudent greenhouse operator will provide an alternate electricity source for emergencies. Normally these are gasoline or diesel powered generators large enough to keep essential equipment running (fig. 6-35). In large greenhouse operations, they are self-actuating. If the regular source of power is off for a certain length of time, they start up and automatically shut down after regular power is restored. Most backup power systems used by CTS operations are manual starting and shut-down types, because of the relatively small scale of the operations.

Greenhouses that rely on fossil fuels for heat rarely have alternative heating systems to insure against loss of fuel supply. Delivery of natural gas has a record of high dependability. Fuel oil or propane supply should be monitored and refilled regularly. Always maintain an adequate reserve. The need for alternative heating systems when depending on solar energy for heat is discussed in section 4.13. Reliability of heating for a greenhouse, exclusive of fuel and power, is increased greatly by redundancy of equipment (i.e. several heaters).

The operation of photoperiod control is important to monitor. Since it operates only at night, malfunctions can be overlooked, especially if there is no resident nurseryman. Sometimes, malfunctions are first noticed after apical growth by the trees ceases. This should not be allowed to happen. The system can be monitored with a recording voltmeter or photometer. With either of these instruments, malfunctions could be detected by checking the chart daily. Latitude for loss of the interrupted night varies among tree species. One or two nights' disruption is usually not catastrophic. A more direct way to monitor the lighting system is to link a photocell to a time clock programmed for the same intervals as the time clock for the photoperiod control. If the photocell did not receive light from the greenhouse lights during the "on" period a switch would be thrown activating a flashing light that would operate until the following morning. The nurseryman would then check operation of the system and locate the problem. The authors know of no such system presently in operation, but it should be simple to construct.

In summary, the CTS greenhouse should have (1) some sort of low and high temperature alarm system, (2) a backup electrical power system, and (3) some method of checking the lights that interrupt the dark period.

6.56 Instrumentation

Every containerized tree seedling greenhouse operation requires certain instruments for adequate control and monitoring of the operation. Some instruments are basic and should be in every greenhouse; others are useful but not essential. Instruments vary from simple hand-operated models to sophisticated ones which automatically record their readings in a data logging system (Kelsoe 1975, Amort et al. 1977).

Hygrothermograph.—A hygrothermograph senses and records temperature and relative humidity (fig. 6-36). It provides the grower with a 24-hour-a-day record of these two measurements. At the end of the growing cycle, there is a documented record of temperature and humidity for the growing period. It provides an accurate check on calibration of sensing devices attached to the control system. The hygrothermograph also can be moved to various locations in the greenhouse to check for hot or cold spots, or it can also serve as a standard at one location while other spots in the greenhouse are checked with thermometers. This instrument is usually housed in some protective structure to keep irrigation water and direct sunlight off it but allowing free air flow over the sensing elements in the instrument. In some cases this shelter needs to be aspirated to assure accurate readings. The housing should be designed for quick and easy access to the instrument so that the graph paper can be replaced, the clock wound, and the pens inked easily.

Hygrothermographs cost between $200 and $400. The most common type has a vertical drum. The recording chart is fastened to the drum which is turned by a manually wound clock mechanism. Pens attached to sensing mechanisms record current temperature and relative humidity on the chart as the drum revolves. Electrically driven drums requiring line power should be avoided, because plugged in appliances in a greenhouse are inherently unsafe, and because their recording will stop if there is a power failure. The grower should plan to have at least one hygrothermograph for each greenhouse. Most hygrothermographs are built to National Weather Service specifications which help assure accuracy and long life. However, each facility should have at least one set of Weather Service approved maximum-minimum thermometers and a psychrometer for checking and recalibrating the hygrothermographs periodically.

pH Meter.—The soil reaction or pH value is a useful index of conditions associated with nutrient availability and plant growth (section 13.3). Wilde (1958) reviewed the relation of soil reaction to the growth and distribution of forest vegetation. The

Figure 6-36.—A hygrothermograph is an essential greenhouse instrument which should be set at plant level, but may or may not be in a shelter.

A

B

Figure 6-37.—Portable pH meter suitable for greenhouse use (A), and commonly used electrodes (B). (Photos courtesy of Beckman Instruments Co.)

importance of proper pH in the soil solution to growth of conifer tree seedlings has been demontrated (Brix and van den Driessche 1974). The optimum pH of soil solution for container tree seedlings is discussed in section 13.3 together with methodology for monitoring the modifying CTS soil solution pH. The CTS nurseryman needs a meter that is accurate and readable to the nearest tenth (1/10) pH unit (fig. 6-37). The instrument should have a general purpose glass combination electrode and be built for rugged field (not laboratory) use. Portable battery-operated units are probably best for CTS operations. Battery-operated units should be the push-to-operate type to avoid battery exhaustion by leaving the switch on. In large operations, where many pH checks are conducted and bench space is available, a 110-volt bench unit may be best. Don't buy more instrument than is needed. Suitable pH meters cost between $100 and $250.

Conductivity meter.—Electrical conductance of solutions extracted from soils gives a quantitative estimate of the salt content (Jackson 1958). Containerized tree seedlings are heavily fertilized to promote optimum growth. If the containers are not adequately leached during irrigation, enough salts may accumulate in the growing medium to damage the trees. The electrical conductivity of the leachate from the containers indicates whether such accumulation is taking place.

Detailed instructions for procedure and interpretation of electrical conductivity readings can be found in section 13.4. Generally, a portable, battery-operated, direct-reading meter providing readings from 1/10 to 5,000 PPM is adequate (fig. 6-38). Accuracy of +2% is good enough. As with the pH meter, a battery powered unit is probably best. It should be equipped with a push-to-read switch to avoid power drain between uses. The meter will have a tuning dial and an indicating needle, or a pair of lights to indicate the balance point. A cats-eye tube is hard to read in bright light. A better type for nursery use is one with lights, usually one red and one green. A low setting turns on the red light; a high setting turns on the green. When both lights are off, the conductivity is read on the dial. Conductivity meters of this type cost $100 to $300.

A hygrothermograph, pH meter, and conductivity meter are essential for good CTS greenhouse operation. Several other instruments are useful but not absolutely necessary.

Flowmeters and pressure gauges.—Many types of nutrient injector and spray nozzles are designed for trouble free operation for a long time. However, they corrode, wear, plug up, and become inaccurate (section 6.4). Properly located flowmeters and pressure gauges will tell the nurseryman if his irrigation and fertilization equipment is working as it should (fig. 6-39).

The proportion of nutrient stock solution to water is determined by the rate of stock solution injection and the flow rate of the water supply. With flow meters of the proper size on both the stock solution intake and the water supply, the nurseryman can divide one flow rate by the other and quickly determine if the injection ratio is correct. If it is not, the injector can be adjusted. If the inaccuracy is caused by wear on a fixed injector, the concentration of the stock solution can be changed to make it right for whatever ratio the old injector is producing. The flowmeter on the water supply is also an easy way to keep track of water consumption during crop growth.

Pressure on the water supply line may fluctuate for many reasons. Although this will not affect proper operation of many injectors, it will affect the length of time needed to complete a watering, and will affect the distribution pattern of water from the nozzles. A pressure gauge on the water supply line will indicate whether the watering time needs to be changed, and if the nozzles will work properly. It will also indicate water supply problems that need correcting.

Some nutrient injectors operate by compressed air and are sensitive to pressure changes in either the air or water supply. A normal complement of instruments for compressed air injectors includes two flowmeters (for stock solution and water supply), two pressure gauges, and two pressure regulators (for air and water).

Figure 6-38.—Portable conductivity meter for greenhouse use.

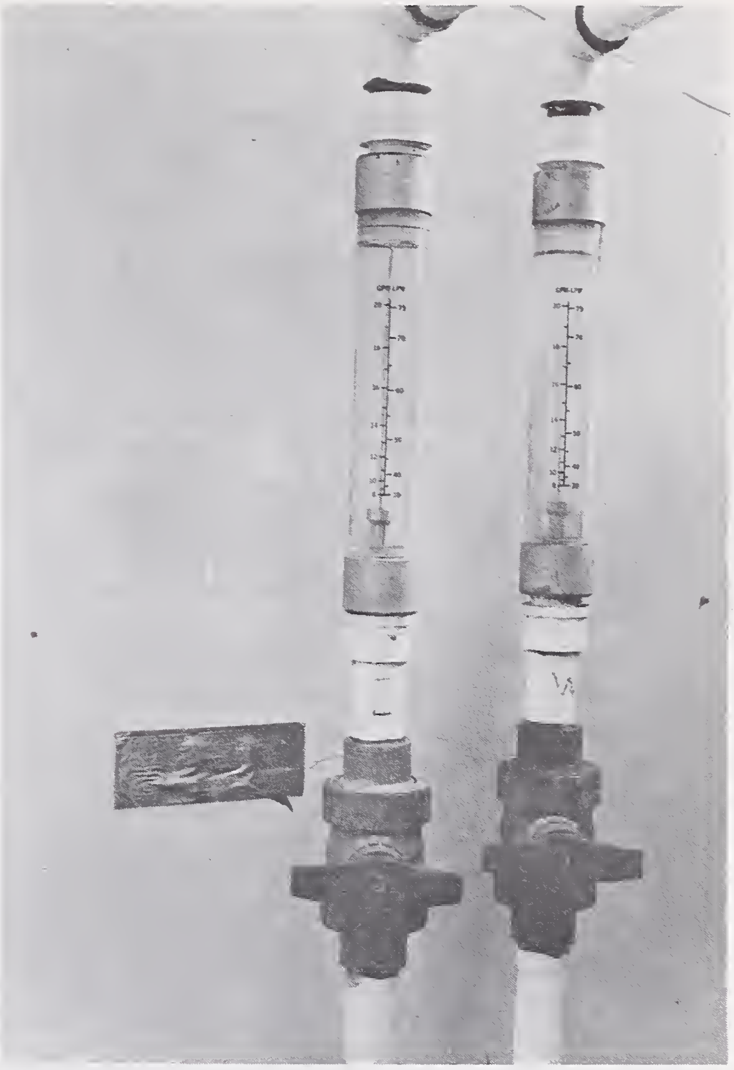


Figure 6-39.—Flowmeters used to control irrigation and fertilization. Flow rate is read from the top of the stainless steel float.

Since nutrient solution is always salty and usually acidic, all instruments downstream from the injection part should be of stainless steel, rubber, and plastic with no brass, copper, or iron parts.

Soil moisture monitoring equipment.—Maintenance of optimum soil moisture conditions in containers is important to achieve growth rates. There are several ways to monitor the amount of water in the container. The simplest is direct visual and tactile observation based on experience. It generally requires little disturbance of the seedlings. The instruments that can be used are limited. Most tensiometers have probes too large to use in small containers. Similarly, most electrical resistance blocks are too large.

Scales are used to weigh the container(s) to compare current weight with the weight of saturated containers and the weight of dry containers. With allowance for the weight of the trees, the amount of water in the container can be determined. Such scales are usually bench models capable of weighing up to 50 pounds (23 kg). Portable scales can be taken into the greenhouse. A high degree of accuracy is not necessary; ±10 gm should be more than adequate. The platform of the scale should be flat and large enough to conveniently accommodate the container used. Spillage of the medium from the container is inevitable, so, a scale with some shield to prevent this debris from lodging in the working parts is desirable.

A special device known as a moisture scale has a movable platform on which a container is placed (fig. 6-40). As the medium in the container dries, the platform rises. At a preset point, an electrical contact is made which turns on water valves or sounds a warning alarm. Again, as the trees grow, this added weight must be compensated for when setting the scale.

Bimetal probes to measure moisture are about the size of a pencil (fig. 6-41). The tip of the probe has two dissimilar metals that, when introduced into the container medium, produce a weak battery. The battery generates a current. A galvanometer needle is deflected proportional to the resistance of the metal plus pot mix. The reading can be calibrated to indicate roughly the amount of water in the growing medium. These probes are relatively inexpensive ($10-$15 each), and rugged.

A pressure bomb measures moisture tension in the plant directly (fig. 6-42) (Scholander 1965). When a leaf or small stem is cut from a plant, internal moisture tension draws the sap in away from the cut surface. The sample is placed in the bomb and nitrogen pressure gradually applied to the leaf or stem, while the cut surface is watched. As soon as liquid or bubbles appear at the cut surface, the pressure is read. This pressure corresponds to the moisture tension in the stem or leaf. When readings are taken in the very early morning, this will also be a good measure of soil moisture tension. There are situations where proper interpretation of pressure bomb readings is not as simple as it might seem. A working knowledge of plant water relations is highly desirable.

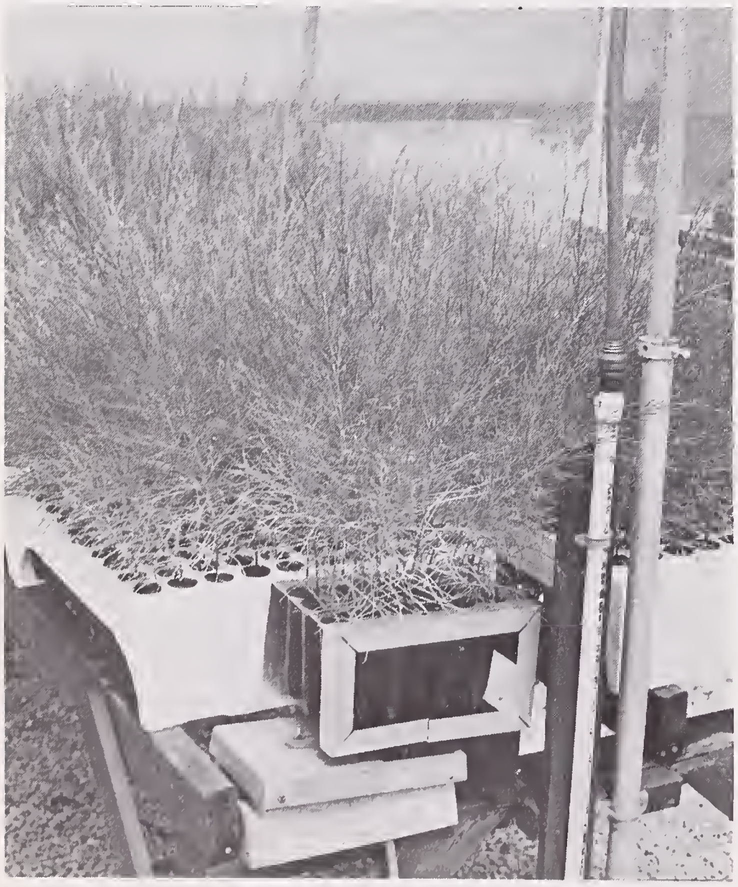


Figure 6-40.—Typical use of moisture scale in the greenhouse.

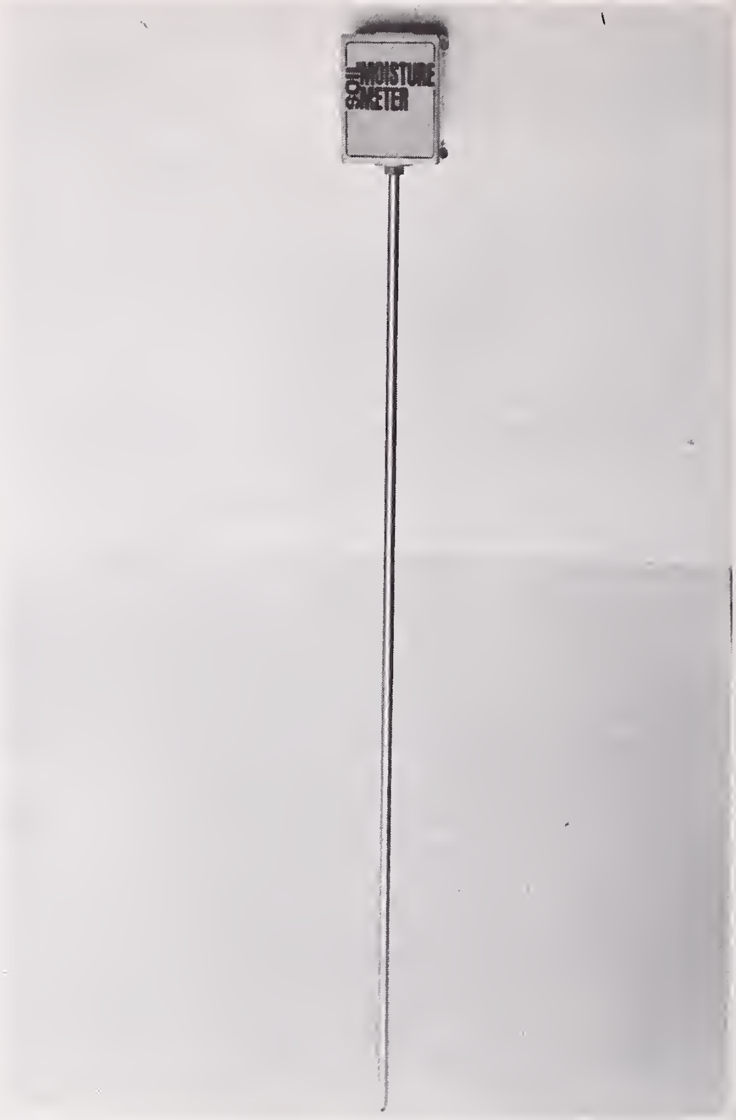


Figure 6-41.—Bimetal moisture probe is simple, small enough to use in even small containers, and accurate enough for spot checking.

Pressure bomb measurements require destruction of part of the plant. Hence, the seedlings must have enough foliage to permit a sampling. Several large nurseries rely on container weight when trees are small, then switch over to the pressure bomb when the trees reach a certain size. This appears to be an excellent method but is somewhat time consuming. However, measuring internal water tension of a tree is the best measure of moisture stress. With some testing the optimum tension ranges for tree growth can be found (McDonald and Running 1979). In general, acceptable tension ranges are from 0 to -3 bars. Pressure bombs cost about $1,000.

Each method for determining moisture status and watering needs has its own advantages and disadvantages, and none of them are applicable in all situations. The authors recommend that the nursery be equipped to use at least several of the methods. The moisture scale can be used throughout the growing cycle, but the meaning of its reading changes with the size and condition of the seedling. It takes careful calibration to use it correctly. The bimetallic probe is cheap, quick, and easy to use, and very portable, but likely to be the least accurate of the methods. Its principal use should be for spot checking. The pressure bomb is an expensive instrument but gives a direct reading of plant moisture stress. After seedlings are large enough to withstand destructive sampling, it can be used as a check on the other methods. Even with all of these instruments nothing can completely replace visual and tactile inspection of moisture in the growing medium.

A recording ammeter records the electrical demand fluctuations for a greenhouse. By interpreting these records, the nurserymen will know if the greenhouse control and lighting system is functioning properly. The alternative is visual observation or use of photocells to check lighting systems. Recording ammeters can be useful for periodic checks of greenhouse function.

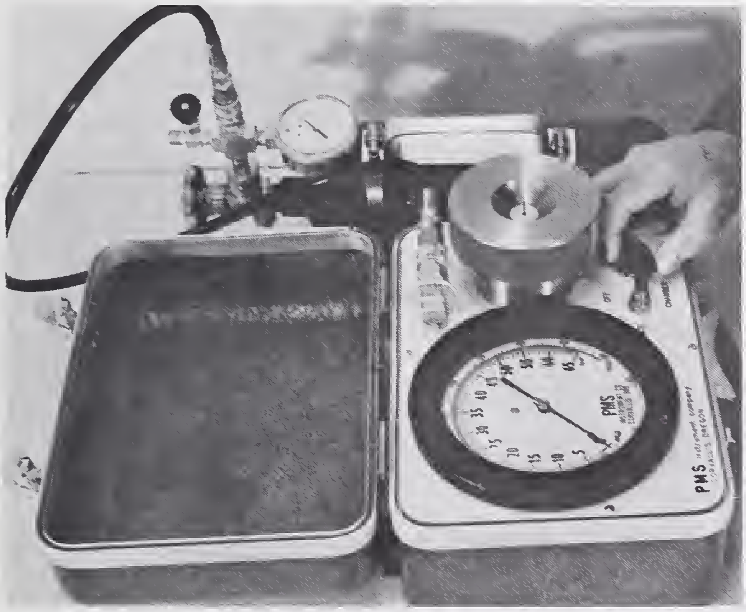


Figure 6-42.—Pressure bomb determines plant moisture stress directly.

Carbon dioxide analyzers are used to periodically check greenhouse CO_2 concentrations to recalibrate CO_2 equipment. The device consists of a manual air pump which forces air through an indicator cartridge or container of liquid. The cartridge or liquid is discolored to a degree proportional to the CO_2 concentration of the air. The cartridge is used once. The price of a manual CO testing device is approximately $75-$100. For small greenhouse operations samples of air from the greenhouse can be sent to laboratories having infrared gas analyzers.

Of the less necessary instruments, the authors consider those for nutrient injection monitoring and soil moisture measurement most important. Recording ammeters and CO_2 analyzers are rarely needed. It may be possible to rent or borrow an ammeter, and have greenhouse air samples gas analyzed by someone else.

6.6 Greenhouse Safety

Greenhouses have a number of inherent safety hazards which can be minimized by proper design and construction and by safe work habits. Greenhouse interiors are commonly wet, which makes floors slippery from spilled growing medium and the growth of algae. Floors should be built to minimize slipperyness and cleaned as needed when they become slippery. Because dampness makes machinery rust, keep as much machinery as possible out of the greenhouse.

Probably the greatest hazard created by wetness is the danger of electrical shock. All wiring should be in waterproof conduit. All outlets should be grounded and equipped with ground fault interrupters. Never use ungrounded tools or appliances of any kind in a greenhouse, unless they are double insulated. When repairing or adjusting electrical equipment, shut off the power first. If this is not feasible, at least wear rubber gloves and boots; use a wooden ladder instead of an aluminum one.

Greenhouse fans may start automatically without warning. For this reason the blades should be shielded so that no one can put their fingers in them.

Some greenhouses have floor-mounted heaters, which should have their flues shielded so that they cannot be touched inadvertently.

SECTION 7.—AUXILIARY EQUIPMENT AND BUILDINGS

SECTION 7.—AUXILIARY EQUIPMENT AND BUILDINGS

7.1 Headhouse and Storage Buildings

A building referred to as a "headhouse" is often located near the greenhouse. It is used for activities such as filling containers, seeding, packaging for shipment, and storage of materials and supplies. Headhouses are usually placed on the north side of greenhouses to avoid shading them. A connection between the headhouse and the greenhouse makes operations much more convenient, but can complicate construction.

The size and type of headhouse and other buildings depend on the activities and storage requirements of a particular operation. Exact headhouse and storage requirements are difficult to establish. Duncan (1975) suggests an area equivalent to one-fourth to one-third of the greenhouse space be allowed in tomato operations, but this seems high for CTS operations. Storage space for materials and supplies can be in the headhouse or separate storage buildings. Storage areas are typically unheated. Headhouse work areas, storage areas, and office space often are concentrated in one structure. Work area space requirements can be determined by allowing room for functions involving shipping, receiving, potting, seeding, and maintenance. Several floor plans can be developed, and flow diagrams made for each phase of work. The plan that accommodates all phases of work best can then be selected (fig. 7-1).

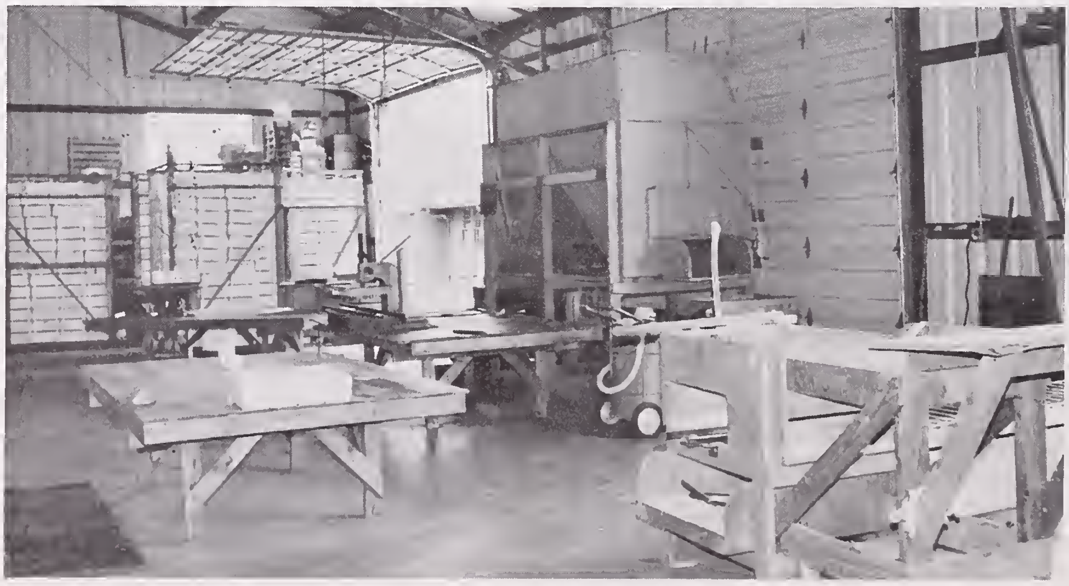


Figure 7-1.—A well laid out headhouse.

7.2 Mixing and Loading Equipment

The growing medium used in CTS culture is most often half vermiculite and half peat moss. Sometimes these constituents vary in favor of ground bark, perlite, or some other material. Mixing can be done at the nursery or commercially mixed potting medium can be bought premixed. The components, advantages, and disadvantages of mixing growing media on-site, and methods are discussed in section 9.3. A growing number of Pacific Northwest CTS operations are purchasing growing medium that is commercially mixed. This alternative should be carefully evaluated before any mixing equipment is purchased.

Growing medium mixing operations vary from simple to complex. Even some of the largest CTS nurseries mix the components by hand on the floor or in a large stock watering tank. The key is thorough mixing. The mixed material is usually shoveled onto a conveyor or auger that moves it to a hopper or bin that supplies a potting table or device. Operators who mix their media this way contend that they get adequate mixing and that it is such a brief job that it is cheaper to buy the labor than to invest in mixing machines.

The two major components of most CTS growing media, vermiculite and peat, are usually bought in bags or bales. The peat is usually in plastic bags, the vermiculite in paper ones. Both are best stored inside or under plastic or canvas tarpaulins outside. Some peat is well decomposed and has a granular consistency; some is fibrous, clumpy, and still resembles the original foliar structure of the peat moss. These clumps of peat may not readily break apart during the mixing process. Some nurserymen put the peat through hammer mills or compost shredders to make it uniform. Patterson (1969) used a shredder as his mixing device by putting all of the components of his pot mix into the shredder together with fertilizers. The mixing was then finished with shovels.

There are many mechanical ways of mixing the growing medium. It can be done on a small scale with a portable cement mixer, small endloader, manure spreader, or a specially designed and manufactured growing medium mixer. In large scale CTS operations, large custom mixing machines can be used. Often, large old cement mixers are used that were originally mounted on trucks. When such units operate efficiently and can be purchased at a reasonable price, these may be a viable alternative. Renting mixing equipment is another alternative. At a U.S. Forest Service nursery in Idaho, this operation is completed in a couple of hours by having a commercial cement mixing truck do the mixing on site. A large amount of material (15-20 yd^3 or 12-15m^3) is mixed in a short time. However, some nurseries have found that the tumbling action creates balls of mix which must be run through a shredder or broken up by hand before the containers can be filled.

Some components of a CTS pot mix are sometimes hydrophobic. If the mixture is put into containers dry, it is frequently difficult to moisten it by sprinkling. Therefore, in contrast to many soil-based or sand-based potting operations, the growing medium must be moistened during the mixing process. This means the moistening must take place before containers are filled and that the containers must be seeded and irrigated before the pot mix in them dries out. Consequently, it is best to mix just before the filling and sowing operation. This, together with capital and labor availability and scale of operation, determines the equipment for the mixing operation. The developer should gain some experience in CTS operations before investing in expensive mixing equipment.

Loading equipment.—In small to medium operations, containers can be loaded with growing medium manually with very simple equipment more efficiently than would be expected. In large operations, mechanization becomes feasible to save labor and time.

The steps of the process are: filling the containers and compacting or compressing the medium in the containers. Seeding equipment is discussed in section 7.3. Containers can be filled by hand, but a raised hopper is commonly used. Such hoppers have manually operated gates on the side that open onto a work surface where the empty container is (fig. 7-2). Gravity causes the medium to flow out of the gate, then it is manually spread across the top of the container block. The cavities are carefully filled to the top to avoid air pockets. To increase work efficiency, the containers are often moved to and from the work station with live rollers. The workers then spend maximum time filling containers and minimum time moving to and from the work station.

Growing medium vibrators and shakers.—In many instances, CTS nurseries have devices to shake containers to settle the medium and avoid air pockets. Many are homemade. One version has a framework with eccentric camshafts underneath which, when turned by an electrical motor, alternately raise and drop the container block.

Several mechanical specialty companies have developed equipment that fills CTS containers semiautomatically (fig. 7-3). These usually consist of a hopper to hold the mix and an integral conveyor to move the mix to where it is sprinkled over the top of the container block which moves by on another conveyor. Most vibrators and shakers are well made and adaptable to a variety of container types and sizes, but some are very expensive.

Compression of the growing medium.—Often, the medium in each filled cavity is compressed from the top of the cavity to some uniform depth below the lip of the cavity. This is done for several reasons:

1. To eliminate air pockets in the container.
2. To bring the mix to a uniform density throughout the container.
3. To avoid later settling in the container.
4. To shape the surface so seeds settle in the center of the cavity.

Not all CTS nurserymen compress the mix in this fashion, but most do. This is important to grow uniform high quality seedlings. There is some evidence that compression of the growing medium enables seedlings to tolerate drought better (Mitchell et al. 1972, and Hocking and Mitchell 1973). The relation between growing medium components and aeration is discussed in section 9.33. Too high a density can slow or limit root development in some conifers (Hocking and Mitchell 1975).

Mix compactors consist of small cylindrical or rectangular plugs conforming to the mouth of the cavity with a length equal to the depth of the depression desired (fig. 7-4). The end of the plug is usually dish shaped. This leaves a depression deeper at the center than the edges, so that seeds roll to the center of the cavity. These plugs are distributed over the face of the plate of metal or wood, or a drum in the case of rotary compactors, so that their positions conform to the spacing of the mouths of cavities. When the plates are pressed onto the top of the container block, the plugs compress and shape the medium in each cavity. Compactors for different container types are commercially available. They may be constructed of wood, metal, or plastic. Many CTS nurseries use homemade compactors. A variety of methods are employed to press the compactors into the cavities. Some do it by hand, others use long armed levers, and some use presses similar to a drill press.

Figure 7-2.—Hopper used to dispense pot mix into containers.

Figure 7-3.—Integrated hopper, filler, and tamper for containers.

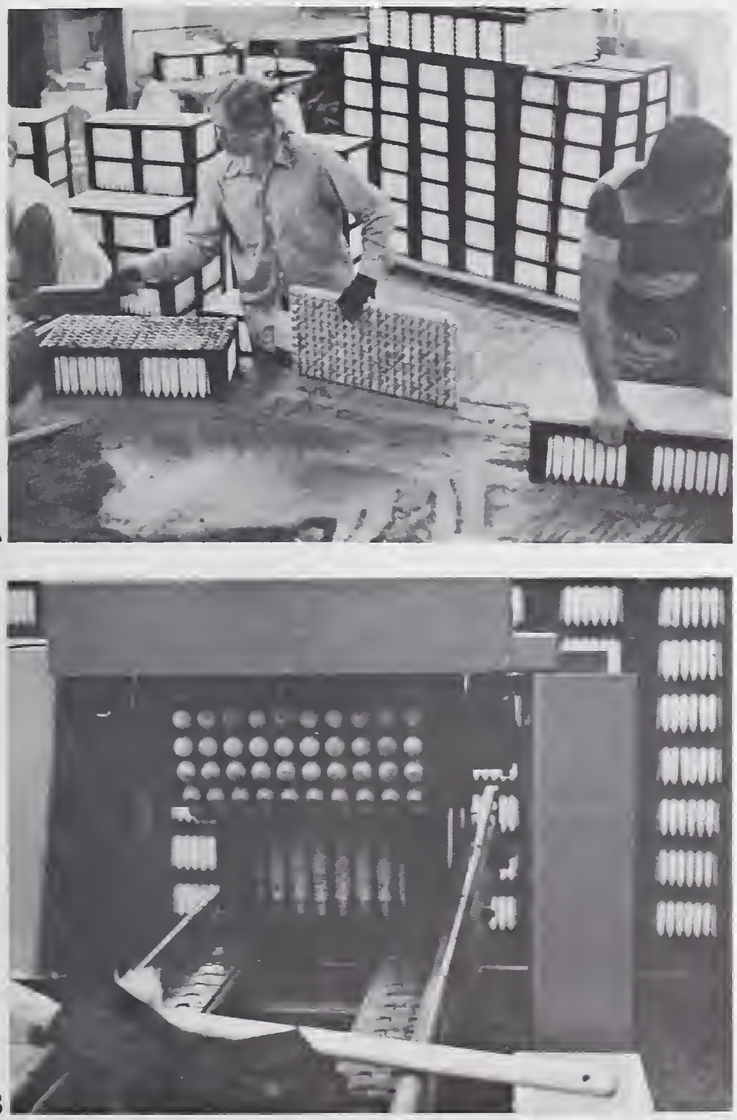
After compression of the medium, the containers are seeded. The seed is covered with a thin layer of sand, grit, barkdust, perlite, or some other material (section 16.3). Perlite or poultry grit are most commonly used. It is spread evenly over the top of the container block in the depth desired (section 16.33). This is often done by hand. Some mechanical sowing devices incorporate spreaders that sift a layer of seed covering material onto the container block as a conveyor carries it by. Many homemade devices are used.

7.3 Seeding Equipment

CTS operations require clean, high quality tree seed. Clean seed simplifies sowing and increases speed and accuracy, and the sowing devices require less cleaning. Mechanical seeders then select fewer bits of trash to sow instead of actual seeds. High quality seed permits sowing fewer seeds per cavity, which reduces sowing and thinning costs.

Hand seeding is the simplest form of sowing. Each seed is placed in a cavity by hand. This procedure is too costly and inefficient except where small numbers of cavities are being sown for test purposes or seeds of difficult to germinate species are placed in containers after the radicle has emerged.

The most rudimentary seeding machines are box seeders made of wood, metal, or plastic. The best are made of clear plastic. The box or tray is constructed so two of the outside edges conform with the outside dimensions of the container block (making up a number of cavities) (fig. 7-5). The box has two levels separated by a space. Each level has holes drilled through it directly above the cavities in a container block. The holes in the upper level are of a size that will contain seeds (1-4 usually) of a given species. The holes in the second level are larger and allow the seeds from above to freely drop through. Between the two sheets of material is another sheet, not fastened to the sowing frame, but free to slide back and forth between the other two like a drawer-pull.



A

B

Figure 7-4.—Compactors for compressing and shaping the surface of the growing medium: (A) Flat compactor used by hand, and (B) rotary compactor as part of an automated filling line.

Figure 7-5.—Box seeder.

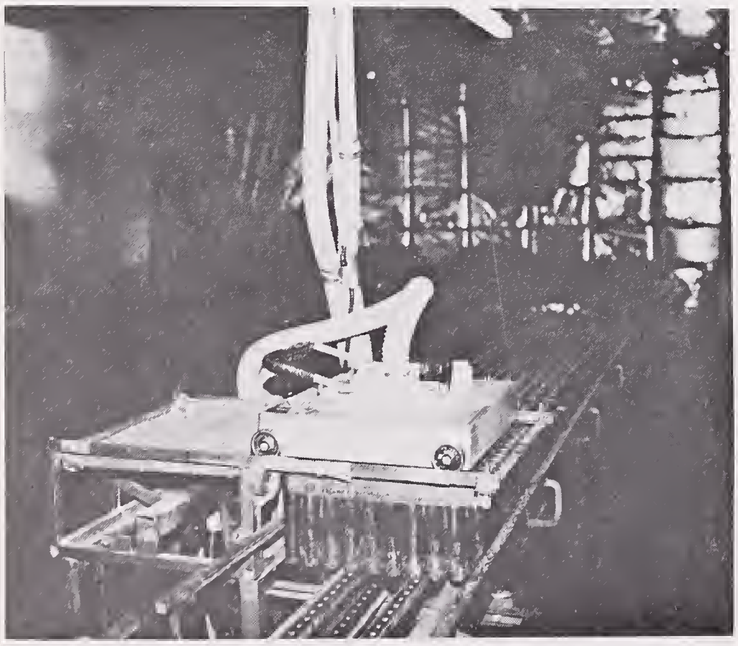
This middle, movable sheet has holes identical to those in the lower level. When the middle "drawer" is shoved all the way in between the upper and lower levels, the perforations in it do not align with those in the upper or lower sheet; when it is withdrawn slightly, they do.

To sow the seed, the box is placed on the container block with the two flanged edges aligning the seed holes above the cavities. With the middle, movable, sheet shoved all the way in between the upper and lower layers, seed is brushed over the top surface. Depending on the size of the top layer's perforations, one, two, or more seeds fall into each hole. They are retained by the middle (movable) sheet. When all holes are filled with seed, the excess seed is removed. The middle sheet is then withdrawn until its perforations line up with those in the upper and lower layers, and the seeds fall through into the cavities. Dirty seed can complicate this method, and low quality seed can require the operation to be repeated for each container. If this simple seeding device is fully utilized by well trained and practiced personnel, astonishing seeding rates can be achieved.

Another simple device for seeding containers is a vacuum plate (fig. 7-6). This consists of a flat surface with small holes drilled in it. The distribution of holes over the surface of the plate corresponds to the centers of the cavities in the container blocks to be used. The size of the holes depends on the seed size. A vacuum is applied to the reverse side of the plate to suck air through the orifices. The plate is then pressed lightly down into a flat pan containing a layer of seed. With some care and patience, the vacuum will hold the desired number of seeds at each orifice. The plate is then aligned over the container block, usually in some prepared framework, and the vacuum is shut off. The seeds then fall into the container cavities. There are a number of variations designed to streamline the process, but again, clean, high quality seed is needed. Vacuum plate seeders are usually relatively inexpensive.

The tray seeding system and the vacuum seeder have several common characteristics. They require low initial capital investment and are surprisingly productive when efficiently used. Neither can be used without adjustment for different sizes of seeds or different containers. To allow sowing in containers with different cavity spacing or to seed different sized seeds, different trays or vacuum heads are necessary. No production figures for these seeders are given here. Reports from users vary widely, probably reflecting variable efficiency of overall sowing setups, labor, seed quality, and supervision. However, the potential production is 300,000 to 500,000 cavities per day. This means that these simple devices are probably practical for small to medium sized CTS operations (up to 10 million trees per year). The developer should, therefore, proceed cautiously when considering purchase of large complex sowing devices.

A



B

Figure 7-6.—Vacuum plate seeder picks up seed from a tray (A), and is rolled from the seed tray to the containers (B) where release of vacuum deposits the correct number of seed in each cavity.

The next level of seeding devices are labor efficient, but are more expensive and mechanically complex. These machines rely on various principles and are evolving rapidly. USDA Forest Service Missoula Equipment Development Center is preparing a catalog, to be published in 1979, listing manufacturers and describing these machines. Some are made in Canada or Europe. Some are very accurate and efficient. In large CTS operations, such high volume equipment may be essential. Instead of discussing the various types of sowing devices, the following recommendations are made:

1. Be sure the cost per unit seeded using the machine is less than the cost of using the simpler seeding devices.
2. Be sure the machine will sow seed in the containers being used and be flexible enough for others which may be used in the future.
3. Be sure to canvass present owners to see if they are satisfied with the machine.

7.4 Conveyors, Live Rollers, and Benches

Conveyors and live rollers are often used to mechanize and speed container movement in container filling and sowing processes. Except for highly customized and sophisticated systems, such items are relatively inexpensive and can effectively expedite flow process. Often, they can be used in other operations at a CTS nursery, such as unloading a greenhouse, multiplying their usefulness. As mentioned in section 4.3, a number of process flow diagrams should be analyzed during facility planning. Flow system hardware should be considered at the time. The alternative is assembly of these articles, piecemeal, as the process evolves and changes.

Emphasis should be placed on minimizing wasted time and motion. Key machines and workers should be supplied with a constant flow of raw materials. Elevator conveyors used to fill hoppers, live rollers to move containers to the filling station, and conveyors to carry filled containers to those doing the seeding will reduce the labor required and make the work go more smoothly. Some CTS nurseries use conveyors to move containers in and out of the greenhouse. Large nurseries often evolve sophisticated flow systems using such equipment.

In most CTS greenhouses the containers are off the floor on some type of bench or table. These bench systems are used because:

1. They place the crop at a comfortable working height for thinning, inspection, and other work.
2. They may be modular and part of a container handling system.
3. They raise the crop above pests that may inhabit the floor of the greenhouse.
4. They allow free air circulation under and around the containers, which allows root pruning and lessens disease problems.
5. They elevate the crop above water that may be standing on the floor of the house.

Height and construction of CTS benches varies considerably. Most are homemade, consisting of wooden or concrete block legs and wooden frames with wire mesh stretched over them to allow airflow to the bottom of the containers. Others are quite elaborate. They may be made of metal and designed to allow the best use of available greenhouse space with a minimum of room devoted to aisles. Figure 7-7 is a diagram of a cartbench system developed by the Forest Service that is a good example of a more sophisticated design (Hiatt 1976). In general, the type of bench system used should:

1. Be sized to fit the type of containers used (section 5.3).
2. Be compatible with the greenhouse door widths and dimensions of the house.
3. Be adapted to the materials handling system to be used.
4. Allow free air circulation below the containers.

Beyond these general guides, the design of the bench system should meet the needs and the resources of the greenhouse developer. Commercially built benches range from simple to complicated designs with a parallel range in prices.

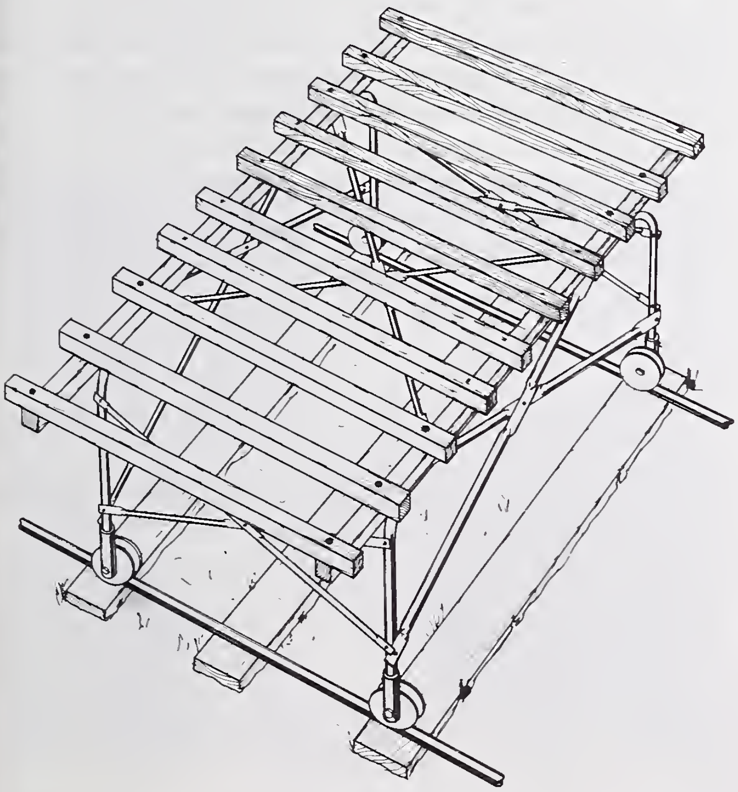


Figure 7-7.—A "cartbench" and track system (Hiatt 1976).

7.5 Rolling Stock and Stacking and Storage Systems

7.51 Rolling Stock

Every CTS nursery has a system to move peat, vermiculite, and containers from storage areas to work areas, and to move containers in and out of the greenhouse, etc. Some operations may use the same method of transport throughout the operation. Forklift trucks or tractors with multipurpose trailers are common. Conveyors are sometimes used for part of the work. Most often, a combination of methods is used. Probably the most efficient approach is to decide on the system to be used early in the development process. The fullest use of the selected item (such as a forklift truck) can then be incorporated in facility design and the need for other equipment minimized. The advantages and disadvantages of electric carts, tractor-trailer combinations, forklift trucks, etc., can all be itemized and compared. Remember that operation of internal combustion engines in closed spaces where people are working is dangerous and may violate safety regulations.

7.52 Stacking and Storage Systems

There are numerous methods for stacking and storing supplies. Materials handling firms will provide much advice free. In headhouse/storage building construction, it is cheaper to build structures with high ceilings. To take advantage of this, use stacking systems that will allow efficient use of such rooms safely.

7.6 Culling, Packing, and Shipping

Not every container cavity yields a usable seedling, and the process of eliminating the failures is called "culling" or "dudding." Culling can be done either at the nursery or at the planting site. To cull at the nursery, the individual containers must be separable one from another, or the tree and rootball must be extracted from the container. Different types of containers vary in their adaptability to culling at the nursery. For instance, single cells are highly adaptable; styroblocks and book planters are also adaptable, but it would be very difficult to handle paperpots this way (section 9). Therefore, which container system is selected will have an important bearing on whether it is desirable or even possible to cull at the nursery and how the seedlings are packed for shipment.

The advantages of culling at the nursery are:

1. The duds are not shipped. This reduces the bulk and weight of the shipment, and the cost.
2. Work is more efficient. Rootball extraction can be mechanized, a grading belt can be used for sorting, and the whole process can be done in assembly line fashion.
3. The container or its supporting rack remains at the nursery, which greatly reduces the wear and breakage on these components and increases their reuseability.

The disadvantages are:

1. It is one more operation to perform.
2. Some container systems are not adapted to culling at the nursery.

The alternative to culling at the nursery is to let the tree planter do it at the planting site. This simplifies the job at the nursery at the expense of making more work for the planter and slowing him down. It is justified if there is an acceptably small percentage of culls, or the nursery gives the customer a price break on the seedlings.

There are two basic methods of packing. If the containers are shipped as is, there is a minimum of handling and processing at the nursery. At their destination the container seedlings may be stored for days, even weeks if necessary, with very minimum facilities. On the other hand, the truck or trailer in which they are shipped needs to be equipped with special racks which allow room for the seedling crowns and prevent them from being crushed.

The alternative is to box the seedlings. The containers may be boxed or the seedlings with their rootball may be removed from the container, culled, packaged in plastic bags, and then boxed. The latter procedure has several advantages:

1. Boxed seedlings, culled and removed from their containers, are much more compact.
2. No special racks are required. The boxes of seedlings can be handled by the same equipment used for any other boxed goods.

However, there are disadvantages:

1. Packaging is one more operation that takes time and costs money at the nursery.
2. Waterproof boxes are expensive, so, many nurseries make them returnable. Then they become another item that must be cleaned, reconditioned, and stored.
3. When packed tightly together in dark boxes, tree seedlings are more perishable than if left open to the light at their original spacing in the original container. They will heat internally if allowed to become warm and may need refrigeration if stored for any length of time.

7.7 Office Space and Accessory Structures

Office space may seem to be a minor consideration when beginning a CTS operation, but it becomes very important once business begins. Accordingly, office space should be planned at the outset, not just patched on later. Office space often is incorporated in a headhouse/storage building, making the structure multipurpose. Restrooms, dressing areas, and lunchrooms for workers are often included. Office space at a large CTS nursery should be organized into three categories: (1) clerical, (2) managerial, and (3) technical. Clerical and managerial space should be relatively high quality. Technical areas can be less so because of the type of work done there. Instruments, such as pH meters and conductivity bridges, can be housed in the technical area. Offices should be designed to expand as the operation grows. The planner must also consider accessory structures such as equipment storage sheds, chemical storage buildings, pumphouses, and visitor information facilities. These structures can be sized to anticipated needs.

SECTION 8.—SHADEHOUSES

SECTION 8.—SHADEHOUSES

Shadehouses are shelters where seedlings can be grown full-term (in mild climates), can finish growing, can be kept over winter, lapse into dormancy, or simply be kept before shipping while the greenhouse is loaded with a new crop (fig. 8-1).

8.1 Functions of Shadehouses

Besides providing space for storing trees, shadehouses can:

1. Reduce the temperature below what it would be in direct sunlight by shading. The degree of shade is usually about 30% to 50% (enough light to allow the trees to remain in a normal condition, but still be cooled). The cooling effect tends to hasten dormancy in the fall and keep seedlings dormant in the spring.

Figure 8-1.—A typical well organized shadehouse.

2. Reduce shock when the trees are removed from the greenhouse in a succulent condition.
3. Reduce foliage scorching caused by dessication of foliage in cold weather when roots are cold or frozen.
4. Reduce evapotranspiration rates in summer. This lessens the need for irrigation.
5. Protect the trees from high winds, hail, heavy rains, and in some cases, animals. Shadehouses designed to counter these impacts must be stronger than the usual structures.

The need for a shadehouse at a CTS operation depends upon the weather and the production scheme. In some conditions, a shadehouse may be nearly mandatory, but in others, it is only a convenience.

8.2 Bedhouses—What Are They?

Traditionally the term "bedhouse" has referred to a minimal structure used to protect plants in the winter in ornamental nurseries. They consist of bow-arch frames covered with plastic sheeting.

Recently, the term "bedhouse" has been used to denote facilities used at tree nurseries to speed seedling growth or allow early sowing to produce tree seedlings more rapidly than with conventional bare-root nursery methods. In this context, bedhouses represent a degree of cultural control intermediate between outdoor bare-root beds and greenhouse container facilities, where bare-root stock is raised under a greenhouse with a degree of climate control. This procedure has been evaluated several times and is currently being tested by the U.S. Forest Service at Coeur d' Alene, Idaho (Tinus 1978a). Indications are that bedhouses can extend growing seasons to a modest degree, possibly provide larger planting stock in a shorter time, and protect young seedlings from severe weather. However, costs must be carefully evaluated on a case by case basis to see if bedhouse operation is economically practical, given the growth and protection benefits accrued. Also, since they are normally engineered with a minimum of automatic equipment, they must be conscientiously monitored and operated to avoid temperature extremes detrimental to the trees.

8.3 Shadehouse Coverings

Shadehouses are normally covered with either lath or woven plastic shade cloth. The lath can be nailed individually on the lathhouse structure, but more commonly, wire-bound snowfence is used. Lath is usually spaced to provide about 50% shade. Sides of a lathhouse are often covered with lath, except for an entrance. South and west sides are nearly always enclosed for shading. Shadehouses used for rearing seedlings through a complete growing cycle must be bird-tight.[1]

Shade cloth can be purchased in various percentages of shade (density of weave) and in various lengths and widths tailored to customer's needs. For CTS shadehouses, 50% shade weave is normally used, but 30% weave is becoming more popular in the Pacific Northwest due to the mild climate there.[1] The material is used on conventional post and beam frames, on large bow-arch frames, or on wire frames stretched over upright border posts. It must be stretched tight and tied down to prevent whipping and tearing in high winds. It also is lighter than lath, so, the supporting structure can be lighter. The life of shade cloth is several years, if it is well cared for. Shade cloth should be furled or taken down in winter, because it will collect snow, rip, and collapse under weight. It is also more prone to wind damage when the weather is cold.

Shadehouses made of lath can also be damaged by heavy snowfall. In areas with heavy snowfalls (12 inches (30 cm) of wet snow) lath on the roof should be in rolls so that it can be rolled up in winter. If the lath is nailed to frames, these should be separate from the roof so that they can be removed and stored on edge. In areas with regular heavy snowfalls, the snow lessens the chance of solar insulation damage. However, in most cases, lath can safely be left up all winter to positively prevent it. Even if lath on the roof of a shadehouse is removed, the walls should be left up to protect the trees from high winds. There is no standard for shadehouse construction. Wood construction is traditional and is usually viewed as more permanent than shade cloth houses. Wooden shadehouses must be well constructed, not only to support their own weight and snow loads, but also to prevent unsightly sagging and bowing of the lath and other structural members as the house ages. Framework designs for shadehouses vary from stretched wire and posts to post and beam wooden and steel frames to metal bow-arches. There seems to be no clearcut advantage to any type of shadehouse frame. So, the selection should be made for least cost, utility for a given operation, and appearance.

Spice (1977) describes an innovative shadehouse constructed at moderate cost. It consisted of a series of parallel wires streched over the area to be shaded. Small pieces of black polyethylene sheeting (about 3 by 12 inches) (7.5 × 30 cm) were lapped over each strand of wire and tied to the wire using an overhand knot so that the two ends of the strip hang vertically down. As many strips are tied to each wire as room permits. The result is a shadehouse providing mottled shade that is highly resistant to wind damage. Construction is labor intensive, but materials needed are inexpensive.

8.4 Using Shadehouses

Seedlings are often stored over winter in shadehouses. This allows crops grown in one season to be held for spring planting the following season without occupying greenhouse space all the while. Where greenhouse space is available for such storage, it is the most protective alternative and should be used. In the Pacific Northwest, a protective roof is desirable for overwinter storage of trees to prevent overwatering from rain and the resultant root-rot problems. Overwinter storage of trees in shadehouses in Pacific Marine climates is not desirable, but can be done. Containers should be placed on boards or pallets to allow for drainage and air circulation. During cold weather, the borders of groups of containers may have to be insulated to prevent root damage. In cold weather, warm air or water may have to be circulated below the roots to prevent freezing damage.

In the interior West, shadehouse storage of seedlings over winter is more practical. Containers should be placed flush on the ground and concentrated. The border of each grouping should be insulated with sawdust, chips, or bark to provide insurance against damage to the roots of the plants from extremely low temperatures. Snowfall normally will not damage the trees.

In summer, container blocks in lathhouses are best spaced apart to allow for air circulation and light infiltration through the crowns. Blocks must be elevated to allow free air circulation underneath to allow air pruning of the roots (i.e. root tip exposure to air and resultant dessication). Container blocks are often placed on boards, pallets, or benches to enhance air circulation.

[1] *Personal communication with Dr. Peyton W. Owston, Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg., June 1978.*

8.5 Shadehouse Irrigation Systems

The irrigation system in a shadehouse can be fixed or portable. Portable aluminum pipe with impulse sprinkler heads on risers is often used. Complete coverage and as much uniformity as is practical should be assured. Fixed systems should be constructed so that the irrigation system will not obstruct production operations. The most efficient way to fertilize seedlings is through the watering system, just as in the greenhouse. To do this, provision can sometimes be made at the nutrient injector for plumbing to the shadehouse. In some cases, a separate nutrient injector is the logical answer. Most of the precautions stated in section 6.4 relating to greenhouse irrigation systems apply to shadehouse systems. However, shadehouse sprinklers can water the trees at higher rates and with coarser droplets, because the trees are bigger. This allows effective irrigation in windy conditions. Also, shorter irrigation periods mean seedling foliage is soaking wet less of the time, lowering the chances of disease infection.

8.6 Shadehouse Floors

The floor of the shadehouse can be gravel, asphalt, or cement. Gravel is commonly used because it is cheap, readily available, and porous, but weed control on a gravel floor is necessary. Asphalt and concrete are more expensive and are nonporous. When using any of the three materials, the developer must properly crown the area and provide for drainage of excess water. Cement or asphalt are used where a hard surface is required.

Shadehouses should be positioned for efficient flow of seedlings from greenhouses to shadehouses and from shadehouse to delivery trucks. This consideration is part of initial site planning.

8.7 Size and Number of Shadehouses

The size and number of the shadehouses depends on the production scheme. Are all trees grown to be in the shadehouses part of the time, only part of them, or will the shadehouses hold just special products? This is determined in the production scheduling associated with greenhouse sizing (see section 5.3). Size of the shadehouses relative to the number of trees to be held is an open question. A general rule is shadehouses should have about one-third more floor space than the trees would require in the greenhouse. The added space is used for aisles and for spacing containers apart for air and light infiltration. This is a guide for approximate estimation of needs. Exact figures are easily developed diagrametrically using the number of trees involved, the spacing of the blocks, and the materials handling system to be employed.

SECTION 9.—CONTAINERS AND GROWING MEDIUM

SECTION 9.—CONTAINERS AND GROWING MEDIUM

9.1 Function of Containers

Biologically, the function of containers is to:

1. Provide a medium for support and nutrition of the roots.
2. Protect the roots from mechanical damage and desiccation.
3. Shape the roots into a form advantageous to the tree.
4. Maximize field survival and early growth, because the root system is not disturbed but remains in intimate contact with the growing medium.

Operationally, the function of containers is to package the seedling into a standard size and shape for ease of handling throughout the nursery, shipping, and planting phases.

Recently, a great deal of concern has been expressed about the root form of planted trees (van Eerden and Kinghorn 1979). There is no question that planted trees, bare-root or container, have a different root configuration than trees grown from seed in place. In some instances, windthrow of plantations has been traced to poor root development. Pines of all species seem to be particularly susceptible. Two problems seem to be most important. When the tree is planted, roots must not be allowed to remain in a circle around the central axis. As they grow in size, they will eventually restrict diameter growth of the tap root. Even if the circling roots graft and fuse with the tap root, a weak spot is created as the stem diameter above continues to enlarge. The tree may suddenly break at the root collar in a high wind. The other problem is lack of an adequate number or distribution of lateral roots near the surface. The container must be designed to overcome these two problems.

In horticulture, the term "container" signifies what most forest tree nurserymen would call a "pot," meaning a cylindrical or rectangular plant container, slightly smaller in diameter at the bottom than the top, with a depth not much greater than the diameter, and having a flat bottom. Containers of this type are referred to by the volume they displace. They are made of fired clay, metal, plastic, compressed wood pulp, or peat.

When forest tree nurserymen refer to "containers" they mean "a container designed specially for the growth and culture of tree seedlings."

The shape of these small containers is very much different from the usual nursery pot. CTS containers are usually much deeper than their top diameter (as much as 10 times). This is because, in many instances, forest tree seedlings produce taproot systems rather than fibrous root systems, and a narrow, deep container is more compatible with this growth habit. Second, in wildland plantings, it is desirable to place the roots as deeply as possible into the soil where moisture will be available the longest. Third, planting holes of necessary depth are easier to punch or auger if the hole has a small diameter, because less earth must be moved and there is less compaction.

9.2 Container Concepts and Types

Basically, the theory of containerized tree seedlings is that, if a tree seedling can be planted with a minimum of root exposure and disturbance, there will be less transplanting shock, and survival and growth rates will be higher (Kinghorn 1974). The design of all containers is intended to minimize this root disturbance.

9.21 The Basic Types of Containers

There are two approaches to container design:

1. The container is planted with the tree. Provision is made for root egress from the container by its biodegradability, or through holes, slots, and expandable seams built into the container.
2. The tree and its plug of rooting medium held together and in shape by the tree's roots are removed from the container and then planted. The container is not planted, but may be either discarded after a single crop, or reused, depending on the type.

Each of these approaches has inherent advantages and disadvantages. In North America, most of the container seedlings are grown in rigid-wall containers that are removed from the tree when it is planted. The advantages of this concept are:

1. In the nursery, it is fairly easy to prevent tree roots from growing from one cavity to the next. When it occurs, this results in root breakage, disruption of contact between growing medium and roots, and greater physical effort to extract the plug from the container.
2. The container can be reusable, which lowers its unit cost per tree.
3. The shape of the container can greatly affect future growth of the seedling in the field (section 9.22). Most rigid wall containers incorporate vertical ribs or grooves, rounded horizontal corners, and a bottom hole for root egress, which successfully prevents lateral roots from circling around the central axis, provided the tree is outplanted on schedule. (Trees can become rootbound in even the best container, if they are held too long).
4. When planting, removal of the container instantly eliminates any barrier to root egress caused by the container. (There may still be a barrier caused by difference in properties between the growing medium and soil, however).

The disadvantages are:

1. The root ball must be removed from the impermeable walled container. This operation is not necessary when the container is planted with the tree.
2. To be reused, the container must be returned to the nursery, cleaned, and sterilized. This is a nuisance, and many damaged containers will not be reusable.

There are several types of containers designed to be planted with the tree. The new Walters' square bullet (fig. 9-1) and ITW One-way® (fig. 9-2) are not degradable, have impenetrable walls, and have the root control features mentioned above, but the walls do not interfere with root egress. This is because the walls of the bullet are intended to come apart into four pieces as the tree grows, and the One-way® has a removable sleeve.

Most containers designed to be planted with the tree are degradable. These are particularly desirable in concept, because they involve less handling and have the potential to produce a more natural form of root system than current, impermeable walled, containers (fig. 9-3). However, the currently available types have three major disadvantages:

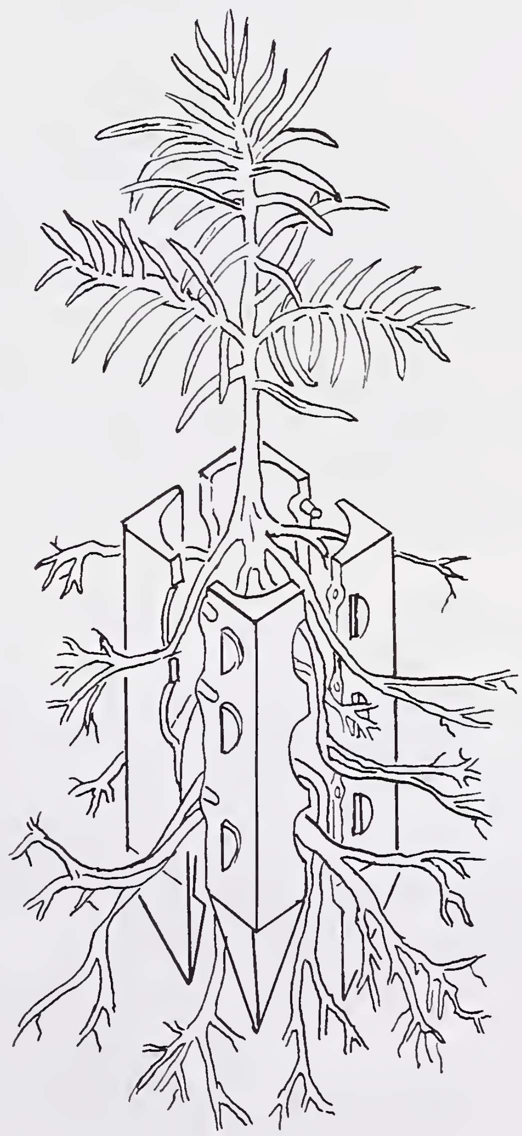


Figure 9-1.—Walters' square bullet showing radial separation of bullet sections caused by force of root growth (Walters 1974).

1. When the container wall remains impermeable to roots through the nursery phase, it will usually continue to restrict root growth after outplanting. If free root egress after outplanting is possible, the container has probably disintegrated to the point that it is difficult to handle in shipping and planting.
2. If root egress from one container to the next has occurred in the nursery, roots will be broken and lost when the containers are separated. Small seedlings, with weak or unlignified roots, will separate cleanly, but large ones will not without considerable effort and root damage.
3. Degradation rate and root penetration is critically dependent on adequate moisture. This type of container cannot be recommended for dry sites.

9.22 Container Characteristics

There are numerous other characteristics of containers that affect their use. Many of these characteristics affect the way they interact with the tree seedlings grown in them.

Volume.—The volume of rooting medium the containers will hold varies. The largest CTS containers are in the 45-cubic-inch (700-cm^3) range, while the smallest are approximately 2 cubic inches (30 cm^3). Container volume is directly related to the size of seedling desired.

Shape.—Containers may be round, hexagonal, rectangular, or square in horizontal cross-section. The ratio of depth of container to surface area at the top of the container also varies, as does the structural rigidity of the unit.

Taper.—Some containers are tapered (become progressively smaller in cross-section from the top to the bottom), and some are not. Some are tapered only over a portion of their length, often near the bottom of the container.

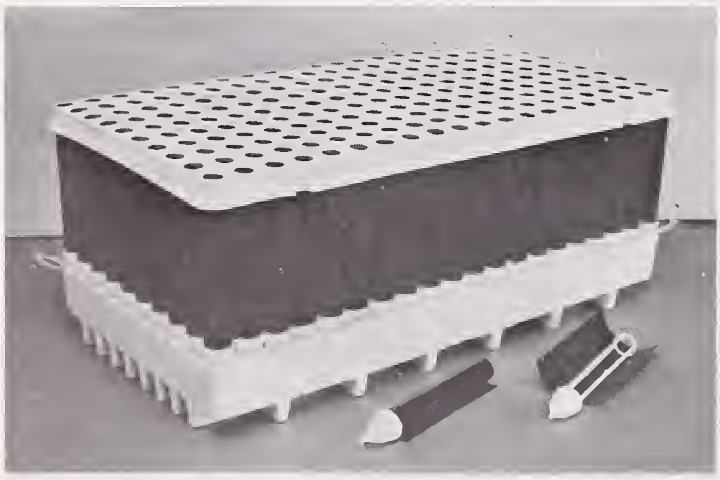
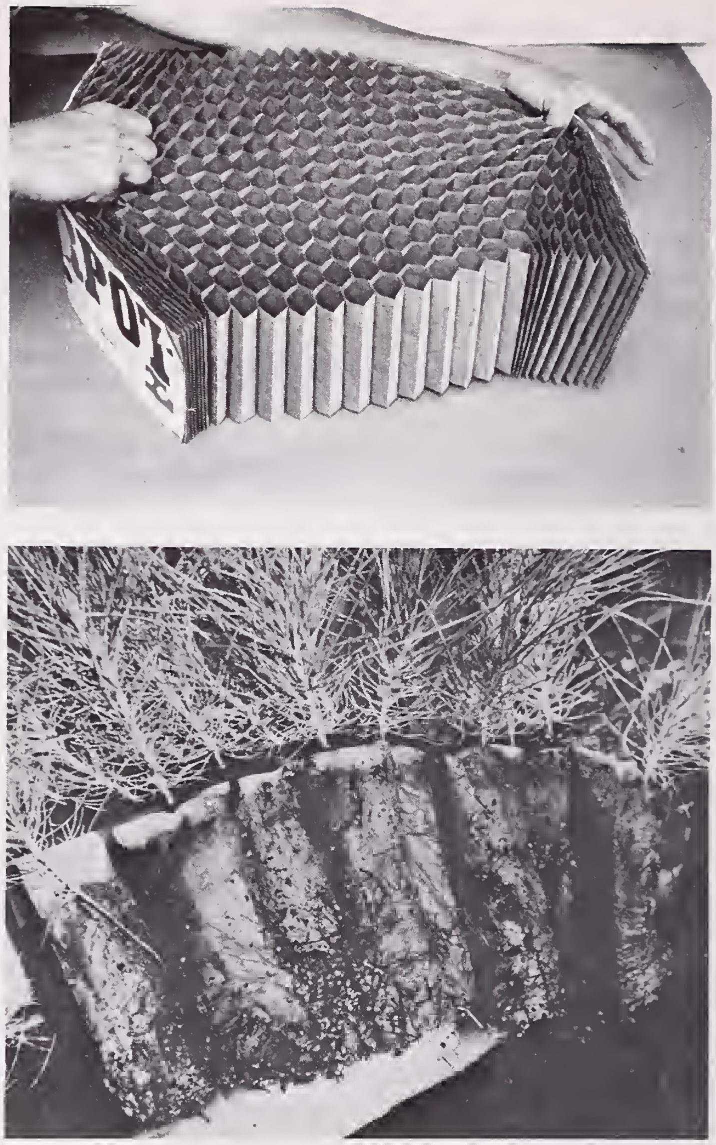


Figure 9-2.—ITW One-way® as the block comes ready to fill and seed. In the foreground, individual containers intact, and with the outer sleeve removed.



A

B

Figure 9-3.—Paperpot as it comes from the manufacturer before filling (A) and after the seedlings are grown (B).

Root control.—As mentioned in 9.21, containers can produce malformed root systems that cause windthrow and breakage later in the life of the tree (Donald 1968, Ben Salem 1971). In general, container shape controls root system configuration (Hiatt and Tinus 1974). Most of the widely used containers designed for CTS growing now incorporate features such as vertical internal ribs to reduce root spiralling in the container and possible future strangulation problems. These ribs, ridges, or grooves direct the roots to the bottom of the container where they are air pruned. Use of a properly shaped container for root control for a proper length of time should result in few root spiralling problems. Kinked roots and container compression of roots can be expected in some containers (Carlson and Nairn 1977).

Root egress opening.—All CTS containers currently in use provide an opening at the bottom for root egress to prevent root balling in the bottom of the container and allow excess water to drain out. This opening can be as large as the cross-section of the container or somewhat smaller. Because the vertical ribs and rounded horizontal corners direct growing root tips to the bottom of the container, the egress hole must be large enough to accumulate a large number of roots without plugging and causing the growing medium to waterlog. The hole should be as large as possible, but still prevent loss of the growing medium.

Construction material.—The container is usually made of plastic or paper. The strength, thickness, durability, and other structural features vary considerably, depending on the intended function and use of the container. All share one characteristic: they must be impermeable to the seedling's roots while the containers are at the nursery. Otherwise, the seedling will lose part of its root system when removed from the container or when the containers are separated (Tinus 1974d).

Unitization.—Some containers are freestanding units that can be used alone, some require a supporting rack system to keep them upright and properly spaced, and others are simply a cavity formed in a larger unit or block and cannot be separated from the larger unit. Each approach has certain advantages and disadvantages.

System design.—The nature of the container unit selected can have profound effects on the design of the greenhouse container handling system and the benches used. Where a variety of containers are to be used, the handling methods and bench system must be flexible. The container unit used also will affect seedling packaging, shipment, storage, and planting methods. In some cases, the container is part of a larger growing, handling, and planting system design.

Density.—Depending on container configuration and size, there will be a certain number of containers on a given area of bench space. This establishes the number of containers that can be placed on the benches of a greenhouse. This is illustrated in section 5.3. In general, as containers become progressively larger, the trees that will be grown in them will be of larger shippable size. These larger trees will have larger tops, and the containers must be spaced further apart, otherwise, the seedlings will compete for light, resulting in slower growth and spindly tops.

9.23 Containers Planted with the Tree

This type of container can be divided into two categories:

Those filled with rooting medium.—These include tar paper pot, the Conwed® open mesh plastic tube, the Alberta peat sausage, the Walters square bullet, and various paper pot systems. In these systems, the container is filled with medium, the tree is grown in the container, and the container is then planted with the tree. The container is either degradable or has openings that allow for root egress as the tree develops after planting. Degradable pots are advantageous, because the roots are not disturbed during shipment and planting (section 9.1.) Operationally, the use of the same unit all the way through the growing and shipping process is efficient. The container protects the root system from mechanical damage and from exposure to drying and temperature extremes. Theoretically, the root-soil interface is never disturbed. Ideally, the walls of the container restrain root penetration and remain structurally sound up to the time of planting, then degrade rapidly after planting to allow free root egress and free exchange of water and nutrients between the root plug and the native soil. However, because of variations in the degradation rate of the container, roots often penetrate the walls of the container before they should, or the structural integrity of the container breaks down too late or too soon. If either occurs, the advantage of using degradable containers is quickly lost. Considerable effort has been expended by manufacturers of degradable containers to control the degradation rate (Clendinning et al. 1974). Some paper pots have components incorporated in the paper that provide differing rates of degradation.

Containers planted with the tree that depend less on biodegradability than mechanical expansion or openings for root growth and egress are available in several forms. With pines especially, the major problems with these types of containers are (1) roots intertwine between containers during culture in the greenhouse, and (2) root development is restricted after outplanting in the field (section 9.1). Advantages of the other plantable containers also apply to these types.

Plantable containers not filled with rooting medium.—In some cases, the container is a molded block of growing medium without a wall. Some examples of this type of container are Polyloam®, Tree Start®, and BR-8 Blocks® (fig. 9-4). The biggest potential advantage of these containers is that there is no need to mix and load a separate rooting medium into a container shell. The other advantages of containers planted with the tree also apply. There is no chance for root binding in the container, because there is no wall. However, roots can readily pass from one container to the next, unless impenetrable dividers are used. The containers then may be hard to separate without damage to the root system. The premise is that such containers will be planted just as roots emerge from the container, so, timing becomes critical as it does with the walled degradable units.

The container is made of various materials including peat, wood pulp, and plastic foam and fiber. The chemical and physical properties of the material can be regulated in the manufacturing process to produce a substrate suitable for plant growth. Control of the growing medium formulation is left to the container manufacturer. This may result in a loss of flexibility. These manufactured substances normally harbor no diseases, insects, or weed seeds.

9.24 Containers Not Planted with the Tree

In 1979, it is most common to remove the tree seedling with its cohesive plug of roots and growing medium from the container before outplanting. Removal can take place at the nursery before the seedling is shipped or in the field just before planting. In such systems, it is essential that the roots of the tree hold the rooting medium together so that the plug retains its structural integrity and shape. This is essential not only to minimize root disturbance and exposure between removal of the root plug from the container and planting, but also so that the plug will conform to, and fit snugly in, the hole prepared for it in the soil. As a consequence, the degree of root development at planting time is critical. The seedlings must be removed and planted when the roots are ready for rapid egress to avoid potbinding (Kinghorn 1974). The plug-like appearance of the roots plus growing medium of seedlings properly grown in these containers, combined with the fact this matrix is "plugged into" a dibbled planting hole, is the reason these containers are called "plug containers" or "plug systems."

Figure 9-4.—Tree Start® is a molded block of growing medium, mainly peat. Polyethylene strips prevent roots from crossing from one row to the next. (Photo courtesy of Keyes Fibre Co.).

Common characteristics of plug containers.—Good plug containers have the following characteristics:

1. The seedling must be easily removable from the container.
2. The container walls are impenetrable by the seedling roots. In properly designed containers, there is no possibility of intertree entanglement.
3. The containers are lightweight to facilitate handling and transport.
4. The containers are constructed of sterile, essentially inert material.
5. Because of the impenetrable container walls, there should be some feature, such as vertical internal ribs, to prevent root spiralling and possible future root strangulation. Such ribs or grooves conduct the roots toward the drainage hole at the bottom of the container.
6. Containers that taper from the top to bottom produce a root plug that is pointed or somewhat bullet-shaped. The plug then fits tightly into a hole created with a pointed planting dibble of similar shape; a desirable feature.
7. When the plug is removed from the container and planted, there is no container barrier at the plug-soil interface.

Container systems or any other new reforestation technique must yield biologically acceptable results as well as be suitable for mechanization (Kinghorn 1970). All systems typically are a compromise between operational or mechanical and biological goals. For simplicity, three general approaches, called "cell," "block," and "book" designs, are explained below.

Cell designs.—A cell is an individual container unit. Although it may be unitized in trays or racks for handling, each seedling is in a container that can be separated from the others (Allison 1974). The most prominent example is the Leach Cone-tainer® (fig. 9-5). Cell containers are usually made of polyethylene.

For nursery operations, the individual cells are usually placed in special racks or trays to hold them upright and in place. The holder or rack for the cells determines spacing between cells and the resultant density of cells per unit area.

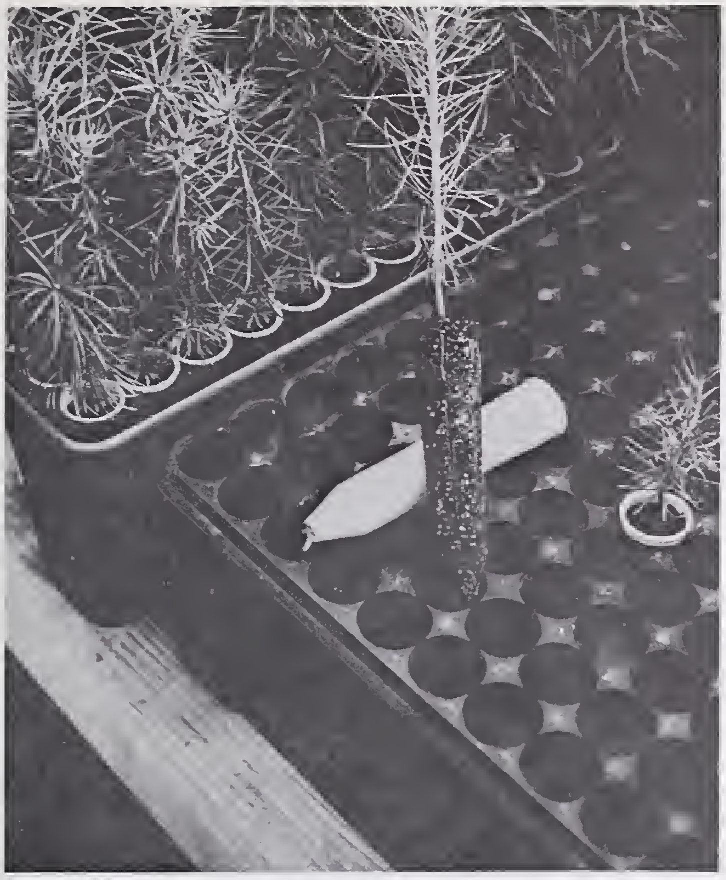


Figure 9-5.—The single cell system consists of separate containers and a rack to hold them.

An advantage of single cell plug container design is that the cells can be handled either singly or as a unit of 100 or more. If, in the growing process, a certain number of cells do not develop actively growing seedlings, the empty cells may be removed and replaced with cells with a tree. This way only good trees are kept in the holder, and maximum bench space can be utilized. Also, if more growing space is desired per tree, the spacing between the cells can be increased rather easily by removing every other cell. This strategy works well in operations where greenhouse space is at a premium. It is not a big advantage in extensive operations where low labor intensity is paramount. This is offset to a degree by the fact that each cell must be handled individually when loading racks or cleaning recycled cells.

It is possible to remove the seedlings from the cells at the nursery and ship only the plugs to the field. The advantage is that the container is not shipped with the tree. Since nearly all cell and block container units are designed to be used for more than one crop, this prevents losses and damage to the containers in shipping and in the field. However, since all mechanical protection for the seedlings is removed and its container-plug interface is disrupted, a different packaging method must be substituted for the cell or block to protect the trees and keep the plug from drying out before planting. The trees must be handled carefully at all stages of this process to preserve plug integrity.

With cell systems, it is common for the seedlings to be sent to the field in the containers. Usually, but not always, the cells are removed from the holders or racks, culled, bundled, and packaged in cardboard boxes for shipment to the field. This reduces the space needed to ship a given number of seedlings (fig. 9-6). Seedlings are extracted from the container in the field just before planting. The cells are saved and returned to the nursery for cleaning and reuse.

With both cell and block systems (discussed below), extracting the seedlings from the cavity is a nuisance. Under the best of conditions, it is time consuming. In the field, it cuts tree planter's production by requiring extra motions in the planting process. The proper development of the root system and the proper moisture content of the plug are important to easy plug extraction. The nature of the container walls and the number and height of root control ridges in the cavity also play a part. Some kneading of cells made of pliable plastic or knocking the container gently against the hand or other object usually facilitates extraction.

Block design.—Blocks are a group of individual cavities or cells that are permanently attached to each

Figure 9-6.—Ponderosa pine grown in single cells and bundled for packing. A rubber band holds the cells together.

other. Examples are the Styroblock® and the Multipot® among others (Sjoberg 1974 and Wood 1974). Styroblocks (fig. 9-7) are formed from expanded bead polystyrene with various sized cavities for different species and sizes of trees. The Multipot® (fig. 9-8) is similar, except it is molded of high density polyethylene. The advantages of these units are:

1. Cavities and block are all one rigid, lightweight unit about the right size to handle.
2. The cavities are always in the same position in the block and cannot come loose or fall out. There are no cells to have to handle individually.
3. The material in polystyrene bead formed blocks provides insulation from temperature extremes for the root systems of the trees.

The disadvantages are:

1. The trees must be extracted without kneading or jarring the container. However there have been few extraction problems with this type of container.
2. The containers must be sent back to the nursery, if they are sent to the field—a problem in common with all recycled containers.
3. Cavities where no tree develops must have seedlings transplanted into them or remain blank. Sowing more than one seed per cavity and then thinning excess trees tends to offset this problem.
4. Damage to the block, beyond a certain degree, results in loss of the whole block, even if most of the cavities are still intact.

Trees are sometimes removed from the blocks at the nursery, packaged, and then sent to the field. The blocks then remain at the nursery, which helps preserve the containers and returns them quickly to production, but the seedling plugs are more susceptible to damage. Removal of plugs from the blocks has some advantages:

1. It allows grading of stock and elimination of blank cavities.

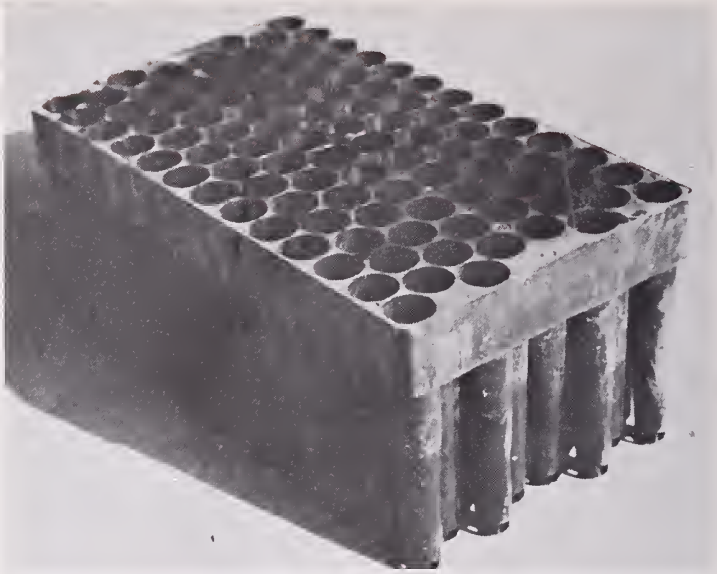


Figure 9-8.—The Crown Zellerbach Multipot.

2. It reduces shipping volume, usually by more than half.
3. It obviates the need for recycling the container from the field and eliminates damage to containers in shipment and field use.

The procedure used in British Columbia (Sjoberg 1974) has been to extract seedlings by hand and wrap in bundles of 25 in stretchable PVC film commonly used for produce and meat packaging. The bundles are placed in waxed cartons in an upright position for truck transport (fig. 9-9).

Nearly all block container designs incorporate root control ridges in the inside of the cavity. Some of the blocks are specially sized and adapted to nursery benches and conveyors to facilitate handling—a reflection of the fact that the modular block design lends itself well to machine handling and mechanization.

At least one block system (the Hahn Quarterblock System) allows for the block to be broken down into smaller unit blocks to facilitate field handling of the trees. Four of these "quarterblocks" are then reas-

Figure 9-7.—BC/CFS styroblock.

Figure 9-9.—Seedlings are extracted from the container, wrapped in bundles of 25 (A), and placed upright in waxed cartons for shipment (B).

sembled with tape into a larger "nursery" block to facilitate nursery production (Hahn 1976).

Book designs.—The term "book" denotes those containers thermoformed from thin polystyrene sheet plastic to produce a row of cavities when each portion is assembled. These may have a plastic hinge at the bottom, as do the Spencer-Lemaire Rootrainers® (fig. 9-10A) so that one piece of formed plastic is folded like a book to form the cavities (Spencer 1974). The Tubepak® is another book system, but two pieces of formed plastic snap together. When assembled, book planters form three to six cavities, more or less rectangular in cross-section, which taper at the lower end to a root egress hole, and have numerous internal ridges to control root orientation and prevent root spiralling.

Book planters must be held together in specially designed trays or with tape, glue, or straps to form units that are multiples of individual books (fig. 9-10B). When such units are assembled, the books are filled with rooting medium and seeded. The thin

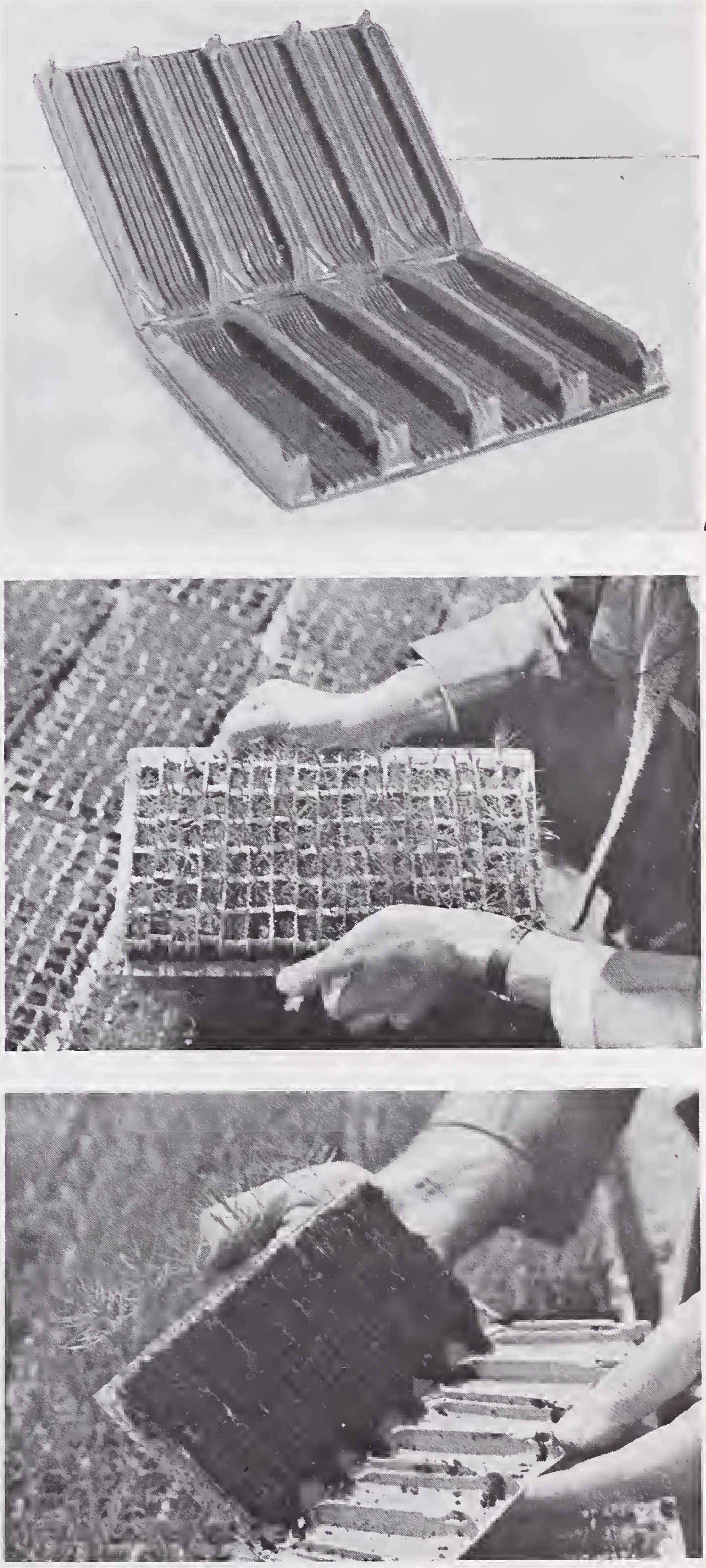


Figure 9-10.—Spencer-Lemaire Rootrainer unit (A), assembled into a block (B), and opened for inspection or to remove seedlings (C).

plastic shells of these containers are generally intended for one crop use. The material usually begins to become brittle near the end of a long growth period (9 months). In the South, where crops are reared 10-12 weeks, the books may be used one or two more times, however.[1] In the field, the book is opened by removing or folding back one side, and the plugs lifted out (fig. 9-10C).

Some advantages of book designs are:
1. The tree is sent to the field in the container.
2. If the container is discarded when the trees are planted; no return to the nursery is necessary.
3. When new containers are always used at the nursery there are no recycled containers to handle or clean for the next crop.
4. Plugs are quickly and easily extracted.

Some disadvantages of the book containers are:
1. The containers must be assembled before loading.
2. The container units require a frame, tray, gluing, or taping to form a unit for handling and shipment.
3. The container is generally used only once, which tends to make it expensive per crop.
4. Blank cavities must be reseeded or have germinated seed transplanted into them to avoid blanks.

9.25 Types of Containers Available by Manufacturer

During the past several years, the numbers and types of containers specially engineered and produced for tree seedling culture have grown considerably. At present, the types and designs appear to be stabilizing, but continuing development work is apparent. Thus, any compilation of container types and manufacturers tends to become obsolete rapidly. The latest, and most complete compilation, by Venator (1975), with some additions by the authors is reproduced in table 9-1.

9.26 Summary and Discussion

Each type of container has advantages and disadvantages in actual use. The selection of the particular size and type of container to use is determined by a number of factors. In the early stages of CTS program development, it is often best not to select any one size or type of container, unless considerable evidence indicates it is the size and type necessary for planting success. Such information is usually not available early in a program, so, container selection is based largely on experience and the developer's knowledge of the market or local field planting requirements.

The developer should test a number of container sizes and types, if possible. In this way, the container best fitting the situation from operational and biological standpoint can be determined. Considerable field testing with different containers may be necessary before sufficient reliable data on planting productivity, nursery production costs, and cost per surviving seedling, is available to permit decision. In general:
1. The best container type and size combination is that which will produce an established, rapidly growing seedling at the minimum cost per tree. In severe climates or very brushy areas, this may mean a very large tree. In ideal situations, a small tree may do equally well. The smaller the container and tree necessary, the cheaper it will be produced at the nursery. This is because more trees can be produced per unit area of greenhouse space, and each crop will be in the house a shorter time.
2. Until the best container system and tree size is determined, it is generally unwise to purchase sophisticated loading and seeding equipment which can handle only one or two types of containers. The equipment options should remain flexible until a definite type of container and container size is selected. Some loading and seeding equipment allows for such flexibility; other types do not.
3. There is no ideal container, but there is usually a best one for a given production and planting situation. This best size and type can be determined by operational cost collection and planting survival and growth results. Where a variety of planting conditions are expected, along with different packaging and transport problems, several container sizes and types may offer the optimum solution.
4. Most of the containers on the market today are good, but container development is continuing and even better ones can be expected in the future. For instance, when a plug seedling is outplanted, most of the new roots develop from the accumulated growing points at the bottom of the plug. Many species, especially pines, produce few roots close to the surface. A possible improvement over currently available rigid wall containers would be to provide holes or slits in the side of the containers and space the containers apart sufficiently to air prune the roots at these openings. A tree grown in such a container should produce lateral roots close to the surface from the growing points developed at the slits. It should develop a balanced, more

[1] *Personal communication with O. C. Goodwin, North Carolina Division of Forest Resources, Raleigh, N.C., May 1978.*

Table 9-1.—Manufacturers or distributors of containers suitable for growing forest tree seedlings.

Supplier	Common name of container	Container material	Container volume (cm^3)	Biodegradable properties	Root egress
Agritec Co. Inc. 4939 D Milwee Houston, Tex. 77018	Polyloam Tree Container	Nutrient enriched synthetic base material	20-37	Slowly	Yes
Beaver Plastics, Ltd. 12806-63 Street Edmonton, Alberta Canada	Styroblock	Polystyrene foam	35-120	No (reusable 2-3 times)	No
Better Plastics, Inc. 2206 N. Main Street Kissimmee, Fla. 32741	Test Tube	Polyethylene	Variable	No (reusable)	No
Brighton By-Products P. O. Box 23 New Brighton, Pa. 15006	Kys-Kube	Organic-inorganic mixture	20-25	Yes	Yes
Brighton By-Products P. O. Box 23 New Brighton, Pa. 15006	0-903	Phenol formaldehyde with residual phosphates, nitrates, and soda ash	20-30	Slowly	Yes
Colorado State Nursery Foothills Campus Colorado State Univ. Fort Collins, Colo. 80521	Tar Paper Pot (Containers are not commercially available; however, blueprints for production systems are available upon request)	15 pound tar paper	Variable	Slowly	Yes
Columbia Plastics, Ltd. 2155 West 10th Ave. Vancouver, British Columbia, Canada	Modified Walter's Bullet	High impact polystyrene	15-10	No	Yes
Conwed Corporation 742 29th Ave. SE Minneapolis, Minn. 55414	Conwed Open-mesh plastic tubing	Plastic webs	Variable	No (products under development)	Yes
Edmonton Nurseries, Ltd., 13332-13th Ave. Edmonton, Alberta Canada	Peat Sausage or Easy Root Container	Low density polyethylene filled with peat	Variable	Slowly	No
Famco, Inc. 300 Lake Road Medina, Ohio 44256	BR-8	Modified cellulose fiber	20-30	Yes	Yes
GASPRO, Inc. 2305 Kamehameha Hwy. Honolulu, Hawaii 96819	Hawaii Dibbling Tube	Polyethylene	30	No (reusable)	No
Green Thumb Products Corp., Drawer 760 Apopka, Fla. 32703	Rack Substratum System 73	Natural and synthetic fibers	Variable	Yes	Yes
Illinois Tool Works Hi-Cone Division 1140 Bryn Mawr Ave. Itaska, Ill. 60143	One-Way	Molded polystyrene and polystyrene sheet	60	No	Yes
Jiffy Products of America, P.O. Box 338 West Chicago, Ill. 60185	Jiffy-7 peat pellets, strips, and pots	Peat	20-40	Yes	Yes
Keyes Fibre Co. Horticultural Div. Department X New Iberia, La. 70560	Kys-Kube	Organic-inorganic mixture	20-25	Yes	Yes
Lannen Tehtaat Oy Paperpot Department SF-27820 ISO-VIMMA Finland	Paperpot Method, Special Paper for the Paperpot Method, consulting service in nursery planning (European distributor)		10-650 (approx. 20 different sizes 3 different qualities)	Yes	Yes

Table 9-1.—Continued.

Supplier	Common name of container	Container material	Container volume (cm^3)	Biodegradable properties	Root egress
Lannen Tehtaat Oy Paperpot Department SF-27820 ISO-VIMMA Finland	NISULA Roll Plant Method Transplanting machines (European distributor) (For above 2, see also Reid, Collins and United Asia)	Polyethylene film	Variable	No	No
J. M. McConkey Co., Inc. P. O. Box 309 Sumner, Wash. 98390	Plug Tray	High density polyethylene	140	No	No
J. M. McConkey Co., Inc. P. O. Box 309 Sumner, Wash. 98390	DEEPOT	High density polyethylene	656	No	No
Micro-Plastics Co., Ltd. P. O. Box 844 Guelph, Ontario, N1H 6M6, Canada	Ontario Tube	High impact polystyrene	Variable	No	No
Poly-cast Plastics Route 2, Box 706 Beaverton, Oreg. 97005	Cone-tainer	High density polyethylene	Variable	No (reusable)	No
Reid, Collins and Associates, Inc. Reforestation Division 550 Burrar Street Vancouver, Canada V6C 2K6	Paperpot Method Equipment for the Paper Method, consulting service in nursery planning (Canadian distributor)	Special paper	10-650 (approx. 20 different sizes, 3 different qualities)	Yes	Yes
Rex Packaging, Inc. P. O. Box 18257 Jacksonville, Fla. 32229	Polypot	Polyethylene coated paper	200 (square dimensions)	Slowly	No
Silvaseed Company P. O. Box 118 Roy, Wash. 98580	Styroblock (USA distributor)	Polystyrene foam	35-120	No (reusable 2-3 times)	No
Spencer-Lemaire Industries, Ltd. 9160 Jasper Ave. Edmonton, Alberta Canada	Rootrainers (Equipment for Rootrainers Method also available)	Polystyrene	30-340	No (perhaps reusable)	No
Tree Tech. Inc. P. O. Box 86 Mason, Mich. 48854	Plant Bands	Paper, polyethylene coated or not	Any size	Yes	Yes
Tri-State Mill Supply Co. P. O. Box 220 Crcssett, Ark. 71635	Styroblock	Polystyrene foam	35-120	No (reusable 2-3 times)	No
Tubepak 402 East 900 South Suite 2 Salt Lake City, Utah 84111	Tubepak	Polystyrene	280	No (perhaps reusable)	No
Union Carbide Corp. Chemicals and Plastics Div., River Road Bound Brook, N.J. 08805	—	Polycaprolactone	Variable	Yes (currently in experimental stages)	Yes

Table 9-1.—Continued.

Supplier	Common name of container	Container material	Container volume (cm^3)	Biodegradable properties	Root egress
United Asia Trading Co. 3840 Crenshaw Blvd. Los Angeles, Calif. 90008	NISULA Roll Plant Method Transplanting Machine (USA distributor)	Polyethylene film	Variable	Yes	No
United Asia Trading Co. 3840 Crenshaw Blvd. Los Angeles, Calif. 90008	Paperpot Method, Equipment for the Paperpot Method, consulting service in nursery planning (USA distributor)	Special paper	10-650 (approx. 20 different sizes, 3 different qualities)	Yes	Yes
Western Pulp Products Co., Box 968 Corvallis, Oreg. 97330	Fiber pot	Wood pulp	Variable	Yes	No (but roots penetrate pot)

windfirm root system more like that of a natural seedling and devoid of detrimental root configurations. In addition, fewer growing points should accumulate at the bottom, which would permit using a smaller bottom hole in the container.

9.3 Growing Media

9.31 General Discussion

"Growing medium" is by no means as standard a term as "container." Other terms used synonymously are "rooting mix," "pot mix," "growth medium," "soil mix," and "potting mix." It is the material that fills the containers and performs the same function for the seedling as soil does in the field. The term "mix" is used in a number of the terms synonymously with medium, because it describes the medium to be a mixture of substances. This is usually, but not always, the case. The term "growing medium" will be used here because it is probably the most general term and least likely to cause confusion.

Many materials can be used as a growing medium, such as sand, compost, peat, sphagnum moss, vermiculite, topsoil, and some synthetic materials, but for functional and economic reasons, peat-vermiculite mixtures predominate (Phipps 1974). Natural soil is not used as a CTS growing medium, because other media have more desirable physical characteristics (i.e., water holding capacity, aeration, and bulk density). Also, natural soil and sand are too heavy for CTS products that often have to be carried over precipitous terrain to the planting sites. Ground bark is used as a medium by a few growers, especially where it is readily available.

For CTS operations, peat-vermiculite mixes are most widely used for several good reasons. When properly prepared:

1. They are lightweight—a consideration of some importance in forest planting, as well as nursery operations.
2. They are uniform in composition, relatively inexpensive, and readily available.
3. They are relatively free of insects and diseases.
4. They have a high cation exchange capacity per unit dry weight compared to ground bark or sandy loam soil.
5. They have a high water holding capacity, so, the frequency of irrigation and fertilization is reduced compared to sandy soil.
6. In most instances, they provide an acid growing medium, conducive to conifer growth.
7. When the peat and vermiculite are in proper proportions, they yield a medium that is well aerated and drained while still holding substantial quantities of water that is readily available to the plant.

In some cases, a spongy volcanic material called "perlite" is used in place of the vermiculite. This is also acceptable. Both materials are used to increase the aeration and drainage capability of the peat.

9.32 Growing Medium Components

A good growing medium should have the following characteristics (Richards et al. 1964):

1. The medium must be sufficiently firm and dense to hold the cuttings or seeds in place during rooting or germination. Its volume must be fairly constant when either wet or dry. Excessive shrinkage upon drying is undesirable.

2. It must sufficiently retain moisture so that watering does not have to be too frequent.
3. It must be sufficiently porous that excess water drains away, permitting adequate aeration. This is crucial in conifer tree culture.
4. It must be free, or nearly so, of weed seeds, nematodes, and various noxious organisms.
5. It must not have a high salinity level.
6. It should be capable of being sterilized with steam without harm.
7. There should be adequate cation exchange capacity to maintain nutrient availability.

In addition, the most outstanding characteristic for containerized seedling tree culture is that it be lightweight. Since sand and soil are excluded primarily because of weight, what have been termed "soil less" media are discussed.

Peat.—The most common component of CTS growing media, and the most highly recommended, is sphagnum peat. Peat consists of the remains of aquatic, marsh, bog, or swamp vegetation which has been preserved underwater in a partially decomposed state (Hartmann and Kester 1959). The composition of this material varies. The differences depend on the plants from which it originated, degree of decomposition, chemical content, and acidity. There are three basic types of peat: moss peat, sedge, and peat humus (Hartmann and Kester 1959).

Moss peat or "peat moss" is composed of sphagnum, hypnum, or other mosses. While hypnum moss is used in many ornamental container growing media and a few coniferous container media, sphagnum moss peat is most highly recommended for CTS media (Armson and Sadrieka 1974, Brix and van den Driessche 1974, and Hellum 1975).

Sphagnum moss is the dehydrated young residue or living portions of acid plants in the genus *Sphagnum*. This material, as opposed to sphagnum moss peat, is not decomposed to any degree. Sphagnum moss peat, not sphagnum moss is needed for CTS growing medium formulation. According to Hellum (1975):

"Peat sold commercially varies in character, causes problems in nurseries where seedlings are to be grown consistently to specific dimensions in a certain length of time. Only sphagnum peat, among organic materials, has the many desirable characteristics for a good CTS potting medium. There are many reasons—high water holding capacity, fibrosity, acidity (which means it is relatively free of fungi and bacteria), its breakdown makes nutrients available, and it has high cation exchange capacity compared to most mineral soils.

"Available commercial sphagnum peat varies by species composition, organic deposit which is mined, vendor, year of mining, and handling and use. Avoid peat composed of mosses other than *Sphagnum* because of desirable sphagnum water holding capacities and fibril strength. *S. fuscum* is the best species. Peat should be from as acid minerotrophic fens as can be found, and peat from fens with pH above 6.5 should be avoided.

"Peat should not be exposed to air for more than a few months before use, because this hastens humification (nitrogen release) and may cause top-heavy seedlings. Therefore:

1. Only sphagnum peat should be used that has a minimum of grass and other moss species.
2. Choose peat from fens where small leaved species of *Sphagnum* are dominant; *S. fuscum* is best.
3. Look for peat that has been hydraulically mined. It will be more consistent than surface mined peat.
4. Avoid force dried commercial peat, which generally gives less consistent results than bulk mined *Sphagnum* peat that has not been force dried."

Armson and Sadreika (1974) note, "Peat should be fibrous and free of woody fragments and mineral soil inclusions. With peat moss it is usually necessary to put it through a hammermill; all peats have to undergo screening in order to produce a uniform homogeneous material for the containers. Physical condition of peat is critical in relation to the filling of containers. If the peat is too dry, it will not flow evenly and great difficulty may be experienced in wetting it. The result will be uneven levels in the containers and large air spaces, both of which will result in uneven seedling development. On the other hand, a peat which is too wet will also not fill or settle uniformly into containers.

"The main chemical property of concern is that of pH; preferably the range should be 4.5 to 6.0. Other properties, such as nitrogen, phosphorus, potassium levels and also those of other nutrient elements are of less concern, because a program of fertilization is necessary if satisfactory growth is to be maintained. Peats with excessively high levels of nutrients which might be toxic should not be used. Table 9-2 gives results of analyses for a range of peats used in container production in Ontario."

Vermiculite.—Hartmann and Kester (1950) explain that vermiculite "is a micaceous mineral which expands markedly when heated. Extensive deposits are found in Montana and in North Carolina. Chemically, it is a hydrated magnesium-aluminum-iron silicate. When expanded it is very light in weight (6 to 10 pounds per cubic foot) (100-140 kg/m^3) neutral in reaction with good buffering properties, and insoluble in water; it is able to absorb large quantities of water—3-4 gallons per cubic foot (400-450 l/m^3).

Table 9-2.—Chemical analyses of unfertilized peats used in Ontario container stock production (all elements % o.d. weight) (Armson and Sadreika 1974).

Origin	pH	Cation exchange capacity meq/100 g	N[1]	P	K	Ca	Mg	Cu	Fe	Mn	Zn
Thessalon	4.8	76	1.61	0.05	0.03	1.00	0.002	0.002	0.775	0.018	0.003
Swastika	6.0	87	1.31	0.05	0.02	1.75	0.002	0.001	0.340	0.012	0.002
Fort Frances	5.9	124	1.91	0.01	0.03	2.60	0.401	0.001	1.300	0.005	0.003
White River	5.8	78	0.81	0.03	0.03	0.14	0.003	0.002	0.330	0.008	0.002
Hearst	6.8	172	0.91	0.04	0.04	4.21	0.407	0.002	0.210	0.024	0.003
Cochrane	4.8	99	1.11	0.17	0.20	2.02	0.311	0.481	0.330	0.102	0.014

[1] *N determined by micro-kjeldahl procedure, all other elements in solution after ashing of peat.*

Vermiculite has a relatively high cation exchange capacity and thus can hold nutrients in reserve and later release them. It contains enough magnesium and potassium to supply most plants. In the crude vermiculite ore, the particles consist of a great many very thin, separate layers which have microscopic quantities of water trapped between them. When run through furnaces at temperatures near 2,000°F (1,100°C) the water turns to steam, popping the layers apart, forming small porous, sponge-like kernels. Heating to this temperature gives complete sterilization. Horticultural vermiculite is graded into four sizes: No. 1 has particles from 5 to 8 mm in diameter; No. 2, the regular horticultural grade, from 2 to 3 mm; No. 3, from 1 to 2 mm; and No. 4, which is most useful as a seed-germinating medium, from 0.75 to 1 mm. Expanded vermiculite should not be pressed or compacted when wet, as this will destroy its desirable porous structure."

In most cases, vermiculite is an important ingredient in growing medium mixtures for CTS production. There is much less agreement about the size of vermiculite to be used. Indeed, there seems to be considerable confusion regarding the terminology surrounding the material. Some writers refer simply to "vermiculite" with no further definition. A number refer to "attic fill" vermiculite. Generally, this means a coarse grade of vermiculite equivalent to horticultural grade No. 1 to 1½. Some users simply refer to using "horticultural grade" vermiculite, which usually means No. 2 (from 2 to 3 mm). Probably horticultural vermiculite grade No. 2 or 3 is the most commonly used if readily available, but the grade of vermiculite used is not as important as how well it works as a mix component. The purpose of incorporating vermiculite or perlite in a growing medium with peat or ground bark is to keep the growing medium from settling and compacting to the point where good root aeration and water drainage is lost.

Horticultural grade No. 1 is recommended for any container of 10 cubic inches (160 cm^3) or more, and No. 2 for smaller containers. Finer vermiculite will not function well as a bulking agent to prevent settling and should be used only for very short-term crops or ones that can tolerate poor aeration. Vermiculite bought as a "poultry litter" or "attic fill" insulation is usually cheaper than the same thing bought for horticultural use. Do not buy "block fill" that has been treated to make it water repellent.

Perlite.—Perlite is used in CTS growing media instead of vermiculite. It is also often used as a seed covering medium (section 16.33). Hartmann and Kester (1959) describe perlite as a "grey-white siliceous material of volcanic origin mined from lava flows. The crude ore is crushed and screened, then heated in furnaces to about 1,400° F (760° C), at which temperature the small amount of moisture in the particles changes to steam, expanding the particles to small, sponge-like kernels which are very light, weighing only 5 to 8 pounds per cubic foot (70-120 kg/m^3). The high processing temperature gives a sterile product. A particle size of 1-3 mm in diameter is usually used in horticultural operations. Perlite will hold three to four times its weight in water. It is essentially neutral, with a pH of 6.0 to 8.0, but with no buffering capacity; unlike vermiculite, it has no cation exchange capacity and contains no mineral nutrients. It is most useful for increasing the aeration in a mixture."

The main advantage of perlite for use in CTS growing media is that it does not compress. However, it sometimes will make root plugs harder to extract, but this is important only in plug container types. Vermiculite is used much more often in CTS media than perlite.

Ground bark.—In some instances, ground bark has been used instead of sphagnum peat (Wood 1974). Some types of fresh bark contain materials toxic to plants (Hartmann and Kester 1959). When finely ground bark is used as a substitute for peat moss, supplemental nitrogen is usually needed to prevent the tree seedlings from becoming chlorotic (Barnett 1974) because the bark begins to break down and uses the nitrogen. Also, van den Driessche (1974) reports that a 1:1 mixture of Douglas-fir bark and vermiculite only has about 70% of the cation exchange capacity (CEC) (72 versus 103 milliequivalents per 100 g of dry weight) of a 1:1 mixture of sphagnum peat-vermiculite.

Unless there is an overwhelming reason to use ground bark, sphagnum peat is probably preferable. The reasons include higher CEC, better C:N balance, less likelihood of less organisms and toxic substances, and greater weight. However, there is work going on regarding the use of sawdust and wood residues (Montano et al. 1977 and Lumis 1976).

Other components are used in some cases, but peat, vermiculite, perlite, and ground bark are the major ones.

9.33 Media Mixes and Mechanics of Aeration and Drainage

There is considerable variation in the proportions of growing medium constituents from one successful CTS operation to another. The most commonly used mix is a 1:1 mix of shredded sphagnum peat and vermiculite. Other ratios are used, most commonly a 3:2 or 3:1 mixture of these same components. Owston (1972) indicates a 1:1 or 3:2 mixture is best for Pacific Northwest species. In Wisconsin, Phipps (1974) found that the medium components and their relative proportions significantly influenced seedling growth, with the largest red pine seedlings produced on a 1:1 peat-vermiculite medium.

After trying numerous mixtures, Tinus (1974b) settled on a 1:1 peat vermiculite mixture. In Louisiana, Barnett (1974) is also using a 1:1 peat vermiculite mix. Some nurseries have successfully used straight peat without any vermiculite or perlite (Routledge 1974).

To determine the best growing medium for a given situation one must consider the degree of aeration and drainage required when using a given container in a given greenhouse, growing certain species. In general:

1. There is some degree of latitude in formulating growing media that the trees will tolerate (Phipps 1974 and Owston 1972). Usually trees will perform best in a certain mix. This can be discovered through simple experimentation.
2. As more and more vermiculite or perlite is added to the peat, the aeration and drainage of the medium in the container increase. Too much vermiculite may allow the mix to fall out of the root egress hole and prevent the root plug from being cohesive upon removal from the container.
3. Larger and deeper containers require greater drainage, because water must percolate through a greater length of medium.
4. The higher the humidity maintained in the greenhouse, the better drained the medium should be.
5. The less evenly the water is distributed in the CTS greenhouse, the better drained the medium must be, because some containers must be overwatered in order to thoroughly soak others.
6. Some tree species require good root aeration; others will tolerate less aeration.
7. Drainage should not be so rapid as to necessitate overly frequent watering.
8. Drainage should not be so slow as to waterlog the container and starve the roots for air.

The proper aeration and drainage can be measured as a percentage of macropore space in the growing medium. Hellum (1975) states that for a straight peat medium, about 25% macropore space is needed for good seedling root development. For peat-vermiculite mixes good macropore space can vary between 10% and 50% depending on the depth of the container, with very deep containers being nearer 50%. Nelson (1973) describes how to measure the macropore space of the various media mixes in figure 9-11A through F.

If the trees grown in the medium do not perform well and the grower suspects poor aeration and drainage may be part of the problem, the proportions of components can be altered. The percentage of macropore space, which is related to how trees grow, can be found for the new mixture. By continued comparisons of the tree condition to the medium mixture, the best macropore space percentage for that container, species, and greenhouse situation can be found over several crops of seedlings.

Symptoms of problems with the mix are:

1. Too coarse (too well drained, aerated): medium falls out of root egress holes, root plug not cohesive, plug easily falls apart, very frequent watering needed to keep the medium damp, trees stunted.
2. Too fine (not well drained, aerated): medium appears waterlogged, dries out slowly, fungal diseases prevalent, infrequent irrigation necessary, high EC reading on leachate, trees stunted, chlorotic, algal development on growing medium surface prevalent, and there may be root rot.

9.34 Preparation of growing medium

Preparation of the growing medium for loading into containers is relatively simple. Essentially, it is the blending of the components to provide a medium of uniform texture and proper moisture content that is free of weed seeds and pathological organisms.

Mixing the growing medium components can be done in a number of ways. Equipment is discussed in

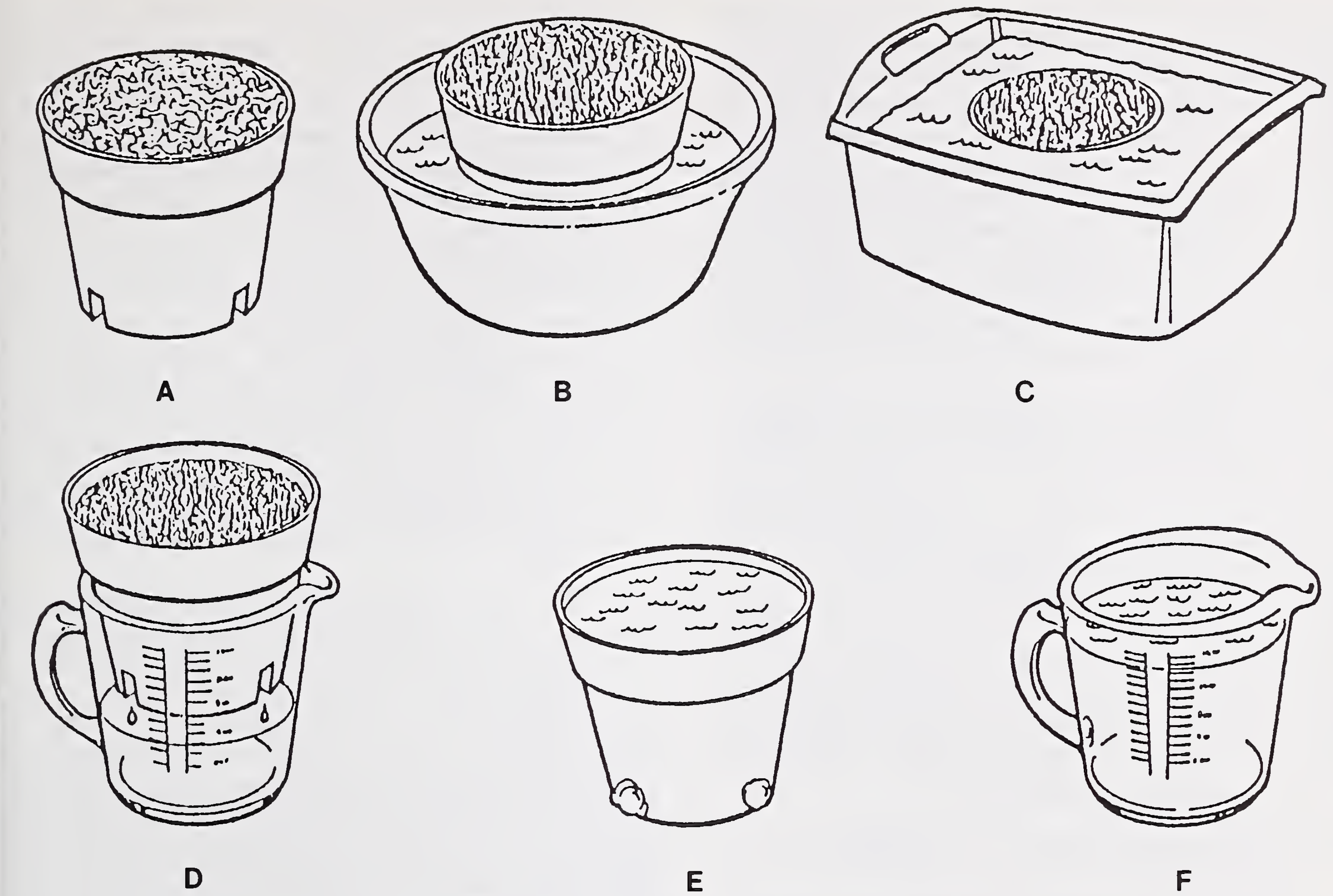


Figure 9-11.—(From Nelson 1973). Water drainage test for greenhouse soils. By means of this test, each grower can analyze his soils before planting and determine if the water drainage meets the standards of other soils he has used successfully. First make the test on a soil (either potting or bench soil) which drains well and is favorable for plant growth. Then make the test on the new soil mix before planting, compare results, and make the necessary adjustments to the soil mixture.

(A) Fill a plastic, 6-inch azalea pot with the soil mixture. Do not pack the soil in the pot, but from about a 3-inch height tap the pot on the counter top three times to settle the soil in the pot. The soil should be level with the top of the pot. (B) Subirrigate the pot of soil by placing it in a bowl with water about 3 inches above the pot bottom. Do not disturb for 24 hours. (C) transfer the pot of soil to a deeper pan and bring the water level in the pan to the top edge of the pot. Keep the pot in this pan until water is visible at the soil surface. (D) Transfer the pot of saturated soil to the measuring glass (a one-quart measuring glass should accommodate the plastic pot about as sketched). Let the pot drain for four hours, record the amount of water that drained, and mark the level of the soil in the pot after draining. Discard the soil and wash the pot. (E) Plug the pot holes with florist clay and fill the pot with water to the soil level after draining. (F) Measure and record the volume of water in the pot. The pot probably will contain more water than the one-quart measure will hold, but fill the measure to the quart level, dump, and measure the balance of the water in the pot.

To find the percentage of the pore volume that drained, as compared to the total volume of the soil, divide the amount of water that drained out of the pot by the total amount of water measured in the pot.

section 7.2. Some other important operational points should be noted.

The area and equipment to be used in the mixing process must be kept as clean as possible, not only free of refuse, but also free of weed seeds, fungi, and bacteria. Equipment should be thoroughly washed with mild disinfectants before and after use. Goodwin (1975) recommends a solution of commercial bleach (5% sodium hypochlorite) diluted 10:1 with water. Two percent formaldehyde, rubbing alcohol, boiling water, or live steam can also be used (Hartmann and Kester 1959). These methods can also be applied to flats, greenhouse floors, walls, and benches, as well as tools.

All growing media for CTS operations should have some water added to it during the mixing process. This is because peat or ground bark absorbs moisture very slowly. Addition of coarse organic materials, such as peat moss, to mixtures can cause a decrease in wettability. No good method for preventing nonwettability (hydrophobicity) is known. Use of commercial wetting agents may improve water penetration, but there are questions about their safety. Owston[2] reports decreased germination in pine resulting from the use of wetting agents. The water repellent quality of dry mixes containing peat is well known to CTS nurserymen who have filled containers with growing medium in a dry condition. In such cases, unlimited irrigation of the containers often will not wet the lower portions of the medium in the containers.

A slightly damp mix will not fall out of root egress holes while the container units are being handled, and will hold its shape after being compressed. The mix must not be wet or sticky, just damp. When it is properly moistened excess moisture can just be squeezed from the mix. Goodwin (1975) has provided some relative weights of dry and wet media shown in table 9-3.

Once moistened, the medium should not be allowed to dry out before or after the containers are filled and seeded. To help avoid this, seeded containers can be kept in cold storage for a period of time prior to loading the greenhouse.

9.35 Commercially Prepared Growing Media

A number of commercially prepared growing media, such as Jiffy-mix®, Micapeat®, Redi Earth®, and Pro-mix® have definite advantages for the CTS grower:

1. The grower does not have to mix his own except to moisten the product prior to filling the container. Large quantities may be ordered custom-mixed.
2. Most of the commercial mixes have nutrients added to them, which may provide needed nutrients to the crop.
3. The commercial mixes are usually claimed to be sterile. The nurseryman should not have to worry about sterilization.
4. They may be more evenly mixed than homemade mixes.

In other words, using commercially prepared mixes for CTS operations is very convenient. But there are disadvantages:

1. The grower gives up control of quality and type of component used in the mixture. This can vary with changes in company management and sources for components of the mix. A number of CTS growers have been surprised by plant responses to changes in growing medium. This is much less likely to happen with homemade mixtures.
2. Fertilizers or wetting agents added to the commercial mix may or may not be beneficial to tree seedling growth. Even if they are beneficial, their solubility in the container cannot be controlled by the nurseryman. In some cases, the fertilizers added are expressed only as N, P, and K, and the chemical source is not specified. Wetting agents are added to some of these mixtures and their possible phytotoxic effects have been mentioned earlier (section 9.34).
3. It may be necessary to alter the proportions of the components of the mix to achieve proper aeration and drainage. This is not possible with commercially prepared growing media, once purchased.

Because the source and preparation of the components of the growing medium is important, use of commercially prepared growing media for tree seedling culture is not recommended unless component specification and quality can be guaranteed. Commercially prepared growing media are used by a number of CTS growers, but a few growers have tried and abandoned them for one reason or another.

9.36 Addition of Fertilizer and Mycorrhizal Fungi to Medium

The addition of fertilizers to the growing medium before filling containers is discussed in section 13.21. For CTS operations it is not recommended. In CTS culture, growth and final dimensions of the trees produced are controlled by adjusting fertilizer regimes and other environmental factors. Soluble fertilizers, placed in the mix, will be leached-out right away and do little good. Persistent fertilizers only complicate later cultural procedures.

Considerable work has been done on the addition of various species of mycorrhizal fungi to the growing medium (section 14.1). Many tree species require fungal symbionts. Although some may not require them, they usually promote growth and make the seedlings less susceptible to root disease.

[2]*Personal communication with Dr. Peyton W. Owston, Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg., June 1978.*

Table 9-3.—Weight (pounds) of 1 cubic foot of medium (Goodwin 1975).

Soil Mix	Dry	Moist	Saturated	Water gain
1 peat: 1 sand	54.00	64.5	84.0	30.0
1 peat: 1 vermiculite	6.25	27.8	46.8	40.5
3 peat: 1 vermiculite	6.90	28.5	47.5	40.6

Research in progress is directed toward addition of pure cultures of specific fungi to the growing media (Marx and Barnett 1974, Zak 1977). CTS nurserymen should expect some useful research results and, perhaps, commercially available cultures, by the end of the decade. Some CTS producers are adding forest duff, assumed to contain mycorrhizal fungi, to growing media. In most cases, this procedure has resulted in excellent mycorrhizal development. However, there is an element of risk involved, because the duff can contain inoculum of phytopathological fungi, nematodes, insects, weed seeds, and other pests. Consequently, the practice of adding duff to growing media cannot be recommended without reservations. The individual grower must make this decision. To follow the practice in research investigations is one thing; to expose millions of trees to such risks in production operations is another.

9.37 Growing Medium Sterilization

The controlled environment of the greenhouse is conducive to the development of insects, disease pathogens, and weeds, as well as crop plants. Every available means should be used to eliminate the source of these problems before they get started. In horticultural potting mixtures, soil is almost always a component. Soil must be sterilized before use to avoid serious disease problems. In CTS greenhouse operations, the growing medium is generally not sterilized, because the medium components are often nearly sterile to begin with (section 9.32). Some bark contains compounds that are biotoxic. Also, the character of bark texture and the way it is usually handled at mills, tends to allow weed seeds, spores, etc., to be incorporated in it. Consequently, CTS growing media mixes containing peat, vermiculite, or perlite usually don't require sterilization, but ground bark components may need to be. In research, it is probably prudent always to sterilize the growing medium. In operational CTS projects, it is recommended only where there is demonstrated need.

There are several ways to sterilize soil or growing media. The best and most widely used is heating the soil with steam to about 180° F (82° C) for 30 minutes. This procedure will kill most harmful bacteria, fungi, nematodes, insects, and weed seeds (fig. 9-12) (Hartmann and Kester 1959). Detailed steam sterilization procedures are available in a number of horticultural texts such as Nelson (1973).

Chemicals are also useful for growing media sterilization, if steam is not available. However, chemical sterilization of mixes with vermiculite in them may be risky because the chemicals become bound within the expanded vermiculite. This can result in toxicity to seedlings even after prolonged aeration.[3] CTS nurserymen, therefore, are advised to use chemical sterilization with this possibility in mind. The more common chemical sterilants and how they are used in horticultural practice are provided in the following excerpt from Hartmann and Kester (1959):

"Chemical fumigation will kill organisms in the propagating mixes without disrupting their physical and chemical characteristics to the extent to which may occur with heat treatments. Ammonia production may increase following chemical fumigation, however, owing to the removal of organisms antag-

[3]*Personal communication with James P. Barnett, Southern For. Exp. Stn., Pineville, La., May 1978.*

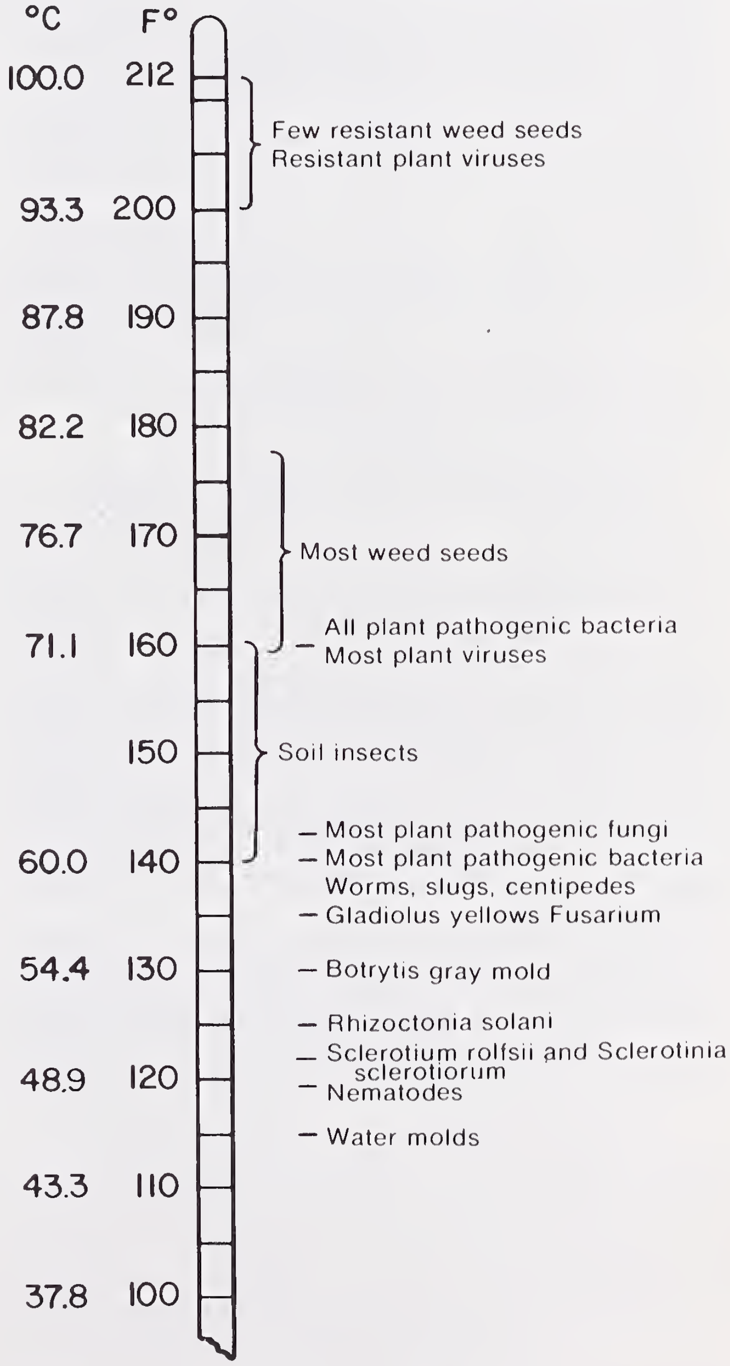


Figure 9-12.—Soil temperatures required to kill weed seeds, insects, and various plant pathogens. Temperatures given are for 30 minutes under moist conditions (Hartmann and Kester 1959).

onistic to the ammonifying bacteria. The mixes should be moist (between 40% and 80% of field capacity) and at temperatures of 65° to 75° F (18° to 24° C) for satisfactory results. After chemical fumigation, a waiting period for dissipation of the fumes of 2 days to 2 weeks, depending upon the material, is required for use.

"**Formaldehyde.**—This is a good fungicide with strong penetrating powers. It will kill some weed seeds, but is not reliable for killing nematodes or insects. Commercial formalin (40% strength) is mixed 1:50 with water and applied to the soil at the rate of 2 to 4 quarts per square foot (20-40 l/m^2) or 1 volume of 0.8% formaldehyde to 9 parts soil). The treated area should be covered immediately with an airtight material and left for 24 hours or more. Following this treatment, about 2 weeks should be allowed for drying and airing, but the soil should not be planted until all odor of formaldehyde has disappeared.

"For small-scale treatments, commercial formalin can be applied at a rate of 2½ tablespoons per bushel (1 ml/l) of a light soil mixture or 1 tablespoon (14 ml) per standard size flat. Dilute with five to six parts of water, apply to soil and mix thoroughly. Let stand 24 hours, plant seeds, and water thoroughly.

"**Chloropicrin (Tear Gas).**—This is a liquid ordinarily applied with an injector, which should put 2 to 4 ml into holes 3 to 6 inches (7-15 cm) deep, spaced 9 to 12 inches (23-30 cm) apart. It may also be applied at the rate of 175 ml/m^3 of soil. The gas should be confined by sprinkling the soil surface with water and then covering it with an airtight material, which is then left for 3 days. Seven to ten days is required for thorough aeration of the soil before it can be planted. Chloropicrin is effective against nematodes, insects, some weed seed, *Verticillium*, and most other resistant fungi. Chloropicrin fumes are very toxic to living plant tissue.

"Chloropicrin and methyl bromide are hazardous materials to use, especially in confined areas. They should be applied only by persons trained in their use and who will take the necessary precautions as stated in the instructions on the containers or in the accompanying literature.

"**Methyl bromide.**—This odorless material is very volatile and very toxic to humans. It should be used mixed with other materials and applied only by those trained in its use. Most nematodes, insects, weed seeds, and some fungi are killed by methyl bromide, but it will not kill *Verticillium*. It is often used by injecting the material at 1 to 4 pounds per 100 square feet (50-200 ml/m^2) from pressurized containers into an open vessel under a plastic cover placed over the soil to be treated. The cover is sealed around the edges with soil, and should be kept in place for 48 hours. Penetration is very good, and the sterilization effect will extend to a depth of 12 inches (30 cm). For treating bulk soil, methyl bromide at 4 pounds per 100 cubic feet (6 kg/m^3) can be used.

"**Methyl bromide-chloropicrin mixtures.**—Proprietary materials are available containing both methyl bromide and chloropicrin. Such combinations are more effective than either material alone in controlling weeds, insects, nematodes, and soil-borne disease organisms. Aeration for 10 to 14 days is required following applications of methyl bromide-chloropicrin mixtures.

"**Vapam® (sodium N-methyl dithiocarbamate dihydrate).**—This is a water-soluble soil fumigant which will kill weeds, germinating weed seeds, most soil fungi, and, under the proper conditions, nematodes. It undergoes rapid decomposition to produce a very penetrating gas. Vapam® is applied by sprinkling it on the soil surface, through irrigation systems, or with standard injection equipment. For seed-bed fumigation, 1 quart of the liquid formulation of Vapam® in 2 to 3 gallons water is used, sprinkled uniformly over 100 square feet of area (1:1 diluted with about 10 parts water covers 9 m^2). After application, the Vapam® is sealed with additional water or with a roller. The soil can be planted two weeks after application. Although Vapam® has a relatively low toxicity to man, care should be taken to avoid inhaling fumes or splashing the solution on the skin."

SECTION 10.—OPTIMUM TEMPERATURES FOR GROWTH

SECTION 10.—OPTIMUM TEMPERATURES FOR GROWTH

10.1 Importance of Temperature

Temperature is the most important controllable greenhouse environmental factor. The greenhouse enclosure itself is the first step toward keeping both day and night temperatures in the best growing range. The most primitive control is to open a door or louvre or roll up the flexible side of a semi-controlled greenhouse, to release excess heat. At the other extreme are banks of cooling pads, fans, and furnaces, with sophisticated multistage automatic electronic controls.

A plant may be considered a complex of physical and chemical reactions. Each individual reaction accelerates by a factor of 2 to 3 for each 10° C rise in temperature up to the point where the enzymes that promote the reaction are damaged. Each reaction has a different rate at any given temperature. However, normal plant growth is the result of many coordinated reactions in balance with each other. The optimum growth temperature is that point at which the whole growth process proceeds rapidly and yet remains in balance (Tinus 1977b).

Some growth processes, such as photosynthesis, occur in the daytime only. Other processes are influenced by light, but to a lesser degree. As a result, optimum day temperature is frequently not the same as optimum night temperature.

There is a great diversity among plants in their adaptation to different sites and climatic regions. Therefore, it is not surprising that there is a great variation in optimum temperatures for growth among, and even within, species (Tinus 1974b, 1970).

Plant growth is not uniform. It can be divided into stages such as seed stratification, germination, juvenile growth, exponential growth, and dormancy. Different metabolic reactions and a different balance among reactions are involved at the different growth stages; therefore, it would be expected that optimum temperatures might be different at different stages.

Growth can be measured in a variety of ways. The most common are height, caliper, and dry weight. Since it is possible to grow more according to one parameter than another, optimum temperatures for one kind of growth are not necessarily the same as for another (Tinus 1977b).

The nurseryman must know where to set the thermostat, and how much deviation from the setpoint can be tolerated. However, to use this information intelligently, the nurseryman should know how it is obtained and what its limitations are. Optimum temperature regimes for tree species can be determined by experimental methods using growth chambers. Such information is provided in this manual. However, all species are not included, because all species have not been studied. Therefore, an explanation of the experimental procedures required to ascertain temperature optima is included for two reasons:

1. To show how existing data was derived.
2. To show how the experiments were accomplished so the methods can be duplicated for other tree species.

10.2 Optimum Temperatures

In a good experiment, all conditions are kept constant except the variables to be manipulated. Temperature experiments almost have to be done in growth chambers, because only there can temperature be held to close enough tolerances. However, the purpose is to extrapolate the results to greenhouse conditions, so, it is important that all conditions other than temperature match expected greenhouse conditions as closely as possible. Experiments conducted at the Rocky Mountain Forest and Range Experiment Station at Bottineau, N. Dak., have attempted to do this. The growth chamber atmosphere is enriched with CO_2. A combination of sodium and multivapor arc lights provide light intensities up to the equivalent of full sunlight. The container and pot medium are the ones used in the greenhouse, and the watering and fertilization are highly favorable, if not optimum. If possible, the pot mix is inoculated with mycorrhizal fungi. The trees are grown from seed to the size required for field outplanting.

In a typical experiment, single tree seed sources are used, whenever possible, in an attempt to reduce the amount of variability in seedling growth. Several sources are used which are selected to represent large differences in latitude, altitude, rainfall, or other factors which might result in differences in response of different seed sources to temperature. Generally, there are differences in growth rate among seed sources, but so far, the day and night temperatures at which optimum growth occurred have not been very different. This is fortunate, because it means that all seed sources of the same species can be grown together in the same greenhouse.

Whenever possible, containers of the type that will be used in the greenhouse are used for the growth chamber experiment, but sometimes this is not practical. Sixteen day and night temperature combinations are produced by resorting the seedlings among four growth chambers twice a day. Some containers such as Rootrainers®, will not tolerate that much handling. Probably the best container for experimental use is the Styroblock® which is not only able to withstand repeated handling, but can easily be cut down to any size needed to fit the desired number of treatments, sources, and replications, in the available chamber space.

The pot mix used is 1:1 peat-vermiculite of a coarseness appropriate for the size of container used. Sufficient seed is sown so that very few cavities are left empty. The extra seedlings are thinned out after the danger of damping off is over, and transplanting is avoided if possible.

Growth chambers are programmed for a 16-hour day and 8-hour night. This corresponds to summer daylength at northern latitudes. For experiments to provide growing data for winter crops or at low latitude a shorter day is better.

The seedlings receive 30,000 to 90,000 lux depending on species.[1] Light intensity selected is at, or slightly above, the saturation point as determined by a search of the literature. This is within the range attainable in the greenhouses and adjustable by shading, except for species such as lodgepole and ponderosa pine which saturate only at extremely high light intensities. A complicating factor is that saturation intensity is a function of temperature and CO_2 concentration, and these relations have not been adequately explored.

Chamber atmosphere is maintained at 1,200-1,500 ppm CO_2 during the 16-hour day. CO_2 added to the atmosphere can as much as double the growth rate (Tinus 1972, 1974c, 1976). However, whereas the high CO_2 is maintained throughout the day in the growth chambers, it can only be maintained when the vents are closed in the greenhouse. In cool or cloudy weather, this may be most of the day, but on bright summer days, the CO_2 may be elevated for only a few hours in the early morning and again briefly at dusk. Under these circumstances, it is hard to tell how much good the high CO_2 is doing. High CO_2 should raise the optimum temperature for growth, which, in turn, should permit the vents to remain closed longer, but detailed information on this relation is lacking.

The 8-hour dark period is interrupted by 1 minute of incandescent light every 15 minutes at about 500 lux. This produces the equivalent of a 24-hour photoperiod which effectively prevents dormancy in the majority of species tested. However, since temperature and photoperiod experiments have usually been done simultaneously on a given species, it is generally not known in advance if that photoperiod regime will be effective.

Rearranging the seedlings among chambers twice a day is not only hard on containers but on the seedlings as well. It is difficult to avoid damaging them, and they are unavoidably subjected to mechanical stress that greenhouse grown trees do not experience. We do not believe this changes their response to temperature, but there is no evidence either way.

Probably the best evidence that results of these growth chamber temperature experiments are valid is that successful crops have been grown using the optimum temperatures recommended. When conditions in the greenhouse have been very different from those recommended, growth has generally been poor.

For some species, the recommendations are based on work by other investigators who were trying to explain something about the ecology or silviculture of that species. In many cases, their experimental conditions were quite different from what they would be in a greenhouse nursery. This information should, therefore, be used with caution, since changes in any of several factors can affect response to temperature (Tinus 1976b).

In these experiments, the seedlings were raised to the size desired for outplanting and then harvested and measured. No intermediate measurements were taken. The temperatures cited as optimum, therefore, are assumed to be constant for the life of the seedling through several stages of growth. It may well be that there are different optimum temperatures for different growth stages. This is indicated by experiments by other investigators which were terminated at different ages (Callaham 1962, Larson 1967, Tinus 1971).

Measurements taken were height, caliper, and fresh and dry weight of shoots and roots. For each measurement a two-way analysis of variance was performed, with day and night temperature as the two variables. The error mean square was used to calculate the coefficient of variability. Mean values for each of the 16 temperature treatments were cal-

[1] *One foot candle equals 10.8 lux (or 1 lumen per m^2).*

culated for each seed source and measurement. These were expressed as a percent of the largest value and plotted on graph paper with day temperature as the abscissa and night temperature as the ordinate. The 90%, 80%, 70%, etc. isolines were drawn by hand by linear interpolation in two dimensions. Judgment as to how best to smooth the curves was guided the following principles:

1. Maximum leeway is one-fourth of the coefficient of variability.
2. Isolines tend to be parallel.
3. Isolines do not have sharp corners.

The coefficients of variability for height and caliper were usually about 3-6% and dry weight 6-12%, which is quite low. Since differences approximately double the coefficient of variability are significant at the 5% probability level, a significant difference on the height and caliper graphs would be about three-fourths the distance between contour lines, and for dry weight about 1½ times contour line distance. This is only approximate, however, because the graphs are hand drawn. Nevertheless, it is a useful indication of how much confidence can be placed in the temperature information.

On the basis of height, caliper, and dry weight, graph recommendations for setpoint and allowable range were formulated. Height, caliper, and dry weight graphs are superimposed. The area within the 90% line of height and caliper and within the 80% line for dry weight is considered the optimum range. The 80% line is used for dry weight, because the coefficient of variability is usually greater. Sometimes the optimums for different growth parameters occur at different day-night temperature combinations. Then, a choice must be made as to which is most important to optimize and how to do it with the least sacrifice of the others.

Then, economic criteria are applied. Stable night temperatures are easy to maintain, because there is no incoming heat load from the sun. However, outdoor night temperatures are almost always lower than optimum, so, heat is required in the greenhouse. Many species have surprisingly high nighttime optimum temperatures. To maintain these would be expensive, especially during cold weather. The strategy is to lower the night temperature from the optimum to a temperature at which both the growth loss and cost of heating are acceptable.

Control of day temperature is complicated by incoming solar radiation. Whether the problem is to keep the temperature up or down depends on the season and the weather. The recommended setpoints in table 10-1 are based on summer conditions where daytime cooling is necessary. The allowable ranges tend to be on the high side, because when the cooling capacity of the system is exceeded, shading is usually the only alternative. Most shading systems require hand labor to put on and take off and are enough of a nuisance that it should be done as infrequently as possible.

The allowable range is the temperature region within which the greenhouse should operate 95% of the time. When temperatures are outside the allowable range for a short time, growth is lost, but usually no permanent damage is done. There are exceptions, however. Except for real extremes of temperature, the principal danger is that the seedlings will be thrown into dormancy and their growth delayed enough that the crop is not ready on schedule. Sometimes this can be as great a loss as if the crop were actually destroyed. However, a certain amount of temperature fluctuation is permissible and even desirable. Within the allowable range, a greenhouse is cheaper to operate, if the temperature is allowed to fluctuate a few degrees than if it is held to very close tolerances.

10.3 Thermostat Settings

The nurseryman will not go wrong using the figures listed in table 10-1 or table 10-2 (Fahrenheit). He may be able to refine them somewhat for his own operation to allow for crops grown in different seasons or experience gained with his species. To do so, use the modification procedures outlined in section 10.2 and the graphs in appendix 1. This will be an especially useful exercise, if the nurseryman intends to grow more than one species at a time. He can use the graph to decide which species are compatible and which should be grown separately. For those that appear compatible, he can pick the best compromise for setpoint and allowable range.

Note that thermostat settings are provided only for those tree species for which data exist. Much more work needs to be done to acquire data for other important tree species.

Table 10-1.—Recommended temperature settings (°C) for maximum growth of tree seedlings from end of germination to dry weight indicated when all other environmental conditions are optimized.

Species	Seed source	Max. dry wt. (*gm*)	Day set point	Temp. allowable range	Night set point	Temp. allowable range	Information confidence level[2]	Authority
Abies magnifica (A. Murr.)	North Coast, Calif., 1,800 m	1.7	17	16-19	5	4-10	B	Hellmers (1966a)
Celtis occidentalis L.	Bismarck, N. Dak.[1]	7.2	31	25-32	19	18-26	B	Tinus
Juglans nigra L.	Manhattan, Kans.[1]	18.4	28	26-30	22	19-28	A	Tinus
Juniperus scopulorum Sarg.	Denbigh, N. Dak.[1]	5.6	25	21-28	18	12-26	A	Tinus
Juniperus virginiana L.	Towner, N. Dak.[1]	11.9	24	21-26	21	19-26	A	Tinus
Larix sibirica Ledeb.	Denbigh, N. Dak.[1]	6.3	25	24-28	22	16-26	B	Tinus
Picea engelmannii (Parry)	Larimer Co., Colo., 3,140 m	8.3	19	17-23	23	22-24	B	Hellmers, et al. (1970)
Picea glauca (Moench) (Voss)	Central Alberta	0.37	22	21-25	19	16-20	A	Tinus
"	Fairbanks, Alaska	0.39	22	20-24	16	13-22	A	Tinus
"	Kenai, Alaska	0.43	22	20-25	19	16-26	A	Tinus
Picea pungens (Engelm.)	Ft. Collins, Colo.	9.4	20	18-25	22	19-26	A	Tinus
"	Indian Head, Sask.[1]	8.9	22	18-25	19	17-23	A	Tinus
Pinus contorta var.	Central Alberta	0.56	25	22-28	16	14-19	A	Tinus
latifolia Engelm.	Whitehorse, Yukon Territory	0.50	22	20-24	19	16-20	A	Tinus
Pinus palustris (Mill)	Mississippi		23	17-26	17	17-23		Bates (1976)
Pinus ponderosa var.	Ruidoso, N. Mex.	19.1	22	18-26	24	18-25	A	Tinus
scopulorum Engelm.	Safford, Ariz., 2,770 m	0.5	17	16-19	22	21-23	B	Callaham (1962)
"	Valentine, Nebr.	15.6	22	20-25	24	20-25	A	Tinus
"	Black Hills, S. Dak.	0.12	23	20-24	23	20-24	B	Larson (1967)
"	Moon, S. Dak., 1,890 m	0.5	23	20-27	22	21-23	B	Callaham (1962)
Pinus radiata D. Don	Cambria, Calif.	12.9	20	19-23	5 or 20	4-7;17-23	B	Hellmers and Rook (1973)
Pinus sylvestris var. *uralensis*	W. Ural Mtns., Russia	9.1	19	18-21	28	25-31	A	Tinus
Pinus sylvestris var. *balcanica*	Central Russia	7.1	19	18-22	25	22-31	A	Tinus
Pinus taeda L.	North Carolina		26	23-29	20	17-23		Bates (1976)
Pseudotsuga menziesii var. *menziesii* (Mirg.) Franco	Vancouver Island, B. C.	2.4	22	17-25	18	13-22	B	Brix (1971)
Quercus macrocarpa Michx.	Devils Lake, N. Dak.	7.2	31	26-32	19	17-26	A	Tinus
Sequoia sempervirens (D. Don) Endl.	Klamath, Calif.	29	19	18-20	16	15-17	B	Hellmers (1966b)
Tsuga heterophylla (Raf.) Sarg.	Vancouver Island, B. C.	1.4	18	17-20	18	13-20	B	Brix (1971), Owston and Kozlowski (1978)

[1] *Location from which seed was obtained, not the origin of native stand.*
[2] *See Section 1.2.*

Table 10-2.—Recommended temperature setting (°F) for maximum growth of tree seedlings from end of germination to dry weight indicated when all other environmental conditions are optimized.

Species	Seed source	Max. dry wt. (*gm*)	Day set point	Temp. allowable range	Night set point	Temp. allowable range	Information confidence level[2]	Authority
Abies magnifica (A. Murr.)	North Coast, Calif., 1,800 m	1.7	63	61-66	41	39-50	B	Hellmers (1966a)
Celtis occidentalis L.	Bismarck, N. Dak.[1]	7.2	88	77-90	66	64-78	B	Tinus
Juglans nigra L.	Manhattan, Kans.[1]	18.4	83	79-86	72	66-82	A	Tinus
Juniperus scopulorum Sarg.	Denbigh, N. Dak.[1]	5.6	77	70-82	65	54-79	A	Tinus
Juniperus virginiana L.	Towner, N. Dak.[1]	11.9	75	70-79	70	66-79	A	Tinus
Larix sibirica Ledeb.	Denbigh, N. Dak.[1]	6.3	77	75-82	72	61-79	B	Tinus
Picea engelmannii (Parry)	Larimer Co., Colo., 3,140 m	8.3	66	63-73	74	72-75	B	Hellmers, et al. (1970)
Picea glauca (Moench) Voss	Central Alberta	0.37	72	70-77	66	61-68	A	Tinus
"	Fairbanks, Alaska	0.39	72	68-75	61	55-72	A	Tinus
"	Kenai, Alaska	0.43	72	68-77	66	61-79	A	Tinus
Picea pungens (Engelm.)	Ft. Collins, Colo.	9.4	68	64-77	74	66-79	A	Tinus
"	Indian Head, Sask.[1]	8.9	72	64-77	66	63-73	A	Tinus
Pinus contorta var.	Central Alberta	0.56	77	72-82	61	57-66	A	Tinus
latifolia Engelm.	Whitehorse, Yukon Territory	0.50	72	68-75	66	61-68	A	Tinus
Pinus palustris (Mill.)	Mississippi		73	73-84	63	63-74		Bates (1976)
Pinus ponderosa var.	Ruidoso, N. Mex.	19.1	72	64-79	75	64-77	A	Tinus
scopulorum Engelm.	Safford, Ariz., 2,770 m	0.5	63	61-66	72	70-73	B	Callaham (1962)
"	Valentine, Nebr.	15.6	72	68-77	75	68-77	A	Tinus
"	Black Hills, S. Dak.	0.12	74	68-75	73	68-75	B	Larson (1967)
"	Moon, S. Dak., 1,890 m	0.5	74	68-81	72	70-73	B	Callaham (1962)
Pinus radiata D. Don	Cambria, Calif.	12.9	68	66-72	41 or 68	39-45; 63-73	B	Hellmers and Rook (1973)
Pinus sylvestris var. *uralensis*	W. Ural Mtns., Russia	9.1	66	64-70	83	77-88	A	Tinus
Pinus sylvestris var. *balcanica*	Central Russia	7.1	66	64-72	77	72-88	A	Tinus
Pinus taeda (L.)	North Carolina		79	73-84	68	63-73		Bates (1976)
Pseudotsuga menziesii var. *menziesii* (Mirb.) Franco	Vancouver Island, B.C.	2.4	72	63-77	65	55-72	B	Brix (1971)
Quercus macrocarpa Michx.	Devils Lake, N. Dak.	7.2	88	79-90	66	63-79	A	Tinus
Sequoia sempervirens (D. Don) Endl.	Klamath, Calif.	29	66	64-68	61	59-63	B	Hellmers (1966b)
Tsuga heterophylla (Raf.) Sarg.	Vancouver Island, B. C.	1.4	64	63-68	65	55-68	B	Brix (1971), Owston and Kozlowski (1978)

[1]*Location from which seed was obtained, not the origin of native stand.*
[2]*See Section 1.2.*

SECTION 11.—HUMIDITY CONTROL

11.1 Definition of Relative Humidity

11.2 Effect of Humidity on Seedlings

11.3 Determination of Optimum Humidities for CTS Growth

11.4 Control of Humidity

SECTION 11.—HUMIDITY CONTROL

11.1 Definition of Relative Humidity

Relative humidity is defined as the vapor pressure of water present in the air divided by the vapor pressure at saturation at the same temperature. Relative humidity is measured in preference to vapor pressure, because it is easy to make direct reading instruments which are almost independent of temperature.

11.2 Effect of Humidity on Seedlings

Relative humidity and temperature control the rate of evaporation from wet surfaces. Rate of evaporation is proportional to the vapor pressure deficit, which is equal to the saturation vapor pressure at a given temperature minus the vapor pressure present at the same temperature. Table 11-1 shows how vapor pressure deficit varies as a function of relative humidity and temperature. The higher the humidity, the less the transpiration.

Some workers believe that a small amount of transpiration is necessary to move mineral nutrients from the roots to the leaves. This is no problem, however, because in strong light, leaf temperature will be higher than air temperature, and, therefore, there will be a vapor pressure gradient from the leaf to the air even at 100% relative humidity.

It would seem that 100% relative humidity would be optimum. This is not so, because fungi, moss, liverworts, and other microorganisms thrive at very high humidities, especially if there is free water present. At humidities above 80-90% foliage diseases and damping off fungi become a major problem.

Plants must have their stomata open to absorb CO_2 during photosynthesis. In the process, they transpire. As the leaves lose moisture, the internal water stress builds up. Elongation, which depends on turgor pressure, slows down, and other internal processes are adversely affected. At some point, the stomata close and net photosynthesis stops. This series of events occurs regularly on sunny days in most species, even when the seedlings are well watered. The roots cannot absorb water as fast as the leaves can lose it. When photosynthesis stops, growth stops. For maximum growth, the stomata must remain open as long as possible, and the less the rate of evaporation, the longer in the day they will stay open.

During germination, the surface must be kept moist so that the seed never dries out. Humidities of 70-80% are desirable to avoid continual watering. As soon as the radicle has penetrated well into the pot mix, the humidity should be reduced to 50-70% so that the surface of the media and the foliage will dry fairly quickly after each watering. It is important that there be adequate air circulation in the greenhouse, otherwise the air will be stagnant within the crowns of the seedlings, and the free moisture present after watering will keep the air in the vicinity of the foliage saturated.

Table 11-1.—Water vapor pressure deficit (mm of mercury) as a function of relative humidity (%) and temperature.

Temperature		Relative humidity (%)										
°F	°C	0	10	20	30	40	50	60	70	80	90	100
104	40	55.3	49.7	44.2	38.7	33.2	27.6	22.1	16.6	11.1	5.5	0
95	35	42.2	38.0	33.8	29.5	25.3	21.1	16.9	12.7	8.4	4.2	0
86	30	31.8	28.6	25.4	22.3	19.1	15.9	12.7	9.5	6.4	3.2	0
77	25	23.8	21.4	19.0	16.7	4.3	11.9	9.5	7.1	4.8	2.4	0
68	20	17.5	15.7	14.0	12.2	10.5	8.7	7.0	5.2	3.5	1.7	0
59	15	12.8	11.5	10.3	9.0	7.7	6.4	5.1	3.8	2.6	1.3	0
50	10	9.2	8.3	7.4	6.4	5.5	4.6	3.7	2.8	1.8	0.9	0
41	5	6.5	5.8	5.2	4.5	3.9	3.2	2.6	1.9	1.3	0.7	0
32	0	4.6	4.1	3.7	3.2	2.8	2.3	1.8	1.4	0.9	0.5	0

11.3 Determination of Optimum Humidities for CTS Growth

There have been few controlled experiments to determine optimum humidity levels. One growth chamber experiment by Krizek et al. (1971) showed that 40% relative humidity was severely limiting to seedling growth of ageratum, petunia, and marigold. Raising the relative humidity to 65% resulted in striking increases in fresh weight, dry weight, leaf area, and height. Increasing the humidity to 90% had no significant effect. The rest of what we know about the effects of humidity is not very precise and has been obtained by experience and general observation. One reason is that precise humidity control is difficult, because it changes so rapidly with temperature. Table 11-2 gives recommended setpoints.

11.4 Control of Humidity

To increase greenhouse humidity:

1. Double layer the greenhouse cover. This is necessary during cold weather to prevent moisture from condensing on the cold outer wall. Without a double layer, it is likely to be impossible to maintain adequate humidity in cold weather regardless of the humidification system.
2. Add steam to greenhouse air. This is highly effective in a closed greenhouse, especially during winter.
3. Irrigate. This is highly effective but can result in overwatering or suboptimum leaf temperatures.
4. Use evaporative cooling. This is an important source of humidity during warm weather in arid climates.

To decrease humidity:

1. Ventilate. Make sure the air flow in and around the seedlings is adequate.
2. Ventilate and heat. Draw in outside air and heat it. Humidity will be lowered, even if the outside air is saturated.

Table 11-2.—Recommended greenhouse humidities.

	Relative humidity	
Growth stage	**Optimum**	**Permissible range**[1]
Germination	80%	60-90%
All other times	60%	50-80%

[1]*Humidity can remain at 100% during and after each watering, but should be lowered as soon as practical.*

SECTION 12.—EFFECTS OF LIGHT

SECTION 12.—EFFECTS OF LIGHT

All green plants require light which they use to control a variety of growth processes. The nurseryman is primarily concerned with two—energy for growth and metabolism (photosynthesis) and prevention of shoot dormancy.

12.1 Photosynthesis

12.11 Characteristics of Photosynthesis

Green plants take up water through their roots, take up carbon dioxide through their leaves, and they synthesize sugars in their leaves. The required energy comes from light. At low light intensities (0 to 1,000 lux), photosynthesis will be less than respiration, and there will be a net loss of carbon dioxide. As intensity is increased to 1,000-3,000 lux, depending on species, temperature, and other factors, photosynthesis will equal respiration, and there will be no net CO_2 exchange. This is the compensation point. Beyond this, photosynthesis increases rapidly and linearly with light intensity up to 10,000 lux and frequently beyond for many species. At higher light intensities, photosynthesis increases further, but not at the same rate. A point is reached at which a further increase in light intensity does not result in more photosynthesis; the tree is "light-saturated." There is no value in providing more light, in fact it is likely to be detrimental.

12.12 Light Intensity and Saturation Levels

Light saturation occurs at different light intensities for different species (table 12-1). It also occurs at higher light intensity when temperatures are higher, when CO_2 concentration is greater, or in leaves that have been grown in full sunlight (sun leaves) as opposed to those grown in shade (shade leaves).

Young seedlings have no shade leaves until after crown closure. They also receive considerable reflection from the light colored grit or perlite covering the pot mix. The effective light they receive is, therefore, likely to be higher than a measurement of direct insolation would indicate. Most germinating seedlings do best with light intensities around 30,000 lux. For locations with high intensity sunlight, a 50% shadecloth over two layers of polyethylene will be about right. For seedlings native to cloudy climates, shadecloth over the greenhouse (30-50%) may still be best, even though the intensity is reduced to less than 10,000 lux. After the seedlings are well established, the light intensity should be raised to the saturation point by removing shade, if necessary. The only reason for not removing the shade would be if the greenhouse could not hold acceptable daytime temperatures without it. Ideally, shading should be adjusted throughout the day and from one day to the next to optimize light intensity. This is generally impractical, however, because most shading is manually applied and removed, which is too slow and laborious to do that often. It is important that the shade be removable to match the light intensity

Table 12-1.—Saturation light intensities for various species.

Species	Saturation light intensity (kilolux)	Authority
	Low	
Douglas-fir	30	Krueger and Ruth (1969)
Sitka spruce	30	"
western hemlock	30	"
white oak	15	Kramer and Decker (1944)
eastern red oak	35	"
dogwood	35	"
	Medium	
Engelmann spruce	50	Ronco (1970)
blue spruce	50-80	Tinus (1970)
red alder	50	Krueger and Ruth (1969)
	High	
lodgepole pine	120 +	Ronco (1970)
ponderosa pine	120 +	Tinus (1970)
loblolly pine	100 +	Kramer and Decker (1944)

with the season of the year and the seedling stage of growth, however.

In sunny climates, during spring and summer, there is usually ample sunlight for seedling growth. In very cloudy climates, and during fall and winter, especially at high latitudes, there is frequently not enough sunlight for normal seedling growth. Certainly, the growth of a crop in a greenhouse will be slower during fall and winter than in spring and summer. Obviously, unless production demands require a winter crop, a summer crop can be raised more quickly and, often, more economically.

12.13 Artificial Light

It is possible to compensate for lack of sunlight by adding artificial light. The entire visible solar spectrum is utilized for photosynthesis, but all wavelengths are not equal in efficiency, and not all of them are needed. This is fortunate, because few of the available light sources closely match the solar spectrum.

The most efficient wavelengths of light for photosynthesis are 600-700 nm in the red part of the visible spectrum. Infrared (700 nm and longer) is not used at all but is absorbed and increases leaf temperature. Green and blue light (400-600 nm) are used with one-half to two-thirds the efficiency of red light. Ultraviolet (wavelengths shorter than 400 nm) is not useful and can be damaging. Therefore, the most efficient light sources for photosynthesis are ones which have maximum output in the red and none in the ultraviolet.

The minimum light intensity that is worth the effort is about 3-5 kilolux, and for good growth, the light intensity should be 7-12 kilolux. This assumes the artificial light is being used as a supplement to sunlight. If it is to be used as the sole source in what amounts to a growth chamber situation, then the intensity may need to be even higher, and it may be desirable to have other wavelengths in the spectrum needed for normal development, but not necessarily for photosynthesis.

For effective photosynthesis, the lights must be on for hours at a time at high light intensity. Such lights are expensive and impractical to install and operate unless electricity is very cheap. In this case, the choice is between building more greenhouse space or installing lights and getting added benefit from the existing space. See section 6.2 for lamp types best suited for photosynthetic lighting.

12.2 Prevention of Dormancy

12.21 Relation of Photoperiod to Dormancy

The other important function of light is control of bud dormancy by the effective length of day. Long daylight periods prevent dormancy in many woody perennials, while short days permit or induce dormancy. When seedlings cannot be reared to the desired size in a container nursery during the normal spring-fall growing season, must be reared over winter, or must be reared in a very short time, some control of photoperiod is necessary. In mild climates, no photoperiod control is needed to rear high quality seedlings of some species in one season. There are numerous examples of this in the semicontrolled environment CTS nurseries in the coastal Pacific Northwest. The determination as to whether lighting for dormancy prevention is needed depends on the nursery location, species to be grown, the time of year the crop is to be raised, and the amount of time available to grow the trees.

Photoperiod sensitivity in plants is caused by light-sensitive protein in the plant called "phytochrome" (Borthwick and Cathey 1962). Red light (660 nm) converts it to an active form which prevents dormancy. Far red light (735 nm) reverses the effect of red light and converts phytochrome to an inactive form. Phytochrome also reverts slowly to the inactive form in the dark. In addition to preventing dormancy, active phytochrome also retards stem elongation. Thus, to achieve maximum growth rate, enough active phytochrome must be present to prevent dormancy, but no more than necessary, because it will reduce height growth.

12.22 Light Required for Dormancy Prevention

There are several important differences between light required for photosynthesis and that required for dormancy prevention. For the latter, wave lengths shorter than 550 nm are of no value, and wavelengths between 700 and 770 nm reverse the effect of red light.

As red light intensity increases from zero, there is a threshold below which there is no growth response. Above the threshold, height growth increases rapidly and then tapers off at an upper limit above which there is no further response (fig. 12-1). For the majority of species, full response can be obtained with 400 lux (even less for some species (Arnott 1974, 1976, 1979)), which is two orders of magnitude less than what is required for photosynthesis.

The light required for photosynthesis is for power, which is why the light must be high intensity and continuous. In contrast, light for dormancy control acts as a trigger; it requires very little power and need not be continuous (Cathey and Campbell 1977). The lights can be on as little as 3% of the time, provided no dark period is longer than 30 minutes. Since the intensity and duration of light required for dormancy control is so small, it is not only economically feasible to provide this amount of light, but under most conditions, it is important to do so.

12.23 Suitable Light Sources and Installations

If the greenhouse is equipped with lights for photosynthesis, these lights will also prevent dormancy if operated to reduce the dark period to no more than a few hours. If lights are to be installed only for dormancy prevention, the lighting specifications will be quite different.

Planned light intensity should be 400 lux, minimum, expandable to 800 in case the species to be grown has a higher light requirement than most, unless it is known for sure that less than 400 lux is effective. The light intensity need not be uniform but must be above the minimum at all points. Second, the lights do not have to be on continuously. In fact, as long as the dark periods are kept shorter than 30 minutes, it is better if they are not. Equipment and lamps for dormancy preventing light systems are discussed in section 6.2 in some detail.

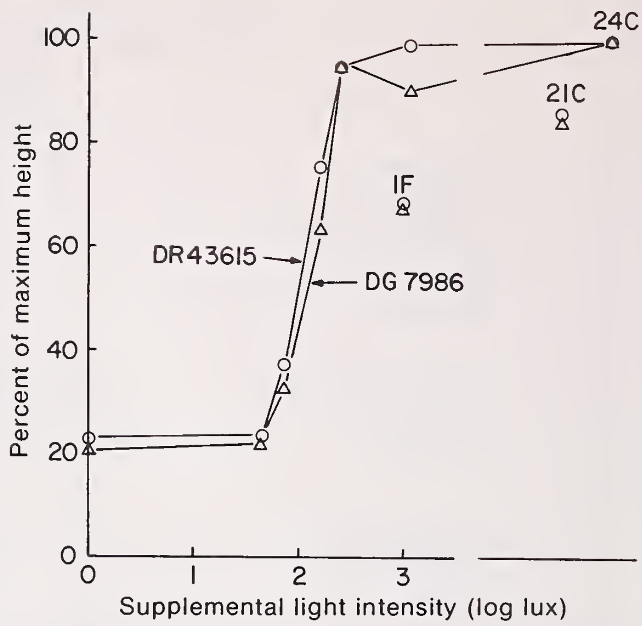


Figure 12-1.—Height growth response of white spruce to different intensity, duration, and quality of supplemental light. Triangles and circles represent two different seed sources as labelled. Unlabelled points are different intensities of incandescent light given 1 minute out of every 15 during the night. IF indicates intermittent fluorescent light on the same schedule; 21C was continuous incandescent light at 1,200 lux with a 3-hour dark period; 24C was the same as 21C with no dark period (Tinus 1976b).

12.3 Light Requirements to Prevent Dormancy

12.31 Determination of Light Requirements

At the USDA Forest Service Experiment Station in Bottineau, N. Dak., many species have been tested to determine the quantity and duration of light needed at night to maintain growth. A typical experiment is outlined here to acquaint the reader with methodology for acquiring lighting recommendations and so the method can be duplicated, if need be.

Seed is obtained from at least two seed sources widely separated in geographic origin and latitude so that any intraspecific differences would be likely to show up. These are planted in containers grouped into convenient-sized blocks. The choice of container is determined by the nursery needing the information. The planted containers are placed on a greenhouse bench which is divided into nine light-tight compartments at night, each of which is given a different light treatment. These are shown in table 12-2. The last four treatments were tried only in early experiments on ponderosa pine and blue spruce. Each compartment is attached to an air exhaust blower to minimize temperature differences between compartments at night. Each month, the positions of the various treatments on the bench are rerandomized to reduce the position effect caused by nonuniformity of daylight and temperature conditions in the greenhouse. The compartment opening and closing is synchronized with the natural day, so that it is closed and the photoperiod treatments operating whenever it is dark, up to a day length of 16 hours. In June, this means shortening the natural day somewhat.

After the seed coats are shed, the seedlings are watered as needed with a modified Hoagland's solution. The seedlings are grown under favorable conditions of temperature, sunlight, mineral nutrition, and watering. Conditions frequently are not optimum, however, either because they are not known at the time or because the conventional glass greenhouse in which the experiments are conducted is not able to maintain the desired conditions. When the average seedling in the best treatment reaches the desired size, the experiment is terminated. The seedlings are photographed, and height, caliper, and fresh and dry weight are measured.

Differences between treatments are tested by the Duncan multiple range test. Results are tabulated in percent of maximum height, caliper, and dry weight. When there are significant differences between seed sources within species, these are tabulated separately.

12.32 Tabulated Results by Species

Table 12-3 summarizes recommendations for long day treatment of each species tested.

Table 12-2.—Treatments used to determine light requirements to prevent dormancy.

Treatment code	Light source	Size (*watts*)	Light intensity (*lux*)	Duration
OW	None	0	0	0 (Dark control)
1W	Tungsten incandescent	12V, 1W	43	1 minute out of every 15
7W	"	7	75	"
15W	"	15	160	"
40W	"	40	270	"
100W	"	100	1,200	"
22F	Fluorescent	22	950	"
24H	Tungsten incandescent	100	1,200	Continuous all night
21H	"	100	1,200	Continuous except for a 3-hour dark period
1/30	"	100	1,200	1 minute out of 30
2/30	"	100	1,200	2 minutes out of 30
1B	"	100	1,200	1 hour light in middle of night
2B	"	100	1,200	2 hour light periods to break night into 3 equal parts

Table 12-3.—Response of various species to extended photoperiod and recommendations for use of extended photoperiod to prevent dormancy.

Species	Seed source	Response[1] Height	Response[1] Dry weight	Recommendation[2] A	Recommendation[2] B	Recommendation[2] C	Information grade[3]
Celtis occidentalis	Bismarck, N. Dak.	1.2	1.8			X[4]	B
Quercus macrocarpa	Devils Lake, N. Dak.	1.2	1.2			X[5]	A
Juglans nigra	Manhattan, Kans.	1.1	1.1			X[6]	A
Juniperus scopulorum	Towner, N. Dak.	1.6	2.3		X		A
Juniperus virginiana	Towner, N. Dak.	1.9	2.4	X			A
Picea glauca	Central Alberta	4.5	> 10	X			A
Picea pungens	Fort Collins, Colo.	1.4	7.7	X			A
Picea pungens	Indian Head, Sask.	1.4	7.7	X			A
Pinus contorta	Central Alberta	2.3	2.6	X			A
Pinus ponderosa	Ruidoso, N. Mex.	1.5	1.8	X			A
Pinus ponderosa	Valentine, Nebr.	3.1	3.6	X			A
Pinus ponderosa	Colorado Springs, Colo.	1.5	2.3	X			A
Tsugu heterophylla (Owston and Kozlowski 1978)	Oregon Coast	1.7	1.6	X			A

[1]Response to long day equals average size in a given treatment divided by average size with no added light at night (control).

[2]Recommendation A—400 lux incandescent light minimum (86 watts/m²) on 1 minute out of every 15 throughout the dark period. Interval is flexible provided lights are on 6% of the time and no dark period exceeds 30 minutes.

Recommendation B—same as A, except 800 lux minimum.

Recommendation C—same as A, but response to long photoperiod is not strong. Other conditions are also required. See individual species footnotes.

[3]Information grade: see section 1.2.

[4]Hackberry seems to maintain growth without long photoperiod, but use it for insurance anyway.

[5]Bur oak requires hot days and warm nights to maintain growth. Effect of photoperiod under these conditions is uncertain.

[6]Black walnut responds to long photoperiod only under high CO_2 (Tinus 1978b).

SECTION 13.—MINERAL NUTRITION AND pH CONTROL

SECTION 13.—MINERAL NUTRITION AND pH CONTROL

Information on nutrient needs of forest tree seedlings is skimpy.

13.1 Water Testing

All consideration of CTS fertilization begins with knowledge about the chemical composition of the water used for irrigation, regardless of fertilization method used. The nurseryman needs to know how to collect water samples for testing, what tests to ask for, and what the test results mean.

13.11 Tests Needed

The following should be included in a mineral analysis of irrigation water:

1. Total dissolved solids (mg/l or parts per million).
2. Electrical conductivity (μmhos).
3. Amount of all nutrient ions present (parts per million or mg/l) including: nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), sulphate (SO_4), iron (Fe), manganese (Mn), boron (B), copper (Cu), zinc (Zn), molybdenum (Mo), and chlorine (Cl).
4. Amount of other ions (parts per million or mg/l) affecting nutrient availability such as: sodium (Na) and carbonate (CO_3 or HCO_3).
5. Considering the possibility of heavy metal contamination of water supply as outlined in section 4.15, tests for the following ions may be advisable in rare instances: chromium (Cr), cadmium (Cd), arsenic (As), and mercury (Hg).
6. Finally, but very important, a titration table is needed to show the amount of a standard acid required to reduce the sample from its normal pH level to any pH down to 4.5. Specify that titration readings be taken at every 0.1 pH unit in developing the table (table 13-1).

13.12 Laboratory Selection

State water testing laboratories are normally equipped to make all of these tests, although they may not usually be asked to check for all of the ions specified or develop pH titration tables. The service is usually free, but often slow. If a private water testing laboratory is used, be sure it is reputable and willing and able to do all the tests. Ask how much water will be required to do the tests. Usually a quart is adequate and is easy to ship, but sometimes, more than a quart will be required.

Table 13-1.—Titration of Mount Sopris irrigation water with 0.02 N H_2SO_4. Sample size is 100 ml.

	Titrant used			Titrant used	
pH	ml	meq per l	pH	ml	meq per l
8.0	0.0	0.00	6.2	43.0	8.60
7.9	5.0	1.00	6.1	43.8	8.76
7.8	10.4	2.08	6.0	44.7	8.94
7.7	15.0	3.00	5.9	45.3	9.06
7.6	18.7	3.74	5.8	46.0	9.20
7.5	21.4	4.28	5.7	46.7	9.34
7.4	24.3	4.86	5.6	47.2	9.44
7.3	26.7	5.34	5.5	47.7	9.54
7.2	29.0	5.80	5.4	48.2	9.64
7.1	31.0	6.20	5.3	48.6	9.72
7.0	32.6	6.52	5.2	48.9	9.78
6.9	34.6	6.92	5.1	49.2	9.84
6.8	36.0	7.20	5.0	49.5	9.90
6.7	37.4	7.48	4.9	49.7	9.94
6.6	38.6	7.92	4.8	49.8	9.96
6.5	40.0	8.00	4.7	49.9	9.98
6.4	41.0	8.20	4.6	50.0	10.00
6.3	42.0	8.40	4.5	50.1	10.02

13.13 Water Sampling

The laboratory selected to do the work can recommend the type of container for shipping the sample. In general, metal containers or glass containers with metal lids should be avoided. Inert polyethylene containers, or glass containers with plastic lids are usually satisfactory. Samples should be collected as near to the location where the water will be used as possible. This is because the conduit between the source and the use point may have an effect on the chemistry of the water. The water should run long enough before the sample is taken to assure that the sample is representative of the production water, not water that has been in the pipeline for any length of time. Water stagnated in the pipe may differ in chemical composition from the norm. When collecting the sample, do not let the lip of the collection vessel contact the mouth of the faucet. The sample should be sealed and delivered to the laboratory promptly. When water test results are received, they are compared to the guidelines in this manual. These are in sections 13.3 (pH), 13.4 (electrical conductivity), and 13.61 (nutrient ion concentrations). Use of the results when contrasted with the guidelines is covered in the sections pertaining to formulation of nutrient solutions (sections 13.6, 13.7, and 13.8) depending on how the nutrient solutions are to be formulated. Frequency of water testing will depend on the nature of the water source. Surface water sources will be, generally, more variable chemically than well water. Annual and/or flow rate variations can be ascertained by frequent testing in the beginning. The changes may or may not be great enough to justify nutrient solution reformulation, but nutrient solution changes should be made whenever it appears warranted. Nutrient solution changes can also be keyed to changes in foliar nutrient content of trees. This is discussed in section 13.52.

A digression into fertilization method alternatives follows as a preface to detailed discussion of CTS mineral nutrition and pH control.

13.2 Fertilizer Alternatives

13.21 Mix Fertilizer with Growing Medium

Incorporating slow release fertilizers into the pot mix or adding granular fertilizer to the pot as a "top dressing" following potting is common in horticultural container nurseries. Topdressing fertilizer in CTS operations is impractical because of the container size. Adding such fertilizers to the potting mix has been tried to limited degree in CTS operations but has been abandoned in most instances. However, some work is proceeding on incorporation of very long-term release fertilizers designed to fertilize the tree 1, 2, or 3 years after outplanting.[1] The goal of this work is not to fertilize seedlings while they are being reared in the greenhouse. The authors do not recommend mixing fertilizer with growing medium in CTS operations for several reasons:

1. At some point in the growing cycle cessation of top growth is desired. This requires a change in fertilizer regimes. With fertilizer incorporated in the growing medium this is impossible. The program of nutrition the authors recommend begins with no nutrients during germination, a high nitrogen formulation during rapid growth, and high P and K during hardening. This program would be impossible to accomplish with solid fertilizers incorporated into the mix.

2. Growing trees in containers can take from a few months to a year, depending on the size of tree wanted and container used. It is very difficult to precisely match fertilizer pellet dissolution rates to the needs of tree seedlings for so long a time, particularly under greenhouse conditions.

3. Many of the slow dissolving fertilizers suitable for pot mix incorporation tend to raise the pH. Since many trees do best in acid or slightly acid conditions, this may not be desirable. Examples are incorporation of micronutrients in the form of slightly soluble glass frits, or ground dolomite ($CaCO_3MgCO_3$) to supply calcium and magnesium and to raise the pH of extremely acid peat.

[1]*Personal communication with Phillip Hahn, Georgia-Pacific Corp., Eugene, Oreg., May 1978.*

13.22 Use Soluble Fertilizer Mixes

Most CTS nurseries use commercial soluble fertilizer. These powders or granules are dissolved in water and injected into the irrigation system of the greenhouse. In some small operations, the solution is sprayed over the trees by hand using equipment separate from the irrigation system. These fertilizers are formulated by a number of manufacturers. A variety of types are available, incorporating various concentrations and proportions of macronutrients and micronutrients.

As experience in growing different species of trees in different locations, containers, and potting mixes has accumulated, a great variety of fertilizer regimes have been developed using soluble fertilizer compounds. A nurseryman considering use of commercially prepared soluble formulations should find out what other CTS nurserymen are using and what their timing and other methods are. However, it is unwise to assume that what works in one situation necessarily works in another. This is because the fertilizer interacts with water composition of a specific site, the pot mix used, the species grown, and the growing conditions peculiar to each greenhouse. These variations can be compensated for by water testing, pH and electrical conductivity monitoring, and following nutrient solution formulation procedures outlined in section 13.7 of this manual.

Commercially formulated soluble chemical fertilizers are convenient to purchase and use. No chemical blending is required. The greenhouse crew merely selects the proper sack of mix, dissolves a measured amount of it in water, and injects it through the water system. But purchased mixes have drawbacks:

1. The manufacturer controls the precision of the formulation.
2. The user often does not know what chemical compounds are used to supply the nutrient ions, or if these compounds are changed from time to time. Both of these questions inject unknowns into the CTS cultural process that are hard to identify if something goes wrong with the trees.
3. The user is limited to the proportions of the nutrients available in mixes.
4. The salts used, especially phosphates, will affect the pH of the resulting solution. Therefore, it may be necessary to modify the pH by separate treatment, if the pH of the nutrient solution as applied to the trees is not what is desired.
5. Many water supplies already contain substantial amounts Ca, Mg, S, and, occasionally, some of the micronutrients. The nurseryman who formulates his own mix can take advantage of what is already in the water and avoid adding unnecessary salts.

In summary, soluble commercially prepared fertilizer compounds are used very successfully for fertilization in most CTS operations. The materials are convenient and easy to use, but some knowledge of the exact nature of fertilizer being applied is usually lost.

13.23 Formulate Nutrient Solution On Site

The third method of fertilizing tree seedlings is with homemade nutrient stock solutions, injected through the irrigation system. "Homemade," in this instance, means a fertilizer solution made by adding various amounts of technical grade chemical compounds to water according to a recipe developed for a particular water supply and crop. The advantages of this method of fertilization are:

1. The user knows exactly what chemical compounds are employed.
2. The user can tailor the fertilizer to his crop, pot mix, and water composition.
3. The components in the mix are entirely flexible.

Disadvantages are:

1. The user must develop the recipe himself or have someone do it for him. Some of the chemicals used may be hazardous, and may require more training to handle them safely.
2. The user must stock the variety of chemical compounds required and formulate the mix at the nursery. Each compound must be weighed into proper quantities for each bath of concentrate, and the opportunity for error is increased.
3. In many cases, the optimum nutrient concentrations are unknown, so, fine tuning the formulation to do an appreciably better job than a commercial mix is problematical.

13.24 Selection of Fertilization Method

The authors recommend that soluble salts at controlled concentrations be applied through the irrigation water. This method gives the best control of nutrition and the most flexibility, if a change is needed. The choice of commercial mix versus home brew is up to the nurseryman. Many fine seedlings are grown using commercial mixes, and it is quite possible that a custom formulation would not result in any improvement. However, if the nurseryman is willing to take the time and effort needed to make up his own, he will gain the confidence that he knows for sure what he has, and he can change it as needed to meet his own requirements or as specific knowledge of mineral nutrition improves.

13.3 Control of pH

13.31 Definition of pH

The pH indicates the relative alkalinity or acidity of a solution. A pH of 7 is neutral, while pH less than 7 are progressively more acid and those greater than 7 are progressively more alkaline. Soil pH is defined by the equation:

$$\text{Soil pH} = \log \left[\frac{1}{a_{H^+}}\right]$$

in which the activity of H^+ in the soil suspension, $a_{H}+$, is expressed as gram-ions per liter (Jackson 1958). Normally, the effective concentration of hydrogen ions includes all sources, such as those arising by dissociation of soluble acids and those dissociated from soil particles. In practical terms, effective pH is defined as the electrical potential measured with a glass electrode applied to the soil system (Bates 1954). The electrical potential is measured with the potentiometer, or pH meter, described in section 6.56. The pH value or hydrogen ion activity of a soil is its most important chemical property as a medium for plant growth (Jackson 1958). The activity in the soils of the 12 or more different ions that enter into plant nutrition is highly dependent upon that of the hydrogen ion.

13.32 The Best pH for Tree Growth

Optimum growth of tree seedlings, and particularly conifer tree seedlings, occurs over a relatively narrow range of pH values (Wilde 1958, Brix and van den Driessche 1974), and control of pH is practical in CTS operations. The authors recommend target pH's of 5.0 to 6.0 for conifers and 6.0 to 7.0 for hardwood species (Wilde 1958 and Tinus 1977). These figures can be used where more specific information is lacking.

13.33 Dynamics of pH Control

Growing medium volume used in CTS operations is small when related to the number and size of plants grown. This means although a growing medium with considerable buffering capacity is used, pH of the medium and its soil solution can change rapidly. Large changes are undesirable for optimum plant growth. These changes can be due to differential removal of ions from the growing medium by the plants, by leaching, malfunction of a nutrient injector, and mistakes in fertilizer solution formulation. It is important, therefore, to start with a pot mix near the target pH for the trees to be grown and to attempt to maintain this pH closely in the growing medium as the crop develops.

The initial pH of growing media is discussed in section 9.32. Some Pacific Coast nurseries regulate pH by applying calcium nitrate or sodium hydroxide to raise the pH or ammonium sulphate or sulphuric acid to lower it (Brix and van den Driessche 1974). In other CTS operations, pH is neither monitored nor modified other than to make sure that the potting mix is initially acid. In most CTS operations, desired low pH levels are maintained by irrigating with acidified water, a procedure often used in horticultural cropping (Matkin and Petersen 1971). Considering the high value of CTS crops and the crucial nature of pH control to plant nutrition and disease control, nursery men should constantly monitor the pH of the growing medium, and make adjustment as needed. The pH is one environmental factor that is economically feasible to control.

13.34 Monitoring Methodology

The pH is conveniently measured at two places: the water applied and the leachate from the bottom of the container. To provide an adequate supply of water to the trees and prevent salt accumulation in the containers, container tree seedlings should be watered enough to insure that water flows through the container during each irrigation. The method for monitoring pH suggested in this manual consists of:

1. Measuring pH of the nutrient solution applied.
2. Measuring pH of the "leachate" (water that runs through the growing medium in the container).
3. Comparing the two readings to make inferences about the pH of the soil solution in the growing medium at time of reading and as a trend over time.

This method avoids the usual method of soil pH determination, where dry soil is mixed with water in some standard proportion, allowing the mixture to stand for about ½ hour, then, while the mixture is stirred, potentiometer electrodes are inserted, and the pH is measured on the soil suspension (Jackson 1958). The standard procedure would be very difficult to use in CTS operations because of the shape of the containers.

13.35 Sample Collection for pH Tests

The difficulty of catching leachate from containers varies with the type of container. It is essential the fluid that is caught is that which has passed through the medium of the container. Several container systems are designed so that irrigation water can reach the bottom of the bench, via cracks, dividers, holes, etc., without going through the container. This "bypass" water must not enter the sample being collected for pH measurement. In most cases, a minimum of 3 to 5 ml of leachate is required to take a pH reading; more is better. The sample size should be standardized. The pH of the first leachate coming from the container will be different from that coming later. This is not important as long as the same volume of fluid is caught at each collection.

13.36 Meaning of the pH Reading

The reading of the obtained leachate is not identical with the pH of the growing medium prior to irrigation. The reading will usually be between the pH of the nutrient solution applied and the pH of the growing medium prior to irrigation. The pH values recorded in consecutive irrigations will show trends. For example, if the desired pH for a conifer crop is 5.5 and the irrigation solution is adjusted to pH 5.3, the pH reading of the leachate may be around 5.5, and the actual pH of the rooting medium can be estimated to be 5.7. This means that the average pH of the growing medium between irrigations is probably around pH 5.5, fluctuating from near 5.3 immediately following irrigation to 5.7 just before irrigation. Uptake of nutrients, such as nitrate, and production of carbon dioxide by root respiration, which forms bicarbonate, usually elevates the pH between readings. The magnitude of such pH changes should be less than one full pH unit. The magnitude of the change can be reduced two ways: (1) irrigate more often, which means more frequent leaching of the growing medium, or (2) alter the chemical components of the nutrient solution, so that ion uptake by the plants releases less alkalinity.

A difference of 0.3-0.4 pH unit between leachate and irrigation solution pH would be considered normal. Large differences should prompt corrective action. First, examine the accuracy of the injection system. Check the irrigation solution pH, metering accuracy, and accuracy of nutrient or acid concentrate formulation. Second, see if increased irrigation frequency will solve the problem. As trees grow larger, they require more frequent irrigation. If actual added irrigation lags behind this need, pH and electrical conductivity readings of the leachate should rise. Last, if the spread between irrigation solution pH and leachate pH is still too wide, increase the acidity of the nutrient solution and perhaps reformulate it.

13.37 Relation of pH to Electrical Conductivity

Electrical conductivity (EC) readings (section 13.4) provide an estimate of the concentration of dissolved salts. EC and pH readings give the following information:

1. If a well-balanced nutrient stock solution is injected at an insufficient rate, then samples of

the irrigation solution (not the leachate) will be too dilute and exhibit abnormally high pH and abnormally low EC values.

2. If a well balanced nutrient stock solution is injected at too high a rate, then samples of the irrigation solution (not the leachate) will exhibit abnormally low pH and abnormally high EC values. This is a check on injector accuracy and concentrate formulation.
3. If the nutrient solution is out of balance, the EC value will be normal, but pH will be above or below the normal reading for the nutrient solution. This could occur in an instance where two solutions (where the concentrate components are not compatible in one concentrate solution) were being injected simultaneously through each of two injectors. Malfunction of the acid concentrate injector would cause the observed readings. The pH would be adjusted by altering either the concentrate or the injection rate for the acid concentrate solution. The other concentrate (containing salts primarily) would usually not require alteration.
4. If the pH fluctuates over time and the EC remains about right, there is reason to suspect corrosion in the acid injector is causing erratic behavior in its metering or a rise or decrease in carbonate content in the water supply (a seasonal phenomenon in some water sources).
5. From water test data and his own tests, the nurseryman will know the normal EC of his water. From tests of his irrigation solution, he will know the normal EC of the nutrient solution used for irrigation. If EC of the leachate is trending higher than normal, there is not enough leaching taking place during irrigation to remove the accumulated salts. Longer irrigations and more leaching are needed.

The pH and EC test results provide the primary data for checking and monitoring CTS acidification and fertilization procedures. These tests will give advance warning of incipient problems. Recording such data on a regular basis will usually show when corrective action is needed before any damage is done.

The foregoing assumes that all irrigation water is a dilute nutrient solution. At many nurseries, trees are fertilized only periodically. In these cases, a pH test is still of value to monitor performance of the injector and to check nutrient balance. It is possible to measure growing medium pH directly by taking a sample of it and measuring its pH in suspension, as previously described for soil analysis. EC readings of the leachate are also very valuable in these instances to prevent excess accumulation of salts in the containers.

13.38 Using a pH Meter

The actual procedures for using pH meters vary depending on type and design of instrument. Section 6.56 gives general recommended specifications for a pH meter. To use such a meter, the test solution is placed in a convenient vessel, the electrode is placed in the solution, and the pH is read directly on the dial. Many pH meters have a temperature compensation dial, since the instrument is temperature sensitive. Often, a warm-up time is needed to balance the instrument before use. This is not necessary with some newer instruments, however. Fragile glass electrodes usually are used. Even heavy-duty ones are subject to rapid deterioration if not properly cared for. Instructions for instrument care supplied with the meter should be followed exactly. Glass electrodes can fail because of rough use or chemical action; periodically the electrode should be tested (see instrument use book) to be sure it is functioning properly. Normally, the electrode of a pH meter is washed off with a strong stream of distilled water and, if recommended in instructions, dipped in the acid pH buffer solution provided. For storage after cleaning, the electrode is normally suspended in distilled water, and the system is protected from evaporation. Avoid letting the electrode dry out.

13.4 Control and Monitoring of Salt Concentration

The use of an electrical conductivity (EC) meter to monitor the EC of the irrigation solution and the leachate is essential in any container operation.

13.41 Definition of Electrical Conductivity

Electrical resistance is defined by the equation $E=IR$, where E is the electrical potential (in volts), I is the current (in amperes), and R is the resistance (in ohms). Electrical conductance, C, or conductivity, of a solution (in mhos) is the reciprocal of resistance (Bates 1954).

For convenience, conductance is read in millimhos ($mhos^{-3}$) or micromhos (μmhos). Actually, the unit read on a conductivity meter is usually micromhos per centimeter (μmhos/cm), or specific conductance.

13.42 Interpreting Electrical Conductivity Readings

The conductivity meter provides a quantitative estimate of the salt content of solutions extracted from soils (in this case leachate caught below the container) or of the irrigation water or nutrient solution. If the normal EC of the water supply and the diluted acidified nutrient solution EC are known, then changes in these figures can be recognized. Changes in EC indicate that the salt content of the water supply has changed, and a new chemical analysis of the water may be needed. In the case of a change in EC of the treated irrigation water, without a corresponding change in untreated water, an injector malfunction or an improperly formulated nutrient concentrate is probably the cause.

A rise in the normal EC of the leachate without a similar rise in the EC of the irrigation solution applied tells the nurseryman there is not enough leaching of the growing medium (i.e. not enough water being applied per irrigation cycle).

13.43 Magnitude of Electrical Conductivity Readings

Very pure irrigation water may be EC's as low as 100-200 μmhos, whereas very salty water may have EC's around 1,200-1,400 μmhos. Water carrying a complete nutrient solution and buffered for conifer growth, will range from 500-1,000 μmhos higher than the untreated water, normally in the 1,500-2,000 μmhos range.

High salt concentrations generally result in stunting, although the seedlings may also be chlorotic. Figure 13-1 shows the yield reduction to be expected from a range of salt concentrations for agronomic crops of various salt tolerances (Maas and Hoffman 1977). Most conifers are sensitive to moderately sensitive, and most hardwoods are moderately sensitive to moderately tolerant, although there are a few tolerant ones such as honeylocust and Russianolive (Dirr 1974, Bernstein et al. 1972).

If the leachate EC exceeds the nutrient solution EC by 1,000 μmhos or more, the nurseryman knows he is in real trouble. Normally, the two should be within 100-200 μmhos. If the EC of the leachate is 3,000 μmhos or more, the trees are probably dead or dying. Normally, total nutrient solutions should not be used if the EC of the irrigation formulation exceeds 2,200-2,400 μmhos. If this occurs, try a reformulation with

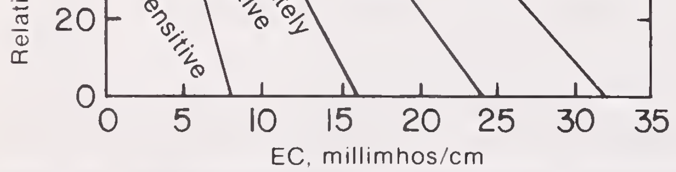


Figure 13.1—Relative crop yield as a function of soil salinity for plants of different salt tolerance (Maas and Hoffman 1977).

different chemicals, because, if the containers dry only slightly at these high salt concentrations, the osmotic potential of the soil solution may become too high for growth. Lower EC levels will give the nurseryman a safety margin.

13.44 Conductivity Meter Operation, Records, and Accessories

The conductivity meter consists of the bridge and the cell (figure 6-38). The cell is ordinarily stored immersed in distilled water. In use, the cell is filled with test solution by immersing it into a container of the solution until the sensitive portion of the electrodes are completely covered. The bridge is balanced (as per specific unit operating instructions), and the meter is read. The EC and pH of the irrigation solution and the resultant leachate should be constantly monitored and systematically recorded.

Pressure gauges and flow meters can monitor water supply pressures and flow rates and check injector function, as discussed in section 6.4. These instruments are relatively inexpensive and provide an additional check on the function of the nutrient injection equipment by directly comparing amount of nutrient concentrate or acid injected to volume of irrigation solution applied. Because injectors wear out, corrode, or scale internally over time, such direct checks are valuable, and installing and monitoring of these simple devices is recommended.

In greenhouse operations, there is nearly always a work area with bench space for the pH meter, electrical conductivity meter, and associated equipment. This increases efficiency of the testing and record keeping, protects the instruments, and is certainly a worthwhile investment.

13.5 Seedling Mineral Nutrient Requirements

All green plants require 15 elements to thrive and develop normally. Each element has a specific function to perform (Kramer and Kozlowski 1960). Carbon, hydrogen, and oxygen make up most of the weight of the plant and are obtained from CO_2 and H_2O. All the other elements are taken up from solution or from the exchange complex in the pot mix. Nitrogen and sulfur are important constituents of proteins. Phosphorus is found in the genetic material of the cell and is important to energy transfer. Calcium pectate is the glue that holds cells together. Magnesium is a constituent of chlorophyll, and iron is a constituent of precursors of chlorophyll. Potassium makes the stomata operate and helps maintain ionic balance. Boron is involved in sugar transport. Zinc, copper, molybdenum, and chlorine activate enzymes.

13.51 Nutrient Deficiency Symptoms

When enough of the essential elements are not present, the plant cannot grow normally. Usually specific, recognizable nutrient deficiency symptoms develop. Although there is much variation in the appearance of the symptoms from one species to another and depending on their severity, the following descriptions taken from Behan (1968), Armson and Sadreika (1974), Hacskaylo and Struthers (1959), and Ingestad (1962), will be useful.

Nitrogen deficiency.—Seedlings are stunted. Older leaves fade and die; younger leaves are pale green to bright yellow. The transition from green to yellow portions of the leaf is abrupt, and there is no extension of chlorosis down the midvein into green areas. Chlorosis extends from the leaf tip toward the base. There may be purple or red spotting of the leaves, especially near the tips. Roots are black and necrotic.

Phosphorus deficiency.—Seedlings are stunted, but leaf size may or may not be reduced. Leaves are dark green turning to purple at needle tips or interveinal areas. Purple areas become brown and die. Appearance of broadleafed species is often varigated. Youngest needle tips of spruce and pine may be gold in color. Roots are sparse and purple to black.

Potassium deficiency.—Stems are short and stout. Youngest leaf tips and interveinal areas turn pale green to light yellow and fade to tan or grey. Transition in color from one part of the leaf to another is diffuse, not abrupt. In the field, uppermost exposed foliage on the largest seedlings is likely to be damaged the worst. Leaves at the tips of lower branches will be most damaged in the greenhouse. Roots are long and threadlike.

Calcium deficiency.—Youngest leaves are stunted, and their tips and interveinal areas may be yellow and faded. Leaf margins are pale yellow and buckled. Terminal and subterminal buds die or fail to elongate. Shoots are deformed and twisted; branching intensifies, resembling insect damage. Roots are black, and tips are dying.

Magnesium deficiency.—Leaf tips are bright yellow to orange, with the color progressing from tip to base along the entire length. Midvein chlorosis extends well into green interveinal tissue at leaf base; transition is diffuse. Cotyledons and lower primary needles of pine remain green.

Sulfur deficiency.—Stems are short and slender, with pale yellowish-green foliage. Leaves are abundant but small. Yellowing is even across veins and interveinal areas. Youngest leaves are most affected; older ones are less so.

Iron deficiency.—Symptoms appear first on the terminal leaves; older foliage is unaffected. New leaves turn pale yellow to almost white in interveinal areas or at needle fascicle bases. Roots are few but long.

Boron deficiency.—Terminal is stunted and forms a rosette. All else appears normal, although some foliage may exhibit interveinal chlorosis.

Deficiencies of Mn, Cu, Zn, Mo, or Cl also cause recognizable symptoms, but they are hard to characterize in a general way. Table 13-2 lists sources of information about deficiency symptoms with colored pictures and descriptions for individual species. Table 13-3 lists additional sources of information with emphasis on micronutrients.

Although specific deficiency symptoms attributable to certain elemental deficiencies have been discussed, it must be kept in mind that deficiency symptoms may be linked to pH levels, which are known to have strong effects on ion availability to plants. Also, high salt concentrations will cause symptoms that are similar to some nutrient deficiencies. The point is that CTS nutrition must be balanced to include proper elemental nutrition, at appropriate pH and electrical conductivity levels, to permit optimum CTS growth and development. All aspects of plant nutrition are interactive.

13.52 Foliar Analysis

When nutrient deficiency symptoms appear, a great deal of damage has already been done. It is best if a developing problem can be diagnosed at a much earlier stage. This can be done by foliar analysis. For each element there is a range of concentration in the leaf which is characteristic of optimum growth. Concentrations in excess of this amount may be toxic, but the margin between optimum and toxic will vary with the particular element. Below optimum nutrient concentrations will result in various degrees of growth retardation, and these will be detected by foliar analysis before the deficiency becomes so acute that specific symptoms are visible and irreversible damage done.

Foliar analysis needs to be calibrated. The levels of deficiency, optimum, and toxicity vary with species and with the growth stage of seedling (van den Driessche 1974). Foliage samples of large, field grown trees are generally taken in the late summer, because there is less variability in nutrient concentration than at other times of the growing season (Smith 1967) (table 13-4). In the greenhouse nursery, this corresponds to the first stage of hardening. However, the nurseryman may need to know the nutrient status of

Table 13-2.—Published color pictures showing symptoms of nutrient deficiencies in forest trees.

Species	Nutrient	Authority
Abies pectinata	N	Hausser (1958)
Chamaecyparis obtusa	P, Mg, Fe, Mn	Tsutsumi (1962)
Cryptomeria japonica	P, K, Ca, Mg, Fe	Tsutsumi (1962)
Juglans nigra	N, P, K, Ca, Mg, S, Fe, Mn, B, Cu, Zn, Mo	Hacskaylo and Struthers (1959)
Larix occidentalis	N, P, K, Ca, Mg	Behan (1968)
Liquidambar styracifula	N, P, K, Ca, Mg, S, Fe, Mn, B, Cu, Zn, Mo	Hacskaylo and Struthers (1959)
Picea abies	N, P, K, Mn	C. O. Tamm and Ingestad (1955)
	N, P, K, Cu	van Goor (1963)
	K, Mg	Ingestad (1960a)
	K	Bjorkman (1953), Themlitz (1958a)
Picea glauca	N, P, K	Armson and Sadreika (1974)
	N, P, K, Mg	Swan (1960)
	K	Heiberg et al. (1954), White and Leaf (1957)
Picea mariana	N, P, K, Mg	Swan (1960)
Pinus banksiana	N, P, K, Mg	Swan (1960)
	P	Armson and Sadreika (1974)
Pinus densiflora	P, K, Mg, Fe	Tsutsumi (1962)
Pinus radiata	N, P, K, Ca, Mg	Purnell (1958)
Pinus resinosa	Fe	Armson and Sadreika (1974)
Pinus strobus	Mg	Heiberg et al. (1954), White and Leaf (1957)
Pinus sylvestris	P, Mg	Moller (1904)
	N, P, K, Mg	van Goor (1963)
	K, Mg	Themlitz (1958a, b)
	Mg	Bruning (1959)
	N, P, K, Ca, Mg, S, Fe	Hacskaylo and Struthers (1959)
Populus deltoides	N, P, K, Ca, Mg, S, Fe, Mn, B, Cu, Zn, Mo	Hacskaylo and Struthers (1959)
Pseudotsuga taxifolia	N, P, K, Cu	van Goor (1963)
Robinia pseudoacacia	K, Mg	Bruning (1959)
	N, P, K, Ca, Mg, S, Fe, Mn, B, Cu, Zn, Mo	Hacskaylo and Struthers (1959)
Tsuga heterophylla	N, P, K, Mg	Swan (1960)

his seedlings at other times of the growing cycle as well. Table 13-5 lists average concentrations of elements found in healthy foliage of 30 woody species (Smith 1967, Powers 1976). Table 13-6 lists sources of information on individual species of nutrient content representing sufficient and deficient amounts and information on optimum nutrient solutions. They should be used only as rough guides until the nurseryman has established his own base line for nutrient content in seedlings growing well versus those that are not. As mentioned in section 13.13 (water sampling), changes in nutrient solution formulation can be attuned to foliar nutrient levels as well as changes in water source chemistry. This requires a highly evolved knowledge of the foliar nutrient content of the species being grown. Hahn reports he is utilizing foliar analysis to define nutrient solutions on a week-to-week basis.[1]

For additional information on mineral nutrition and the use of foliar analysis see Tamm (1964), Lavender (1970), Bates (1970), Commonwealth Bureau of Soils (1969).

13.6 How to Formulate Nutrient Solutions

The recommended method for calculating nutrient concentrate solutions is as follows:

1. Set the target nutrient concentrations and pH, as discussed in sections 13.32 and 13.61.
2. Determine from the water titration table how much acid must be added to meet the target pH.
3. Calculate how much of various chemical compounds must be put into a nutrient concentrate solution to supply the plants with the target quantities of nutrients. The solution must also correct the water pH to the target pH.
4. Decide how the compounds must be mixed and injected into the water system, and how much of the compounds should be kept in a working supply.

The process is more complex than these four steps indicate. To accomplish this requires a knowledge of chemistry and plant physiology beyond that normally expected of forest tree nurserymen. The fol-

Table 13-3.—Published works on nutrient element effects in forest trees.

Species	Element	Field	Laboratory	Deficiency	Toxicity	Growth reduction	Analysis of: Soil	Analysis of: Plant	Method	Authority
Agathis australis	Fe		x	x	x	x		x	Solution culture	Peterson (1962)
"	B		x	x	x	x			"	"
"	Mn		x	x	x	x		x	"	"
"	Zn		x	x	x	x		x	"	"
"	Cu		x		x	x		x	"	"
"	Mo		x	x	x	x		x	"	"
Betula verrucosa	Fe		x	x		x		x	"	Ingestad (1957)
"	B		x	x	x	x		x	"	Ingestad and Jacobson (1962)
"	Mn		x	x				x	"	"
"	Mn	x		x		x		x	Foliar spray	Ingestad (1958)
Carya illinoensis	Mg	x		x			x	x	Fertilizers, foliar spray	Worley et al. (1975)
Eucalyptus spp.	B	x		x		x		x	"	Savory (1962)
Fagus sylvatica	Fe	x		x		x	x	x	Foliar spray, stem injection	Olsen (1943)
Juglans regia	Mn	x		x						Braucher and Southwick (1941)
Larix decidua, *Picea abies*	Cu		x	x		x			Soil culture	Rademacher (1940)
Larix laricina	All	x							—	Tilton (1977)
Liquidambar styraciflua	N,P,K	x				x			Fertilizers	Blackmon (1974)
Liriodendron tulipifera	N,P,K	x				x			"	"
18 Minnesota tree spp.	All	x						x	—	Henry (1973)
Picea abies	Fe		x	x		x		x	Solution culture	Ingestad (1959)
"	Mn	x		x		x		x	Foliar spray, stem injection	Ingestad (1958)
"	Mn	x				x		x	—	Madgwick (1967)
Picea glauca	N,P		x			x			Solution culture	Etter (1971)
"	Fe,Mn	x				x		x	Fertilizers	Iyer and Wilde (1973)
Picea mariana	Fe,Mn	x	x	x	x			x	Solution culture	Morrison and Armson (1968)
Picea rubra	All	x						x	—	Safford and Young (1968)
Picea sitchensis	Cu	x		x		x		x	Fertilizers, foliar spray	Benzian and Warren (1956)
Pinus banksiana	Ca,Mg	x		x		x	x	x	Fertilizers	Sadreika (1969)
"	Mn,Fe	x	x	x	x			x	Solution culture	Morrison and Armson (1968)
Pinus contorta	N,P		x			x			"	Etter (1971)
Pinus elliottii	N,P,K	x				x			Fertilizers	Shoulders (1974)
Pinus ponderosa	N,P,K		x			x			Pot test	Vlamis et al. (1957)
Pinus radiata	N,P,K							x	Fertilizers	Burdon (1976)
"	Ca,Mg	x				x				
Pinus radiata	B		x	x		x			Solution culture	Smith (1943)
"	Mn		x	x		x			"	"
"	Zn	x		x					Foliar spray	Knight (1976)
"	Zn		x	x		x			Solution culture	Smith (1943)
"	Cu		x	x		x			"	"
"	Mo		x	x					"	"
Pinus radiata, P. patula	B	x		x		x		x	Fertilizers, foliar spray	Vail et al. (1961)
Pinus radiata, P. pinaster	B	x		x		x		x	"	Will et al. (1963)
"	Zn	x		x		x		x	Foliar spray, stem treatments	Stoate (1950)
Pinus radiata, P. taeda	B		x	x	x	x			Solution culture	Ludbrook (1940, 1942)
Pinus resinosa	Fe,Mn							x	Fertilizer	Iver and Wilde (1973)
	Zn,Cu	x				x			Foliar spray	Korstian et al. (1921)
Pinus spp.	Fe	x		x		x		x	Solution culture	Ingestad (1960b)
Pinus sylvestris	Fe		x	x		x			Soil culture	Rademacher (1940)
"	Cu		x	x		x			Fertilizers	Schmidtling (1975)

Table 13-3.—Continued.

Species	Element	Field	Laboratory	Deficiency	Toxicity	Growth reduction	Analysis of: Soil	Analysis of: Plant	Method	Authority
Pinus taeda	N,P	x			x		x	x	"	Wells and Crutchfield (1969)
"	P	x				x			"	Shoulders (1974)
"	N,P,K	x				x			Solution culture	Lyle (1969)
"	All		x	x		x			Sand culture	Wilson (1953)
Pinus taeda, P. echinata	Zn		x	x		x			Fertilizers	Blackmon (1974)
Platanus occidentalis	N,P,K	x				x			"	"
Populus deltoides	N,P,K	x				x		x	Fertilizers, foliar spray	Benzian and Warren (1957)
Populus robusta	Cu			x		x			Stem injection	Starr (1940)
Populus spp.	Fe	x		x			x	x	Fertilizers	van den Driessche (1969b)
Pseudotsuga menziesii	N,P,K, Mg	x				x			"	van Goor (1963)
"	Cu	x		x					Foliar spray	Korstian et al. (1921)
Pseudotsuga taxifolia	Fe	x		x		x			Stem injection	Pirone (1940)
Quercus palustris	Fe	x		x					Fertilizers, leaf treatment	Hacskaylo and Struthers (1959)
Quercus palustris	Fe	x		x					Fertilizers	Blackmon (1974)
Quercus spp.	N,P,K	x				x				
"	N,P,K, Ca,Mg, Fe,Mn	x						x	—	Auchmoody (1972)
Thuja plicata	Fe		x	x		x		x	Solution and sand culture	Walker et al. (1955)
"	B		x	x		x		x	"	"
Tsuga canadensis	K,Ca		x	x		x			Solution culture	Olson et al. (1959)

Table 13-4.—Average monthly foliar mineral element content in percent of dry weight for 14 deciduous woody plants (Smith 1967).

Month	N	P	K	Ca
May	4.25	0.61	1.61	0.95
June	2.63	0.31	1.22	1.26
July	2.30	0.26	1.25	1.32
August	2.16	0.32	1.46	2.05
September	2.22	0.28	1.09	2.16
October	2.14	0.27	1.14	2.20

lowing sections provide a "cookbook" procedure for developing a tailored nutrient solution with minimal technical complication.

13.61 Desirable Concentrations of Nutrient Elements

This has been studied by quite a number of workers, but the results vary in their usefulness to nurserymen. In many experiments, the best treatment was at one of the scale of values tested. So, it cannot be said that the best treatment found is optimum. The concentration of one element frequently affects the optimum concentration of another. So, attempts to optimize concentrations of all of them become involved in very large factorial experiments. Few really complete optimizations have been attempted. Another complication is the variation between, and even within, species. Table 13-7 lists concentrations of nutrient ions found to be favorable and, in some cases optimum, according to species. Fortunately, the range of concentration which is adequate for normal growth is quite broad, and the nurseryman can do all right with whatever intelligent choice he makes, pending the development of more precise information.

13.62 Chemicals Used to Supply Nutrients

A number of chemical compounds can be used to supply the nutrients elements and acidity. Often there is a choice of several almost equally suitable compounds (table 13-8). A number of these compounds are acids. Table 13-9 shows the safety hazards and cost of the four most commonly available acids.

Most water supplies will need acidification in order for the water to provide nutrient solutions suitable for optimizing tree growth. The amount of acid to do this is found by reading the titration table for the water at the site. The question then becomes which acid to use. For acidification of water in a bare-root nursery, the cost of the acid may dictate use of sulfuric acid, the cheapest common acid. However, in the greenhouse nursery the volume of water used is only 10% of that used in a bare-root operation for the same number of trees, so the most expensive acids can be used economically.

Table 13-5.—Average foliar mineral element concentrations in percent or parts per million oven dry weight from monthly sampling May through October (Smith 1967, Powers 1976).

	Percent					ppm						
	N	P	K	Ca	Mg	Mn	Fe	B	Cu	Mo	Zn	Al
Average for deciduous plants[1]	2.56	.33	1.27	1.80	.39	222	227	37	21	3.60	52	463
Broadleaf evergreens[2]	2.16	.27	1.09	1.49	.29	300	338	39	23	3.00	66	469
Narrowleaf evergreens[3]	2.18	.33	1.05	.89	.19	197	189	34	18	1.66	56	279

[1]*Species sampled:* *Betula pendula*, *Cornus florida*, *Crataegus phaenopyrum*, *Liquidambar styraciflua*, *Prunus subhirtella 'Pendula'*, *Pyrus calleryana 'Bradford'*, *Sorbus aucuparia*, *Rhododendron 'Cascade'*, *Chaenomeles speciosa*, *Cotoneaster apiculata*, *Euonymis alatus 'Compacta'*, *Syringa vulgaris 'Edith Cavell'*, *Viburnum plicatum*

[2]*Species sampled:* *Euonymus fortunei vegetus*, *Hedera helix*, *Ilex crenata 'Convexa'*, *Ilex opaca*, *Leucothe catesbei*, *Pieris japonica*, *Pyracantha coccinea 'Lalandi'*, *Rhododendron 'Nova Zembla'*, *Vinca minor*

[3]*Species sampled:* *Juniperus chinensis 'Pfitzeriana'*, *Picea omorika*, *Pinus strobus*, *Taxus media 'Browni'*, *Taxus media 'Hicksi'*, *Thuja occidentalis 'Pyramidalis'*, *Tsuga canadensis*

Table 13-6.—Sources of information on nutrient element content by foliar analysis and optimum nutrient solutions for individual species.

Species	Elements	Authority
Betula papyrifera	N, P, K	Bjorkbom (1973 a & b)
Betula verricosa	N, P, K, Ca, Mg, S	Ingestad (1962)
"	N, P, K, Ca, Mg, S	Ingestad (1970, 1971)
Picea abies	N, P, K, Ca, Mg, S	Touzet and Heinrich (1970)
"	N, P, K, Ca, Mg, S	Ingestad (1962)
Picea glauca	N, P, K, Ca, Mg, S	Hocking (1971)
Picea mariana	N, P, K, Ca, Mg	Stewart and Swan (1970)
Picea pungens	N, P	Esau (1970)
Picea sitchensis	N, P, K, Ca, Mg	van den Driessche (1969a)
Pinus banksiana	N, P, K, Ca, Mg	Stewart and Swan (1970)
Pinus contorta	N, P, K, Ca, Mg, S	Hocking (1971)
Pinus densiflora	N, P, K	Kawada (1968)
Pinus larico	N, P, K, Ca, Mg, S	Touzet and Heinrich (1970)
Pinus pinaster	N, P, K, Ca, Mg, S	Touzet and Heinrich (1970)
Pinus strobus	N, P	Lister et al. (1968)
"	N, P, K, Ca, Mg, S	Touzet and Heinrich (1970)
"	All	Schomaker (1969)
Pinus sylvestris	N, P, K, Ca, Mg, S	Ingestad (1962)
Populus deltoides	N, P, K	Bonner and Broadfoot (1967)
"	N, K	Baker and Randall (1975)
"	N, P, K, Ca, Mg	Phares (1966)
Populus spp.	N, P, K, Ca, Mg	Einspahr (1971)
"	N, P, K, Ca, Mg	Garbaye (1972)
Pseudotsuga menziesii	N, P, K, Ca, Mg	van den Driessche (1969a)
"	N, P, K, Ca, Mg, S	Touzet and Heinrich (1969)
"	All	Krueger (1967)
Vaccinium myrtillus	N, P, K, Ca, Mg	Ingestad (1973)
Vaccinium vitis	N, P, K, Ca, Mg	"

When a considerable amount of acid is used, it should contribute nutrient ions that are needed. Chlorine (as Cl^-) is needed in very small quantities, and this is already present in the water or present as impurities in the other fertilizer chemicals used. Thus, it makes little sense to use hydrochloric acid. It is included in table 13-9 for completeness, but is never recommended. Many water supplies will also contain enough sulfur (as $SO_4^=$). In these cases, sulfuric acid contributes additional salt, which is not beneficial. Lower cost may still dictate its use, however, especially when the water is acidified separately and a commercial fertilizer mix is used.

Phosphoric and nitric acids are recommended because they always contribute needed nutrient ions. Whenever possible, phosphoric acid should be used, because it is the safest of the four common acids to handle, especially by personnel with limited training (Jaramillo and Owston 1977). It does not react violently with water, there are no toxic fumes, it is not an oxidizer, and it does the least damage if it touches the skin. Its major drawback is relatively high cost.

Table 13-7.—Optimum nutrient solutions for various species. Blanks indicate elements not tested for optimality; not lack of the element.

Species	Nutrient element concentration (ppm)													Authority
	N	P	K	Ca	Mg	S	Fe	B	Mn	Cl	Zn	Cu	Mo	
Barley and tomatoes	210	31	240	170	48	64	4	0.50	0.50	4	0.05	0.02	0.010	Hoagland and Arnon (1938)
Betula papyrifera	400	50	35	120	48	64	3	0.50	0.50		0.06	0.06	0.009	Bjorkbom (1973b)
Betula verricosa	140	100	175	120	48	64	2.80	0.50	0.50		0.06	0.06	0.009	Ingestad (1962)
Picea abies	50	10	50	40	15	20	0.93	0.17	0.17		0.02	0.02	0.003	Ingestad (1962)
Picea glauca	112	31	156	80	48	150								Hocking (1971)
Picea mariana	100+	10+	10+	40+	10+									Stewart and Swan (1970)
Picea mariana									0.10					Morrison and Armson (1968)
Picea sitkensis	50	30+	20											van den Driessche (1969a)
Pinus banksiana	100+	10+	10+	40+	10+									Stewart and Swan (1970)
Pinus banksiana									0.10					Morrison and Armson (1968)
Pinus contorta	112	31	156	80	48	150								Hocking (1971)
Pinus strobus	280	93	273	200	73	96								Schomaker (1969)
Pinus sylvestris	50	20	50	40	15	20	0.93	0.17	0.17		0.02	0.02	0.003	Ingestad (1962)
Populus deltoides	100	75	100											Bonner and Broadfoot (1967)
Populus deltoides	100	18	120	202+	134+									Phares (1966)
Populus tremuloides	105	22	75	46	21									Einspahr (1971)
Pseudotsuga menziesii	100	30+	30											van den Driessche (1969a)

Nitric acid is the second choice. It is usually used where more acidification is required beyond the amount of phosphoric acid required to supply needed phosphorus. Sufficient nitric acid is added to achieve the target pH, but needed nitrogen beyond this point is normally provided by other compounds, such as ammonium nitrate, ammonium sulfate, ammonium phosphate, calcium nitrate, or potassium nitrate.

Potassium can be supplied as potassium nitrate, phosphate, sulfate, or carbonate. Potassium chloride should not be used for the same reason that hydrochloric acid is not used for acidification: it increases the salt concentration by adding ions that are not needed. Potassium carbonate is used to raise the pH and introduce potassium without adding other anions. Addition of potassium phosphate alters pH of the solution, and this usually is adjusted with acids.

Magnesium can be supplied as magnesium sulfate or as dolomite, which is calcium magnesium carbonate ($CaCO_3MgCO_3$). Dolomite raises the pH of the water and is not soluble, except in acid. Therefore, magnesium is usually supplied as magnesium sulfate, even if there is already a surplus of sulfate in the solution.

The choice of compounds containing micronutrients is simpler than for macronutrients, because only one nutrient element is dealt with per compound. Iron is supplied as a chelate or as ferrous sulfate. The chelate is preferred, because it stays in solution better, and thus is more available to the plant. Chelates containing different percentages of iron are on the market, and these may be used interchangably.

Potassium chloride is used to supply a small amount of chlorine, if needed. This is not likely to be needed, because fertilizer grade chemicals commonly contain chlorides as impurities.

Boron is supplied as boric acid. Borax (sodium tetraborate) can also be used, but it is alkaline in reaction, and there is no need to add sodium.

Zinc, copper, and manganese are supplied as sulfates, because they are soluble but not deliquescent, stable, and readily available.

Molybdenum is added as ammonium molybdate for the same reasons, but may also be added as molybdic acid or sodium molybdate.

13.63 Proportions of the Ions in the Solution

Plants take up some ions rapidly and other ions more slowly. When there is not a balance in the rate of uptake between nutrient anions and cations, the pH of the medium changes. When more anions than cations are taken up, the pH rises. When the reverse is true, it falls. Therefore, it is desirable to balance the rapidity of cation and anion uptake so that the

Table 13-8.—Nutrient element content of common fertilizer chemicals.

Compound	(NO_3) N	(NH_4) N	P	K	S	Ca	Mg	M.W.
	Fraction of element in compound							
KNO_3	0.139			0.386				101
NH_4NO_3	0.175	0.175						80
$Ca(NO_3)_2 \cdot 4H_2O$	0.119					0.169		236
$(NH_4)_2HPO_4$		0.212	0.235					132
$(NH_4)_2SO_4$		0.212			0.242			132
HNO_3	0.222							63
H_3PO_4			0.316					98
KH_2PO_4			0.228	0.287				136
$Ca(H_2PO_4)_2 \cdot H_2O$			0.246			0.159		252
K_2CO_3				0.565				138
$CaCO_3 \cdot MgCO_3$						0.217	0.130	184
$MgSO_4 \cdot 7H_2O$					0.130		0.097	246
K_2SO_4				0.448	0.184			174
H_2SO_4					0.326			98
P_2O_5			0.437					142
K_2O				0.830				94
NO_3^-	0.226							62
NH_4^+		0.778						18
$SO_4^=$					0.333			96

Compound	Fe	Cl	B	Mn	Zn	Cu	Mo	M.W.
	Fraction of Element in Compound							
$FeSO_4 \cdot 7H_2O$	0.231							278
Fe Chelate (10%)	0.100							—
KCl		0.480						75
H_3BO_3			0.177					63
$MnSO_4 \cdot 4H_2O$				0.247				223
$ZnSO_4$					0.404			161
$CuSO_4 \cdot 5H_2O$						0.256		250
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$							0.544	1,212

Table 13-9.—Characteristics of the four common mineral acids.

Acid	Cost	Reaction with water	Toxic fumes	Contact Hazard: Concentrated	Contact Hazard: Dilute	Strong oxidizer	Nutrient element needed
Sulfuric	low	violent	no	chars flesh	dissolves clothes	yes	yes
Nitric	moderate	some heating	yes	dissolves flesh	stains skin yellow	yes	yes
Phosphoric	high	none	no	stings in cuts	none	no	yes
Hydrochloric	moderate	none	yes	stings	none	no	no

pH remains stable. The most rapidly absorbed nutrient ions are potassium, ammonium, and nitrate. It is possible to achieve stability without changing the proportion of elements in solution by adjusting the ratio of ammonium nitrogen to nitrate nitrogen in the fertilizer solution. For those tree species that have been studied, a favorable ratio is about 30% N as NH_4^+ and 70% N as NO_3^- (Ingestad 1970, 1971).

Occasionally, there may be so much of one element in the water that the uptake of the other elements is suppressed. For instance, there is competition between molybdenum and manganese (Matkin 1976), between iron and the other heavy metals (Daniels and Struckmeyer 1973, Beauchamp and Rossi 1972, Rogers 1973, Agarwala et al. 1977), between zinc and manganese (Singh and Steenberg 1974), and between calcium and magnesium (Phares 1966). Generally, the ratio of calcium to magnesium should be kept between 2:1 and 6:1. Another rule is: if the concentration of one ion is three to five times the recommended concentration, it may be necessary to increase the concentration of the competing ion to enable it to be taken up in sufficient amounts.

Water test results should be supplied for the specified ions in parts per million (ppm) or mg/l, which is the same (section 13.11). The optimum nutrient concentration targets provided here are in ppm of the solution.

The titration table provides the milliequivalents (meq) of strong acid to bring about a certain change in the pH of the test water. For nitric acid, 1 meq equals the gram molecular weight (MW) (63) in mg/l.

For sulfuric acid, 1 meq equals half the MW ($98 \div 2 = 49$ mg/l). However, phosphoric acid is a weak acid and the acidity released is a function of pH. Nutrient solutions are rarely formulated to be below pH 4 or above pH 7.5. For nutrient solutions between pH 4 and 5, it can be assumed that 1 MW yields 1 equivalent of phosphoric acid. Between pH 5.0 and 7.5, 1 MW yields between 1 and 2 equivalents. Appropriate factors can be interpolated from table 13-10.

13.64 Nutrient Solution Formulation: An Example

To formulate nutrient solutions, the nurseryman must first have a chemical analysis and titration table for his water supply (section 13.1). As examples an analysis and titration table for Bottineau, N. Dak. city water is given in table 13-11 and table 13-12, respectively. Next, select target concentrations for each nutrient ion and a target pH for the nutrient solution. These may vary according to the crop to be grown, the experience of the nurseryman, and the nutrient research information available. The targets used successfully by Tinus in western conifer culture are listed in table 13-13. The chemical compounds to be selected and the quantity needed to produce the target concentrations of nutrient ions are outlined below. Figure 13-2 is provided as a worksheet. The following example is for preparation of the Tinus high N solution formulated using Bottineau water.

Table 13-10.—Equivalents of acid per gram molecular weight of phosphoric acid (H_3PO_4) as a function of pH.

pH	Acid equivalents
5.0	1.05
5.4	1.1
5.7	1.2
6.0	1.3
6.3	1.5
6.6	1.7
6.9	1.8
7.2	1.9
7.6	1.95

Table 13-11.—Analysis of Bottineau, N. Dak. city water on July 27, 1970.

	(ppm)
Total solids by ion summation	1,245
Total alkalinity as $CaCO_3$	475
pH	7.5
Iron (Fe)	0.20
Manganese (Mn)	1.37
Calcium (Ca)	212
Magnesium (Mg)	33
Chloride (Cl)	1
Sulfate (SO_4)	366
Nitrate (NO_3)	1
Potassium (K)	0
Sodium (Na)	60

Table 13-12.—Titration table of Bottineau, N. Dak. city water.

pH	Titrant used meq/liter	pH	Titrant used meq/liter
7.1	0.00	5.9	7.22
7.0	0.50	5.8	7.77
6.9	0.90	5.7	8.10
6.8	1.40	5.6	8.42
6.7	1.90	5.5	8.65
6.6	2.53	5.4	8.96
6.5	3.10	5.3	9.14
6.4	3.82	5.2	9.28
6.3	4.59	5.1	9.40
6.2	5.61	5.0	9.52
6.1	6.13	4.9	9.58
6.0	6.68		

Table 13-13.—Target nutrient ion concentrations successfully used for western conifers by Tinus.

Element	Desired concentration (ppm) High N	Low N, High PK
N as NO_3^-	156	12
N as NH_4^+	67	8
P	27	60
K	155	155
Ca	60	60
Mg	40	40
S	63	63
Fe	4	4
Cl	4	4
Mn	0.5	0.5
B	0.5	0.5
Zn	0.05	0.05
Cu	0.02	0.02
Mo	0.01	0.01
pH	5.5	5.5

To begin, fill in the target concentrations on lines 1 and 11 of the worksheet. Next, fill in element concentrations from the water analysis on lines 2 and 12. Notice that the water analysis reports sulfate ($SO_4^=$) and not sulfur (S). Look in table 13-8 for the proportion of sulfur in sulfate. Then (ppm $SO_4^=$) = (proportion of surfur in sulfate) (ppm S).

$$336 \times 0.333 = 122$$

Record 122 in line 2, column 6 of the worksheet. (Notice that this water is quite salty. In fact, if the water were any saltier, it would be good reason to locate the nursery elsewhere. See section 4.15 on water tests before site selection).

On the worksheet, subtract line 2 from 1 and 12 from 11, and write the difference in lines 3 and 13 respectively. Notice that the water already contains more than enough sulfur, calcium, and manganese. It will not be necessary to add these to the nutrient solution. The form should now look like figure 13-3.

Most water supplies will need acidification. The amount of acid needed to reach the desired pH can be obtained from the titration table of the water supply. Table 13-12 shows a titration table for Bottineau, N. Dak. city water supply taken during December. The sample composition will vary somewhat with

column

Line 1	2	3	4	5	6	7	8	9	10	11
	Nutrient Elements (ppm)							Total	Stock soln. x ____	Cpd. com-pat.
	(NO_3) N	(NH_4) N	P	K	S	Ca	Mg	Cpd mg/l		
1. Target Conc.										
2. Water anal.										
3. Net to Add										
Cpds. used:	–	–	–	–	–	–	–	–	–	–
4.										
5.										
6.										
7.										
8.										
9.										
10. Total										
	Fe	Cl	B	Mn	Zn	Cu	Mo		x____	
11. Target Conc.										
12. Water anal.										
13. Net to Add										
14.										
15.										
16.										
17.										
18.										
19.										
20.										

Figure 13-2.—Worksheet for calculation of fertilizer stock solutions.

					column					
Line 1	2	3	4	5	6	7	8	9	10	11
	Nutrient Elements (ppm)							Total	Stock soln. x ____	Cpd. com-pat.
	(NO_3) N	(NH_4) N	P	K	S	Ca	Mg	Cpd mg/l		
1. Target Conc.	156	67	27	155	63	60	48			
2. Water anal.	0	0	0	0	122	212	33			
3. Net to Add	156	67	27	155	0	0	15			
Cpds. used:	–	–	–	–	–	–	–	–	–	–
4.										
5.										
6.										
7.										
8.										
9.										
10. Total										
	Fe	Cl	B	Mn	Zn	Cu	Mo		x____	
11. Target Conc.	4	4	0.5	0.5	0.05	0.02	0.01			
12. Water anal.	0.2	1	0	1.4	0	0	0			
13. Net to Add	3.8	3	0.5	0	0.05	0.02	0.01			
14.										
15.										
16.										
17.										
18.										
19.										
20.										

Figure 13-3.—Worksheet for calculation of fertilizer stock solutions after calculation of net elements to be added.

the season. The nurseryman should be aware of this seasonal variation and be prepared to adjust the amount of acid accordingly. This particular water supply is high in carbonates, which is why it requires so much acid to lower the pH. Most water supplies require less acid. If the target pH is set at 5.5, by reading the titration table we find that 8.65 meq of acid will have to be added to each liter of this water.

Next determine what acid to use (section 13.62). Phosphorus is needed, so, use phosphoric acid first. How much phosphoric acid is needed to supply 27 ppm P? Table 13-8 lists the fractions of nutrient element in a variety of compounds which might be used to supply it. Then:

$$\frac{\text{Amount of Element}}{\text{Fraction of Element in Compound}} = \text{Amount of Compound}$$

$$\frac{27 \text{ ppm P}}{0.316 \text{ P in } H_3PO_4} = 85 \text{ ppm } H_3PO_4$$

On line 4, record H_3PO_4 in column 1, 27 ppm in column 4 under element P, and 85 ppm in column 9 under total compound. To find if 85 ppm of H_3PO_4 is enough acid, it must be converted in milliequivalents of acid:

$$\frac{\text{MW of acid}}{(\text{meq per MW}) \times (\text{amt. of acid})} = \text{acid equivalent}$$

From table 13-8 MW of H_3PO_4 = 98
From table 13-10 at pH 5.5, meq per MW = 1.13
Then:

$$\frac{98}{(1.13) \times (85)} = 1.0 \text{ acid equivalents represented by 85 ppm } H_3PO_4 \text{ at pH 5.5}$$

Since 8.6 meq must be neutralized, then 8.6 − 1.0 = 7.6 more meq/l that must be neutralized with nitric acid.

The molecular weight of nitric acid is 63, so,

(meq/l) x (MW) = mg/l of acid
(7.6) x (63) = 479 mg/l nitric acid to be added.

This completes the acid required to lower the pH to 5.5 and to supply 27 ppm P. The nitric acid also adds nitrate nitrogen. The amount is found by multiplying the amount of the acid used by the fraction of N in it from table 13-8. Therefore:

(479) x (0.222) = 106 ppm NO_3 nitrogen.

The figure for the nitric acid should now be added to the worksheet. On line 5, enter HNO_3 in column 1, 106 in column 2, and 479 in column 9.

Notice that the nitrogen requirement for both nitrate and ammonium nitrogen is not yet fulfilled, so next, seek a compound to fill that need and perhaps another macronutrient. A lot of potassium is needed. Either potassium nitrate, phosphate, sulfate, or carbonate could be used, but for reasons discussed in section 13.63 and because of the need for more nitrogen, potassium nitrate (KNO_3) is chosen to supply all of the potassium. On line 6, enter KNO_3 in column 1 and 155 in column 5.
Then:

$$KNO_3 \text{ required} = \frac{\text{amount of K needed}}{\text{fraction of K in } KNO_3}$$

$$= \frac{155}{0.386} = 401 \text{ ppm}$$

Enter 401 in column 9 on line 6.

The next question is how much nitrate N did the KNO_3 supply.

(amount of KNO_3) (fraction of N in KNO_3)
= (amount of N) 401 x 0.139 = 56

Record 56 on line 6, column 2. Note there is now a little more nitrate than the target (162 ppm versus 156 ppm), but this is inconsequential.

Magnesium is most conveniently supplied as a sulfate, even though there is a surplus of sulfate. To supply 15 ppm Mg, we need:

$$\frac{15}{0.097} = 154 \text{ ppm } MgSO_4$$

(where 0.097 is the percentage of Mg in $MgSO_4$ from table 13-8).

On line 7, record $MgSO_4$ in column 1, 15 in column 8, and 154 in column 9. The $MgSO_4$ is also supplying sulfur, so,

(154 ppm $MgSO_4$) x 0.130 = 20 ppm S
(0.130 is the fraction of S in $MgSO_4$ from table 13-8).

Enter 20 on line 7, column 6 of the worksheet.

As discussed in section 13.63, the proportions of nitrogen types in the nutrient solution should be about 30% N as NH_4^+ and 70% N as NO_3^-. In this example, an ammonium salt is needed. Ammonium phosphate, sulfate, or nitrate may be used. The phosphate will affect the pH, and there is already enough P present. There is already a surplus of sulfate, and there will be a surplus of nitrate N, if ammonium nitrate is selected. No choice is clearly best. A decision is made to accept a moderate surplus of nitrate rather than add to an already large surplus of sulfate or throw off pH control. To yield 67 ppm of ammonium N we need:

$$\frac{67}{0.175} = 383 \text{ mg/l of } NH_4NO_3$$

(where 0.175 is the percentage of NH_4 nitrogen is ammonium nitrate, from table 13-8). This salt also yields nitrate N in the amount: 383 x 0.175 = 67 ppm NO_3 in nitrogen.

On line 8 enter NH_4NO_3 in column 1, 67 in both columns 2 and 3, and 383 in column 9 on the worksheet. This completes the formulation of the macronutrients.

The choice of salts to satisfy micronutrient needs is simpler, because we deal with only one nutrient element per salt. There are few enough accompanying ions that they may be neglected, because they contribute little to either salt buildup or amount of other mineral nutrients.

Iron is usually supplied as a chelate (section 13.62). Chelates come in different percentages of iron. To obtain the amount of chelate to use, divide the ppm iron desired by the fraction of the iron in the compound. For this example, we use a 10% compound:

$$\frac{3.8}{0.10} = 38 \text{ ppm chelate}$$

On line 14, enter Fe chelate (10%) in column 1, 3.8 in column 2, and 38 in column 9 on the worksheet.

Potassium chloride is used to supply the small amount of chlorine required. Boron is supplied as boric acid. Zinc and copper are supplied as sulfates. Molybdenum is added as ammonium molybdate. The amount of compound required to give the desired concentration of these micronutrient elements is calculated as for iron, using the same formula and table 13-8, and the information is recorded on the worksheet which should now look like figure 13-4.

13.65 Nutrient Concentrate Formulation

In column 9 of figure 13-4, the concentrations of compounds required to give the desired nutrient solution are recorded. This is what the seedlings will receive, but the nutrients will be injected into the irrigation water from concentrated or stock solutions. To determine the concentration of salts in the stock solutions, the dilution factor or injection ratio must be known. For the macronutrients, this normally ranges from 100:1 to 400:1. At ratios above 400:1, solubility becomes a problem, and the salts may not dissolve completely. At ratios below 100:1, the volume of stock solution required may become a nuisance to make up and store. Anything in between these extremes is usually satisfactory. There may not be a choice if the injector on hand is fixed ratio type.

For this example, 200:1 was picked for the macronutrients. Column 9 figures are concentrations in milligrams per liter. Multiply each macronutrient value by the dilution factor (200) and divide by 1,000. Enter the values in column 10, which is the stock solution concentration in grams per liter.

Continue the procedure for the micronutrients. If all nutrients are to be combined into a single stock solution, then the dilution ratio must be the same for all. If the micronutrients are in a separate stock solution from the macronutrients, they may have a dilution factor in excess of 1,000:1. Here, the upper limit is not the solubility of the salts, because there is so little of them, but the ability of the injector to operate at those rates. The advantage of a more concentrated solution is that there is less of it to handle, and it is usually made up less often.

If we pick 1,000:1, then the arithmetic is simple. Multiplying by the dilution factor (1,000) and dividing by 1,000 gives the micronutrient stock solution values in grams per liter (column 10).

13.66 Nutrient Salt Compatibility

To determine if the nutrient salts must be in several different nutrient solutions and how to divide them, consult table 13-14. For each salt or acid selected, follow across the row to see with which salts it is not compatible. In the example, notice first that at least one stock solution will be strongly acid because of the nitric and phosphoric acids in it. All of the macronutrient compounds are stable and soluble in strong acid, so, label them "A" in column 11. All of the micronutrients are also soluble in acid, but the iron chelate will be destroyed. It must, therefore, be in a separate solution. Label it "B" in column 11. That means there must be at least two stock solutions. Careful examination of table 13-14 shows no other incompatibilities, so two stock solutions are all that is needed. The rest of the micronutrients could go in either solution (label them AB), but because they are needed in such small amounts, it is more convenient to put them in with the iron. To make sure the copper and zinc stay in solution in the presence of boric acid, add 5 ml/l of nitric acid. At a dilution factor of 1,000:1, this will add a negligible amount of nitrate to the nutrient solution. The worksheet is now complete and should look like figure 13-5.

13.67 The Nutrient Recipe and Mixing

The nutrient recipe is the result of the size of the batch of nutrient concentrate solution the nurseryman decides to make up at each mixing. In our example, suppose we want 100 l for the acid solution, then the figures for each compound in the grams per

Line 1	2	3	4	5	6	7	8	9	10	11
	Nutrient Elements (ppm)							Total	Stock soln. x ____	Cpd. com-pat.
	(NO_3) N	(NH_4) N	P	K	S	Ca	Mg	Cpd mg/l		
1. Target Conc.	156	67	27	155	63	60	48			
2. Water anal.	0	0	0	0	122	212	33			
3. Net to Add	156	67	27	155	0	0	15			
Cpds. used:	–	–	–	–	–	–	–	–	–	–
4. H_3PO_4			27					85		
5. HNO_3	106							479		
6. KNO_3	56			155				401		
7. $MgSO_4$				20			15	154		
8. NH_4NO_3	67	67						383		
9.										
10. Total	229	67	27	155	142	212	48			
	Fe	Cl	B	Mn	Zn	Cu	Mo		x____	
11. Target Conc.	4	4	0.5	0.5	0.05	0.02	0.01			
12. Water anal.	0.2	1	0	1.4	0	0	0			
13. Net to Add	3.8	3	0.5	0	0.05	0.02	0.01			
14. Fe chelate	3.8							38		
15. KCl		3						6		
16. H_3BO_3			0.5					2.8		
17. $ZnSO_4$					0.05			0.123		
18. $CuSO_4$						0.02		0.078		
19. $(NH_4)_6Mo_7O_{24}$							0.01	0.018		
20.										

Figure 13-4.—Worksheet for calculation of fertilizer stock solutions after selection of compounds.

column

Line 1	2	3	4	5	6	7	8	9	10	11
	Nutrient Elements (ppm)							Total	Stock soln. x 200	Cpd. com- pat.
	(NO_3) N	(NH_4) N	P	K	S	Ca	Mg	Cpd mg/l		
1. Target Conc.	156	67	27	155	63	60	48			
2. Water anal.	0	0	0	0	122	212	33			
3. Net to Add	156	67	27	155	0	0	15	mg/l or ppm	g/l	
Cpds. used:	–	–	–	–	–	–	–	–	–	–
4. H_3PO_4			27					85	17.0	A
5. HNO_3	106							479	95.8	A
6. KNO_3	56			155				401	80.2	A
7. $MgSO_4$					20		15	154	30.8	A
8. NH_4NO_3	67	67						383	76.6	A
9.										
10. Total	229	67	27	155	142	212	48			
	Fe	Cl	B	Mn	Zn	Cu	Mo		x 1000	
11. Target Conc.	4	4	0.5	0.5	0.05	0.02	0.01			
12. Water anal.	0.2	1	0	1.4	0	0	0			
13. Net to Add	3.8	3	0.5	0	0.05	0.02	0.01	ppm	g/l	
14. Fe chelate	3.8							38	38	B
15. KCl		3						6	6	AB
16. H_3BO_3			0.5					2.8	2.8	AB
17. $ZnSO_4$					0.05			0.123	0.123	AB
18. $CuSO_4$						0.02		0.078	0.078	AB
19. $(NH_4)_6Mo_7O_{24}$							0.01	0.018	0.018	AB
20.										

Figure 13-5.—Complete worksheet for calculation of fertilizer stock solutions.

Table 13-14.—Compatibility of nutrient compounds in concentrated stock solutions. An "X" at the intersection of a row and a column means the compounds are not compatible. "A" means soluble in strongly acid solutions only. "N" means stable in neutral or only slightly acid solutions, but not strong acid. "S" indicates strong heating and effervescence when the two are combined. Mixing should be done with great caution. Where there is no letter at the intersection point, the compounds are compatible.

Compounds	Compounds: KNO_3	NH_4NO_3	$Ca(NO_3)_2 \cdot 4H_2O$	$(NH_4)_2HPO_4$	$(NH_4)_2SO_4$	HNO_3	H_3PO_4	KH_2PO_4	$Ca(H_2PO_4)_2 \cdot H_2O$	K_2CO_3	$CaCO_3 \cdot MgCO_3$	$MgSO_4 \cdot 7H_2O$	K_2SO_4	H_2SO_4	$FeSO_4 \cdot 7H_2O$	Fe chelate	KCl	H_3BO_3	$MnSO_4 \cdot 4H_2O$	$ZnSO_4$	$CaSO_4 \cdot 5H_2O$
KNO_3	—																				
NH_4NO_3		—																			
$Ca(NO_3)_2 \cdot 4H_2O$			—																		
$(NH_4)_2HPO_4$			A	—																	
$(NH_4)_2SO_4$					—																
HNO_3						—															
H_3PO_4			A				—														
KH_2PO_4			A					—													
$Ca(H_2PO_4)_2 \cdot H_2O$				A	X				—												
K_2CO_3			X			S	S		X	—											
$CaCO_3 \cdot MgCO_3$	A	A	A	A	A	A	A	A	A	A	—										
$MgSO_4 \cdot 7H_2O$			X	A					A		A	—									
K_2SO_4			X								A		—								
H_2SO_4			A							S	A			—							
$FeSO_4 \cdot 7H_2O$			A						A		A				—						
Fe chelate						N	N				A			N		—					
KCl											A						—				
H_3BO_3			A						A		A				A			—			
$MnSO_4 \cdot 4H_2O$				A			A		A	A	A							A	—		
$ZnSO_4$				A			A		A	A	A							A		—	
$CaSO_4 \cdot 5H_2O$				A			A		A	A	A							A			—
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$										A	A										

liter column of the worksheet would be multiplied by 100. For instance for $MgSO_4$, 30.8 g/l would become 3,080 g or 3.08 kg.

To make up the solutions, dry chemicals are weighed and dissolved in about three-fourths of the water required. If hot water is available, they will dissolve quicker. After solution is complete, the liquid acids are added, and the solution is made up to final volume. Column 10 of the worksheet lists the weight of chemical needed, but it is more convenient to measure liquids by volume. Commercial acids come in varying strengths which are measured in percent, specific gravity, or degrees Baumé (Bé). Use tables 13-15, 13-16, and 13-17 to determine grams of pure acid per liter of commercial acid. Divide the weight of acid by this figure to get the volume required; (weight of commercial acid in grams) ÷ (grams per liter) = liters of acid. In our example, suppose 75% phosphoric acid is used, and 17.0 gm/l is needed from column 10 of the worksheet. Then: 17.0/1,184 = 0.014 or 14 ml per liter of stock solution. Suppose the nitric acid is 42° Bé and 95.8 gm/l is needed, so, 95.8/946 = 0.101 liters or 101 ml per liter of stock solution.

13.68 A Second Example of Nutrient Solution Preparation

The following is a second example presented in briefer form using data from the Mount Sopris Nursery at Carbondale, Colo. If the reader can follow through the procedures outlined in both of the examples, he is ready to formulate nutrient solutions for his own nursery. The water analysis and target concentrations for nutrient ions are shown in figure 13-6, and the water titration in table 13-18.

Calculations for macronutrients.—

1. HNO_3 will be used to lower pH to the optimum 5.5 and add needed nitrogen. For nitric acid, 1 meq = 63 mg/l (parts per million) (section 13.63), and we need 9.54 meq to lower the solution to pH 5.5 (table 13-18). Therefore, (63) x (9.54) = 601 mg/l. (601) x (0.222 N) = 133 ppm N.
2. KNO_3 will be used next to add nitrogen and potassium. We need 145 ppm K and know that KNO_3 is 0.386 K from table 13-8. Therefore, (145 parts per million) ÷ (0.386) = 376 mg/l

column

Line 1	2	3	4	5	6	7	8	9	10	11
	Nutrient Elements (ppm)							Total	Stock soln. x ____	Cpd. com-pat.
	(NO$_3$) N	(NH$_4$) N	P	K	S	Ca	Mg	Cpd mg/l		
1. Target Conc.	140	60	30	150	40	100	50			
2. Water anal.	0	0	0	5	16	160	29			
3. Net to Add	140	60	30	145	24	0	21			
Cpds. used:	–	–	–	–	–	–	–	–	–	–
4.										
5.										
6.										
7.										
8.										
9.										
10. Total										
	Fe	Cl	B	Mn	Zn	Cu	Mo		x____	
11. Target Conc.	4	4	0.5	0.5	0.05	0.02	0.01			
12. Water anal.	0	3	0.1	0	0	0	0			
13. Net to Add	4	1	0.4	0.5	0.05	0.02	0.01			
14.										
15.										
16.										
17.										
18.										
19.										
20.										

Figure 13-6.—Worksheet for calculation of fertilizer stock solutions with target concentrations and Mount Sopris water analysis entered.

KNO_3 required. the amount of nitrogen gained will be (376 mg/1 KNO_3) x (0.139) = 52 ppm N.

3. Diammonium phosphate $(NH_4)_2HPO_4$ will be added next to meet the phosphorus demand as well as complete the nitrogen requirement.
   (30 ppm P) ÷ (0.235 P) = 128 mg/l $(NH_4)_2HPO_4$
   (128 mg/l $(NH_4)_2HPO_4$) x (0.212 N) = 27.0 ppm N
4. Magnesium and sulfur are the only two remaining macroelements, and they both can be supplied by magnesium sulfate.
   (21 ppm Mg) ÷ (0.097 Mg) = 216 mg/l $MgSO_4 \cdot 7H_2O$
   (216 mg/l $MgSO_4$) x (0.130 S) = 28 ppm S

Calculations for micronutrients.—

1. We need 4 ppm Fe
   (4 ppm Fe) ÷ (0.10 Fe) = 40 mg/l Fe chelate
2. We need 1.0 ppm Cl
   (1.0 ppm Cl) ÷ (0.48 Cl) = 2.1 Mg/l KCl
3. We need 0.4 ppm B
   (0.4 ppm B) ÷ (0.177) = 2.2 mg/l H_3BO_3

Table 13-15.—Phosphoric Acid. Relation between degrees Baumé (Bé), specific gravity (Sp. gr.), percent acid, and grams of acid per liter (gm/l) (Hodgman et al. 1953).

Bé	Sp. gr.	Percent H_3PO_4	gm/l
0.6	1.0038	1	10.04
1.3	1.0092	2	20.18
2.8	1.0200	4	40.80
4.3	1.0309	6	61.85
5.8	1.0420	8	83.36
7.3	1.0532	10	105.3
8.8	1.0647	12	127.8
10.3	1.0764	14	150.7
11.8	1.0884	16	174.1
13.3	1.1008	18	198.1
14.8	1.1134	20	222.7
16.3	1.1263	22	247.8
17.8	1.1395	24	273.5
19.2	1.1529	26	299.8
20.7	1.1665	28	326.6
22.2	1.1805	30	354.2
25.8	1.2160	35	425.6
29.4	1.2540	40	501.6
32.9	1.2930	45	581.9
36.4	1.3350	50	667.5
39.9	1.3790	55	758.5
43.3	1.4260	60	855.6
46.7	1.4750	65	958.8
50.0	1.5260	70	1,068
53.2	1.5790	75	1,184
56.2	1.6330	80	1,306
59.2	1.6890	85	1,436
62.0	1.7460	90	1,571
63.1	1.7700	92	1,628
64.2	1.7940	94	1,686
65.3	1.8190	96	1,746
66.4	1.8440	98	1,807
67.5	1.8700	100	1,870

Table 13-16.—Nitric Acid. Relation between degrees Baumé (Bé), specific gravity (Sp. gr.), percent acid, and grams of acid per liter (gm/l) (Hodgman et al. 1953).

Bé	Sp. gr.	Percent HNO_3	gm/l
31.50	1.2775	43.89	560.6
31.75	1.2804	44.34	568.0
32.00	1.2832	44.78	574.6
32.25	1.2861	45.24	581.8
32.50	1.2889	45.68	588.8
32.75	1.2918	46.14	596.0
33.00	1.2946	46.58	603.0
33.25	1.2975	47.04	610.3
33.50	1.3004	47.49	617.6
33.75	1.3034	47.95	625.0
34.00	1.3063	48.42	632.6
34.25	1.3093	48.90	640.2
34.50	1.3122	49.35	647.6
34.75	1.3152	49.83	655.4
35.00	1.3182	50.32	663.0
35.25	1.3212	50.81	671.3
35.50	1.3242	51.30	679.3
35.75	1.3273	51.80	687.5
36.00	1.3303	52.30	695.7
36.25	1.3334	52.81	704.2
36.50	1.3364	53.32	712.6
36.75	1.3395	53.84	721.2
37.00	1.3426	54.36	729.8
37.25	1.3457	54.89	738.7
37.50	1.3488	55.43	747.6
37.75	1.3520	55.97	756.7
38.00	1.3551	56.52	765.9
38.25	1.3583	57.08	775.3
38.50	1.3615	57.65	784.9
38.75	1.3647	58.23	794.7
39.00	1.3679	58.82	804.6
39.25	1.3712	59.43	814.9
39.50	1.3744	60.06	825.5
39.75	1.3777	60.71	836.4
40.00	1.3810	61.38	847.7
40.25	1.3843	62.07	859.2
40.50	1.3876	62.77	871.0
40.75	1.3909	63.48	882.9
41.00	1.3942	64.20	895.1
41.25	1.3976	64.93	907.5
41.50	1.4010	65.67	919.4
41.75	1.4044	66.42	932.8
42.00	1.4078	67.18	945.8
42.25	1.4112	67.95	958.9
42.50	1.4146	68.73	972.3
42.75	1.4181	69.52	985.9
43.00	1.4216	70.33	999.8
43.25	1.4251	71.15	1,014.0
43.50	1.4286	71.98	1,028.3
43.75	1.4321	72.82	1,042.9
44.00	1.4356	73.67	1,057.6
44.25	1.4392	74.53	1,072.6
44.50	1.4428	75.40	1,087.9
44.75	1.4464	76.28	1,103.3
45.00	1.4500	77.17	1,119.0
45.25	1.4536	78.07	1,134.8

4. We need 0.5 ppm Mn
   (0.5 ppm Mn) ÷ (0.247 Mn) = 2.02 mg/l
   $MnSO_4$
5. We need 0.05 ppm Zn
   (0.05 ppm Zn) ÷ (0.404 Zn) = 0.12 mg/l
   $ZnSO_4$
6. We need 0.02 ppm Cu
   (0.02 ppm Cu) ÷ (0.256 Cu) = 0.8 mg/l
   $CuSO_4$
7. We need 0.01 ppm Mo
   (0.01 ppm Mo) ÷ (0.544 Mo) = 0.02 mg/l
   $(NH_4)_6Mo_7O_{24}\cdot 4H_2O$

Table 13-17.—Sulfuric Acid. Relation between degrees Baumé (Bé), specific gravity (Sp. gr.), percent acid, and grams of acid per liter (gm/l) (Hodgman et al. 1953).

Bé	Sp. gr.	Percent H_2SO_4	gm/l
44.7	1.4453	55	749.9
45.4	1.4557	56	815.2
46.1	1.4662	57	835.7
46.8	1.4768	58	856.5
47.5	1.4875	59	877.6
48.2	1.4983	60	899.0
48.9	1.5091	61	920.6
49.6	1.5200	62	942.4
50.3	1.5310	63	964.5
51.0	1.5421	64	986.9
51.7	1.5533	65	1,010
52.3	1.5646	66	1,033
53.0	1.5760	67	1,056
53.7	1.5874	68	1,079
54.3	1.5989	69	1,103
55.0	1.6105	70	1,127
55.6	1.6221	71	1,152
56.3	1.6338	72	1,176
56.9	1.6456	73	1,201
57.5	1.6574	74	1,226
58.1	1.6692	75	1,252
58.7	1.6810	76	1,278
59.3	1.6927	77	1,303
59.9	1.7043	78	1,329
60.5	1.7158	79	1,355
61.1	1.7272	80	1,382
61.6	1.7383	81	1,408
62.1	1.7491	82	1,434
62.6	1.7594	83	1,460
63.0	1.7693	84	1,486
63.5	1.7786	85	1,512
63.9	1.7872	86	1,537
64.2	1.7951	87	1,562
64.5	1.8022	88	1,586
64.8	1.8087	89	1,610
65.1	1.8144	90	1,633
65.3	1.8195	91	1,656
65.5	1.8240	92	1,678
65.7	1.8279	93	1,700
65.8	1.8312	94	1,721
65.9	1.8337	95	1,742
66.0	1.8355	96	1,762
66.0	1.8364	97	1,781
66.0	1.8361	98	1,799
65.9	1.8342	99	1,816
65.8	1.8305	100	1,831

Table 13-18.—Titration of Mt. Sopris Nursery irrigation water with 0.02N sulfuric acid. (Courtesy of Thomas Landis.)

	Titrant used			Titrant used	
pH	ml	meq/l	pH	ml	meq/l
8.0	0.0	0.00	6.2	43.0	8.60
7.9	5.0	1.00	6.1	43.8	8.76
7.8	10.4	2.08	6.0	44.7	8.94
7.7	15.0	3.00	5.9	45.3	9.06
7.6	18.7	3.74	5.8	46.0	9.20
7.5	21.4	4.28	5.7	46.7	9.34
7.4	24.3	4.36	5.6	47.2	9.44
7.3	26.7	5.34	5.5	47.7	9.54
7.2	29.0	5.80	5.4	48.2	9.64
7.1	31.0	6.20	5.3	48.6	9.72
7.0	32.6	6.52	5.2	48.9	9.78
6.9	34.6	6.92	5.1	49.2	9.84
6.8	36.0	7.20	5.0	49.5	9.90
6.7	37.4	7.48	4.9	49.7	9.94
6.6	33.6	7.92	4.8	49.8	9.96
6.5	40.0	8.00	4.7	49.9	9.98
6.4	41.0	8.20	4.6	50.0	10.00
6.3	42.0	8.40	4.5	50.1	10.02

Next calculate the stock solution concentrations using a dilution factor of 1:200 for both macro and micronutrients. Then determine chemical compatibilities from table 13-14 and convert weight of nitric acid to volume (table 13-16). The completed worksheet should look like figure 13-7.

13.69 Safety, Chemical Quality, Quantity, and Storage

Those making up the stock solutions should be trained to handle the chemicals safely. Rubber boots, a rubber apron, rubber gauntlet gloves, and a face mask or goggles should be provided when nitric acid, sulfuric acid, or highly acid stock solutions are handled. It is prudent to wear this equipment even when the solutions are not highly acidic, because splashing can still damage clothes and sting in cuts. At no time should concentrated salt solutions be handled without eye protection.

The quality of chemical used should be the lowest possible pure enough to do the job. Fertilizer grade chemicals are good enough. Some of the micronutrient compounds may only be available in the higher grades, but these are needed in such small amounts that cost is not a problem.

The method for estimating the gross amount of irrigation water needed in greenhouses for trees is provided in section 4.15. This figure divided by the dilution factor can be used to estimate the amount of concentrated stock solution needed for each solution used, and this, in turn, can be converted to the amount of chemical needed for a season. This figure can be rounded up to the commercial units sold (i.e., 100-pound sacks, 30-gallon drums, etc.) for ordering purposes.

column

Line 1	2	3	4	5	6	7	8	9	10	11
	Nutrient Elements (ppm)							Total	Stock soln. x 200	Cpd. com- pat.
	(NO_3) N	(NH_4) N	P	K	S	Ca	Mg	Cpd mg/l		
1. Target Conc.	140	60	30	150	40	100	50			
2. Water anal.	0	0	0	5	16	160	29			
3. Net to Add	140	60	30	145	24	0	21	ppm	g/l	
Cpds. used:	–	–	–	–	–	–	–	–	–	–
4. HNO_3	133							601	120	A
5. KNO_3	52			145				376	75.2	A
6. $(NH_4)_2HPO_4$		27	30					128	25.6	A
7. $MgSO_4 \cdot 7H_2O$					28		21	216	43.2	A
8.										
9.										
10. Total										
	Fe	Cl	B	Mn	Zn	Cu	Mo		x 200	
11. Target Conc.	4	4	0.5	0.5	0.05	0.02	0.01			
12. Water anal.	0	3	0.1	0	0	0	0			
13. Net to Add	4	1	0.4	0.5	0.05	0.02	0.01	ppm	g/l	
14. Fe chelate	4							40	8	B
15. KCl		1						2.1	0.4	AB
16. H_3BO_3			0.4					2.2	0.4	AB
17. $MnSO_4 \cdot 4H_2O$				0.5				2.0	0.4	AB
18. $ZnSO_4$					0.05			0.12	0.025	AB
19. $CuSO_4 \cdot 5H_2O$						0.02		0.08	0.016	AB
20. $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$							0.01	0.02	0.004	AB

Figure 13-7.—Completed worksheet for calculation of fertilizer stock solutions at Mount Sopris.

All of these chemical compounds will store well if they are kept dry and cool.

13.7 Preparation of Nutrient Solutions from Commercial Mixes

The first steps are the same as for custom formulation:

1. Decide on target concentrations for each mineral nutrient.
2. Subtract from this the mineral concentrations already in the water supply. The difference is what needs to be added.
3. Select a target pH.
4. Using the titration table for the water supply, determine how much acid must be added to reach the desired pH.
5. Select the acid to be used. Subtract the concentration of nutrient added by the acid from line 3 of the worksheet. This leaves the nutrient to be supplied by the commercial mix. In the first example (section 13.6), if we used nitric acid to supply the 8.6 meq of acid needed that would be 542 mg/l nitric acid or 542 x 0.222 = 120 ppm N
   Subtract this from the total needed,
   223 − 120 = 103 ppm N yet to be added.
6. Select the commercial mix to be used based on the ratio of N, P, and K needed. However, commercial fertilizers generally express P as P_2O_5 and K as K_2O, so, requirements must be stated in the same terms. In example 1, we need 27 ppm P. Using table 13-8, we find the fraction of P in P_2O_5 and divide.
   $(27) \div (0.437) = 62$ ppm P_2O_5
   We need 155 ppm K, so by the same calculation we need
   $(155) \div (0.830) = 187$ parts per million K_2O
   The ratio of N: P_2O_5 : K_2O that we need is then 103:62:187. This is approximately 1⅔:1:3, and we look for a fertilizer mix with approximately that composition. We can come close if we select a "pot mum special" having an analysis of 15-10-30.

To calculate how much is needed in the nutrient solution, select one of the nutrients and divide by the percent present. If we use potassium as K_2O then,

$(187) \div (0.30) = 623$ mg/l of fertilizer mix.

This is multiplied by the dilution factor to obtain the concentration of the stock solution.

The manufacturer normally selects compounds that are compatible. Unless the nurseryman experiences problems with precipitation, he needn't worry about keeping everything in solution. Prepared fertilizers frequently do not show sulfur, calcium, and magnesium on the analysis. If these are not in the NPK fertilizer, they must be added separately, and that is where any precipitation problems will occur. Some fertilizers contain all required micronutrient elements as well. If they do not, these must also be added.

Micronutrient elements may either be included in the nutrient solutions as a soluble mix or may be mixed with the pot mix as a powdered glass frit. Fritted micronutrient elements are available in several formulations.

For tree seedlings, it is recommended that the ratio of elements be approximately that recommended by Hoagland and Arnon (1938) or Ingestad (1971).

13.8 Preparation of Nutrient Solutions the Easy Way

Read the instructions on the bag, follow them, and hope it works. Many fine seedlings are produced with very minimal knowledge of the mineral nutrients available to the tree, but the authors do not recommend operating this way. If anything goes wrong, it is much harder to find the cause and correct it.

13.9 How to use Nutrient Solutions

The amount and kind of nutrient solution needed will vary with the phases of the growing cycle. During germination, mineral nutrients are not needed, because they are supplied by the seed. At this point, maintaining a relatively sterile medium will help control damping-off fungi. During germination, the surface is kept moist by frequent light waterings. If a nutrient solution is used, this can result in salt buildup, because there would not be enough water put on for leaching. The water applied during germination should be acidified as needed, however.

Nutrients should be applied when the seed coat is shed. During the juvenile and exponential growth phases, nutrient solution should be applied in excess each time it is used. This insures that the entire rootball is wetted and any excess salts are flushed out. Frequency of irrigation is determined by season of year and size of the seedlings relative to the containers.

The nurseryman may fertilize at every watering or only occasionally. Each method has its merits. Occasional fertilization puts less wear on the injector, is less work, and generally consumes less fertilizer. Further, if the nurseryman has more stock solutions than he has injectors, he can inject one first and then another. However, he will not be certain of the nutrient environment to which the seedlings are exposed, nor will he have as good control of the pH. By fertilizing at every watering, the nurseryman provides the seedlings with a known, constant, and highly favorable pH and nutrient environment (McGuire 1972).

SECTION 14.—OTHER GROWTH FACTORS

SECTION 14.—OTHER GROWTH FACTORS

14.1 Mycorrhizae

Certain fungi have the ability to invade plant root tips and live within them to the mutual benefit of the fungus and the plant (Zak 1975, Marx and Barnett 1974, Hacskaylo 1972). Ectomycorrhizae are most common on conifers. Their presence is indicated by the color and shape of small side roots characteristic of the particular fungus, and confirmed by the presence of a Hartig net visible under a microscope. Fungal hyphae extend from within the roots out into the soil.

14.11 Effects on Seedlings

Mycorrhizal fungi are pathogen antagonists. They help prevent damping off and root rot. These fungi also assist in mineral uptake and possibly water uptake, probably by increasing the effective absorbing area. Perfectly good non-mycorrhizal seedlings can be grown in the greenhouse, because conditions are controlled to minimize stresses of all kinds. Even so, mycorrhizal seedlings will frequently be healthier and more robust than nonmycorrhizal ones, and if anything goes wrong, the non-mycorrhizal seedlings will suffer much more quickly. In particular, non-mycorrhizal seedlings are subject to root rots caused by a poorly aerated pot mix plus overwatering or excessive humidity.

14.12 Which Mycorrhizal Fungus Is Best?

Many fungi will form mycorrhizae with a variety of tree species, and within both species of fungi and species of trees there are genetic differences in the ability to form a union (Trappe 1969). The question is which isolate of which fungus will best adapt this particular seedling to the site on which it is to be planted? Research to answer that is just beginning.

The procedure is to isolate a fungus that is known to form mycorrhizae with the tree species of interest. The fungus is propagated in pure culture and introduced into sterilized pot mix either as spores or mycelium. Seedlings are grown in the inoculated medium, and their roots are examined to see if and to what extent they become mycorrhizal. The seedlings are then outplanted either in the field or in a controlled environment where they can be subjected to simulated field site stresses. After a suitable period, the seedlings are examined for survival and vigor, and differences between groups of seedlings with different mycorrhizal fungi or no fungi are noted. Marx and Barnett (1974) have isolated a strain of *Pisolithus tinctorius* which forms profuse mycorrhizae on a variety of species, and has been shown to be very beneficial to southern pines. It has enabled slash pine to thrive on mine spoils with a pH of 3.5. It is being widely tested and may be commercially available in a few years.

Riffle and Tinus[1] have found a *Suillus* strain which is highly beneficial for ponderosa and Scotch pine planted in North Dakota.

14.13 Inoculating Seedlings

In humid regions, such as the Southeast and the Pacific Northwest, seedlings in greenhouses may become mycorrhizal by windborne inoculation. If so, no effort to inoculate them is needed. Even if the seedlings are non-mycorrhizal when they go to the

[1]*Unpublished data by J. W. Riffle and R. W. Tinus, Rocky Mountain Forest and Range Experiment Station, Lincoln Neb., and Bottineau, N. Dak., respectively.*

field in these regions, they usually become inoculated quickly because of the presence of the fungi at the site.

In drier climates, however, inoculation is not automatic either in the greenhouse or in the field. In the Plains, appropriate fungi may not be present at the planting site. In these situations, it is important that the nurseryman inoculate his seedlings deliberately. The following methods are available:

1. The most readily available and reliable method is to incorporate 2-3% by volume of forest duff into the pot mix. The duff is best collected fresh from under a stand of trees of the species to be grown. If that is not feasible, collect it from under a stand of trees closely related by both species and native site. For instance, duff from under a ponderosa pine stand will probably be equally good for inoculating lodgepole and white pine, and even larch and spruce. Rake aside the undecomposed litter and pick up the humus or top inch of mineral soil with a flat shovel. Screen out particles that are too large to mix well with the rest of the pot mix. Keep the inoculum moist until used. In small quantities, it is convenient to store it in burlap sacks lined with plastic garbage bags. For large quantities, line a bin with polyethylene, fill with inoculum, and cover tightly with polyethylene. When the pot medium is mixed, add 2-3% by volume of the inoculum.

   Although duff inoculum works well, using it risks adding harmful organisms. This risk may be assessed by collecting some inoculum well in advance of the need to use it. Fill a few containers and seed them to the species to be grown. Watch them carefully for several months for signs of damping off, root rot, nematodes, or harmful insects. If the trees grow normally and no problems develop, use the inoculum in the production run. If problems with insects or nematodes develop, treat the inoculum with an appropriate pesticide before use. If pathogenic fungi are the problem, try a different source of inoculum.
2. Allow mycorrhizal fungi to fruit in the greenhouse. Some fungi, such as *Thelaphora terrestris,* will fruit readily, while others will not. Conditions in the greenhouse may not be right for fruiting, except at certain times. This method of inoculation is much less certain than using duff, and it severely restricts the variety of fungi that will inoculate the seedlings. Its advantage is that it does not introduce anything harmful into the pot mix.
3. Incorporate a pure culture of the desired fungus into the pot mix before seeding. This is not a viable option at present, because pure cultures are not available in quantity yet. When they are, this will become the recommended procedure.

14.2 Carbon Dioxide (CO_2)

14.21 Why Plants Need CO_2

In the atmosphere, there are about 325 ppm CO_2. This small concentration is the source of carbon for all land plants. Plants take up CO_2 during photosynthesis and give it off through respiration. In the light, photosynthesis is usually greater than respiration, which results in a net uptake of CO_2, but under conditions of high temperature or reduced CO_2 concentration, it may not be. When photosynthesis equals respiration (equals the compensation point), the plant can maintain itself in the light, but it does not grow. This occurs frequently on bright days in closed greenhouses (Tinus 1972).

14.22 Growth Response to CO_2 Enrichment

The strategy for producing large seedlings in a hurry is to optimize all growing conditions possible. When CO_2 becomes limited, growth slows down and may even cease. CO_2 must be added to the atmosphere to at least bring it back up to normal concentrations.

Almost all woody plants that the greenhouse nurseryman is likely to grow exhibit "photorespiration." This is a loss of CO_2 which occurs only in the light. Its function is not well understood, but it appears that plants can do without it. Photorespiration is suppressed by high concentrations of CO_2, and net photosynthesis increases accordingly. High CO_2 also increases the diffusion gradient from the outside air to the chloroplast where it is consumed. However, high CO_2 tends to close the stomata which decreases the amount entering the leaf (Tinus 1974c). Extremely high concentrations can be toxic.

The CO_2 concentrations most often used in greenhouses are 800-1,500 ppm, which represents a good compromise between increased CO_2 gradient and depressed photorespiration and closure of the stomata. In growth chamber experiments, where these concentrations have been maintained through the day, dry weight growth of seedlings has been increased 50-100% (Tinus 1972, 1976).

In a greenhouse, the response is likely to be somewhat less, because on warm days it will be necessary to ventilate to maintain proper temperature. Unless huge quantities of CO_2 are available, it will be impossible to maintain CO_2 levels much above that of the outside air. The growth response expected will depend on how much of the time the vents remain closed. During the winter, this may be all day, but during midsummer, it is usually possible to raise the CO_2 level for only a few hours in the early morning and again in the evening. The loss may not be as great as it sounds, however, because plant stomata commonly close during midday because of water stress, even when the plants are well watered. Thus, photosynthesis is normally most rapid in the early morning with a secondary peak in the evening.

14.23 Providing Added CO_2

One method used some years ago was to pile fresh manure in the greenhouse. Decomposition released CO_2, and the remains were added to the pot mix after composting was complete. This method has fallen into disfavor, because it takes up valuable space, and release of other gases degrades the working environment.

Release of CO_2 from a tank is a more suitable method. This is costly, however, and is generally reserved for growth chamber use.

Scrubbed stack gas from industrial or electric generating plants can be used, if available. This would be practical if the greenhouse is located close enough so that it could use the waste heat produced. If available at all, stack gas would probably be available in sufficient quantity so that elevated CO_2 levels could probably be maintained even when the vents were open.

The most common method is combustion of propane or natural gas. There are burners designed specially for CO_2 generation available from nursery supply houses. Actually, any burner will do, provided it burns with a blue, non-turbulent flame. If the flame is yellow, there may be harmful products of partial combustion given off, particularly carbon monoxide and ethylene. Carbon monoxide is probably more dangerous to humans than to plants, but ethylene is a potent plant hormone that promotes dormancy and leaf absicission among other things. If the flame is short and very turbulent, there is likely to be some gas that escapes unburned into the greenhouse.

For a glass or fiberglass greenhouse of average tightness, it takes about 2.5 BTU per hour of gas per cubic foot (22 Kcal per m^3) of greenhouse to maintain 1,000 ppm CO_2 in the atmosphere. For polyethylene covered or tight houses of other construction, gas consumption can be reduced somewhat.

Propane is fairly standard in composition and can be relied upon to be low enough in sulfur so as not to damage plants. Natural gas varies in composition, and its sulfur content should be checked. For safe use, the carbon to sulfur ratio must be 10,000 to 1 or greater.

The burner is conveniently controlled by a timeclock in series with the open-on-rise side of the thermostat that controls the first stage of cooling. The timeclock turns the burner on during daylight hours, and the thermostat turns it off when the vents open and the fans come on.

CO_2 concentration is regulated by the size of the flame on the burner. Once the correct setting has been found, it is not necessary to monitor CO_2 levels continuously. An occasional spot check is enough. CO_2 testers with sufficient accuracy are available for less than $100. If the nurseryman is located near a university or agricultural research station, he can probably arrange for analysis of air samples on an infrared gas analyzer. Samples can be taken by filling an inner tube with greenhouse air with a bicycle pump. Butyl rubber is highly impermeable to CO_2, and such samples should be good for days. Do not use plastic bags, unless the samples can be analyzed in a matter of minutes. Be sure no human breath is mixed with the sample taken.

SECTION 15.—GROWING SCHEDULE FORMULATION

15.1 Definition of Growing Schedules

A "greenhouse rotation" is a program for space utilization in the shadehouse and greenhouse throughout the year. It is planned to insure that there will be a place to put the containers and seedlings when they need to be moved from the greenhouse to the shadehouse or when a new crop is to be started in the greenhouse. The greenhouse rotation must be planned during design of the facility so that necessary space will be available (section 5.3). It is useful to keep a written record of the planned rotation and what actually happened, so that if errors are made, they will not be repeated.

A "growing schedule" is a chart of environments to be maintained and operations to be done as a function of calendar date from seed preparation to shipment from the nursery. It incorporates much of what is known about how to grow a particular crop and have it in proper physiological condition on the required shipping date. Some thought must be given to the growing schedule during facility design to insure that the greenhouse will be able to maintain the required conditions. The growing schedule also specifies the time needed to grow the crop under a given environment. This is crucial to planning the greenhouse rotation. A detailed record of conditions maintained and growth progress should be kept so that errors in the original growing schedule can be corrected.

15.2 Growing Schedule Format

15.21 How to Read a Growing Schedule

Figure 15-1 is an example of a growing schedule. Time is on the horizontal axis at the top. This particular crop has a 1-year rotation. The factors to be controlled and operations to be performed are listed on the vertical axis at the left. The body of the schedule specifies the level or condition of each environmental factor and the time at which that takes place. This figure summarizes everything we know about how to grow that size of white spruce at Palmer, Alaska, for spring outplanting. Refer to it throughout the following discussion.

Species White spruce **Container** 10 cubic inches **Outplanting** Spring **Location** Palmer, Alaska **Cycle** Summer (1/yr.) Info. Grade B

Source Fairbanks, Alaska

Season		MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
Growth stage		Sow; Germination	Juvenile growth		Exponential growth			Natural hardening					Maintain dormancy	
Day temp (°F)	**Optimum**	70	72		72			65 (declining with the season)						
	Permissible	65-75	68-75		68-75			55-70						
Night temp (°F)	**Optimum**	70	61		61			55						
	Permissible	65-75	56-72		56-72			50-70						
Rel. Hum. (%)	**Optimum**	80		60										
	Permissible	60-90		50-70										
Daylight					75% Sunlight (unshaded 2 layer ghs.)			50% Sunlight (shadehouse)						
Supplemental light			8 watts/ft² incandescent light at least 6% of the dark period. No dark period over 15 min.					None						
Water		Frequent, light, surface always wet			As needed with nutrient solution. Surface should dry. Rootball always near field capacity.		Leach with water. Dry to wilting.	As needed. Treat as before.						
Fertilizer		None		Complete, high N, pH 5.5-6.0, EC 1,500-2,000 μmhos. Water in excess each time. Rinse foliage with water.			None	Complete, low N, high PK. Otherwise, as before.						
CO_2 level		Normal atmos.		1,000-1,500 ppm whenever vents are closed during daylight hours.				None (Normal atmosphere)						
Operations		Fill, seed, load ghs.	← Thin →				← → Move trees to shade-house.							Ship May 1

From left to right, is a time line. Points along this line are designated as growth stages of the crop or points at which certain management activities take place. From top to bottom, at the left of the sheet, are environmental parameters (temperature, humidity, light, water, fertilizer, CO_2) and operations to be controlled. In the body of the schedule, below the time line and to the right of the parameters itemized, is a statement of the condition or setting and the permissible limits of parameter at that point in time. When reading the growing schedule, one is really scanning the condition of the environment in which the plant is growing at any given time. By reading the time line and correlating the graduated distance along it between management activities indicated, the length of the various growth stages (germination, juvenile, elongation, caliper growth, and dormancy) can be seen.

There are other formats that can be used to set up growing schedules. How it is done is not important as long as they provide the grower with an adequately detailed plan of action while the crop is in the nursery. The growing schedule must be flexible, of course. Disease and equipment problems can occur to slow the growth. In semicontrolled greenhouses, weather can also have a significant influence.

15.22 Common Features

All growing schedules should have these attributes:

1. They should define the dates between which the crop will be in the greenhouse, the crop conditions at any time during the growth cycle, targets for height, caliper, and other indicators of growth stage, and the condition of the environment in the greenhouse at any given time during the growth cycle.
2. Generally, the location of the crop in the greenhouse and specific benches to be used are not part of the schedule. These items belong in the greenhouse rotation plan.
3. The environmental control designated in the growing schedule should be based on the best biological information available for that particular species. The full capability of the greenhouse environmental modification system should be used to meet these growth optimization guides.
4. The growing schedule should show the complete cycle from seed to crop maturity, even if the crop is moved to a shadehouse partway through its schedule.
5. The length of each segment of the growing schedule and the calendar dates it covers should be defined. This is valuable not only for reference while the crop is being reared, but also to record the true length of time needed to produce a satisfactory crop. Records of the length of time and cultural modifications necessary to rear good crops of trees are valuable for more precise growing schedule formulation for future crops.

15.23 Relation of the Schedule to the Rate of Crop Development and Condition

Stages of hardening.—The species and required size determines the container size and the time required to grow it. The site on which it is planted and the time of year determine the physiological condition of the tree when it leaves the nursery.

Start with the date the end product must be ready to ship, and work backward in time. After the seedlings have reached the desired size, they may need hardening. There are three distinct stages of hardening.

Fully hardened seedlings are dormant with well developed winter buds. They have reached a high degree of cold hardiness, and the chilling requirements for bud break have either been met or will be by the time warm weather arrives at the planting site. This condition requires 6 to 10 weeks to achieve and is generally needed for spring, fall, or winter planting. The seedling can be expected to put on a large flush of top growth the first season in the field.

Dormant seedlings have set bud, and all of the stem tissue has lignified, but they are not cold hardy. This degree of hardening takes 3 to 5 weeks to produce and is sufficient for planting in summer or early fall when frosts are not expected. Normally, there will be no top flush until the following year.

Succulent seedlings have had no hardening. Their top growth is very active, and the upper part of the stem is not lignified. They are as tender as lettuce and are usable only in the most favorable weather on the best sites (i.e., where site conditions are not very different from greenhouse conditions). When used judiciously, these seedlings will continue growth without interruption, and no time for hardening needs to be allotted in the growing schedule.

Stages of growth.—At the date when the seedlings must be full height and ready for hardening or shipment, they will have passed through three growth stages.

Germination begins when the seed is placed in warm, moist pot mix; it should be complete in 10 to 14 days. If it is not, either the seed has not been properly prepared, or the seed is poor. Prompt and complete germination in the greenhouse nursery is important. Any delay is costly. The germination stage generally requires more frequent watering, no fertilization, less light intensity, lower temperatures, and more vigilance against disease than later in the life of the seedling.

Juvenile growth begins when the seed is exhausted and the tree becomes autotrophic. There frequently appears to be a pause in growth as the seedling forms a rosette above the cotyledons. The first green leaves are frequently different in shape, size, and ontogeny from the ones on a mature plant. No buds are visible. The seedling grows continuously. Less frequent watering than during germination is desirable so that the pot surface will dry. This helps control damping off. Light intensity may be the same or somewhat higher than during germination, but the seedlings must have sunlight, whereas, during germination, they may or may not need it. At this time, the temperature may be increased somewhat. CO_2 in the greenhouse atmosphere should be elevated, lights for the photoperiod control turned on, and fertilization begun. The length of this stage varies with the species and seed source anywhere from a few days to several weeks.

Exponential growth occurs after the seedling has fully taken hold and frequently begins to resemble a mature tree morphologically. The length of this stage is determined by how close growing conditions are to optimum, how large a tree is desired, and how soon one or more factors becomes limiting.

To know the time required for each of these growth stages, assume that the nurseryman has growth curves and a table of optimum conditions for the species he is growing. Moving backward in time through these three growth stages establishes the seeding date.

Next, allow time for seed preparation. Does it require stratification, water soaking, or other time consuming treatment? Finally, consider seed collection and proper storage, which brings us to the beginning of the growing cycle.

15.24 Timing

Given the date at which the product is needed, and once it is known how rapidly the seedlings will grow and how rapidly they can be put through the required stages, it is easy to establish the dates at which each stage must begin. These dates may need to be adjusted to allow one crop cycle to mesh with the next, and to coordinate the use of space and manpower. If the trees will remain in the greenhouse from sowing until shipment, the only requirement is that they be shipped in time to start the next crop. If shipment is delayed, the seedlings may need to be moved to a temporary holding area or cold storage. If the trees are to be moved to a shadehouse for part of their residence at the nursery, they must be able to tolerate conditions there. If the trees are fully hardened, they can be moved to the shadehouse at any time.

Species and ecotypes differ greatly in their ability to tolerate freezing. Many West Coast ecotypes must be protected by insulation and heat so that their roots do not freeze at all. Ecotypes of the interior West can generally be frozen without root damage after they are properly hardened. Roots do not harden to the degree the tops do, however, and must be maintained above their killing temperature. (For list of known root killing temperatures see Havis 1976). Rootballs of conifers should not remain frozen for more than a few days at a time, unless the tops are treated with antitranspirants, covered with polyethylene, or mulched with snow. This is because, even though the roots may not be damaged, the trees will be unable to take up water and the foliage may be desiccated and damaged. If seedlings are dormant but not hardened, they may be moved to the shadehouse during mild weather. Many West Coast ecotypes cannot tolerate frost at this stage, but in the interior West depending on the species and seed source, light frosts should not hurt, but the seedlings should not be subjected to temperatures lower than 27° F (−3° C) before they have had a chance to harden. In the interior West, if the trees are succulent, they must have at least 3 weeks of frost free conditions before being subjected to low temperatures. Further, they should be protected from intense sunlight, strong winds, and very dry air. For each location, the nurseryman must determine from weather records what his limiting dates are for transferring plant material out of the greenhouse.

In addition to the climate, the nurseryman must consider how the proposed timing will mesh with starting the next crop. Generally, each crop will start and end about the same time each year. Thus, there will be one, two, or three crops per year, but not 1½ or 2½. A crop must be moved out of the greenhouse before the next one is started; but the shadehouse or other storage area may accumulate more than one crop at a time. Space must be allowed, if crops are expected to overlap.

15.25 Facilities Available

The sequence of growth stages outlined in section 15.23 will be the same regardless of the quality of the facilities in which the trees are grown, but the time required will depend on how closely conditions can be optimized. Several situations apply:

1. The greenhouse may be fully controlled, or it may have a lesser degree of control. How much that lengthens the required growing time depends on the species, the climate, and time of year.
2. The crop may be grown in the greenhouse for only part of the growing cycle and finished off in a shadehouse.
3. Time of year is important, because it affects the amount of sunlight available. Winter crops without supplemental high intensity light for

photosynthesis always take longer to grow than summer crops.

4. Climate is important, because there may be seasons of cloudy or foggy weather which affect light intensity, and depending on how mild or harsh the climate is, cost of seedling production may vary greatly with season.

15.26 Growing Data Needed

For many species desirable conditions for each stage of growth are known. These are listed by species in sections on temperature, light, watering, humidity, mineral nutrition, and other factors. However, good information on rate of growth is available for relatively few species, especially as related to the interaction between the various environmental factors. In the previous sections, when optimum conditions for one factor are described, it is assumed that all other conditions for growth are also favorable, if not optimum.

15.3 Growing Schedule Assembly

To show how growing schedules are constructed, a step by step procedure and three examples are provided.

15.31 General Procedures and Rules of Thumb

1. Select species, size of seedling, time of outplanting, location of planting, location of nursery.
2. Determine dates for all growth stages from the shipping date or other fixed time, using what is known about the time required for each stage. This will depend on species, seed source, size of container, time of year, location, and capabilities of the greenhouse.
3. Select environmental conditions to be maintained during each growth stage.

15.32 Sowing

During sowing, conditions can be whatever is comfortable for people to work in. If it takes more than a day or two to fill a greenhouse, germination uniformity can be increased by keeping the temperature just above freezing until it is full. Then warm it up and allow germination to occur.

15.33 Germination

A temperature of 70° F (21° C) is good for many species' germination. It is warm enough for prompt germination, although germination is usually faster at higher temperatures. However, at higher temperatures, it is harder to keep the germinating seed from drying out, and the seedlings tend to be spindly because of excessive hypocotyl elongation. Note that best greenhouse germination temperatures are not necessarily the same as those used in standard germination tests (Schopmeyer 1974).

Relative humidity should be high enough so that the seed will not dry out and the young seedling is not under high transpiration stress. Seventy percent is a good target figure, which is also low enough so that the danger of disease is not increased.

Light intensity is frequently lowered during germination, because young seedlings can be damaged by very intense light. How necessary this is depends on the species, the location, and the time of year. Shading is not necessary during long periods of cloudy weather and is rarely necessary during the fall and winter. Shading is frequently necessary during spring and summer both to avoid excessive light intensity and to avoid excessive day temperature.

If supplemental light is needed, it should be applied to lengthen the photoperiod soon after germination. How critical this is depends on the sensitivity of the particular species and seed source. For instance, high latitude (54° N and above) origins of white spruce are very sensitive to short photoperiod and are capable of setting bud in the cotyledon stage. Early budset would be a disaster, because the bud would require many weeks of chilling to break, and that would completely upset the growing schedule. However, Engelmann spruce from New Mexico does not seem to be sensitive to photoperiod, although supplemental light should probably be applied as insurance.

Watering should be frequent and light so that the pot surface does not dry. Small seeded species especially will be on or very close to the surface.

During germination, the seedling receives mineral nutrients from the seed. By not fertilizing until after the seed coats have dropped, the chance of damping off is reduced.

There is no point in providing a high CO_2 atmosphere until there is enough photosynthetic tissue to absorb it.

15.34 Juvenile Stage

After the seed is used up and the radicle is well down into the pot, conditions should be changed. Temperature should be set at the optimum for the species (table 10-1).

Humidity should be reduced somewhat to about 60% ±10 to insure that liquid water does not stand on the foliage for any length of time. The seedling has now established root contact with the pot mix and can tolerate a little more transpiration stress in the interest of avoiding foliage disease and root rot.

Likewise, it is no longer desirable to keep the surface wet. The frequent light waterings are discontinued, and the surface is allowed to dry between waterings. From this point on, each watering will contain nutrient solution formulated high in N to maximize growth rate. The rootball will be kept near field capacity, unless this causes insufficient aeration. Each watering will be in excess so that the rootball will be recharged with nutrients, but no unused salts will be allowed to accumulate. The final few minutes of each watering will be with plain water to rinse the foliage. This will prevent algae growth and salt burn.

As the seedlings get older, they can generally use more light, especially after the crowns close. Spring crops will get more sunlight automatically as the days lengthen and the sun angle increases. Late summer or fall crops may need to have shade removed to achieve this effect. The CO_2 level should be elevated to about 1,000 ppm during daylight hours, whenever the vents are closed.

15.35 Exponential Growth

Many species show no sharp transition between the juvenile and exponential growth stages. The conditions required for both stages are essentially the same, but they will change somewhat, because the season is changing. The warm days of summer may make it difficult to keep day temperatures down to the optimum, and there will be less time that CO_2 can be elevated, because the vents will be open more. Frequency of watering will increase because of the warm weather and increasing size of seedlings.

The exponential growth stage continues until the seedlings are as tall as desired. At this point, seedlings will be tall but quite slender with rather few, if any, short side branches. The foliage will be soft and limber, and the upper part of the stem will be green and unlignified. Few, if any, of the seedlings will have a visible terminal bud. Since growth during this state is exponential, a small change in growing time may make a large difference in the size of trees produced. If they grow faster than expected, the exponential phase can be terminated sooner. If they grow slower than expected, a decision must be made as to whether to accept smaller trees or to continue to grow them longer. If the trees are to remain in the greenhouse during hardening, can the entire hardening period be shifted later in time? If that will interfere with the planting of the next crop, or if the season of the year is changed so that hardening is difficult or impossible, the answer is probably no. If there is a slack time in the schedule, the answer is probably yes.

If the trees are to be moved to a shadehouse for hardening, they must leave the greenhouse during frost free weather and not be frosted for at least several weeks after they go out. This places a cutoff date on any movement out of the greenhouse somewhere in the late summer or fall, depending on location. If extending the growing time will move the transfer beyond the cutoff date, then smaller seedlings must be accepted, or they must be hardened in the greenhouse.

15.36 Bud Development and Stem Lignification

Spring planting requires a tree that is able to put on a good flush of top growth after outplanting. In many species, such as spruce, the cells that make up that flush are laid down in the buds formed at the end of the previous season. A good flush is directly related to good bud development. Thus, conditions must be right and sufficient time allowed for adequate bud development.

Bud development is initiated by changing the growing conditions and subjecting the seedlings to a moisture and nutrient shock. When the seedlings are moved to the shadehouse during the summer, the day temperature probably becomes warmer than optimum and the night temperature cooler than optimum. Both decline as the season advances into fall. Relative humidity drops and becomes much more variable. Shading in a shadehouse is usually 40-50% which is somewhat lower light intensity than in an unshaded greenhouse. There will be no supplemental light in the shadehouse, a key variable in the control of dormancy. In fact, be sure that the darkness is not interrupted by nearby street lights or by work lights inside. Shade alone may or may not hasten dormancy, and Hahn[1] reports that shade promotes more height elongation of coastal Douglas-fir.

Upon transfer to the shadehouse, the seedlings are watered heavily with plain water to remove nitrogen, and then they are allowed to dry to the wilting point. This process, which will be termed "drought stressing," must be done with care so that the seedlings are not permanently damaged. Because drying will not be completely uniform, it may be necessary to water a portion of the crop by hand so that damage is prevented, but the rest of the crop can continue to be stressed. As soon as the growing medium reaches the wilting point, the crop is then rewatered with a low N, high PK solution.

Drought stress is an effective way to stop height growth quickly, especially when used in conjunction with a shortened photoperiod. Reduction of nitrogen and increasing phosphorus and potassium in the nutrient solution is a widely used practice that seems to produce good seedlings, but the evidence that it is necessary is not very strong (Christersson 1973, Hulten 1976, Kelly 1971, Timmis and Tanaka 1976, Tanaka and Timmis 1974, Tmmis 1974).

[1]*Personal communication with Phillip Hahn, Georgia-Pacific Corp., Eugene, Oreg., May 1978.*

15.37 Cold Hardening

After the buds have developed sufficiently, the stem is completely lignified, and caliper growth is sufficient, then low temperature and short photoperiod may be used to develop cold hardiness. When stock is overwintered in a shadehouse, this happens naturally, and the nurseryman has only to keep the stock watered when temperatures are above freezing, and adequately mulched to prevent the roots from becoming too cold. Roots never develop as much cold hardiness as do the shoots, but with good thermal contact between the container and the ground and with adequate mulching for insulation, the seedlings will overwinter in good shape. Hardening in the fall is fairly easy to accomplish in the interior West, but is much more difficult on the West Coast.

In climates with warm but rainy winters, it may be necessary to overwinter the seedlings in a structure with a solid roof to shield them from excessive moisture. Continuously saturated rootballs mean poor root aeration, which encourages root rot.

One important function of cold temperature is to remove the inhibitors in the plant that hold the buds dormant. The length of time required to meet the "chilling requirements" also varies with species and seed source. For most species, the minimum requirements are unknown, but 5 weeks is enough for many species. Only a few require longer periods, such as green ash which requires 8 weeks, and coastal Douglas-fir which requires 8-12 weeks. If the chilling requirements have not been met, the buds will not break and grow promptly, if at all. For many species of spruce and fir, the terminal remains dormant, but the lateral buds grow. Lack of height growth after outplanting is a common problem of winter grown seedlings which are shipped in the spring or early summer without cold hardening.

15.4 Testing and Adjustment of the Growing Schedule

After a growing schedule has been formulated, plans can be made for the operations needed to grow the crop. Supplies can be ordered and a crew hired, so that they will be available when they are needed. Space can be allocated and transportation arranged. If any of these factors do not fit or are not feasible because of poor timing, competition for available space, or other problems, the growing schedule may need to be revised.

Progress of the crop should be monitored continually, and any discrepancies between expected and observed performance should be carefully noted. If the nurseryman is inexperienced at running a greenhouse container operation, or if this is his first crop of a particular species, it is likely that the crop will not grow exactly according to the growing schedule. This will make it necessary to change the timing of growth stages and operations from what was originally planned. The nurseryman should note carefully what happened to make the change necessary so that the growing schedule for the next crop cycle will be more accurate. There also will be year to year variations in weather and management decisions that will make it necessary to continually fine tune the growing schedule.

15.5 Examples of Growing Schedule Development

The following specific examples are intended to help the reader follow the procedure and reasoning behind the development of growing schedules so that he can generate his own.

15.51 White Spruce for Interior Alaska

Following the procedure outlined in section 15.3, suppose we want sturdy white spruce with an 8- to 12-inch (20- to 30- cm) top for late spring planting in the interior of Alaska. The nursery will be at Palmer, Alaska. That information fixes the first set of variables. At that latitude, the best cropping cycle will be one per year, with the exponential phase of growth centered on the longest days of summer. We only want a medium sized tree, so, there should be plenty of flexibility in timing. Plan for delivery of fully hardened stock about May 1.

Container size should be 8-15 cubic inches (139-250 cm^3) for a spruce with a 10-inch (25-cm) top. Since there will be plenty of time but a very cold winter, the most economical strategy will be to transfer the fully grown seedlings to a shadehouse in late August and let them go dormant and harden naturally. The greenhouse can then be shut down in winter.

Since the seedlings will be overwintered in a shadehouse, they can be shipped almost any time, so that is not a fixed date. However, they must be moved to the shadehouse at least 3 weeks before frost, and preferably 5 weeks. At Palmer, Alaska, that sets the date for moving the seedlings to the shadehouse at August 15. To reach the desired size, it will take about 20 weeks from seed in a fully controlled greenhouse. That means germination must begin March 15. Seed stratification, if required, must be complete by March 7, which allows 1 week for filling and sowing.

The reader should examine figure 15-1 and follow down the column of environmental conditions for each growth stage as we proceed through them.

Germination.—Conditions for seed germination are determined by the requirements of the species and seed lot, not by the location of the nursery. White spruce from interior Alaska apparently requires no stratification, and there is nothing unusual about temperature requirements. In this example, we sow dry, unstratified seed, with temperatures, humidity, watering, fertilizer, and CO_2 as described in section 15.3.

In March, at Palmer, Alaska, light intensity inside an unshaded greenhouse is not likely to be excessive, or should shading be necessary to avoid excessive day temperatures. Therefore, use no shading.

Supplemental light should be applied as soon as germination begins, because white spruce from high latitudes is very sensitive to short photoperiod and is capable of setting bud in the cotyledon stage.

Juvenile and exponential stages.—Spruce shows little distinction between a juvenile and exponential growth stage in the greenhouse nursery, and the requirements of the seedlings are almost the same for both. As they get older, the seedlings can tolerate more intense light, which they will receive automatically as the season advances. Likewise, as the seedlings develop some bark thickness and especially after the crowns close, they can tolerate more heat. However, the spruce will not grow rapidly at high temperature.

Note (fig. 15-1) that the recommended temperatures are quite low. As the season advances, it will be harder to hold greenhouse temperatures down to what is specified. Shading may be needed.

Seedlings should reach 10 inches (25 cm) in height within 18 weeks after germination. If they grow faster than expected, the exponential growth phase can be terminated sooner. If they grow slower than expected, we will have to settle for a smaller tree, because we cannot move succulent seedlings to the shadehouse and have them go dormant and harden properly, if we wait much beyond August 15. An alternative would be to overwinter the seedlings in the greenhouse. This would give more growing time, but would also be more expensive. The decision has to be made about August 15.

If time were found to be too short on the first crop, the schedule could be modified on the second crop to start a few weeks sooner. In Alaska, there is a limit to how much sooner, because there is so little sunlight in winter. Another possibility is to improve cultural practices so that the second crop grows faster than the first. This is common because no book of instructions or list of recommendations can completely replace actual experience.

Hardening.—Assuming everything goes right and the full-sized crop is moved to the shadehouse on schedule, the environment will change. The atmosphere will no longer be high in CO_2. The daylength will be shortened, because there will be no supplemental light at night. The photoperiod will still be on the order of 16 hours, but that is short enough to permit dormancy of high latitude white spruce. The humidity will generally be lower outside than in the greenhouse. The temperature initially will probably be in the same range as in the greenhouse during the day, but cooler at night. Both temperature and humidity will be more variable.

The nurseryman now needs to be concerned with only four factors: water, fertilizer, mulch, and protection from animals. To initiate hardening, the seedlings are watered heavily to remove nitrogen and subjected to moisture stress. This must be done carefully, and errors on the wet side are preferable. After most of the succulent shoot tips have visibly wilted, but before any of them are irreversibly damaged, the seedlings are rewatered with a nutrient solution containing about 10% as much N and 50-100% more P than before. The seedlings are watered with this formulation whenever watering is needed as long as the rootball is not frozen.

When the seedlings are moved to the shadehouse, they should be up on racks with adequate ventilation under the pallets for air pruning. They should be kept that way until rootball temperatures become cold enough to stop root growth (about 36° F) (2° C). Ideally, the container bottoms should then be placed flat on the ground for good thermal contact, but if this would involve too much handling, they can be left where they are. About the time the rootballs become frozen, the seedlings should be mulched with sawdust, shredded peat, straw, or something similar. The mulch must cover the sides of the container and a loose covering over the top. If the seedlings are left up on racks, this will require a great deal more mulch than if they are flat on the ground. The covering over the top must not be put on until the trees are thoroughly dormant, which they should be if the rootballs are freezing. If there is any danger that rodents may live in the mulched seedlings overwinter, scatter poison bait on the surface of the containers before mulching. Ideally, the tops should be covered with snow soon after the rootballs freeze, but other waterproof coverings or heavy shade are acceptable.

Snow mold is not likely to be a problem in Alaska, but if it is encountered, the seedlings can be sprayed with a suitable fungicide such as Captan® before mulching.

If warm spring weather comes before it is time to ship the seedlings, the mulch should be removed and the seedlings placed back on racks with enough ventilation for air pruning of root growth. Just prior to shipment, they should be watered thoroughly with high N nutrient solution.

15.52 Bur Oak for North Dakota

In this example, we want large (20-25 cm) sturdy stock in large containers for spring planting in the northern Great Plains. Under optimum conditions, oak is fast growing, so, we can plan for two crops per year. However, oak requires high temperature for rapid growth, so, the most economical approach is to grow both crops during the spring and summer. This will be possible by starting early and hardening the first crop in a shadehouse and the second crop in the greenhouse (Appendix 2).

Bur oak is also a good example of a species requiring special seed handling. With most species, multiple seeding can compensate for low or slow germination. However, this is impractical with large seeded species such as walnut, pecan, or oak, because only one seed per cavity will fit. Acorns have a short storage life compared to many species. They cannot be allowed to dry out, and they cannot be frozen. Bur oak from North Dakota is unusual in that it is one of the few white oaks that requires stratification. The acorns are frequently infested with weevils, although they appear to have little effect on viability if the following collection and storage guidelines are followed (Tinus 1977a):

1. Collect the seed from the ground or shake the tree, but do not pick green seeds. This insures adequate ripeness and is also the easiest way to collect the seed.
2. Immediately float test the seed in water. Anything that sinks will germinate 80-90%, and anything that floats will germinate 0-30%. This eliminates seeds which have been damaged by drying or weevils, and it stops the drying.
3. Place the wet acorns in a plastic bag. Store them in a cooler just above freezing, but do not freeze them. This will provide the right moisture and temperature for storage and stratification.
4. When it is time to plant, bring the acorns into a warm room for a few days in advance and allow them to sprout. Plant one germinant per cavity. This will insure a virtually 100% stand. Return the ones that did not germinate to the cooler, and save them for the second crop.

Seed collection time would normally be September, and with 60 days' stratification, sowing could be scheduled any time after December 1. Let us schedule sowing for March 15. After 135 days in stratification, the acorns will germinate very quickly, so, no more should be brought out of the cooler than can be planted in 2 days. After the first crop is planted, the remainder of the acorns should be stored as cold as possible without freezing them to prevent germination in storage.

The first crop is expected to reach full height by the middle of June, at which time it can be transferred to a shadehouse to complete its caliper and dry weight growth, and the second crop can be started in the greenhouse. The second crop might reach full height in time to be hardened in the shadehouse, but that is not certain. Hardening in the shadehouse is cheaper than hardening in a greenhouse. The greenhouse can either be shut down for the winter, or another crop can be grown, preferably one that does not demand a lot of sunlight and has a relatively low temperature optimum. It would be possible to begin germination of crop 1 several weeks earlier, but this is pushing greenhouse operation into the expensive part of the year. Perhaps crop 1 could be removed from the greenhouse before height growth is completed, because it would have most of the summer to finish its growth. This is risky, because the oak will stop height growth unless the weather is hot and humid. Even in midsummer, that is often not the case in North Dakota. Therefore, assume the second crop will be hardened and overwintered in the greenhouse.

Germination.—Initial germination will occur in bags or trays at room temperature. After planting, the greenhouse should be set for about 70° F (21° C) day and night with the cooling set to hold temperatures under 81° F (27° C) until the seedlings are well established and the first set of leaves have expanded.

Relative humidity can be set at 70% with an allowable range of 50-90%. It is not necessary to give frequent light waterings to oak, because it is a large seed, and the bulk of it is 10-15 mm below the surface. Leaves should not have standing droplets of water on them for more than a few hours a day, because that invites fungal infection.

Photosynthesis of oak saturates at quite low sunlight intensities, and yet, bur oak can tolerate high light intensity. Shading is not necessary unless day temperatures cannot be held in optimum range. That range is high, however, and as often as not, intense sunlight may be beneficial to help raise the temperature.

We do not know for sure whether supplemental light is necessary to maintain height growth, but we do know it is ineffective unless temperature is kept high. Since intermittent incandescent light is not expensive, it would be advisable to have it on after the first leaves have expanded, just for insurance.

Watering should be as needed to keep the rootball moist. The surface should dry between waterings, and no fertilizer is applied until the seed is largely used up, or until the majority of seedlings have their first leaves expanded. There is no point in turning on the high CO_2 until the first leaves are expanded either.

Juvenile and multiple flushing stages.—There is little or no distinction between a juvenile and a more mature stage. Bur oak does not grow in height in a recognizable exponential fashion, but rather in very distinct flushes with pauses in between. Each flush, up to four, is roughly the same size.

After the seedlings are well established, the day temperature should be raised to about 90° F (32° C). An efficient way to do this would be to leave the furnace setting at about 75° F (24° C) and set the first cooling stage at 90° F (32° C) with full cooling on by 98° F (37° C). This may seem incredibly hot to some nurserymen, but it is the environment required to maintain multiple flushing of bur oak.

Relative humidity should be kept fairly high, because at high temperatures the transpiration stress is greater for a given relative humidity than at lower temperatures (table 11-1). Note that the combination of high temperature and humidity will make working in the greenhouse very uncomfortable, and jobs in the greenhouse should be scheduled for the early morning. Workers not used to the heat and humidity should eat enough salt, drink enough water, and take occasional breaks (Johansson and Mattsson 1975).

After the supplemental light and CO_2 are turned on and fertilization with each watering has begun, no further changes are needed until the crop has reached full height and is moved to the shadehouse. There are some cultural differences between oak and spruce (section 15.51) that should be noted, however.

The broad horizontal leaves of oak and other hardwoods shed water, which makes uniform watering harder and increases the edge effect. Because hardwoods generally grow faster and often transpire more, the available moisture in the pot mix does not last as long, and they must be watered more often as they grow. With hardwoods, it is easier to tell when they are moisture stressed, because wilting of the leaves is more obvious than with conifers. However, foliage is damaged more quickly, and it is important to avoid wilting during rapid height growth.

Hardwoods will grow at the same low pH used for conifers, but they seem to be healthier and grow faster when the nutrient solution is kept at pH 6-7. After watering with nutrient solution, the foliage is usually rinsed to remove salts and avoid leaf injury when the droplets dry. Conifer needles wash clean easily, but broadleafed hardwoods require more thorough rinsing.

Hardwoods require more protection against insects. Whereas conifers rarely have major problems, anything that can bite or suck will attack hardwoods. Every hardwood nurseryman should familiarize himself with the appearance of aphids, whiteflies, spidermites, and plant bugs, and the damage they cause. The best control is to clean out the house completely between crops, and then fumigate. Second, be vigilant. Insect populations start small and grow rapidly. Spot spray when harmful insects are first noticed. If populations are building, begin regular weekly spraying and rotate insecticides to catch a wider spectrum of insects and retard the development of resistance (section 20).

Hardening.—When the first crop is moved to the shadehouse, the nurseryman immediately loses control of temperature and humidity, and there will be no supplemental CO_2 or light at night. In mid-June, there should be no problem moving very succulent material out of the greenhouse, but the transition to cooler nights, probably cooler days, and much lower humidity, should trigger budset without any need to drought stress. Once in the shadehouse, watering should be as needed but with the low N, high PK formulation. This should be continued throughout the summer and fall as long as the day temperatures are above freezing and the rootballs are not frozen. About the time the rootballs begin freezing and after the leaves have fallen, bait the containers with rat poison and mulch around the sides and over the tops of the seedlings with sawdust, straw, coarse peat, or other suitable material. The shadehouse must be rabbit-proof. No other care is required until the stock is ready to be shipped in the spring. At this time, the mulch is removed, and the stock is watered thoroughly with high N nutrient solution just prior to shipment.

The second crop is handled exactly the same way through the germination and multiple flushing stages. On October 1, when hardening in the greenhouse begins, temperatures are reduced to levels that will stop flushing, set buds, and continue caliper growth, particularly in the taproot. It is not necessary to drought stress the seedlings to cause this.

Supplemental light at night is shut off to put the crop on a short photoperiod. This is standard procedure with all species, but unlike with conifers, the high CO_2 is also turned off. High CO_2 during the first stage of hardening is beneficial to evergreens, because it promotes caliper and dry weight growth. However, the high CO_2 must be turned off at the beginning of hardening of deciduous species, because CO_2 also retards leaf abscission and may promote bud break and renewed height growth.

Watering is continued as needed but with the low N, high PK formulation.

Another major difference between most conifers and most hardwoods is that the latter are deciduous, and normal abscission of the leaves is an important part of the hardening process. Accelerating leaf abscission has not been very successful. A number of investigators have sought chemical means to defoliate seedlings without damaging them. So far, nothing suitable can be recommended. Chemicals that effectively remove the leaves cause dieback the following spring.

Cold nights will cause the development of fall colors and begin the development of an abscission layer, but the leaves will generally not fall off until well into the second stage of hardening, in which the temperature is brought very close to freezing. No other changes in conditions are needed to go from the first to the second stage of hardening. These conditions are maintained throughout the winter. After 2 weeks at low temperatures, frosts will not hurt the seedlings, but the rootballs should not be allowed to remain frozen for weeks at a time.

The second crop will have to be removed from the greenhouse before about March 7 so that the next year's first crop can be planted. This can be done anytime after December 15. They should be moved to the shadehouse in mild weather, if possible, and the seedlings should be placed flat on the ground and mulched immediately just like the first crop. Both crops will be ready to ship for spring planting.

15.53 Large Ponderosa Pine for the Southwest

In this example, we need a husky seedling with a 6-inch (15-cm) top and ¼-inch (6-mm) caliper ready for outplanting about July 15 (Appendix 2). In the Southwest, mid- to late summer is the best time to plant, because that is when the rains come. A cold hardened seedling is not necessary, but the top should not be actively flushing. This means it should receive the first stage of hardening, but not the second. Hardening must begin about June 7 if we allow 5 weeks. To be sure that a large enough seedling can be grown, allow about 22 weeks from seed, which means seeding the first week in January. In New Mexico or Arizona, winter does not pose the same problems for greenhouse operation that it does in colder, high latitude climates. Day length, sun angle, and sunlight intensity are generally still favorable even in December and January. Heat requirements to maintain growing temperatures are within reason in a properly designed facility.

Germination.—Conditions for ponderosa pine germination are not very different from white spruce in the first example (section 15.51). The seed usually does not need stratification, and 70° F (21° C) day and night is a good germination temperature. Relative humidity should be kept high and the surface always moist until germination is complete. Use no fertilizer until the seed coats are shed.

Shading may or may not be necessary. Sunlight intensity in January is near its minimum, but some nurseries may be located at fairly high elevation (4,800-8,000 feet or 1,200-2,500 m). If it is hard to keep the soil surface moist and the temperature down to 70° F (21° C), then shade; otherwise don't.

Juvenile stage.—In ponderosa pine, the juvenile stage is distinct and may be defined as the period between the shedding of the seedcoat and the appearance of buds and needle fascicles. As soon as the seedcoat is shed, begin fertilization with high N nutrient solution of about pH 5.5. Turn on the high CO_2 whenever the vents are closed during daylight hours. Turn on the supplemental light at night to lengthen the photoperiod. This is not as critical with a low latitude seed source as it was in white spruce (section 15.51), but it is cheap insurance against premature budset, which could delay reaching full size, and there is an appreciable growth response both in height and dry weight.

As the seedlings grow older, they can use more light and higher temperatures. Excessive temperatures must be avoided, especially before the hypocotyl lignifies and develops some bark.

Multiple flushing and exponential growth.—The seedling will grow exponentially until the first buds appear. Thereafter, there will be periods of elongation interspersed with budset. Each successive flush tends to be larger than the previous one until the crowns close and the container size becomes limiting. As long as nearly optimum conditions are maintained, budset should cause no alarm.

Sunlight intensity will gradually increase with the advancing season, and so will the capacity of the seedling to use it. For most, if not all, of the growth period, shading should be applied only if near optimum temperatures cannot be maintained.

Hardening.—Only the first stage of hardening is needed, but time is likely to be short. To maximize the rate of hardening, the first step is to water heavily to leach out N. Then allow to dry to the wilting point. This will occur the second week in June, when greenhouse temperatures could become hot and humidity is quite low. The drying will have to be monitored closely. If there is much non-uniformity of conditions, some trees will be much drier than others and may have to be spot watered by hand, so that the remainder can continue to dry. When the trees have reached the wilting point, they are rewatered with low N, high PK solution, and thereafter watered with the same as needed.

Hardening may be done either in the greenhouse or a shadehouse. In either case, supplemental light at night and the high CO_2 are turned off. In the greenhouse, it will probably be difficult to keep day temperatures down below 75° F (24° C). Shading will certainly be necessary, but evaporative cooling in the dry climate of the Southwest is very efficient and effective. Moving the seedlings to a shadehouse will subject them to much lower humidities than in the greenhouse. They will need good wind protection and shading down to perhaps 30% of full sunlight. The containers should remain up on racks to permit air pruning.

By July 15, the buds should be well set and the stem fully lignified. They should be well watered and fertilized with high N nutrient solution immediately prior to shipment. After outplanting, root growth should be extensive, but renewed top growth that season is unlikely.

15.54 Other Examples of Growing Schedules

Appendix 2 contains a collection of growing schedules developed for individual nurseries. They are presented as models to further illustrate the strategy for growing the desired product. In certain cases, they may fit a new operation closely enough to be used as a first try with little modification, but, in most cases, they will require some changes to fit local conditions.

SECTION 16.—SEED AND SOWING

SECTION 16.—SEED AND SOWING

16.1 Propagation Materials and Methods

Most trees grown in forest tree seedling containers are conifers. Most of this production is in the western United States, with a limited amount in the South and East (McDonald 1977). A few broadleaf tree seedlings are reared in containers in the Plains states for shelterbelts and windbreaks. Nearly all of these trees, both conifer and broadleaf, are propagated from seeds. Very few container trees are propagated from cuttings, with the exception of some cottonwood in the Plains and South. However, considerable research is underway on vegetative propagation of conifers, mainly oriented toward acquiring genetic gains more rapidly. The reader should expect vegetative propagation to be increasingly used in nursery operations in the future.

Considerable work is being done on greenhouse propagation of native shrub and grass species. Forest seedling tree containers are sometimes used. Such shrub seedlings and grass plugs are valuable in disturbed land revegetation projects, range improvement, and park landscaping (Cable 1974). Seed for these plants is usually scarce, and greenhouse propagation yields the most plants for the available seed.

16.11 Seed Quality

Generally, only very high quality seed should be used, because it is costly to carry blank cavities through the growing cycle in the greenhouse and to thin excess seedlings from the containers. High quality seed helps avoid both situations by providing reliable germination with the use of fewer seeds per cavity. From the seedling production probability tables in appendix 3 (Balmer and Space 1976), it can readily be seen how high quality seed can provide seedlings in most cavities, requiring little thinning.

As a rule of thumb, seed with viability lower than 50% should never be used in CTS operations, and 75% is minimum under most circumstances. Many CTS operations "size" their seed prior to stratification. "Sizing" means taking only the largest and heaviest one- to two-thirds of a seed lot. Sizing may result in more reliable establishment and higher total germination percentage, because those seeds that are full and that have the largest endosperm capacity are selected. Some geneticists are concerned that seed sizing reduces the genetic base, because seed size tends to be a characteristic of the parent tree. However, seed size also varies from one crop to the next on the same tree. Consequently, when this is the case and seed crops are available over a period of years, seed sizing would not discriminate against individual parent trees nearly as much as it might in any one year. Tinus (1978) has shown this to be true of Scotch pine.

However, many western conifers do not have seed crops every year. Nurseries rely heavily on infrequent heavy seed crops for their production. This maximizes the discrimination against certain parent trees. It is not hard to show that seed sizing has operational advantages at the container nursery, but it may be quite difficult to demonstrate that seed size is genetically linked to other traits we want to preserve in the next generation.

In cases where seed is very valuable, as from tree improvement experiments, every seed may be sown, even though the average viability may be low. In such instances, relatively few seeds may be sown per cavity and numerous blanks accepted, or excess trees in some cavities may be transplanted to empty cavities by hand. Expensive or rare seeds or seeds that do not germinate evenly may also be germinated in flats and then placed in the container. This procedure is used with some species of native shrubs and with walnut, oak, and pecan (Tinus 1977). This procedure also allows blocks of containers to be grown with seed that all germinated about the same time. Several blocks of trees or shrubs of different size levels are thus created as the seeds germinate, but plants within a block are more or less uniform. Such procedures are expensive, but the alternative of oversowing, a great deal of thinning, seed wastage, and inter-plant competition and suppression is expensive, too.

Knowledge of the quality of seed used at a tree nursery is essential. Sowing tree seed without adequate seed test data and carefully calculated sowing rates is archaic and wasteful. This is especially true in CTS production. Excellent tree seed testing services are available from a number of seed laboratories in the United States.

16.12 Seed Source Identification and Its Importance

Source identified seed should be used in all CTS operations. This identification should be preserved through the growing process, and trees produced should be planted at or near to the original seed collection site (in accordance with locally accepted rules established by professional forest geneticists). Production of source identified seedlings will identify the nursery as a truly professional operation. The dangers of planting stock that is not well adapted to the site are well known. Failure of containerized trees due to genetic incompatibility with the planting site can question the creditability of nursery, the container system, and the parent forestry organization. Finally, nurserymen are entrusted to produce trees that will live and grow. By distributing stock of unknown origin for widespread planting, the nurseryman betrays trust placed in him.

16.2 Filling the Containers

To unitize and fill the containers requires the growing medium, the containers, a place to work, the labor force to do the job, and a system or plan to do the work.

16.21 The Growing Medium—Operational Considerations

The component parts of the growing medium must be on hand in sufficient quantities to provide adequate medium for the whole job. The combination of components and a small amount of water should take place in bulk a few days before the filling operation (see section 9.34). At container loading time, be sure the mixture is uniformly mixed, with the proper moisture content. Ideally, the peat and vermiculite should be kept sealed in plastic or paper bags up to mixing time. The mixing equipment and area should be cleaned before, and every couple of days during the process. The medium should be covered with clean plastic film to prevent drying and contamination when not in use.

16.22 The Containers

If the containers have been used for a previous crop, they should have been sanitized before re-use. For efficiency, damaged containers should be sorted out and discarded prior to the filling process. Those requiring assembly or placement into racks or trays can be set up in advance.

16.23 Work Location

The area for the mixing operation should be (1) large enough to do the work (i.e., encompass the workers, equipment, and materials), and (2) be free of contaminants such as soil, dust, etc. A building with a smooth concrete floor is best. Having this work area near the greenhouse(s) is a distinct advantage.

16.24 Labor Force

Enough labor should be employed to assure smooth functioning of the filling operation. This operation is usually short term for a variety of reasons, so, large amounts of labor can be employed economically. Adequate supervision will assure a high quality, fast moving operation.

16.25 A Work System or Plan

A plan is needed to allow completion by a certain date. This plan should provide for smooth, fast progress of the container filling through the sowing process. Unanticipated problems are sure to arise, but good preplanning should minimize them by helping isolate equipment shortages and bottlenecks in advance. A simple schematic diagram of the materials flow and work stations is usually helpful.

The container filling process integrates growing medium, containers, work area, equipment, and labor into a high intensity production effort that takes place over a relatively short period of time. This work can consume a large part of a CTS nursery budget, so, every effort should be made to do the work efficiently and rapidly. The degree of mechnization of the process depends on the size and sophistication of the operation. Containers can be filled with growing medium and stored. The work area can then be converted to a seeding and seed covering operation. This process can make the best use of a limited work area or a few workers, and the whole crop is started nearer to the same time. However, the filled containers have to be handled an extra time, and the growing medium must be kept moist.

16.3 Sowing Seed in the Containers

Equipment used for sowing and covering the seeds is discussed in section 7.3. The equipment and methods used vary widely.

16.31 General Sowing Considerations

The number of seeds that will germinate and result in an established seedling is correlated directly with seed viability. In CTS nurseries, the difference between the germination test percentage and the actual number of trees produced is less than in a conventional nursery. This is because environmental factors are controlled, optimized, and the growing medium is sterile. The size of these differences in CTS nurseries is not well known. Good records can pinpoint what such sowing factors actually are, but knowing them is not nearly as critical in CTS nurseries as in bare-root nurseries. This is because CTS nurserymen habitually oversow to acquire the maximum number of filled containers, not total trees germinated. Only a few blank containers can be tolerated, because greenhouse growing space is costly. The number of seeds to sow in each container must be decided. Probabilities of achieving tree establishment for a certain number of seeds sown per container is the crux of the sowing process.

Quality of seed is important. Probability tables provide estimated numbers of seedlings to be produced from seed. Earlier, it was recommended that seed with viabilities below 75% should not normally be used. This is because sowing large numbers of seed per cavity requires (1) many repetitions of the sowing process per container, and (2) excessive thinning later on. Also, as the quality of seed declines, there is generally an increasing divergence between the number of live seeds according to a germination test and the number that will develop into self-sufficient tree seedlings. If very low quality seed must be used, consider sowing germinated seed. The same applies to rare, costly, or uneven germinating seed. In some cases, the sheer size of the seed precludes putting more than one in a container. With very large seeds, the orientation of the seed and radicle is important. Walnuts should be centered in the container with the nut on its side, with the seam between the halves vertical, and the radicle end of the nut pointing toward a corner of the container; pecans and acorns should be placed in a corner or against one wall with the radicle end pointed toward the center of the container (or radicle pointed down if developed to any degree) (Tinus 1977a). With such large seeds a large container is needed. The point is that, for some species and instances, manual planting of germinated seeds is best.

The type of container used, the greenhouse space available, the local labor costs, the external pressure to reliably produce trees, the current price for containerized seedlings, fuel costs, and seed availability all can influence the nurseryman's decision on how many seeds to place in each cavity.

Container used.—In book or block style containers (section 9.2), if a tree does not develop in a cavity, it must be left in the unit. A seedling must be transplanted into it for it to be a productive cavity. The tendency should be to oversow at the outset to ensure a high percentage of filled cavities.

Empty cells of cell container systems can be removed from the unit racks on an individual cell basis. Consequently, the grower can sow extra cells and replace blank cells with the extra full ones. The strategy here might be to sow fewer seeds per cavity to reduce thinning, and to sow extra cells to replace blank ones.

Greenhouse space available.—If greenhouse space is limited and demand for seedlings is high, there may be justification for placing more seeds per container. This is the case if high priority on maximum production overrides possible added thinning costs.

Local labor costs.—High local labor costs can discourage oversowing in an effort to avoid high thinning costs. It may be cheaper to carry added blank cavities and do less thinning and transplanting. However, relatively low local labor costs may encourage the converse.

Fuel costs.—Fuel costs would affect seed sowing about the same way labor costs do, but in just the opposite way. High fuel costs encourage maximum greenhouse productivity, and, therefore, encourage oversowing per cavity.

Profit margin.—A high profit ratio on containerized tree seedlings encourages oversowing to maximize production, even if this elevates unit production costs. Smaller profit margins compel the nurseryman to minimize unit production costs to maximize unit production profits, not mass production profits, as in the first case. Space and Balmer (1977) have developed a computer program that provides the optimum number of seeds to sow per cavity to minimize seeding, transplanting, and thinning costs for a given seed quality and cost factors for the seed, sowing, thinning, and transplanting at a nursery. Figure 16-1 is a sample of a printout from this computer program. To use this potentially valuable tool, the CTS nurseryman must estimate, or have records of, the unit costs for the labor associated with the various activities in his operation. The program entitled, "Minimum Cost Calculations for Container Planting" published in January 1977, is available from the USDA Forest Service, Atlanta.

Seed availability.—Seed shortages tend to prevent oversowing in each cavity and encourage transplanting excess trees from one container to blank ones. Adequate supplies of seed help assure the most economical operation of CTS nurseries.

16.32 Procedure

The sowing procedure actually begins with determination of how many trees of what species and seed source will be grown. The steps leading up to sowing are:

a. Determination of seed needs
b. Stratification of the seed
c. Preparation of stratified seed for sowing
d. Sowing

Determination of seed needs.—The task of the nurseryman is to translate production goals into tree seedlings. The following example is reproduced from Space and Balmer (1977):

BLANK CELLS WILL NOT BE REPLANTED

NUMBER OF TREES TO BE PRODUCED	272000
NUMBER OF SEEDS PER POUND OR KILOGRAM	3900
COST OF SEED PER POUND OR KILOGRAM	4.10
PERCENT GERMINATION AND SURVIVAL	60.00
COST OF SOWING SEED IN CELLS	.07/100 SEEDS
COST OF CARRYING EMPTY CELLS	.77/100 CELLS
COST OF THINNING EXCESS TREES IN CONTAINERS	.42/100 EXCESS TREES

SEEDS/ CELL	NO. OF CELLS	NO. OF SEEDS	BLANK CELLS	EXCESS TREES	LB. OF SEED
1	453333.	453333.	181333.	0.	116.24
2	323810.	647619.	51810.	116571.	166.06
3	290598.	871795.	18598.	251077.	223.54
4	279146.	1116585.	7146.	397951.	286.30
5	274814.	1374070.	2814.	552442.	352.33
6	273119.	1638712.	1119.	711227.	420.18
7	272446.	1907125.	446.	872275.	489.01
8	272178.	2177427.	178.	1034456.	558.31
9	272071.	2448642.	71.	1197185.	627.86
10	272029.	2720285.	29.	1360171.	697.51
11	272011.	2992125.	11.	1523275.	767.21
12	272005.	3264055.	5.	1686433.	836.94
13	272002.	3530024.	2.	1649614.	906.67

SEEDS/ CELL	COSTS SEED	SOWING	BLANK CELLS	THINNING	TOTAL	
1	476.58	317.33	1396.27	.00	2190.18	
2	680.83	453.33	398.93	489.60	2022.70	= MINIMUM COST SOLUTION
3	916.50	610.26	143.21	1054.52	2724.49	
4	1173.85	781.61	55.03	1671.39	3681.87	
5	1444.54	961.85	21.67	2320.26	4748.31	
6	1722.75	1147.10	8.01	2987.15	5865.62	
7	2004.93	1334.99	3.44	3663.55	7006.90	
8	2289.09	1524.20	1.37	4344.72	8159.38	
9	2574.21	1714.05	.55	5028.18	9316.99	
10	2859.79	1904.20	.22	5712.72	10476.92	
11	3145.57	2094.49	.09	6397.76	11637.90	
12	3431.44	2284.84	.04	7083.02	12799.33	
13	3717.36	2475.22	.01	7768.38	13960.97	

Figure 16-1.—Sample printout showing least cost solution to a sowing problem (Space and Balmer 1977).

Laboratory seed tests provide germination percent, purity, expected survival, and seed per pound for each seed lot. A nurseryman can calculate the number of seeds needed per cell to provide a given number of filled cells by the use of probability formulas. In addition, by determining the numbers of blank and filled cells, the number of excess seedlings that will have to be replanted or removed by thinning can also be predicted. Balmer and Space's (1976) tables can save the nurseryman the trouble of making many sowing calculations by hand (probability tables are provided in appendix 3). From that publication the authors have drawn the following examples to illustrate this:

"Assume 250,000 seedlings are desired, and test of seed lots indicate a 75% germination rate and expected survival rate of 60% and 20,100 seeds per pound (44,300 per kg): tables 16-1 and 16-2 show the calculations for two options using 60% expected survival and comparing the use of two and three seeds in each cell.

"If two seeds are sown per cell, option 1 indicated 120,000 cells would not need thinning or replanting. Containers seeded to three seeds per cell would have 72,000 cells not requiring thinning or replanting. Cost of seed, containers, and thinning, would be lowest for two seeds per cell, and cost of replanting would be lowest for three seeds per cell, with 16,000 blank cells. Under Option 2, cost of containers and media would be lowest, when three seeds per cell are used. Cost of seed and thinning would be lowest for two seeds per cell.

"The same comparison between the two approaches can be made for larger numbers of seeds per cell. While computations are more involved, the tables can be used to predict the number of seedlings per cell when seeding methods used produce a range in the number of seeds per cell. Sampling seed containers will provide the information necessary to carry out the computation. Table 16-3 is an example of this procedure using the 60% expected survival rate and 250,000 cells: from a sample count after sowing, 5% of the cells were blank, 20% contained one seed, 36% contained two seeds, and 39% contained three seeds.

"From this information, the nurseryman can estimate the number of seedlings that will require thinning, and the number of cells that will be blank. If replanting blank cells is planned, he can determine if the extra seedlings will be sufficient for replanting needs or how many seedlings he needs to raise in flats.

"The importance of using high quality seed can be readily seen by examining the probability tables. For two seeds per container the number of blank cells changes from 4 per 100 cells at 80% germination to 16 per hundred at 60% germination.

"A nurseryman can use the information developed from the probability tables to select the cost effective seeding rate, utilize seed to the best advantage and estimate future costs related to seeding practices. For example, if containers with 272,000 cells are to be used and excess seedlings are to be replanted as needed with the balance to be removed by thinning, estimated costs and seed requirements can be calculated. Suppose the seed used has a 60% germination rate, costs $4.10 per pound, and has 3,900 seeds per pound. Estimated costs in this case are: 7¢/100 for sowing seed; 98¢/100 containers replanted; and 42¢/100 for excess trees removed by thinning. Under these estimates the following figures would apply:

	Seeds per cell	
	2	3
Pounds of seed	140 (63.5 kg)	210 (95.3 kg)
Seed costs ($)	574	861
No. seeds	544,000	816,000
Sowing costs ($)	380	571

"The estimated number of containers to replant for two seeds per container will be 0.16 x 272,000 + 43,250 and for three seeds per container will be 17,408. Excess seedlings resulting will be 54,400 in the cells with two seeds and 217,600 in the cells with three seeds.

"Costs for replanting and thinning would be:

Seeds/Cell	Replanting	Thinning
2	$426	$228
3	$171	$913

Total costs for seed, sowing, replanting, and thinning would be $1,608 when two seeds per cell are used and $2,516 when three seeds per cell are used."

There are simpler less exacting, ways to figure seed needs using rules of thumb such as: for germinations from 60-75% use three seeds per cavity; 75-85% use two seeds; 85-99% use one seed, etc.

These sowing rules are generally arrived at by trial and error and refined through experience. They can work very well or very poorly. The authors recommend the method outlined by Space and Balmer (1977), because it uses the best information in an effective way.

Seed stratification.—Many tree seeds germinate more uniformly if they have been stratified. If this is not done, many tree seeds will germinate intermittently over a long period. Intermittent and prolonged germination is intolerable in a greenhouse. Seeds of some conifer species may germinate reliably in 2 weeks without stratification. Where this is known, stratification is not warranted. Where germination takes longer, seed should be stratified.

Table 16-1.—Option 1. Calculation of seed required and seedlings produced assuming a 60% survival rate, replanting blanks with extra seedlings, and thinning the remainder.

Total no. of cells needed	No. of cells by predicted[1] no. of seedlings per cell				Total no. of seedlings predicted	Pounds of seed required
	Blank	1	2	3		
			Using 2 seeds per cell			
(1.00)	(0.16)	(0.48)	(0.36)			
250,000	40,000	120,000	90,000		[2]300,000	[3]24.9 (11.3 kg)
			Using 3 seeds per cell			
(1.00)	(0.064)	(0.288)	(0.432)	(0.21)		
250,000	16,000	72,000	108,000	54,000	450,000	37.3 (16.9 kg)

[1]*Figures in parentheses are percentages taken from appropriate probability table.*
[2]*Expect 120,000 cells with one seedling + 2 x 90,000 cells with two seedlings = 300,000.*
[3]*Number seeds sown divided by seeds per pound (i.e., 250,000 x 2 ÷ 20,100 = 24.9).*

Table 16-2.—Option 2. Calculation of seed required and seedlings produced assuming a 60% survival rate and thinning only.

Total no. of cells needed	No. of cells by predicted[1] no. of seedlings per cell				Total no. of seedlings predicted	Pounds of seed required
	Blank	1	2	3		
			Using 2 seeds per cell			
[4](1.00)	(0.16)	(0.48)	(0.36)			
297,619	47,619	142,857	107,142		[2]357,141	[3]29.6 (13.4 kg)
			Using 3 seeds per cell			
(1.00)	(0.064)	(0.288)	(0.432)	(0.216)		
267,094	17,094	76,923	115,384	57,692	480,767	39.9 (18.1 kg)

[1]*Figures in parentheses are percentages taken from appropriate probability table.*
[2]*Expect 142,857 cells with one seedling + 2 × 107,142 cells with two seedlings = 357,141.*
[3]*Number seeds sown divided by seeds per pound (i.e., 297,619 x 2 ÷ 20,100 = 29.6).*
[4]*Divide number of seedlings desired by total percent of cells predicted to have seedlings, i.e., 250,000 ÷ (0.48 + 0.36) = 297,619.*

Table 16-3.—Prediction of number of seedlings per cell by seed count.

Seed cell	Number of cells	No. of cells by predicted[1] no. of seedlings per cell				Total no. of seedlings predicted
		Blank	1	2	3	
Blank	12,500	12,500				
		(0.40)	(0.60)			
1	50,000	20,000	30,000			30,000
		(0.16)	(0.48)	(0.36)		
2	90,000	14,400	43,200	32,400		108,000
		(0.064)	(0.288)	(0.432)	(21.6)	
3	97,500	6,240	28,080	42,120	21,060	175,800
Total	250,000	53,140	101,280	74,250	21,060	313,500

[1]*Figures in parentheses are percentages taken from appropriate probability table.*
[2]*Estimate 43,200 cells with one seedling + 2 × 32,400 cells with two seedlings = 108,000.*

Stratification of conifer seeds usually means exposure of the seed to low temperatures (32-50° F; 0-10° C), and moist conditions for 1-6 months (Schopmeyer 1974). Often, the seeds are subjected to a moist, warm soak before chilling. The mechanics of the stratification procedure vary and can be accomplished in a number of ways. Probably the best and most comprehensive reference on the subject is Schopmeyer (1974). This publication provides species by species guides for stratification.

Preparation of stratified seed for sowing.—Conifers usually require a cold moist stratification. This means the seed will have to be surface dried at low temperature to be dry enough to flow through seed handling machines. Seed coats of some tree seeds may harbor spores of pathogenic fungi. In such cases, surface sterilization with 30% hydrogen peroxide or 1% sodium hypochlorite may be useful. The time of soaking will vary with the species, but all seed should be thoroughly washed with running water following treatment (Barnett 1976, Riffle and Springfield 1968). However, this treatment should only be used where necessary and when it has been tested on the species in question. Improper application can damage the seed.

Surface dried seed is sometimes mixed with talc to promote smooth flow through seed sowing devices and to minimize seed stickiness.

Sowing seed into the containers.—Sowing equipment and methods are described in section 7.3. The prime conditions of the sowing operation are accuracy and efficiency. Accuracy means putting the exact number of seeds desired into as high a percentage of the cavities as possible. Also, it is best if the seed is placed in the center of the cavity when sowing conifer seed. A dish shaped depression in the surface of the growing medium can be created as described in section 7.2. The seed is normally not firmed into the medium, but rests on its surface in the depression.

16.33 Covering the Seeds

In CTS nurseries, the seeds are normally covered with a thin layer of crushed rock (poultry grit) or perlite. In a few instances, the seed is covered with a thin layer of growing medium, ground bark, sand, or not covered at all. Conifer seed should generally be covered with grit or perlite. Covering with organic materials or materials such as fine sand promotes proliferation of mosses, fungi, liverworts, etc., on the surface of the cavity. This tends to inhibit water infiltration into the potting medium. Perlite and grit particles should be no less than 2-3 mm in diameter. With some brands of perlite, smaller particles may have to be screened out. In the proper size range, both perlite and grit provide several positive effects.

1. They shield the seed from the direct rays of the sun, but allow diffuse light to reach it. This aids germination in some species (Harrington 1977).
2. They provide some minimal weight on the seed which facilitates mechanical entry of the radicle into the growing medium.
3. They are sterile and provide a droughty surface, uninhabitable by moss, liverworts, and fungi.
4. They are readily permeable to water.
5. They are particulate and more or less uniform, which facilitates mechanical application of thin layers of them to the surface of the containers.

Perlite has the added advantage of being lightweight, but can be blown away, floated away, or knocked out of the cavity by impacts of large water drops. Grit will stay in place, but adds appreciable weight. The layer of perlite or grit applied should vary from zero or very thin layers for small seeds up to about 5 mm for large seeded species. Some small seeded conifers, such as Engelmann spruce, may do well with no covering.

Fast growing or large seeded broadleaf species can be covered with growing medium, because they emerge and shade the containers in a short time. This shade inhibits moss and liverwort development, so, water infiltration into the growing medium never becomes a problem.

The depth of seed covering applied to any species should be as uniform as possible to facilitate uniform plant growth and development.

SECTION 17.—GROWING THE TREES

17.1 Germination, Thinning, and Transplanting

17.2 Juvenile Development and Exponential Growth

17.3 Caliper Development and Cold Hardening

17.4 Movement of Trees to a Shadehouse

SECTION 17.—GROWING THE TREES

When the containers have been filled, seeded, and moved to the greenhouse, the actual growing of the trees begins. These procedures fall into three phases: (1) germination, (2) juvenile development and exponential growth, and (3) caliper development and cold hardening. Each phase is characterized by differences in the seedlings and the greenhouse environment.

17.1 Germination, Thinning, and Transplanting

Germination, thinning, and transplanting all occur in a relatively limited period of time after the seeded containers are placed in the greenhouse. As mentioned in section 16, the greenhouse should be loaded with all the seeded containers at about the same time so that the trees get off to an even start. This promotes crop uniformity and helps the operator of the greenhouse determine when germination is complete. The greenhouse environment can then be altered to promote growth instead of germination. The greenhouse should be loaded in no more than 2 to 3 days. This may mean some container units have to be filled, seeded, and stored while the rest are seeded. Seeded containers should be kept in high humidity cold storage conditions to retard drying and seed germination.

17.11 Germination Conditions

During the germination period, seeds are kept moist and reasonably warm (65°-70° F or 18°-21° C). Higher temperatures may result in germination of conifer seed, but may also result in excessive hypocotyl development. Frequent light watering may be needed. Overwatering should not cause the problems common when plants are grown in soilbased media. The humidity of the greenhouse atmosphere should be in the 60-80% range. In single layer greenhouses, in cold weather, even supplemental watering or other humidification may not be able to maintain these levels.

17.12 Covering Containers During Germination

In many horticultural operations and some CTS nurseries, the flats of seed to be germinated are covered with plastic to reduce evaporation and keep the seeds moist with a minimum of irrigation. Some precautions must be taken when using plastic coverings.

Black plastic, or other completely opaque, impermeable covering materials can become very hot from the sun. Also, light stimulates germination of many tree seeds. These light levels are not high (75-125 foot-candles), but are important to germination (Association of Official Seed Analysts 1970). Section 16.33 notes that one of the reasons for using coarse particles is to allow diffuse light to reach the seeds. For these reasons, black plastic is not recommended for covering containers during germination.

Clear plastic sheeting can be used to cover containers. However, the layer of clear plastic can trap enough solar energy to cause unacceptably high temperatures under the film. Its use is not recommended. The best covering lets some light through to the containers, but not too much. White polyethylene sheeting will do this. Clear plastic sheeting with a layer of butcher paper or newspapers over it will also work.

In CTS greenhouses with both germinating seeds and actively growing trees, covering containers containing germinating seeds will keep the seeds moist without frequent watering, which might not be good for the established seedlings. Covering the containers during germination is not required but simplifies maintaining optimum germinating conditions for the seeds, but the covering must not create complete darkness or high temperatures.

17.13 Completion of Germination

If properly stratified prior to placement in the greenhouse, germination of most conifer seeds should be complete in 10 to 25 days (average 15 days). It is judged to be complete when: (1) most of the seeds have germinated, (2) most conifer seed coats have been shed, (3) the root systems of the trees have grown into the growing medium. If the containers have been covered, the cover should be removed before the seedling shoots are pressing against it. As the seedling develops, water less often to let the soil surface dry between waterings. Greenhouse temperatures and humidity levels are changed to those best for the juvenile growth phase of the tree species in question (section 15.3). In greenhouses where northern latitude tree ecotypes are grown in fall and winter, lights should be turned on at night for dormancy control immediately after germination is complete.

17.14 Thinning

More than one seed is usually sown per container cavity to assure most cavities are finally occupied by at least one tree (section 16.32). This results in cavities being occupied by more than one tree.

Extra trees are removed once the seedlings are judged to be sufficiently established. Thinning is started when: (1) the seed coats have been cast off, (2) the crop has been on the juvenile environmental control regime for at least a week, and (3) the danger of serious losses to damping off fungi appears to be diminished.

17.15 Thinning Procedures

There are two thinning procedures that are normally used—whole tree removal and clippings. Whole tree removal is the recommended procedure. It involves removal of the seedling, root included, from the container. This can continue until seedlings develop lateral roots, usually 3-4 weeks after germination for western conifers. When lateral roots develop to the point where seedling removal is seriously disrupting the growing medium and the seedling left in the container, whole tree thinning should be stopped. Consequently, western conifers can be thinned during about 2-3 weeks. It is important the work does not start before germination is complete, because rethinning may be required to remove late germinants. To get the job done in the limited time available, the nursery crew has to be large enough. Estimated production rates can be based on thinning rates recorded in past years or by working a small thinning crew to start with, observing production per man day, then adjusting the crew size accordingly.

After lateral roots develop, any excess trees remaining will have to be clipped at ground level with scissors. This is less desirable than removing the entire tree, because it is easy to inadvertently cut off the residual crop seedling, too. Also, the roots of the excess trees are left in the container. This dead organic matter can become the substrate for pathological organism development.

Clipping is best done before appreciable inter-seedling competition develops. This avoids growth losses from competition. However, the timing is not as critical as with whole tree removal, and clipping can go on up until the time that the trees are shipped.

Whichever method is used, thinning must be done with sufficient care so that the remaining seedling is undamaged. There is disagreement as to whether whole tree removal or clipping is more likely to cause inadvertent removal of the remaining seedling.[1] Such

[1]*Personal communication with Phillip Hahn, Georgia-Pacific Corp., Eugene, Oreg., May 1978.*

mistakes can be minimized by holding the tree to remain with one hand and pulling or clipping the rest with the other.

17.16 Other Thinning Considerations

In either type of thinning operation, the trees or tree parts removed should be placed in refuse containers (cans, boxes, etc.) as the work proceeds. This refuse should be removed from the greenhouse each day. Leaving these dead plant parts scattered in the greenhouse is an invitation to disease and insect problems.

Bench design should take into account that workers must be able to reach each cavity (section 7.4). Thinning is tedious and rather exacting work, and if it must be done from a strained or unorthodox position, production inevitably suffers, and labor costs can soar.

17.17 Transplanting

Some CTS nurserymen transplant thinned seedlings into the blank cavities which contain no successful germinant. Since those seedlings removed in the whole tree thinning method have few or no lateral roots, transplanting them is easy but time consuming. Holes are made in the center of the growing medium in the blank containers with a sharpened pencil, nail of sufficient size, or a table knife. The seedling's root is placed in the hole and the medium is pressed against the roots to close the hole. This same procedure is followed when placing the plants germinated in flats into CTS containers. Transplanting is difficult and less successful when the containers are covered with perlite or grit.

The economics of transplanting are questionable. Some seedlings inevitably die from transplanting shock. Assessments of these losses and labor costs to do the work will determine if transplanting is economical. The cost of transplanting is usually quite high. For this reason, it should be avoided if possible. Data should be collected on just what the operation does cost and how many more plantable seedlings are produced so such judgments can be made from accurate figures.

17.2 Juvenile Development and Exponential Growth

17.21 Characteristics

During this period of CTS crop production, the nurseryman operates the greenhouse in accordance with the environmental conditions specified in the growing schedule and monitors greenhouse equipment function (section 15.34, 15.35). Records on activities and instrument readouts are kept. The crop is observed daily for disease or insect problems and for proper growth, color, etc. Excess trees are removed and empty containers are filled with transplants, as desired.

17.22 Greenhouse Operation

The environmental parameters controlled are those listed in section 15 dealing with guides for formulating growing schedules. The greenhouse needs to be programmed to provide the specified environmental conditions. In new greenhouses, this may require mechanical adjustments and modifications beyond routine adjustment of time clocks, set points, injector calibrations, etc. As seasons change, these adjustments and settings may have to be altered to cope with changes in the outside environment. A detailed record of these changes should be kept for future reference (section 18.2). Records of all cultural activities (section 18.3), instrument readings, and condition of seedlings should be kept also (section 18). Such records are valuable when planning another crop or when tracking down the reason for a problem with a crop. Trends in leachate pH and EC readings should be charted (section 18.34). The crop should be constantly monitored for insect, disease, or animal damage, and abnormal plant development in general. Corrective action must be taken when evidence of damage or abnormalities are observed (section 21).

17.23 Difference between Juvenile and Exponential Growth Stages

The most visible difference between juvenile and exponential growth periods is the nature of the foliage. The first leaves are often morphologically different than mature foliage and may form a rosette above the cotyledons. Length of this period will vary with the species. Culturally, the main difference is that during the juvenile stage, lower light intensity is recommended to reduce moisture stress and avoid solarization. Thinning usually is done early in this period. Also see sections 15.23, 15.34, and 15.35.

The exponential growth period is characterized by rapid shoot elongation, development of mature leaf forms, and proliferation of roots. Growth will be exponential during this period unless one or more factors become limiting. This does not mean that height growth is continuous; buds may set between flushes of growth. Every effort must be made to keep the environment for the seedlings as close to optimum as possible during this period. Malfunctions in equipment or inattention to seedling needs, such as irrigation, can result in apical dormancy that will extend the time to crop maturity for weeks or months. Seedlings may tend to be somewhat spindly. Highly accelerated growth can result in stems with some kinks, whorled foliage, and other anomalies which will not be seen in an outdoor nursery. These are most frequently observed in the fall and winter. Unless they are extreme, all of these symptoms are normal during the exponential growth phase. This period ends when an acceptable percentage of the seedlings reach the desired shoot length.

17.3 Caliper Development and Cold Hardening

17.31 Caliper Development and Cessation of Apical Growth

To stop height growth and set buds, the plants are moisture stressed severely for a day or two at the wilting point, lights at night are turned off, temperatures are reduced, and the fertilizer regime is shifted from high nitrogen to low N high PK. The result of these steps is the onset of apical dormancy (section 15.3). The seedling continues to grow rapidly, but in caliper, bud development, and roots, not height. Needles may continue to elongate for a while. This growth continues until the nurseryman considers caliper, bud, and root development to be sufficient. Height and caliper growth of West Coast ecotypes is not easily separated and the procedure suggested here is most appropriate for the interior West.[1]

Induction of apical dormancy in the spring or summer may be difficult with some species, unless the photoperiod is artificially shortened using curtains. However, this problem can usually be circumvented by proper scheduling of the growing cycle. Normally, tree crops should be in germination and height growth periods in the spring and early summer (section 15.2). Details of the changes in the plant's environment to induce apical dormancy are included in section 15.3 dealing with growing schedule formulation.

The next step, when seedlings have adequate caliper, bud, and root development, is to harden the seedlings for winter or for transfer to the field for planting.

17.32 Cold Hardening

Before tree seedlings are subjected to an environment harsher than they are accustomed to, they must be hardened or acclimated, if damage is to be avoided. This is done by gradually exposing them to more severe conditions to bring about physiological changes that will enable the trees to tolerate the new conditions. To cold harden, turn off supplemental carbon dioxide enrichment and lower the temperature of the greenhouse to a little above freezing, and hold it there for about 5 weeks. The development of cold hardiness is progressive. Seedlings might endure a light frost after a week of 35°-40° F (1°-4° C) temperatures and severe freezes after 3 or 4 weeks of such preparatory conditions. After 6 weeks of temperatures down to 32° F (0° C), the trees are ready to take any subfreezing temperature common to their native environment. Remember that ecotypes cannot be conditioned to withstand freezing temperatures below what they are genetically coded to stand. Consequently, an Oregon Douglas-fir seedling will probably succumb to Great Plains winter temperatures, even if preconditioned carefully.

17.4 Movement of Trees to a Shadehouse

17.41 Strategy for Use of Shadehouses

Whether is is necessary to move trees to a shadehouse prior to shipping them is determined by the growing rotation developed for successive crops of trees utilizing a given set of greenhouses. (The general construction and attributes of shadehouses are discussed in section 8).

The shadehouse may be utilized as a management tool in three ways:

As a growing facility.—Trees are grown from seed there or are moved there from a greenhouse to complete their growth prior to shipment or the onset of winter weather. This strategy is most useful in mild climates. If used for the full growth cycle, the shadehouse may need to be rodent or bird proof.[2]

As a holding facility.—This usually means the growth objectives for the trees have been achieved in the greenhouse, and it is time to put another crop of trees into the greenhouse, but the previous crop has not been shipped. In these instances, the mature crop is held in the shadehouse, usually overwinter, until the planting sites are ready to receive it.

A combination of both.—A shadehouse may serve for both storage and growth depending on the crop rotations.

17.42 Biological Requirements for Movement to a Shadehouse

The seedlings must be in a physiological state that will allow them to successfully cope with the environment of the shadehouse, otherwise they will be

[2]*Personal communication with Dr. Peyton W. Owston, Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg., June 1978.*

damaged or die. The idea is to transfer the seedlings outside into environmental conditions that approximate those previously encountered in the greenhouse or for which the seedlings have been conditioned in the greenhouse. If the transfer is made after the longest days of summer, and for some species, at any time, little added height growth should be expected. Actively growing trees usually may be transferred from the greenhouse to the shadehouse in summer without damage, but apical growth may cease once the interrupted night and warm night temperatures of the greenhouse are absent. Generally, growth in the shadehouse will be slower and, of course, very dependent on the length of the growing season remaining. Some species, such as coastal Douglas-fir, harden better if exposed to full sun than if shaded.[1]

The shadehouse should be rabbit-proof. In the fall, before the seedlings are mulched for the winter, poison bait should be placed under the containers and on the surface for rodent control.

17.43 Severe Weather Protection of Seedlings.

Trees moved to the shadehouse in late fall or winter must be cold hardy to successfully endure the low outdoor temperature. In areas of severe winter weather, the roots of the containerized seedlings may have to be protected by putting sawdust, peat, straw, or some other insulation around the groups of containers. Often, if container units are on pallets, they are removed and set flat on the floor of the shadehouse to increase thermal contact with the ground. The sides of the shadehouse should be left in place to reduce wind velocities over the seedlings and prevent winter burn. The trees should be shaded in the winter to reduce solarization and temperature fluctuation in the shadehouse. Because of the small volume of most CTS containers, moisture content must be watched closely both in summer and winter. In the interior West, accumulation of snow on seedlings in a shadehouse is usually beneficial and will not be detrimental, unless it becomes very deep (more than 2 feet or 60 cm). A moderate accumulation will help insulate the trees and prevent foliage desiccation from wind. This does not apply to West Coast ecotypes whose roots must not be allowed to freeze.[1]

17.44 Relation to Planting Site

Nurseries located at elevations lower than the intended planting sites frequently have problems keeping seedlings dormant until the planting sites are ready to receive the trees. Under such conditions, it may be necessary to move the seedlings either the previous fall or in the early spring from the nursery to a higher elevation holding area. This will assure that the seedlings will be dormant for spring planting at high elevations, so that they will not be damaged by frost following planting. This certainly adds handling and more costs, but it usually comes at a low workload period for foresters. It may be a small price to pay for long mild growing seasons at the nursery. An alternative is to put the seedlings in cold storage after they have hardened.[2]

17.45 Half-Way Houses

Where seedlings must be removed from the greenhouse to make room for another crop, protective "half-way house" structures are sometimes used. These are more sophisticated than shadehouses. Usually, they have waterproof transparent coverings, internal irrigation systems, and provision for supplemental heating to protect the seedlings during cold snaps. These protective units are used in Pacific Coast nurseries, primarily where sensitive tree species, mild weather, and cloudy skies make them practical. They are of doubtful value in the interior West, where high insolation rates, wide daily temperature fluctuations, and severe winter weather would make them uncontrollable.

SECTION 18.—DATA COLLECTION AND RECORDS

SECTION 18.—DATA COLLECTION AND RECORDS

The data collected in CTS operation is very important, because it can be used to maintain and improve the biological, mechanical, and economical efficiency of the operation.

18.1 Cost and Productivity Data

The CTS nurseryman's role is to grow quality containerized trees efficiently and economically. Both efficiency and economy of nursery operation can be measured by analysis of cost and productivity data. In the short run, the data tell:

1. Whether the budget is being overspent or underspent for a job, season, or crop.
2. What price should be placed on a given crop to avoid a loss or achieve a certain profit.
3. How materials and labor costs change from one year to the next.
4. How efficiently a certain part of production process was executed, and if recent modifications resulted in an improvement over the previous year.
5. If a certain machine is too expensive to operate.

In the long run, such data will tell:

1. Whether business trend is profitable and the business is growing.
2. About trends in costs of material or labor, which may indicate major changes in the operation are needed.
3. If certain machinery is worn out and should be replaced.

18.11 Cost Data

Cost data should be accumulated on each part of the CTS growing process. This way the total cost of the trees produced is known and can be recaptured in the price, and the cost of each part of the production process can be assessed.

Bookkeeping and accounting methods are well established. These vary in sophistication from simple ledgers to computerized systems with instant recall. Small operations require only simple methods; large, complex operations need more sophisticated methods. Many consultants are available in this field.

Cost data is an indirect indication of work productivity, because labor time can also be converted to monetary terms. This is very useful when comparing labor and material costs. When comparing labor productivities, it is best to compare times to do the same job.

18.12 Productivity Data

Productivity data can be accumulated on the various operations in a CTS operation. Different ways to employ labor in a given operation can be evaluated in terms of output per unit labor input. The nurseryman can then select the alternative providing the most efficient use of labor. Also, the amount of work to do a given job and its cost can be weighed against the cost of acquiring new machines.

Productivity data, as time to do a job, are a direct measure of labor utilization efficiency. If a job is taking 5 minutes per unit for five workers, and reorganization of the effort reduces the time to do the work to 4 minutes or requires one fewer worker, efficiency has been increased. The only tools needed for productivity assessment in simple operations are a watch and a scratch pad. More complex operations may require timeclocks and job category coding.

Management and supervisory impacts on productivity can also be evaluated by relating output to intensity of supervision.

18.2 Mechanical Operation Data

In this context, mechanical operation data refers to records of the function of greenhouse systems. These include hygrothermograph charts of temperature and humidity, records of frequency of operation of greenhouse heating and cooling equipment, records of electrical conductivity and hydrogen ion concentration in irrigation solutions, and a diary of observations.

18.21 Importance of Mechanical Operation Data

Such information tells how well the mechanical system of a greenhouse is working. Evaluation of these data allows the nurseryman to:

1. Compensate for changes in the outside climate which the greenhouse system cannot do by itself.
2. Locate mechanical trouble spots before the crop is seriously affected.
3. Relate abnormal crop condition to mechanical malfunction of the greenhouse system.

18.22 Mechanical Operations Records

Records of temperature and humidity usually consist of charts from hygrothermographs. These instruments are discussed in section 6.56. Larger operations sometimes have instruments that record readings from several remote temperature or humidity sensors. Data are usually recorded on a scroll of paper. In very large installations, data may be recorded by computer.

Records of equipment sequencing and operation can be recorded by a voltmeter or photorecorder (for light systems). Sophisticated systems recording the phase or stage of operation are available but seldom are justified in CTS operations.

Records of pH and EC of the irrigation solution are usually logged in a daily diary of greenhouse operation by a technician. A method of charting these readings, both for the irrigation solution and the leachate, is discussed in section 18.3.

Weather records from the area around the greenhouse are necessary to interpret greenhouse system function. Unusual outside conditions are often the cause of aberrations in internal temperature and humidities. Greenhouses are designed for a site on the basis of weather averages, not the rare extremes.

18.3 Biological Data

Biological data are derived from the crop itself, such as physical measurements and observations of the trees such as height, weight, and foliar nutrient analysis.

18.31 Importance of Biological Data

These factors are very important to the nurseryman, because they provide a measure of the well-being of the crop, they provide a standard for the progress of the crop and the quality of the culture being practiced on it, and they show the relationship between crop progress and the mechanical operation data (section 18.2). In other words, these measures tell the nurseryman how well the crop is doing and what he might do to make it better.

18.32 Biological Data Records

Format and methods for keeping biological data records for CTS operations are not standardized at all. At the very least, some notes are kept of abnormalities observed in the crop. However, since there is no established system for this recordkeeping as there is for cost or mechanical operation data, some suggestions are provided based on experience, observations, and logic.

18.33 Morphological Condition and Development Records

The progress of the crop should be recorded, along with observed abnormalities that occur. This should be done on a systematic, daily basis, as a "logbook" of crop progress. Notes on mechanical problems with the greenhouse system should be included, because crop responses are directly related to the functioning of the mechanical system. The logbook should also include notations on cultural activities as they take place. Anything unusual, such as severe weather conditions, should be noted. The logbook serves two very important purposes.

First, it provides a day-to-day record and serves as the prime record of the crop development. Therefore, if anything goes wrong with crop progress, it is the first place to look for clues to the cause. Also, it serves as the model for future culture. Things that work well can be duplicated; things that do not can be abandoned. Duration of the growth stages serves as the basis for changing the timing of the growing schedule.

Second, the logbook makes the greenhouse operator accountable. If forced to enter activities and observations, he is more likely to do the work right and be observant. Performance can be reviewed by the supervisor on an intermittent basis by reviewing the logbook. Certain activities should always be noted and be scheduled events. These should include: fertilization, checks of mechanical functioning of greenhouse equipment, seedling measurements, observations on seedling condition, and outside weather. Sophistication of these records should vary with the operation. Plotting growth rates on charts of crop development would allow easy comparisons of crop progress from year to year. This comparison might alert a nurseryman to incipient problems.

18.34 EC and pH Records

Both these readings are indirect indications of what the pH and EC of the soil solution in the growing medium is, because they are made on a leachate of that solution (sections 6.56 and 13). The importance of the reading is mainly in the trend they express over a period of time. Any large change from one reading to another would indicate a serious equipment malfunction. A chart can display trend and large changes visually, without the need to scan a long list of numbers. Figure 18-1 portrays a suggested chart. The vertical axis has both pH and EC units. The range of the units for pH and EC should be wide enough to encompass the normal range to be expected but not much more. This allows for good vertical separation of readings, so, the differences between the applied solution and the leachate are readily apparent as are differences from time to time.

The horizontal axis is time in days. The width between day points should be great enough so that a difference in measurements 2 or 3 days apart is ap-

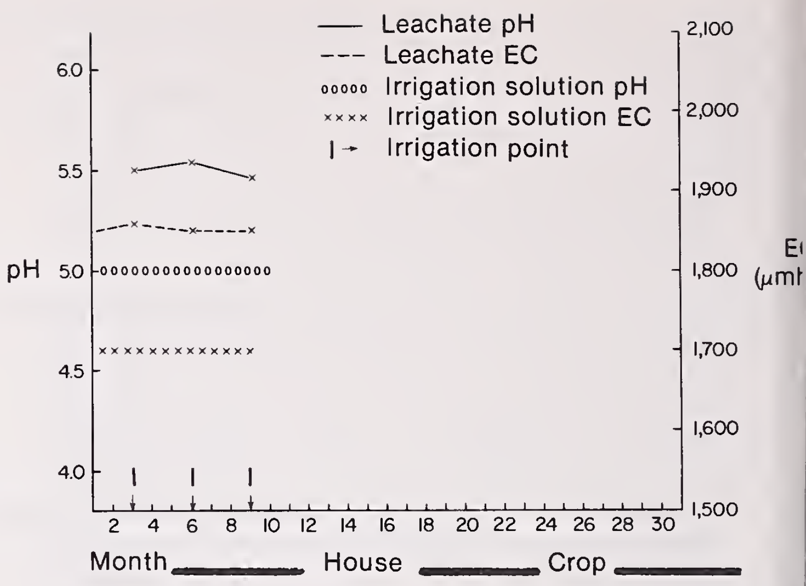


Figure 18-1.—Leachate EC and pH record chart.

parent. EC and pH readings for both the irrigation solution and the leachate are marked on the chart at each irrigation. The latest points should be connected with a straight line to the last point for that reading. The line for each measure should be color coded. This should develop four lines on the chart, one each for leachate EC, irrigation solution EC, leachate pH, and irrigation solution pH. The relationships between these readings and the implications of the trends they portray are discussed in sections 13.3 and 13.4. Display the chart where it can be scanned without having to get it out of a drawer or file. This way, it is constantly available for quick visual checks. It also immediately shows the manager if the recorded data is up-to-date.

18.35 Foliar Nutrient Analysis Records

Foliar nutrient analysis usually takes place after the crop is well into the growing schedule and sufficient mature foliage is available for testing. The best nutrient levels for a given state of development are often in doubt (section 13.52), but if a crop is normal in appearance and growth rate, the foliar nutrient levels in it become the target or "norm" for next year. Several years records represent the best information available. Effects of cultural changes can be weighed in light of changes in foliar nutrient levels from this norm. The importance of these records is long term.

SECTION 19.—GREENHOUSE MANAGEMENT AND SUPERVISION

SECTION 19.—GREENHOUSE MANAGEMENT AND SUPERVISION

19.1 Definition of a Greenhouse Manager

Nelson (1973) defines a manager as: "an organizer, a planner, a person capable of great capacity for work, a decision-maker, a diplomat, a problem solver, a firm believer that all activities must be for the betterment of the business, a person of good judgment, and one who is knowledgeable, honest, and forthright, and challenged by the accomplishment of the job."

It is rare to find all of these sterling qualities in one person, but the definition illustrates the multifaceted nature of the manager's job. The manager must be honest and be able to think and reason. Problems will arise that will require solutions that can only be arrived at by careful analysis and deduction. The CTS nursery manager must know something about greenhouses, trees, and the economics and management of business or government enterprises. He must know enough about these things and have sufficient intellect and self assurance to handle business management procedure, personnel management, physical facility management, crop rotations and scheduling, seedling culture, marketing, and delivery. If the nursery is part of a large organization, staff and other managers may share these loads and help with these jobs. However, the nurseryman must see that overall management is coordinated.

19.2 Principles of Greenhouse Management Success

19.21 Greenhouse Cleanliness

Greenhouse cleanliness is essential. The cheapest insurance against disease, insect, mechanical, or seedling physiological problems in a greenhouse is to keep it clean and in good order. Not only is cleanliness advised for sanitation, but it is good business management. It is much easier to sell seedlings to potential tree buyers or potential supporters within the organization, if the operation is clean, orderly, and well manicured. These visitors equate a clean, neat operation with efficiency and good management; this usually proves to be correct.

The emphasis on cleanliness, neatness, and maintenance also affects the nursery workers. By emphasizing these things, management indirectly indicates, "we care about this place; it reflects on you as well as us; it is going to be something we can all be proud of." Under these conditions, workers, especially long timers, will respond with added pride in their work and feel they belong and have a stake in the place.

19.22 Clear Managerial Goals

The mission of the nursery must be kept foremost in the manager's and workers' minds. An example might be, "to grow high quality seedlings at a reasonable cost." Often, nursery expansion activities, maintenance work, preoccupations with economy, and interest in other activities, such as tree improvement, can unwittingly override the prime reason for the operation. This is often directly attributable to management emphasizing supplemental activities without providing adequate support, monetarily, technically, or in personnel, to avoid compromising the prime goal of the unit.

19.23 Relating to the Crop

The manager and his staff must learn to "think like trees." They should view nursery activities from the standpoint of how the tree seedlings will react. The goal at the nursery usually is to grow good trees on a reliable basis. This cannot be emphasized to the crew enough. The crew should have at least a rudimentary knowledge of the effects that their activities will have on the tree seedlings. In recent years, the American Association of Nurserymen has been emphasizing basic horticultural trainning for nursery workers. This training not only gives more meaning to the work they do, but an appreciation of the effect of their activities on the plants being grown. Such education will often prevent disastrous errors on the part of CTS greenhouse workers who, for instance, might not understand the biological implication of turning down the heat, because it is too hot to work comfortably. However, in the final analysis, the manager is the prime trainer of the crew. His knowledge and attitude toward the CTS crop will largely determine how well the crew learns to "think like trees."

19.24 Commitment to the Operation

To successfully operate a CTS nursery, someone always has to care about it. Trees that lapse into apical dormancy may not begin shoot growth again until the following year. This means the crop will be a year late, and its prolonged occupation of the greenhouse may preclude sowing the next crop. A house full of dead, damaged, stunted, dormant, or otherwise compromised tree seedlings usually results when there is no one who conscientiously looks after the trees and the functioning of the greenhouse all the time.

Growing trees in a greenhouse allows control of the environment, so, it is optimal for seedling growth. This is a great advantage, but at the same time, the greenhouse manager takes on added responsibilities for the well-being of the crop that the conventional nurseryman does not. Nature provides buffers against plant damage in the natural environment. These include reserve water holding capacity in soils, soil buffering of chemical changes, and late summer conditioning of plants for cold weather. The CTS nursery operator is protected by few of these natural buffers. When a container dries out, no rain will water it. If the irrigation water is too acid, the soil will not neutralize it. So, the CTS nurseryman has mechanical advantages that can lead to very rapid tree growth, but there is little room for error. The price of rapid CTS growth is knowledge and vigilance.

Many people have the idea that a nursery can be run at half or full throttle like a factory with one of two production lines shut down. To a limited extent this is true, but the proper conditions for growth must always be maintained in a greenhouse, even if it is half full.

19.25 Unity of Command

Raising trees in containers is not simple when done right. Consequently, because the nurseryman is knowledgable and held responsible, only he should direct nursery activities and make changes in schedules and control settings. In all CTS nursery operations where there has not been a clear assignment of responsibility, the operation has run into trouble. The nurseryman needs a clear assignment of responsibility together with authority to carry it out. When he sinks or swims on the strength of his own actions, the result is usually good trees.

19.26 Technical Competence

Traditionally, forest tree nurserymen have come from the ranks of the forestry profession. There are good reasons for this, not the least of which is that foresters with field experience know how difficult tree planting is and how important it is that each tree be a good one. These foresters, serving as nurserymen, assistant nurserymen, or trainees, learned to grow tree seedlings in conventional nurseries by observation, trial and error, and study of various publications on the subject. While this mechanism for producing forest tree nurserymen has been viewed with disdain by some horticulturists, researchers, and other segments of the botanical community, the process has developed a stable, if small, core of able professional forest tree nurserymen, who are currently producing more than one billion forest tree seedlings per year in the United States.

At present, more CTS nurseries are being constructed than there are forest tree nurserymen to manage them. This deficit is being ably filled by horticulturists. The requisite for a CTS nurseryman is that he understands and is able to grow tree seedlings regardless of his background. He must have the knowledge from education on the job or in school to understand how trees react to cultural treatment. This does not mean that he has to be a forester, horticulturist, or botanist.

The nurseryman must be allowed to grow the trees. Too often, he is buried in administrative detail, because he is the ranking manager at the nursery. This is a waste of resources and poor management. Adequate support staff must be provided to allow the nurseryman to do the job he is hired to do.

SECTION 20.—GREENHOUSE PEST MANAGEMENT

SECTION 20.—GREENHOUSE PEST MANAGEMENT

20.1 Principles of Pest Management

Control of pests in a CTS greenhouse is a constant challenge. Several types of control procedures are available.

20.11 Facility Design and Sanitation

Pest control really begins with site selection and physical plant development. The site should be well drained and away from other crops. Work areas should be easy to clean. There should be gravel or a hard surface outside the greenhouses to prevent weed growth and tracking soil into the greenhouse.

The greenhouse and work buildings should be designed for easy cleaning. Storage areas should be adequate in size and neat. The greenhouse should provide continuous internal forced air circulation (Averre 1975). It should be able to hold relative humidities below 90%, except when irrigating, and near 70% most of the time. The watering system should be designed to apply water at as high a rate as the crop will stand to minimize the time the seedling foliage is wet.

All greenhouse hardware, benches, hand tools, containers, and floors should be clean and disinfected before introducing a new crop of trees. Solutions of 1% sodium hypochlorite are effective and convenient for large areas. Hand tools can be cleaned with the same solution or 70% denatured alcohol or 5% formaldehyde. All hardware and equipment should be kept as clean and sanitary as possible all the time. However, fumes from some disinfectants, such as formaldehyde, are toxic to plants. So, these must not be used in the greenhouse while plants are being cultured.

The greenhouse structures should be tight to minimize entrance of animals, insects, or disease organisms. Where insects are serious pests, air intakes may have to be screened. All doors should be screened and have automatic door closers on them. Irrigation water from surface sources should be filtered (section 4.15). Pruned or thinned parts of plants should be removed at the end of each day's work.

Rotation of plant species in a greenhouse from crop to crop is recommended to prevent pest buildup. A period of non-use of the greenhouse is also recommended, but frequently neither rotation nor non-use is practical.

Turf, gravel, asphalt, or cement (not bare soil) should be used around greenhouses. Soil can be tracked into the greenhouse. Also, blowing dust can be sucked into greenhouse ventilators and contaminate the crop.

Every effort should be made to control weeds in and around the greenhouse. Weeds may harbor insects, disease, and animal pests. Vegetables or ornamental plants should be kept away from the greenhouse because they often harbor pests. Vegetative or animal refuse should never be allowed to accumulate around a greenhouse. This includes leaves from ornamental trees and grass clippings. Many fungi and insects overwinter in such material. The best disposal method is burning or burying in a sanitary landfill.

Remove all trees harboring known pathogens of crop seedlings from the vicinity of the greenhouse.

This is particularly important for diseases spread by airborne spores. For instance, oaks harboring fusiform rust fungus should not be near greenhouses growing loblolly or slash pines. Pines with western gall rust should not be near greenhouses growing ponderosa, lodgepole, or other susceptible pines. Do not permit any non-crop plants in the greenhouse. These form a reservoir of disease and insects of many kinds (section 19.21).

20.12 Natural Controls

In some instances, pests can be controlled by their natural enemies. The best example is reduction of rodents around greenhouses by a cat. Ladybird beetles feed on aphids. The practical applications of such natural controls are limited but growing.

20.2 Pesticide Use

Pest epidemics are best avoided, not treated. CTS nurserymen can go to great lengths to avoid pest problems and still be better off than having to control them with pesticides. Most pest problems in CTS operations are due to poor greenhouse design and operation, or lack of sanitation or exclusion practices. However, when certain tree species are grown or greenhouses are in certain climates, the need to control certain pests is unavoidable. Preventative measures, such as chemical applications, should be used before damage occurs, when it is nearly certain the target pest will be encountered. Otherwise, see-and-treat procedures are best. The nurseryman must be observant and alert in order to notice the presence of pests before serious damage is done.

20.21 Identification of the Pest

Once a pest is noticed in a CTS greenhouse, it must be accurately identified. Proper identification allows prescription of the best pesticide to use, the best formulation, the best application method, and the best time and frequency of application. The best treatment minimizes human exposure while maximizing control of the pest. The greenhouse operator should carry with him a 10X hand lens for close examination of damage symptoms. Many times, problems can be diagnosed on the spot, even by personnel with limited experience. If expert technical assistance is required to make accurate pest identifications and prescribe the treatment, assistance can be requested from a variety of sources including the state department of forestry, the state department of agriculture, the Agricultural Extension Service of the state university, and the Forest Insect and Disease Management Section, State and Private Forestry, Forest Service, United States Department of Agriculture.

Several steps have been listed to help diagnose tree seedling pests (Peterson and Smith 1975). Observances of these steps by nurserymen will expedite diagnosis by an expert.

1. Determine as accurately as possible the part of the plant affected. Death, or damage to only needles, indicates a needle disease or needle mining or defoliating insect; death or damage of the stem and/or branches indicates a canker disease. Death of the whole tree indicates a root disease or drought. Note the pattern of damage in the seedlings. Is it limited to the south side? To the lower crown?
2. Note what tree species are affected.
3. Note the pattern of occurrence. What areas of the greenhouse show the problem most severely? How do these areas differ from those areas free of the problem? Are these areas related to any cultural activity, irrigation pattern, structural feature?
4. If the cause of the damage is not immediately evident, look first for obvious causes, such as animal damage, waterlogged growing medium, high salt concentration in the soil solution, improper fertilization leading to nutrient deficiencies or toxicities, excess humidity or heat (check hygrothermograph charts), etc.
5. Can insects be seen with or without a hand lens? Can fruiting bodies, or mycelia of a disease organism be seen? Note shape, size, color, and other features, if all or part of an organism that may be the pest can be seen. Observe accurately, and try to judge whether the organisms found are the main cause of the trouble or just secondary.
6. If the whole tree is dead or unhealthy, and nothing is found above ground to indicate the cause of the damage, expose the roots for examination.
7. If still unsure, learn or record the recent history of the problem in the greenhouse. Does it occur in other greenhouses in the area? When was it first noted? What cultural practices have been used on the crop? Can these be related to the injuries?
8. Record all of the information before contacting an entomologist or pathologist. Experts can't help without information. Samples of damaged trees are usually most helpful, and should be as fresh as possible. Refrigerate samples if possible.

When the pest is identified and treatment with a chemical pesticide is prescribed, the chemical should be promptly applied exactly as specified. The careless use of pesticides by inexperienced workers sometimes cause more damage to the crops than the target pest.

20.22 Pesticide Safety

Pesticides must be used safely. Some are highly toxic to humans. The degree of toxicity is usually stated on the label of the container, but it is best to treat all pesticides with the respect due any poisonous material. Numerous lists of precautions are available. The following one is from the Entomological Society of America (1975):

1. Store all pesticides in original containers and in a locked cupboard or closet where they are out of the reach of children, pets, and livestock.
2. Keep all pesticides away from food or animal feed.
3. Use pesticides only when necessary, and be sure to use the correct material for the job.
4. Read the entire label on the pesticide container and follow instructions and precautions exactly. Application of a pesticide in a manner not consistent with its labeling is a violation of federal law.
5. Avoid inhaling sprays or dusts when mixing or applying them.
6. Avoid spilling pesticides on skin or clothing. If spilled, wash off at once with soap and water. Clothing wet with spray chemicals should be removed at once. Particles or drops of pesticides which may accidentally get into the eyes should be flushed out immediately with large volumes of clean water.
7. Do not eat or smoke when working with pesticides. Wash hands and face and change clothing after handling pesticides; wash contaminated clothing daily.
8. Discard any pesticide container without a label or with a damaged label. Do not guess at contents. Be familiar with Title 40, Chapter 1, Environmental Protection Agency Post 165 "Regulations for the Acceptance of Certain Pesticides and Recommended Procedures for disposal and Storage of Pesticides and Pesticide Containers."[1]
9. Don't allow spray or chemical dusts to drift onto adjacent crops or fields. Cover feed and water containers in livestock areas if there is any danger of contamination.
10. Wear protective masks and clothing, if so directed on the label.
11. Use pesticides only at the recommended dosages and timing.
12. Destroy all empty nonreturnable pesticide containers. Break or puncture glass or metal containers to prevent reuse. Incinerate paper or cardboard containers (avoid coming in contact with the smoke) and bury all ashes, unburned residues, and broken containers in a sanitary land fill (item 8).
13. Use clean, properly functioning equipment to apply pesticides. Fill and clean application equipment where the rinse water or spills will be absorbed into the earth without polluting nearby streams or ponds or harm crops or animals.
14. If symptoms of illness occur during or after spraying or dusting, call a physician or get the patient to a hospital immediately.

[1]*Federal Register, Vol. 39, No. 85, May 1, 1974.*

20.23 Pesticides Used in CTS Greenhouse Operations

The registration and use of pesticides are regulated by law. These include several federal laws, regulations, and acts and various state pesticide control laws. The major federal legislation is the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which is administered by the Environmental Protection Agency. This law makes it illegal to use a chemical pesticide in any way other than that specifically labeled on the container. The chemical pesticide registrations and labels are being continuously reviewed and amended. Therefore, any specific recommendations in this manual as to what pesticides may be used against specific pests should be checked to be sure they are legal.

Table 20-1 lists fungicides for disease control, and Table 20-2 lists insecticides in current use. Because of frequent changes in federal and state laws, the CTS nurseryman should consult his state agricultural chemical coordinator in each instance before purchasing or using any chemical.

20.3 Types of Pests

20.31 Weeds

In CTS operations, where sterile growing media are used and tree seed is weed free, weeds in the containers are not a problem. Weed seeds can be drawn into the greenhouse through the ventilation system or carried in on workers' feet. This can be minimized by controlling weeds close to the greenhouse and through proper sanitation. The weed seeds introduced into the greenhouse will germinate in the containers or on the floor. Those that germinate and grow in the containers can be removed by hand. If the growing medium is free of weed seeds, weeding of containers will be minimal. Greenhouses with gravel floors can develop a considerable growth of weeds on the floor. This is not only unsightly but also unsanitary. These weeds may harbor other pests. Because the weeds develop between and under benches, they may be hard to control manually. The gravel floors

Table 20-1.—Fungicides for disease control (Powell 1975).

Disease	Chemicals for control	Remarks
Damping-off and cutting rots	PCNB (Terraclor) (1), Diazoben (Cexon) (2), ethazol (Truban, Terrazole) (3) Captan (4)	(1) For rhizoctonia only. (2) and (3) for pythium and phytophthora only.
Water mold, root rots	Diazoben (Dexon), ethazol (Truban, Terrazole), Captan	
Other root and stem-rotting fungi	benomyl (Benlate)	
Leaf spotting fungi	benomyl (Benlate) (1), Chlorothalonil (Daconil, Termil) (2), Captan (3), maneb (Manzate D, Dithane M-22) (4), Mancozeb (Fore, Manzate 200) (5), ferbam (Fermate, carbamate) (6), zineb (Parzate C, Dithane Z-78) (7), folpet (Phaltan) (8), fixed copper or Bordeaux mixture (9)	(1), (2), and (3) for botrytis control; (3) through (9) for other diseases; check labels for specific information. Copper may cause plant injury.
Rusts	Zineb, ferbam (Fermate, Carbamate), mancozeb (Mantzate 200, Fore)	Frequent application generally necessary with all these materials.
Powdery mildews	benomyl (Benlate), cycloheximide (actidione PM), dinocap (Karathane), sulfur	Frequent application and good coverage essential. Cycloheximide and sulfur may cause plant injury.
Bacterial diseases	streptomycin (Agri-Strep), fixed coppers or Bordeaux mixture	Both materials may cause plant injury.
Nematodes, soil	Aldicarb (Temik), DBCP (Nemagon), oxamyl (Vydate L)	Highly toxic materials, use caution.

Table 20-2.—Insecticides for greenhouse pests (Pirone et al. 1960).

Type of insect	Chemicals for control	Remarks
Thrips	malathion, dieldrin, lindane, parathion, Sulfotepp	Apply malathion and lindane frequently.
White Flies	Pyrethrum, rotenone, nicotine sulphate, malathion	Pyrethrum, rotenone and nicotine sulphate control nymphal stage.
Scale	malathion best, nicotine sulphate and soap	
Aphids	nicotine sulphate and soap, lindane, malathion, Sulfotepp, parathion, Thiodan	nicotine sulphate on warm days only; do not apply parathion before or after sulfur.
Mites	sulfur, Aramite, Dimite, Kelthane, Ovex, malathion	

of greenhouses can be treated with herbicides. Be sure to select non-volatile broad spectrum herbicides such as Hyvar X® or simazine and apply them so that the tree seedlings are not contaminated. Be sure the herbicide is registered for that use (Whitcomb and Santelmann 1976).

20.32 Rodents

Exclusion of rodents from the greenhouse is important. The principal pests are mice, which can eat or cache large numbers of seeds from containers in a short time. They will also clip young succulent seedlings. The main defenses are construction of physical barriers, minimizing suitable habitat surrounding the greenhouse, and trapping or baiting. Areas around the greenhouse should be clean and free of debris or plants that will shelter or provide food for rodents. The greenhouse should be tightly constructed at the base, and all doors should automatically close when released. Elimination of habitat for mice, combined with barriers to greenhouse entry, will usually prevent serious rodent problems. Some limited trapping or baiting may be necessary, however. Warfarin® as treated oat bait is the most commonly used rodenticide at present. Keeping a cat or two around a nursery complex also helps hold rodent populations in check.

20.33 Insects

Many common insect pests, such as ants and caterpillars, are not serious pests in CTS culture. They can usually be controlled by sanitation, barriers, and baiting. Usually, serious insect pests enter the greenhouse through the ventilation system. Under greenhouse conditions, these insects can reproduce rapidly and cause extensive damage. The most bothersome are aphids, whiteflies, scales, thrips, and mites. Large insects occur less frequently. They are more obvious, and are easier to identify and control.

Whiteflies.—The greenhouse whitefly *(Trialeurodes vaporariorum)* is a sucking insect which secrets masses of honeydew. Black sooty mold develops on this sticky substance. At average greenhouse temperatures, whiteflies complete a generation in 3 to 4 weeks (Sorenson 1975). The whitefly nymphs are pearly white and are attached to lower leaf surfaces. Adults are small pure white flies that dart away swiftly when the leaves are disturbed (Pirone et al. 1960).

Thrips.—Thrips *(Thysanoptera)* are very minute insects that are often wingless, even when mature. They rasp the tissues of plants and suck the sap. This causes leaves to curl and become deformed. The damaged areas have a silvery or glassy appearance. A hand lens or low powered dissection microscope is useful for identifying these insects.

Aphids.—Aphids belong to the order *Homoptera,* as do whiteflies, mealybugs, and scale insects. Aphids have a complex reproduction cycle, which involves the production of a series of generations without fertilization. Many aphids, mealybugs, and scale insects cover themselves with a white waxy secretion, under which the young develop. The secretion of honeydew by aphids, whiteflies, and scale insects may result in growth of unsightly black molds on surfaces of leaves and stems. *Homoptera* are often carriers of viruses of several destructive plant diseases (Pirone et al. 1960). Aphids are soft-bodied, small, sluggish, gregarious insects that multiply rapidly. They are usually green or white.

Scale insects.—Scale insects form a waxy, hard, white, gray, or black secreted shell over themselves. This shell adheres to the plant.

Mites.—Mites are small spider-like animals that suck the juice from the tender growing points and leaves. Greenhouse plants are especially susceptible to attack. Mites are only about 1/50 inch (½ mm) long and may be green, yellow, or red. Leaves usually assume a gray or yellow cast when severely infested and may be occasionally covered with fine silken webs. Mites complete a generation in 9 to 10 days and often pass unnoticed until severe damage results.

A well planned insect control program can prevent insect damage in a greenhouse. Preventive control is easy. Eradicative control should be used only when needed. Plants such as potatoes, tobacco, milkweed, plantain, chickweed, catnip, groundcherry, horsenettle, and jimson weed, should not be grown within 150 feet of the greenhouse (Sorenson 1975), because they serve as hosts for insect pests. The area around the greenhouse should be clipped lawn, crushed rock, etc. The greenhouse should be kept free of debris. Regular inspections should be made to look for insect pests. Greenhouse doors and air intakes should be screened.

If harmful insects are present, eradicate with approved insecticides. In most cases, some limited use of chemical controls is needed despite the most careful avoidance measures. If management is alert and observant, the see-and-treat program should be best. The mode of application and chemical used should be designed for the target insect. Timing the application is also very important to achieve optimum effectiveness.

The greenhouse manager should seek help in identifying pests unless he is very certain of the identification. Various state extension specialists are available for consultation. They can also recommend chemicals, formulations, and application methods. Expert and up-to-date assistance in this area of greenhouse operation is vital.

In recent years, the use of agricultural chemicals for pest control has been increasingly regulated by environmental protection legislation. Most older textbooks on diseases and pests of plants contain specific recommendations on chemical use. Such lists itemized the best and most effective chemicals available at the time the books were written. Many of these chemicals are no longer available, or restrictions have been placed on their use. Therefore, it is best to consult knowledgeable people before selecting a pesticide.

Some of the currently registered insecticides are: malathion, Thiodan®, naled, mevinphos, nicotine sulfate, parathion, metaldehyde, dichlorovas, lindane, Tedion®, and calcium cyanide. Each of these chemicals must be used in accordance with the pesticide label on the container. In general, soft-bodied insects can usually be controlled by sprays of malathion, nicotine sulfate, or lindane. Scale insects should be sprayed when they are crawling. Application timing and rate should be determined from the label and expert advice. Care must be taken to be sure the chemical is not phytotoxic. Generally, if repeated applications are needed, it is best to rotate applications of the various chemicals, to avoid buildup of pests tolerant of any single chemical.

Malathion and difocal (Kelthane®) are effective against mites. If the mites become resistant to the miticides, combinations or rotating applications of the effective chemicals may be best. Lindane is effective against moth and sawfly larvae.

20.34 Diseases

Peterson (1974) summarized the most common disease problems encountered in CTS operations.

Grey mold fungus *(Botrytis cinerea)*.—Grey mold has caused higher losses in CTS facilities than any other pathogen. Most forest tree seedlings are susceptible. Grey mold is almost universally present on dead and dying plant material. It usually spreads from dead parts of the host to healthy tissues, but can infect healthy tissue directly. The infected tissue first turns light, then dark brown and eventually becomes covered with fine grayish-brown powdery growth. Infections are usually first seen on the lower needles and old juvenile bracts.

The disease is likely to occur when humidity is high or surface moisture is present for long periods in the greenhouse. This occurs when:

1. The growing medium is poorly drained and a high humidity persists at the surface of the container.
2. There is extended high humidity in the greenhouse due to lack of ventilation and air mixing or watering at low application rates.
3. The outside humidity and temperature are high, which makes it very difficult to cool and dehumidify the greenhouse.
4. Dead plant matter is present in and around the seedlings.
5. Seedlings are large and lush which keeps their lower crowns in deep shade.

The best preventive measures are to avoid these circumstances. Keep greenhouse humidities at an average of 60-70% relative humidity as much of the time as possible by ventilating the greenhouse, providing good air circulation around plants, and watering as rapidly as the seedlings and pot mix will tolerate. Irrigate during the warmest time of day and then ventilate. The greenhouse should be kept free of dead plant matter, and the growing medium should be well drained. Leaky valves and nozzles should be immediately replaced. The greenhouse floor should be well drained and should dry rapidly following irrigation. With these precautions, grey mold may never be a problem. However, if it does develop, benomyl (Benlate®) is probably the safest and most effective fungicide available at this time, although some resistance has been demonstrated. To avoid development of resistance it is best to alternate fungicides. Some of these chemicals reduce growth in some tree species, so, expert advice from an experienced plant pathologist is recommended (Low 1975).

Most fungicides act as protectants and do not cure the disease once it is in the plant (Smith 1975). Therefore, fungicides should be applied at the first sign of the disease. Applications should be continued as long as the disease persists. Where climatic conditions favor grey mold or species are grown that are particularly susceptible, a regular fungicide treatment program may be required from the start of the crop. Applications of fungicide may be needed as frequently as every 2 weeks. Such applications on a regular, preventive basis should not be necessary in well engineered and operated greenhouses in the interior West and Great Plains, because relative humidity of the air is normally low. In contrast, high humidity conditions on the Pacific Coast have made regular preventive fungicide applications necessary in some instances.

Damping-off.—Fungi such as *Pythium, Rhizoctonia, Phytopthora,* and *Fusarium* are common in CTS culture. Only very young seedlings are attacked. As soon as stems begin to lignify, 3 to 4 weeks after germination, the incidence of disease declines rapidly. Early attacks on the seed radicle prior to seedling emergence are called "pre-emergence damping-off" and may go undetected. Post-emergence infection generally occurs at or just below the root collar. A water-soaked or necrotic lesion develops. In conifers, this tissue collapses and the seedling falls over. Hardwoods usually remain upright, gradually wilt and break off (Filer and Peterson 1975).

The key to preventing damping-off in a CTS greenhouse is avoidance. Use a well drained growing medium, and do not introduce nitrogen into the soil solution until germination is completed. The greenhouse and containers should be clean, the growing medium should be sterile, and the seedcoat should be free of spores. If an acid peat-vermiculite or perlite growing medium is used, it is usually nearly sterile. If damping-off problems are encountered and seed coat contamination is suspected, the surface of the seedcoats may be sterilized by a short soak in concentrated hydrogen peroxide solution followed by a thorough rinsing in clean water (Riffle and Springfield 1968, Barnett 1976). The tolerance of different tree seeds to this treatment varies, so, germination tests should be conducted for treated and untreated groups of seed, unless the technique is well documented for the species. There are other methods of seed coat sterilization such as soaking the seeds for 30 minutes in mercury bichloride solution (Pirone et al. 1960).

Seeds can also be coated with fungicides such as Captan® or Thiram®. There is conflicting evidence about the suitability of some of these materials, since adverse effects on seed germination have been reported (Peterson 1974, Denne and Atkinson 1973, Low 1975, Aldous 1972).

Fusarium root rot *(Fusarium oxysporum).*—This fungus has been isolated from a number of CTS nurseries as an agent of seedling mortality (Landis 1976). This and some other species of *Fusarium* are responsible not only for damping-off in young seedlings, but also root rot of older seedlings. Affected seedlings show root dieback and the formation of corky black tissue over yellow-brown dead vascular tissue of the roots. The tops become stunted, wilted, and chlorotic, and most seedlings eventually die. Those that live and are shipped do not survive as well in the field, although studies in the western United States indicate *Fusarium* disappears in 3 to 4 years from the roots of outplanted seedlings that survive (Smith 1975).

Cultural methods have not been effective in controlling this disease (Smith 1975). Recently, benomyl used as a soil drench has shown promise, because it moves systemically within the tree (Pawuk and Barnett 1974). Drenches with other fungicides are sometimes effective in controlling *Fusarium.* These include Captan® and Truban®, but these fungicides, as well as benomyl, may retard seedling growth when added to the growing medium. Consequently, they should be used only when there is an identified need.

As with other greenhouse problems, sanitation will help prevent root rot. Use a growing medium that does not waterlog, do not overwater, and keep adequate air circulation under the containers. Be especially vigilant if the containers are placed on the ground to overwinter them.

Other diseases.—Other diseases have rarely been serious problems in CTS greenhouses. However, the greenhouse environment is very amenable to many pathogenic organisms, and diseases can spread with lightning speed in such environments. The nurseryman must constantly watch for any changes in seedling appearance. Insect and disease infestations must be detected, the pest identified, and control measures instituted as rapidly as possible. Most of the discussion in this section has related to conifer tree seedlings. Hardwood seedlings host many more pathogens and even greater vigilance is required during their culture.

SECTION 21.—TROUBLESHOOTING CTS NURSERY PROBLEMS

SECTION 21.—TROUBLESHOOTING CTS NURSERY PROBLEMS

21.1 Introduction

No enterprise is devoid of problems. The timing of their occurrence cannot be accurately predicted, but with proper management the frequency of their occurrence and the damage they do can be minimized.

Crises are action-demanding situations which are both important and urgent. Some require corrective action within minutes; others may require a response on a time scale of hours to several days. The nurseryman must size up each situation and react accordingly. Over-reacting can be just as harmful as not acting quickly enough, not only for the welfare of the crop, but for the smooth running of the whole nursery.

21.2 Be Prepared

Although no one can prepare for all possible contingencies, there are certain things that can be done ahead of time to prevent most emergencies from becoming disasters. Any production facility has certain standard operating procedures which, after the initial shakedown, represent the best procedures known. Changes in procedure, control settings, or timing should be made with caution. A record of the change should be kept, and everyone who needs to know should be informed of it.

A stock of spare parts should be kept of those items whose function is critical, that need regular replacement, are hard to find, or take a long time to get (section 6). Those items that may be needed in an emergency should be labeled to indicate where they go or what they fit.

Since no one is available all of the time, more than one person should know what to do in an emergency (section 19.2). Everyone who may be called upon should know:

1. What conditions are normal. This is necessary to recognize an abnormal situation which requires correction.
2. What conditions require immediate attention, and what can wait. No one likes to be hauled out of bed in the middle of the night to fix something that could have waited until morning, but it is at least as bad to be complacent about something that should be fixed immediately.
3. How to fix what is wrong. Everyone involved should be familiar with the troubleshooting procedure.
4. Where the tools and spare parts are. Tools and spare parts should always be kept in the same place, always be in their place, and be where someone can get to them quickly. When there is a crisis, nothing is more exasperating and time wasting than having to hunt for tools and parts.
5. Who to call if help is needed.

21.3 Be Alert to Problem Development

The sooner an abnormal condition is recognized, the more time there is to correct it before any damage is done. The key is to know what constitutes the normal condition and be alert enough to recognize when something is out of place.

There should be a checklist posted in the greenhouse indicating what the control settings are, the condition of the crop, and other information necessary to recognize a normal situation.

21.31 How to Use All of Your Senses All of the Time

When approaching the greenhouse, make a conscious effort to observe if things are normal. On a warm sunny afternoon, fans should be running. On a cold day, the furnaces should be on and the vapors from the flue pipe visible. If they are not, investigate. Is the double layer of plastic inflated and firm, or flapping loose? If it is loose, check the inflation blower. If the blower is running properly, check for holes in the skin. If you are visiting the greenhouse at night, notice if the lights for photoperiod control come on when they should. If it is during the hardening phase, has someone left a light on where it shouldn't be?

Listen as you approach the greenhouse. Does any running motor squeak like it needs oiling? Do you hear the hum of a running motor, but nothing is turning? Look for a broken belt or a stalled and overheating motor. Do you hear water running? Should it be running? Is the furnace running smoothly, or is combustion uneven?

Use your nose. Is the furnace properly tuned, or is combustion not complete? Did the pilot light go out? Has the house just been fumigated? If so, are the warning signs posted on the doors?

Enter the greenhouse. In fact, make it a point to visit the greenhouse on your way from one place to another, just to walk through. This will increase the supervision of the greenhouse without the need to make extra trips. As soon as you enter, your sense of touch will tell you if temperature and humidity are within an acceptable range. Your nose should indicate whether heaters and CO_2 generators are operating properly and if insecticides or certain fungicides have recently been applied. Your ears can tell you a great deal about proper operation of electric motors and fans, and indicate problems needing attention. Look around and observe carefully. Are the fans and furnaces doing what they should, considering the ambient temperature and humidity? Is the CO_2 generator on? Are pilot lights lit? Check the hygrothermograph (section 21.32). Are the lights coming on when they should? Are any burnt out?

Examine the seedlings closely. Is the morphology of the shoot correct and normal for their current stage of growth? Any signs of nutrient deficiencies or toxicities? Is the rootball moisture at or close to field capacity? Are the roots healthy, or is there evidence of root rot? (Mycorrhizae will appear on healthy roots. Do not mistake them for rot organisms). Is the foliage healthy, or are there signs of mold or mildew? Are insects present? (On hardwoods look on the underside of the leaf). If so, what are they? If they can damage the trees, apply control measures. If they are harmless, do nothing.

Each greenhouse is a little different, and it is hard to be specific about how to check out greenhouses and greenhouse crops quickly. The nurseryman should make a checklist to use as a training aid to teach his staff how to be alert and what to look for.

21.32 How to Read Hygrothermograph Charts

A hygrothermograph gives a record of temperature and humidity independent of all the other machinery (section 6.56). It can indicate normal operation, various intermittent and continuing failures, and give important clues as to what went wrong and how to correct it. Below are examples of hygrothermograph patterns and how to interpret them. Figure 21-1 represents "normal" tracings. The following items describe the features numbered on the chart:

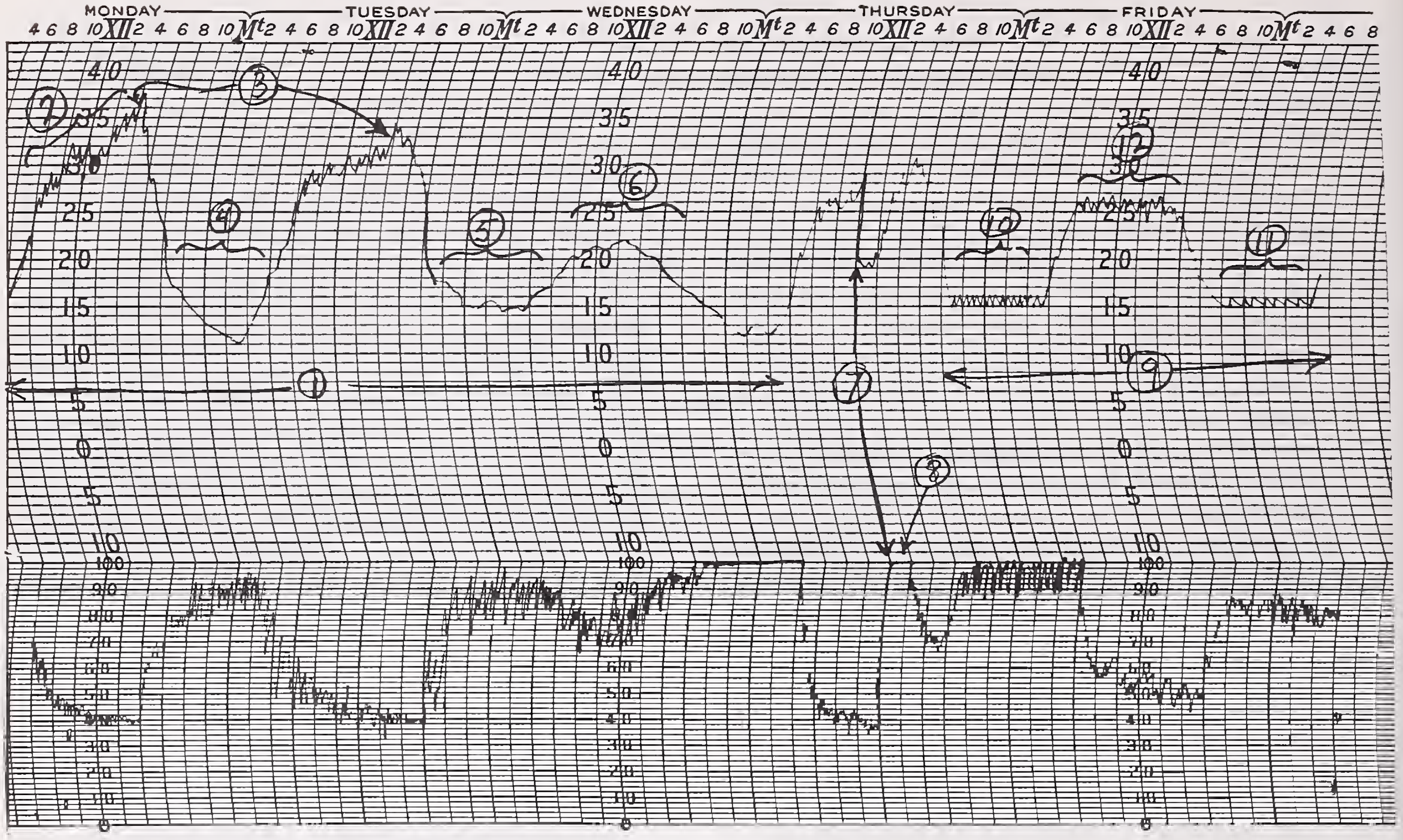


Figure 21-1—Normal hygrothermograph patterns.

1. This represents 3 days in a situation where neither heat nor cooling is applied.
2. The irregular and frequently rising pattern is typical of a sunny day. The rapid and random fluctuations are caused by clouds and the rapid fluctuation of sunlight intensity.
3. Certain fluctuations are caused by shadows from fixed objects. These occur at almost the same time each day, gradually changing with sun angle and season. As long as the hygrothermograph is kept in the same position and orientation, preferably with the sensor end facing north, these shadow patterns become recognizable markers which can be used to check on the timing of the hygrothermograph and are known to be normal, i.e., do not indicate a malfunction of any kind.
4. During a clear night, the temperature usually falls steadily until dawn. An interruption in this pattern usually signals a weather change.
5. Cloudy nights generally do not get as cold and reach minimum temperature sooner. They remain near minimum most of the night.
6. Overcast days do not get nearly as warm as sunny days, and the chart does not exhibit shadow patterns.
7. When the crop is watered during the day, there is a sudden drop in temperature and a sudden rise in humidity to 100%. This is a very useful marker which shows when each watering occurs. To show this the hygrothermograph must not be removed during watering.
8. The pen draws a straight line at 100% humidity. If the instrument is watered along with the seedlings, it will read 100% as long as there is any liquid water on the sensing element. This is also a good indication of the length of time the foliage stays wet during and after watering. In this example, that is about 2 hours. The straight horizontal trace indicating 100% humidity is quite characteristic and can be used to check the calibration of the hygrothermograph. If the trace is not reading 100%, adjust the instrument until it does.
9. A greenhouse in which the temperature is controlled by heating and cooling is characterized at night by temperatures oscillating in a 1°C range at the furnace thermostat setting. On a sunny day, the temperature rises above the furnace setting until the cooling comes on.
10. A rapidly fluctuating level night trace indicates that the furnace is cycling on and off at short intervals. On cold nights, that is normal. If the night is not that cold, look for major heat leaks.

11. An open sawtooth pattern indicates that the furnace comes on at infrequent intervals, typical of a mild night.
12. The daytime pattern is rarely as uniform as nighttime, because shadow patterns are superimposed on the cooling cycle pattern. Nevertheless, if the cooling system is adequate and working properly the trace should be more or less level at the set cooling temperature.

Figure 21-2 shows patterns to watch for which indicate equipment inadequacy or malfunction. The following numbered items describe the features numbered on the chart:

1. There are three malfunctions of the hygrothermograph itself that are easily recognized. When it draws a vertical trace on both the temperature and humidity scales and the pen is no longer at the correct time, the clock has stopped. Wind the clock and set the drum for the correct time. If it is not ticking, or if it will not keep time, the clock mechanism needs repair.
2. When one trace fades away, but the other remains normal, the pen is out of ink or is not in contact with the paper. Refill the pen or adjust the arm so that it makes positive contact with the chart.
3. When the humidity trace draws a stright line at its upper limit and that line is not on the 100% mark, change the humidity calibration adjustment until it reads 100%.
4. A daytime pattern in which the temperature is not held at the setpoint during the hottest part of the day, but is held satisfactorily in the morning and late afternoon indicates inadequate cooling capacity. Check all fans, the evaporation pads, water pump, and louvres for proper operation. Part of the system may not be working. If everything is working properly, then perhaps this is one of those few days of the year when the heat load exceeds the design capacity of the cooling system. If it happens frequently, the cooling system is not adequately designed, or the climate is too humid for evaporative cooling to be efficient.
5. When the temperature falls well below the setpoint before the furnace comes on, suspect a sticking thermostat. This usually occurs at the very beginning of the heating period and tends to be self-correcting, but if it occurs repeatedly, replace the thermostat.
6. In a well designed system with two stages of heating, failure of the first stage automatically turns on the second stage after a drop of only a few degrees. No damage is done, but the first stage should be examined promptly and made operational again.
7. On a sunny day, sudden failure of the entire cooling system causes an abrupt rise in greenhouse temperature. The most frequent cause is a power failure. On hot sunny days, these peak temperatures can be highly damaging and call for immediate action. Excessive temperature should trigger an alarm which will summon help. The temperature will come back down when the power comes back on,

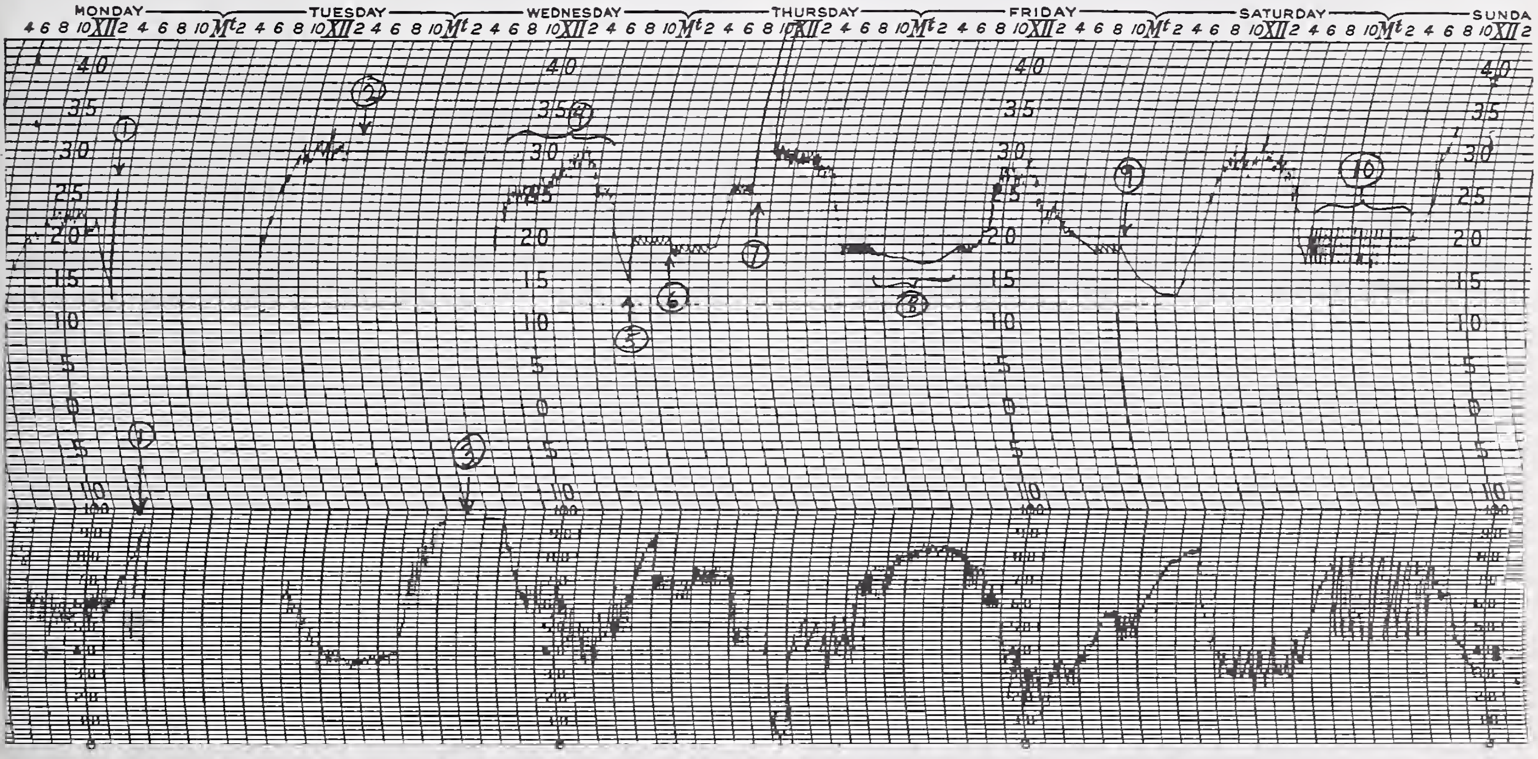


Figure 21-2—Hygrothermograph patterns which indicate malfunctions.

and unless someone was there, no one would know that the outage occurred except for the hygrothermograph record. The damage will show days or weeks later.

8. If the temperature gets so cold that the furnaces remain on continuously and still can't maintain the set temperature, the trace will be a line which parallels the outside temperature plus the differential that the heating and insulating system can maintain. This may occur a few times a year on the coldest nights. If it occurs regularly, the heating system is underdesigned.
9. When the entire heating system fails, the temperature drops in an uncontrolled fashion. This is most frequently caused by power outage or lack of fuel. If the heating system depends on a single furnace, look for a variety of things that can go wrong.
10. A wide fluctuation between high and low temperature during furnace operation can mean a variety of things, none of which are serious. This pattern will appear if the hygrothermograph is in direct line with the hot air blast from the heater. If so, try another location for the instrument. The temperature will commonly fluctuate more in an empty greenhouse than in one full of trees. In that case don't worry about it. The air from the furnaces may be too hot or not getting distributed evenly. Adjust furnace temperature or air flow system accordingly. Finally, the thermostat may have too great a differential, either because it is not set right or because it is wearing out. Readjust or replace it as needed.

21.4 Temperature Crises

When the temperature becomes either too hot or too cold because of failure of the temperature controlling machinery, a crisis frequently occurs which requires immediate action. Since emergency measures are sometimes damaging in themselves, the nurseryman must decide in each instance how fast to react and what actions represent the least of the evils.

21.41 Lack of Heat

When it is very cold outside and the furnace fails, temperatures in a double wall polyethylene greenhouse can fall at the rate of 0.5° C per minute. This allows only 20 minutes between 10° C, a typical alarm temperature setting, and freezing. If the plant material is succulent, immediate action is required. Even if the seedlings survive freezing, they may be thrown into irreversible dormancy. In the early stages of hardening, freezing may damage seedlings, but growth stoppage usually is not important. If the freeze occurs late in the hardening process, usually no harm is done.

First, locate the cause of lack of heat. If it will take long to correct, prepare to apply emergency heat. Look for the simple things first.

Power failure.—If all of the power is off, start the emergency generator and shut off everything that is not essential in order not to overload the generator.

Furnace off.—Check the fuel supply first. If it is adequate, check the furnace, the pilot light may be out. Relight it. If it will not stay lit, replace the burned out temperature sensor. If the fan is not running, check the circuit breaker and press the reset button. If the fan does not start, smell the motor and turn the fan blades by hand. If the motor smells burnt or the fan will not turn, try oiling the bearings and turning the blades. If it still won't start, replace the motor. If the motor runs but there is little or no air flow, tighten or replace belts. If it is an oil furnace that is off, push the reset button. If it fails to start, check the circuit breaker and motors as above. If it starts but won't stay lit, clean or replace the electric eye or faulty stack switch.

Cooling fan on.—Check for stuck thermostat or wrong setting. Shut fan off at circuit breaker if necessary.

Vents stuck open.—Close them manually. Free and oil them. Check for stuck thermostat or wrong setting.

Loss of skin or roof.—Cover seedlings with plastic. Apply heat underneath.

21.42 Emergency Heat Sources

If greenhouse temperatures can be kept above −8° C, the most generally useful and readily available emergency heating is the irrigation system. Turn it on and let it run continuously, until the heat is back on and greenhouse temperatures are well above freezing. The pipes will not freeze as long as the water is flowing in them, and the freezing of the water on the foliage of the seedlings will release enough heat to protect them from freezing. Irrigation is also effective if the cover or roof is lost, but is of limited usefulness in a strong wind, and should not be attempted if the temperature is expected to go below −8° C. (First the nozzles and then the pipes will freeze.)

Lights for photoperiod control can be turned on continuously to the limit of the capacity of the electrical circuit (section 6.2). The heat output is limited, but since it is radiant energy heating the foliage, it is being applied very efficiently.

The CO_2 generator is also a small heater, and in an emergency can be of significant value (section 6.3).

Portable heaters can be moved into the greenhouse. Oil burning types produce fumes toxic to both humans and plants. Their use should be limited to situations where there is no alternative to save the crop.

21.43 Excessive Heat

An overheated greenhouse demands prompt action (section 6.1). The usual cause is a cooling system failure, and temperatures on a hot sunny day can rise at the rate of 1° C per minute. If a power outage has occurred, switch to the emergency generator, and shut off everything that is not essential. If that is not the problem, check thermostats to be sure they are set correctly and working. Reset or replace as needed. Failure of only part of the cooling system usually does not result in a crisis, but should still be corrected promptly.

There are generally two alternative cooling methods: 1) manually open all of the doors and louvres; 2) turn on the irrigation. In a small greenhouse the first can be quite effective, but is of limited value in a large one. The second method is quite effective in holding the temperature within bounds, can be done quickly, and often is independent of public electric power.

21.44 Fire

Although greenhouses are generally low hazard areas, fires do occur. The immediate response should be to turn on the irrigation and turn off all nonessential electricity in the vicinity of the fire, especially the cooling system. The cooling fans will, otherwise, come on in response to the rise in temperature and quickly spread the fire throughout the house (Hartman 1978).

In a glass and metal frame greenhouse, the structure is fire safe, but most types of container are made of polystyrene or polyethylene, both of which will burn vigorously once ignited. The risk in the greenhouse, especially after the containers are filled with mix and wetted, is quite minimal, but fire hazard should be kept in mind where the empty containers are stored.

If a wooden framed plastic film covered greenhouse burns, heat builds up near the roof, the plastic melts, opens a hole, and releases the heat, so the fire does not spread rapidly. In contrast, a fiberglass greenhouse is strong enough to hold the heat until the whole structure is on fire. Once fiberglass reaches its decomposition temperature, the fire spreads very rapidly, and most of the fire is above what would be wetted by the irrigation system. Irrigating may still save the crop.

21.5 Water Crises

Too much or too little water is never a good thing, but there is usually more time available to solve the problem than there is with temperature crises.

21.51 Flood

Properly sited facilities should not be subject to flooding from the outside. However, if a flood can be anticipated, the facility can be diked and then bailed. If there is not time, about all that can be done is to wait for it to subside and then clean up. If there is any time at all, shut off all electrical equipment that will be flooded, and if possible, move anything that can be damaged to someplace above the flood.

Flooding from the inside is usually caused by a broken water line. Immediately shut off the water main, and then repair the break.

Localized excesses of water are usually caused by uneven distribution of the watering system or drips from nozzles and other structures (section 21.64).

21.52 Lack of Water

Depending on temperature and humidity, lack of water can continue without damaging the seedlings for a matter of hours up to several days, except when water is needed immediately for emergency heating or cooling during a temperature crisis. If the nurseryman is watching his crop at all, any lack of water will be due to equipment malfunction and not lack of attention. When waterlines break or pumps quit working, there is usually no water at all, and the problem and its solution immediately become apparent. Sometimes an automatic watering device in the greenhouse will break down. Then there is water available in the greenhouse, but no way to apply it automatically. The greenhouse should be equipped with valves where hoses can be attached, so that in an emergency, the house can be watered by hand.

A lack of water which is harder to find is moisture stress caused by uneven distribution of water. This can be caused by a poorly designed irrigation system, but even the best systems must be watched for plugged nozzles, stuck impact sprinklers, valves that are not set right, or wrong pressure on the lines (section 6.4).

21.6 Cultural Problems

The previous sections of this chapter have dealt with machinery and environmental controls. When something goes wrong with these, a crisis often develops which demands action within minutes. Sometimes, the time frame for action is measured in hours, but never more than a few days. In contrast, cultural problems develop more slowly, require closer observation to detect at an early stage, and rarely are so urgent that the remedy cannot wait a day. However, cultural problems are just as important, and it is usually harder to find the cause and correct it than it is for mechanical problems. If the nurseryman recognizes he has a problem but can't identify the cause, he should seek professional help.

This section deals with diagnosis and prescription for maladies that have developed. However, in most cases if adequate care and preventive measures have been taken, these situations should not develop.

21.61 Delayed or Erratic Germination

If the seed has been tested and found viable, given the appropriate treatment required for germination, and if good sanitation procedures are followed, germination should be prompt and normal (section 17). The nurseryman should know what is normal for rate and total germination of the species and seed lot he is growing. This is the only way to recognize late or slow germination. If it occurs, take action immediately. This is especially true if there is partial germination and resowing is necessary. If there is much difference in age between the two batches of seedlings, dominance will be expressed, and some of the late comers will be suppressed, unless the first batch can be consolidated and the second kept separate.

First, dig up and examine the seed. If the seed is not there, the containers may have missed being seeded, or rodents may have taken it. Set bait or mouse traps and reseed.

If the seed is there but not viable, possibly bad seed was sown. If inadequate testing is suspected, reseed with good seed. If it appears to be preemergence damping off, apply fungicide (section 20.24) and reseed. If it is possible that the disease organism is borne on the seedcoat, surface sterilize the seed with 30% hydrogen peroxide or 1% sodium hypochlorite. (Be sure to check out the procedure before treating a large batch of seed. Soaking time can be critical, and the seed may heat up in the hydrogen peroxide.) If serious damping off occurs on the second try, resterilize the mix and containers.

If the seed is viable, but hasn't germinated, check recommended germination temperature against current greenhouse temperatures. Change greenhouse temperature if needed. Check depth of seed covering. If too deep, scrape some of the growing medium away. If too shallow, increase irrigation frequency.

Possibly there was inadequate pretreatment of seed. Resow with properly pretreated seed.

21.62 Insects

The greenhouse should be inspected regularly for the presence of insects (section 20). Do not wait for damage symptoms to appear. The frequency of inspection and the urgency of action depends on the stage of growth and the nature of the probable pest. For instance, sucking or chewing insects are serious pests during the juvenile and exponential growth phases. They are of little importance during hardening of hardwoods when the leaves are about to abscise anyway.

Examine the foliage thoroughly, especially the underside of the leaves. Look carefully; some insects are so small and so well camouflaged that they can easily be missed. When insects are found, identify them. Some are beneficial, some are harmless, and some require control. If harmful insects are found, apply recommended control measures (section 20.33).

21.63 Growth Problem Distribution

A great deal can be deduced by examining the spacial pattern in which the growth problem occurs. This section discusses the most common patterns and their probable cause, but the reader should also keep spacial pattern in mind when reading the following sections as well (sections 21.64-21.68).

Bread loaf effect.—Height growth will sometimes be greater in the middle than it is at the edges of a bench or sometimes a whole greenhouse, giving that block of seedlings the shape of a loaf of bread. The most common cause is inadequate air circulation, which causes localized differences in temperature and humidity. The cure is to have positive air circulation, especially during daylight hours and preferably under the bench (section 6). Another cause is that the containers at the edge of the bench are exposed to more light. This accelerates drying and may cause above optimum rootball temperatures. The problem can be minimized by using white or light colored containers. Styrofoam is especially good in this respect because of its insulating as well as light reflecting qualities. Watering should be programed to maintain adequate moisture in those edge containers subject to the most rapid drying. This means that the pot mix must be porous enough so the interior containers can tolerate the excess of moisture they will receive. Maintenance of adequate humidity will reduce the difference in water consumption between edge and interior cavities (section 11).

Rings or streaks.—Chlorosis or stunted seedlings grouped in rings, circles, or streaks usually indicates a non-uniform watering pattern (section 6.4). The watering pattern should be tested with an array of paper cups to determine whether the poor seedlings are getting more or less than the rest of the house. Usually, they are getting too much, and the problem is often compounded by a pot mix that is too fine to tolerate overwatering (section 9.3). The cure is to revamp the watering system to produce a more uniform distribution. On the next crop, use a coarser, more porous medium. If the poor seedlings are getting less than the more vigorous ones, increase the duration of watering and check to be sure that some solution leaches from the bottom of the least watered containers. If the medium is too fine, however, this can reduce the growth of the once healthy seedlings. The nurseryman should be alert to this and steer an intermediate course, if possible. Another alternative would be to hand water the deficient cavities without watering the entire house. The ultimate cure, of course, is a more uniform watering system and a more porous pot mix. This is definitely the way to prevent the problem from developing in future crops, but in the middle of the growing cycle, changing pot mixes is out of the question and changing irrigation systems is difficult.

Another cause is variation in light intensity at night (section 12.3). If there is a portion of the greenhouse that does not receive enough light at night, premature budset may result. When it is a matter of distance from the light the effect will be gradual over quite a distance. Sometimes an object will create a shadow, and the division between actively growing and dormant seedlings will be quite sharp. The best way to diagnose this condition is to visit the greenhouse at night. A hand light meter will tell you whether you are below minimum recommended intensity or not. If the pattern of growth is caused by variation in light intensity, it will be apparent without any instrumentation.

Scattered problem spots.—Although the development of disease may be aided by certain combinations of temperature and humidity which will occur in a recognizable pattern in a non-uniform greenhouse, disease often occurs in spots without any apparent spacial relation. Suspect disease, especially if the problem areas are confined to one species in a house where several are growing. Examine the symptoms carefully and see section 20.24 for help in diagnosis and cure.

No pattern; problem widely distributed.—Disease and insect attacks can be generally distributed and widespread throughout the greenhouse, but with any vigilance at all, most will be detected and corrective action taken when the problem is still confined to scattered spots. One exception is if a serious error has been made in the preparation of the growing medium(Section 9.3). For instance, if too much dolomite has been incorporated into the growing medium, the pH will become too alkaline after the crop is well underway. In this case, increase the acidity of the nutrient solution, and use less dolomite next time. If the growing medium contains toxic materials, such as anerobically fermented sawdust or fresh cedar shingle tow, or easily biolizable carbon sources, such as fresh sawdust or rice hulls, or it has not been sterilized adequately, or it lacks a required mycorrhizal fungus, then the problem may become apparent quickly and throughout the whole crop at once.

If the growing medium contains materials that have not been properly composted, about all that can be done is to raise the nitrogen level to 400 ppm, apply light doses of protective fungicides, and hope. If the problem can be discovered early enough, it would be much better to dump the whole crop, resterilize the containers, refill with a proper mix, and start over.

Fungus diseases (section 20.34) can usually be suppressed with fungicides, but most fungicides will not cure the seedlings that have already been damaged. They will only prevent the fungus from spreading to healthy tissue. If a mycorrhizal fungus is needed (section 14.1), it can sometimes be successfully added after a growth problem is recognized, either as duff or spores which are applied to the surface and watered in.

Another possibility is mineral nutrient deficiency or toxicity. Examine the symptoms carefully. Compare them with the symptoms listed in section 13.51. Have the leachate from the bottom of the container analyzed to see how much of each mineral nutrient is present and compare that with the formulation listed in section 13.61. If any of the quantities found by analysis are very different from what was expected, adjust the formulation of the nutrient solution accordingly. Another more precise way to measure nutrient status is by foliar analysis. Compare the foliar nutrient content with what is known to be normal for the species, seed source, and age class of the seedlings being grown. However, these analyses may not be useful to the nurseryman unless they can be done quickly (in less than a week). Otherwise, the crop may be too badly damaged to recover.

A third possibility is air pollution. If the nursery is located in a large urban area or downwind from certain pollutant-emitting industries, sensitive tree species, such as white pine, may suffer. Elaborate air filters or washing systems can alleviate the problem, but they are expensive. Air pollution should have been considered when selecting a location for the nursery (section 4.1).

If the source of pollution is within the nursery itself, it can be eliminated. The most common source is SO_2 produced by burning sulfur-containing fuels for heat and CO_2 generation. The latter is most critical, because the flue gases are emitted directly into the greenhouse. Check with the fuel supplier to make sure the carbon to sulfur ratio is 10,000 to 1 or more (section 14.23). If it is not, change fuels or shut off the CO_2 burner until a low sulfur fuel can be found. If the heating system is burning a high sulfur fuel, make sure the flue gases are carried well away from the greenhouse and do not enter it. If this is not possible, switch to a low sulfur fuel. If an oil burning space heater must be used for emergency heat, use kerosene or number 1 diesel oil. Do not use number 2 diesel or number 2 fuel oil.

The other internal source of pollution is ozone. Electric motors that are dirty or badly worn will arc excessively and generate appreciable quantities of ozone. Clean or repair the motors if this condition is found.

21.64 Disease

Sometimes the mycelium or fruiting bodies of a fungus are visible on necrotic parts of the seedling. This is of great help in diagnosing the disease, but more often the diagnosis must be based on location, color, or shape of deformity. See sections 20.21 and 20.34 for assistance. Always identify the disease before treating it. Success is more likely than if a shotgun approach is tried.

21.65 Wilting

Wilting is caused by the inability of the roots to replace moisture as fast as the foliage is losing it. The most common cause is lack of moisture in the rootball. If this is the case, water immediately and modify the watering schedule to be sure that wilting does not occur repeatedly. Sometimes wilting will occur on hot days in otherwise healthy, well watered seedlings. Try increasing the humidity and decreasing peak day temperatures by watering in the hottest part of the day.

Wilting can also be caused by poor root aeration caused by a tight waterlogged mix. In this case, wilting is usually accompanied by chlorosis and stunted growth. Reduce the frequency of watering, and use a more porous mix for the next crop.

A waterlogged mix can lead to root rot. If this is found, apply fungicide periodically (section 20.34) and reduce the frequency of watering. Do not reduce the amount of water per irrigation, however, as this may lead to a buildup of salts. Use a more porous mix for the next crop.

If the mix is both well watered and well aerated, and root rot is not evidence, look for wilt disease inside the stem. If nothing can be found, look for nematodes in the pot mix. If found, treat as in section 20.34. On the next crop, do a better job of sanitation in the greenhouse and sterilization of the mix and containers.

21.66 Chlorosis

Chlorosis is a reduction in the amount of chlorophyll present and is a general symptom of many maladies, but careful observation of where on the leaf and seedling it occurs can yield important clues.

If only the newest growth is chlorotic and the foliage is of normal size, suspect iron deficiency (section 13.51). Increase the iron chelate in the nutrient solution, and make sure the pH of the nutrient solution is close to your target: 5.5 for most conifers and 6.5 for most hardwoods (section 13.32).

If needle tips are chlorotic with necrosis frequently occurring at the very tip or there is yellow interveinal mottling of hardwoods, suspect SO_2 injury, and proceed as in section 12.63. If the damage is general or concentrated on the older foliage and is accompanied by stunting, suspect nitrogen deficiency. Increase the amount of nitrogen in the nutrient solution and check the pH. Similar symptoms can be caused by waterlogged pot medium. If this is the case, reduce the frequency of watering, but do not reduce the amount of water per watering.

In the Pacific Northwest, root rot and chlorosis caused by waterlogged pot mix may occur in seedlings stored outdoors in the winter, especially when roots have effectively clogged the drainage holes. The cure in this case is to shelter them so that they do not receive large and uncontrolled amounts of rainfall.

Deficiencies of magnesium and sulfur will also cause chlorosis somewhat different in pattern from either iron or nitrogen deficiency (section 13.51). In general, if a nutrient deficiency is suspected, 1) check the pH and formulation of the nutrient solution, 2) get a foliar analysis of some damaged tissue and compare with the analysis of healthy tissue, and 3) try painting or spraying a salt solution of the suspected element on the damaged tissue. If the problem is corrected in 1 to 2 weeks, you have probably guessed right.

21.67 Brown or Necrotic Spots on Leaves or Stem

This is a commonly observed symptom which could be due to many causes. It is characteristic of ozone damage. Check electric motors in the greenhouse for excessive arcing. If due to photochemical smog, filter all incoming air through activated charcoal, or move the nursery.

Deficiencies of P, Ca, Mg, and toxic levels of B may produce necrotic spots in combination with chlorosis or other characteristic colors. See section 13.51 for details of nutrient deficiency symptoms.

Diseases can also produce similar symptoms. See section 20.21 or consult Peterson and Smith (1975).

21.68 Lack of Growth or Premature Dormancy

If the species being grown is one that has been well researched and requirements for optimum growth can be specified with reasonable certainty, then the first step is to check all of the environmental controls for proper setting and function. If anything is off, return it to the known optimum. Check the hygrothermograph charts and daily log for short term malfunctions or mistakes in procedure, such as too long a period without water, or failure to inoculate with a required mycorrhizal fungus.

If there is limited knowledge about the requirements of the crop, examine the herbarium specimens or measurement records from previous crops to determine what was different about the procedure or conditions that produced good crops before. If a specific lead can be found, it will make it much easier to either restimulate growth or to show that growth is not likely to resume.

If a specific probable cause can be found, correct whatever is non-optimum, but for many species that will not be enough to reverse the onset of dormancy. If better or more specific information is not available, try the following in sequence until one works.

1. Increase the intensity of light at night to 60 foot-candles (650 lux) and the duration to 1 part in 8 (section 12.3).
2. Increase the night temperature to 72°-75° F (22°-24° C).
3. Raise the nitrogen level in the nutrient solution. Most species can tolerate 400 ppm without adverse effects.
4. Spray with 50 ppm gibberellic acid.
5. Add a suitable mycorrhizal inoculum and water it in.
6. Accept a smaller tree.
7. Put the crop through dormancy and hardening. Flush again, then harden and ship.

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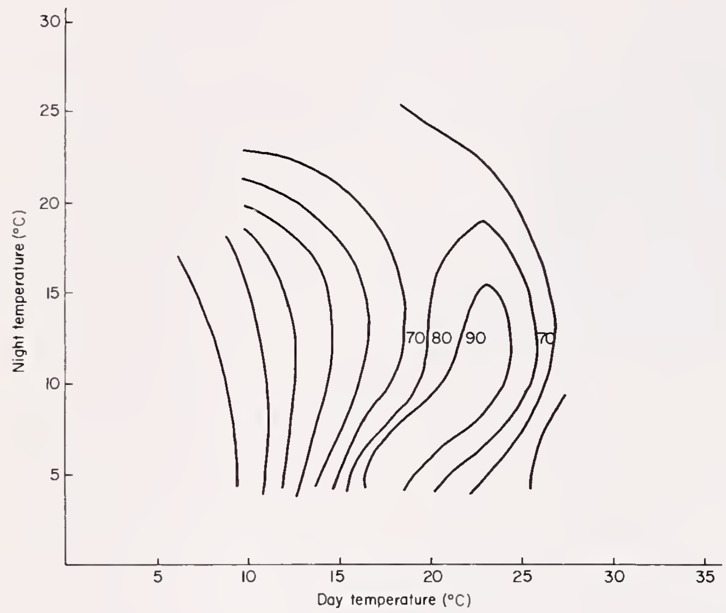
Appendix 1

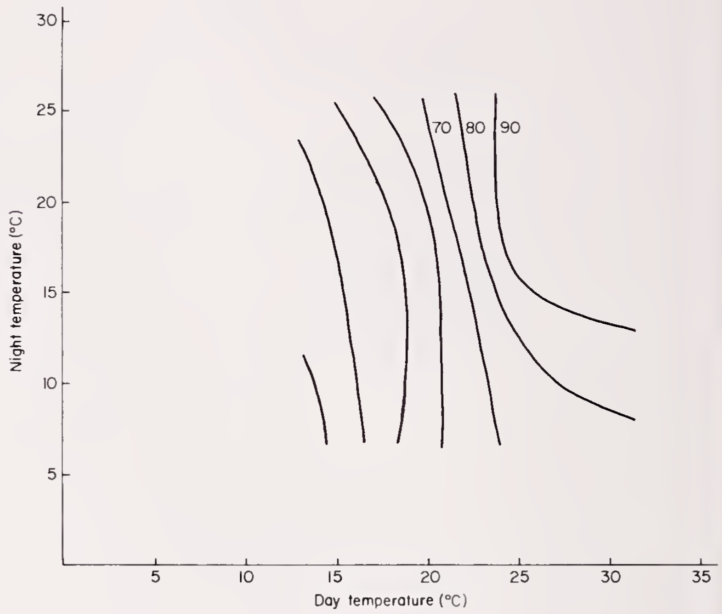
Growth in percent of maximum of various tree species and seed sources as a function of day and night temperature. See section 10 for interpretation and use of the graphs. Some information is also available about the following species:

Species	Authority
Western hemlock	Brix (1971) Owston and Kozlowski (1978)
Jeffrey pine	Hellmers (1963)
Loblolly pine	Hellmers (1962)
Northern red oak	Hellmers (1962)
Douglas-fir	Hellmers (1962)
Digger pine	Hellmers (1962)
Eastern hemlock	Olson et al. (1959)
Pitch pine	Good and Good (1976)

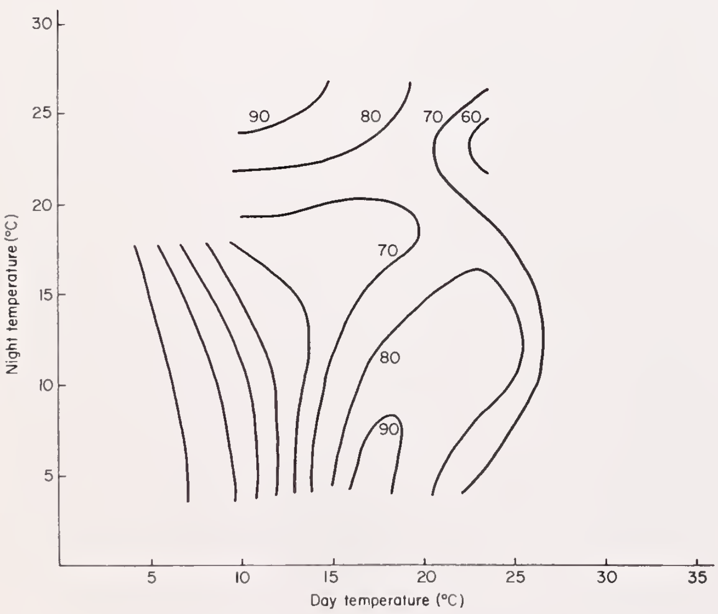
Species: *Abies magnifica*
Growth Parameter: Height
Maximum Size (= 100%): 108mm
Seed Source: Calif., No. Coast Pine Region, 6,000 feet (1,800m)
Coefficient of Variability: 8%
Authority: Hellmers (1966)



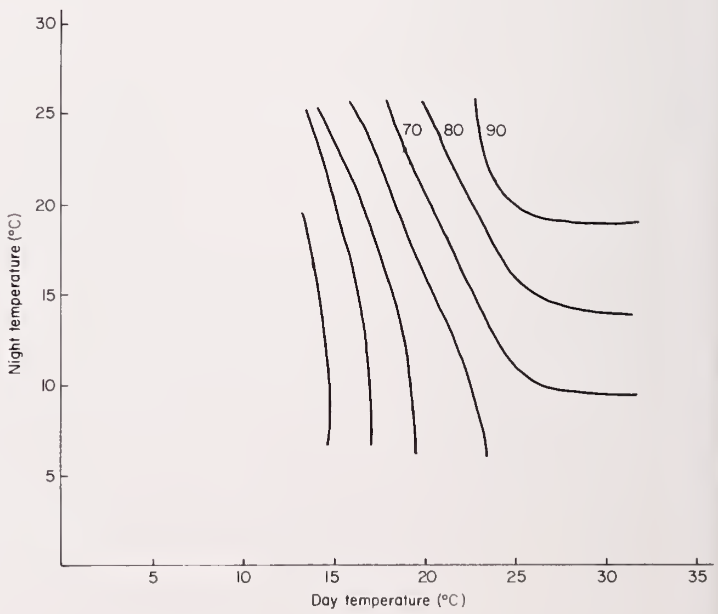
Species: *Celtis occidentalis*
Growth Parameter: Height
Maximum Size (= 100%): 615mm
Seed Source: South Dakota
Coefficient of Variability: 5.2%
Authority: Tinus (1974)



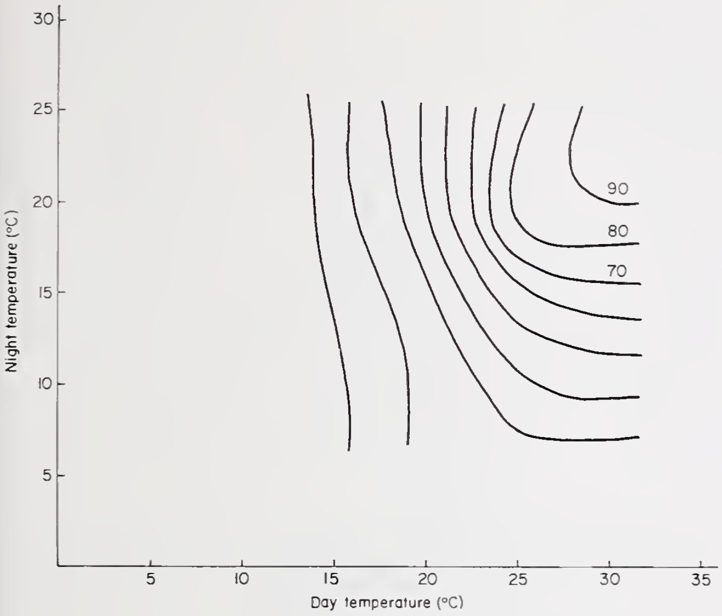
Species: *Abies magnifica*
Growth Parameter: Dry weight
Maximum Size (= 100%): 1.7gm
Seed Source: No. Coast Pine Region, 6,000 feet (1,800m)
Coefficient of Variability: 9%
Authority: Hellmers (1966)



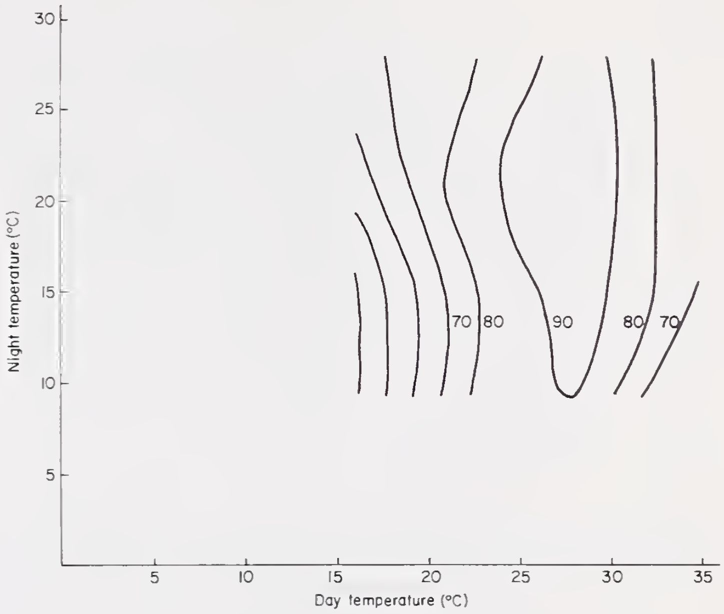
Species: *Celtis occidentalis*
Growth Parameter: Caliper
Maximum Size (= 100%): 5.2mm
Seed Source: South Dakota
Coefficient of Variability: 4.1%
Authority: Tinus (1974)



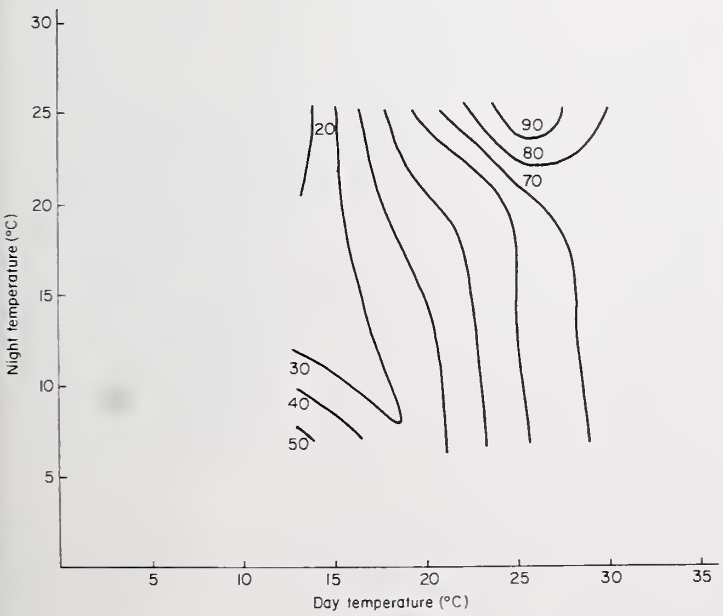
Species: *Celtis occidentalis*
Growth Parameter: Dry weight
Maximum Size (= 100%): 7.2gm
Seed Source: South Dakota
Coefficient of Variability: 13.5%
Authority: Tinus (1974)



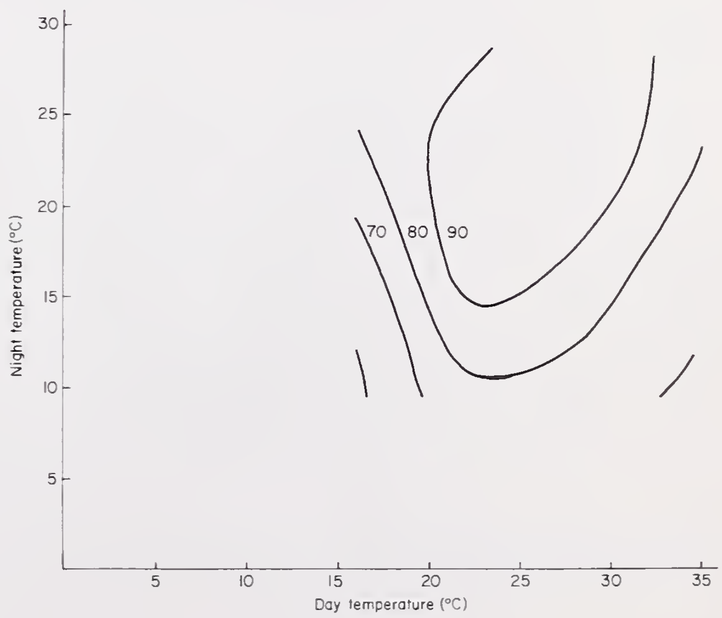
Species: *Juglans nigra*
Growth Parameter: Height
Maximum Size (= 100%): 680mm
Seed Source: Kansas
Coefficient of Variability: Not available
Authority: Tinus (unpublished)



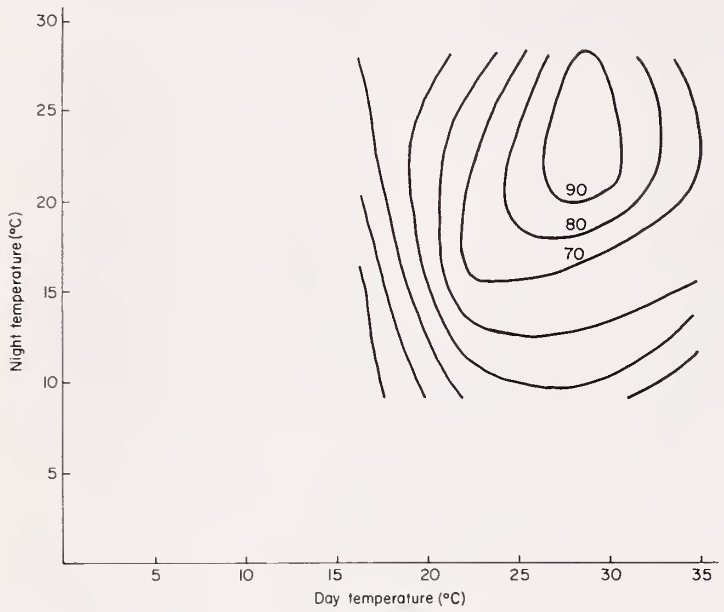
Species: *Celtis occidentalis*
Growth Parameter: Root/shoot ratio (dry weight)
Maximum Size (= 100%): 0.21
Seed Source: South Dakota
Coefficient of Variability: Not available
Authority: Tinus (1974)



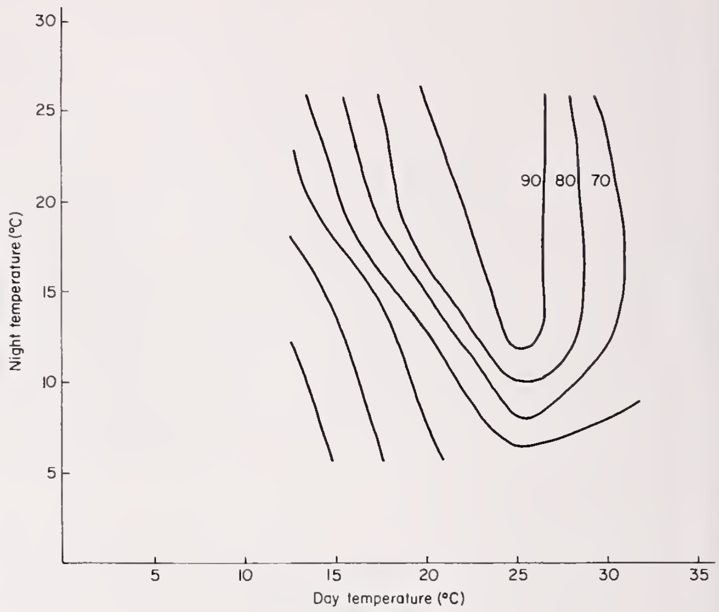
Species: *Juglans nigra*
Growth Parameter: Caliper
Maximum Size (= 100%): 7.35mm
Seed Source: Kansas
Coefficient of Variability: Not available
Authority: Tinus (unpublished)



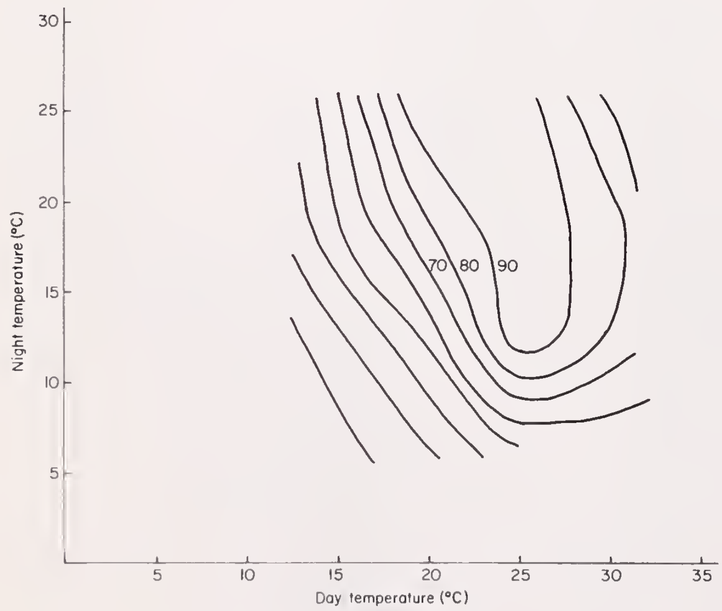
Species: *Juglans nigra*
Growth Parameter: Dry weight
Maximum Size (= 100%): 18.4gm
Seed Source: Kansas
Coefficient of Variability: Not available
Authority: Tinus (unpublished)



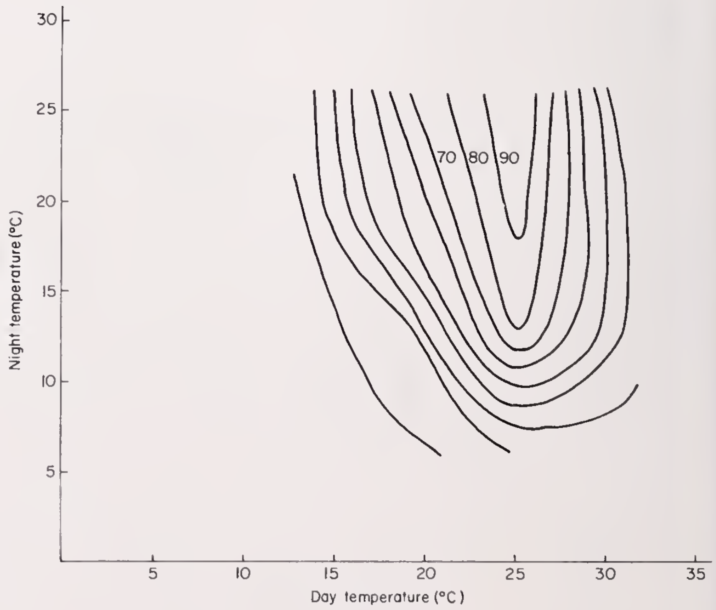
Species: *Juniperus scopulorum*
Growth Parameter: Caliper
Maximum Size (= 100%): 2.6mm
Seed Source: Towner, N. Dak.
Coefficient of Variability: 6%
Authority: Tinus (1972)



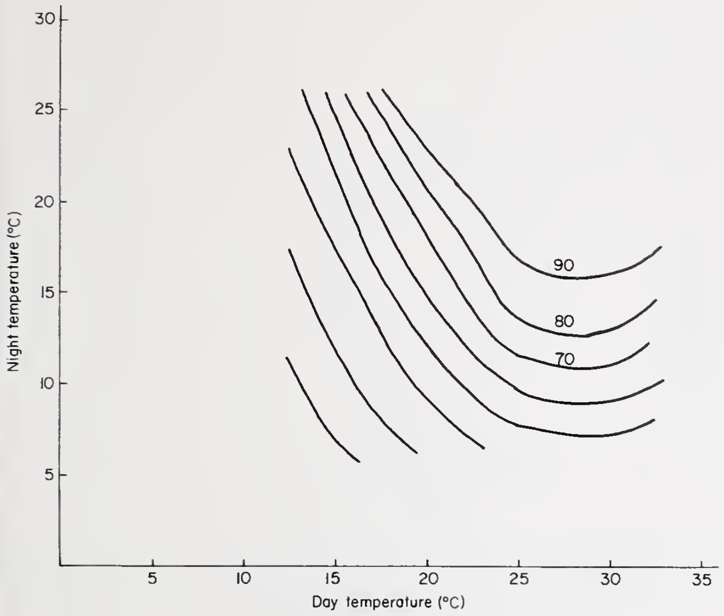
Species: *Juniperus scopulorum*
Growth Parameter: Height
Maximum Size (= 100%): 224mm
Seed Source: Towner, N. Dak.
Coefficient of Variability: 8%
Authority: Tinus (1972)



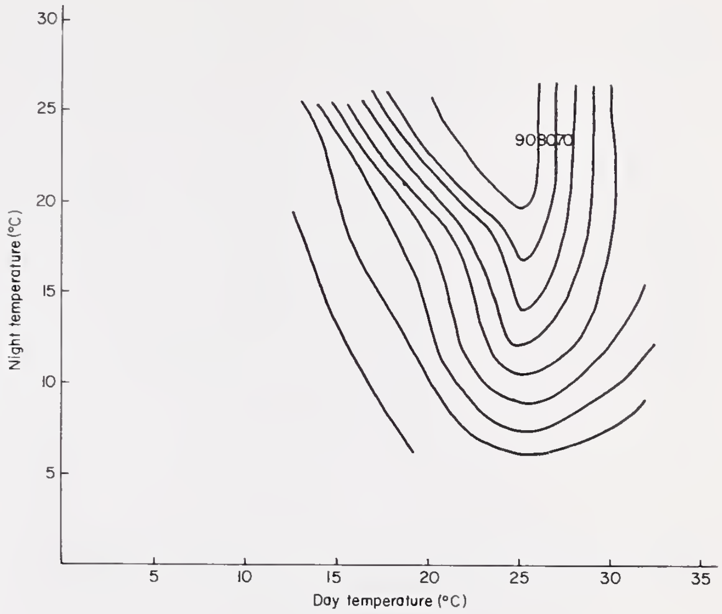
Species: *Juniperus scopulorum*
Growth Parameter: Dry weight
Maximum Size (= 100%): 5.6gm
Seed Source: Towner, N. Dak.
Coefficient of Variability: 18%
Authority: Tinus (1972)



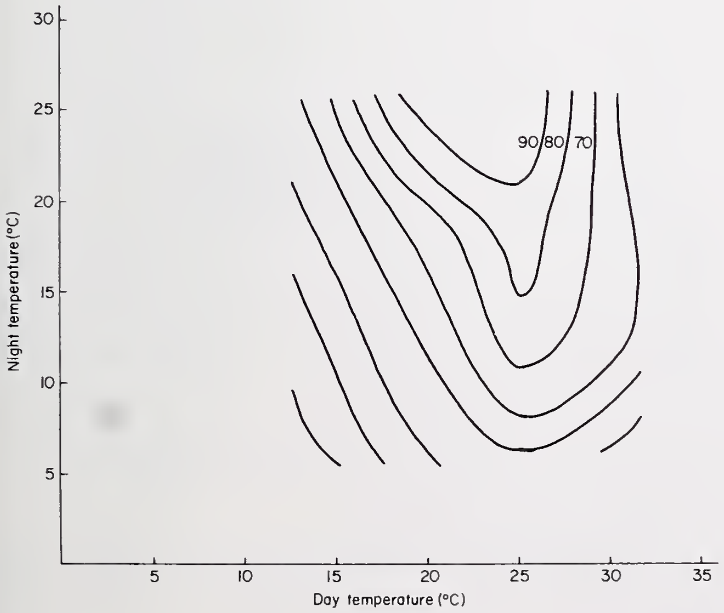
Species: *Juniperus virginiana*
Growth Parameter: Height
Maximum Size (= 100%): 279mm
Seed Source: Towner, N. Dak.
Coefficient of Variability: 6%
Authority: Tinus (1972)



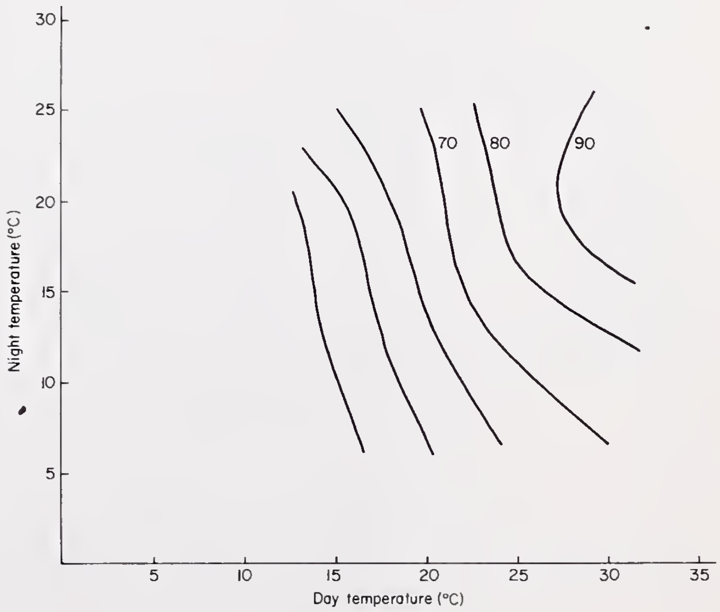
Species: *Juniperus virginiana*
Growth Parameter: Dry weight
Maximum Size (= 100%): 11.9gm
Seed Source: Towner, N. Dak.
Coefficient of Variability: 16%
Authority: Tinus (1972)



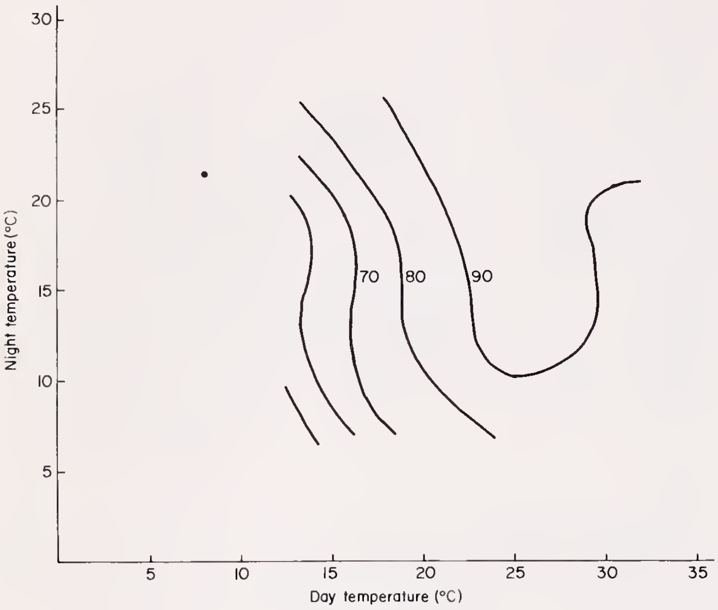
Species: *Juniperus virginiana*
Growth Parameter: Caliper
Maximum Size (= 100%): 6.2mm
Seed Source: Towner, N. Dak.
Coefficient of Variability: 5%
Authority: Tinus (1972)



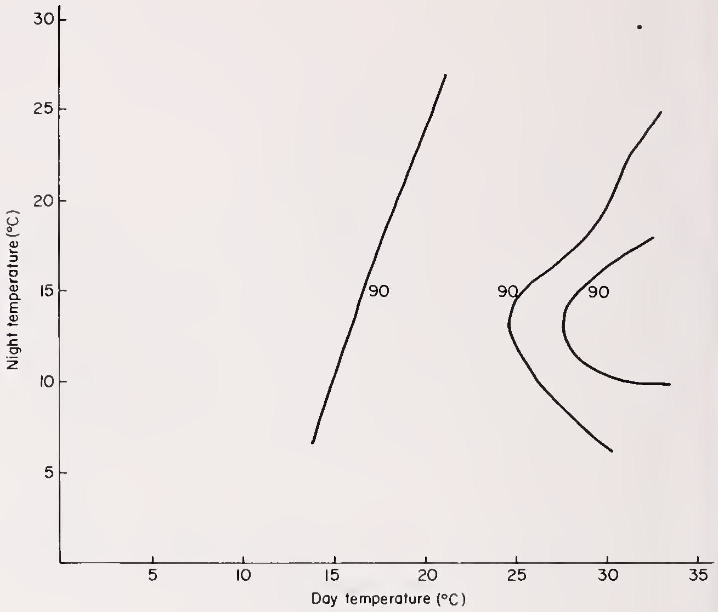
Species: *Larix sibirica*
Growth Parameter: Height
Maximum Size (= 100%): 314mm
Seed Source: Denbigh, N. Dak. (Russian origin)
Coefficient of Variability: 4.4%
Authority: Tinus (1973)



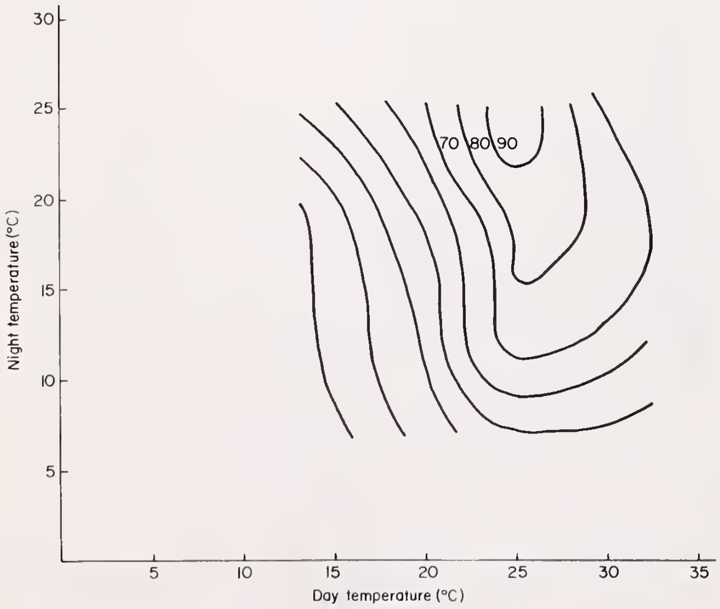
Species: *Larix sibirica*
Growth Parameter: Caliper
Maximum Size (= 100%): 6.3mm
Seed Source: Denbigh, N. Dak. (Russian origin)
Coefficient of Variability: 3.8%
Authority: Tinus (1973)



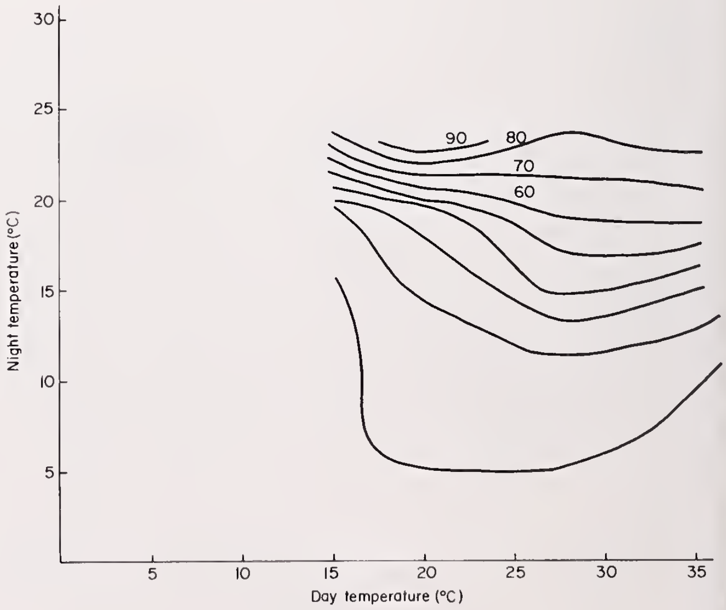
Species: *Larix sibirica*
Growth Parameter: Root/shoot ratio (dry weight)
Maximum Size (= 100%): 0.33
Seed Source: Denbigh, N. Dak. (Russian origin)
Coefficient of Variability: Not available
Authority: Tinus (1973)



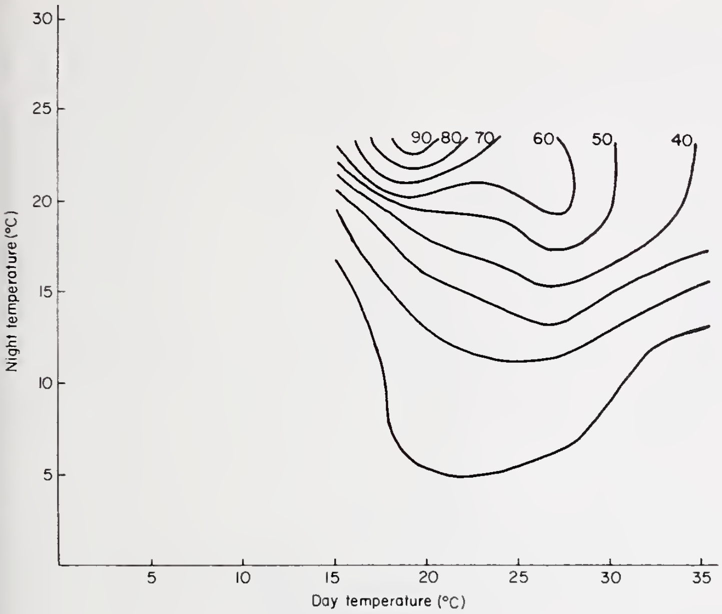
Species: *Larix sibirica*
Growth Parameter: Dry weight
Maximum Size (= 100%): 6.3gm
Seed Source: Denbigh, N. Dak. (Russian origin)
Coefficient of Variability: 10.9%
Authority: Tinus (1973)



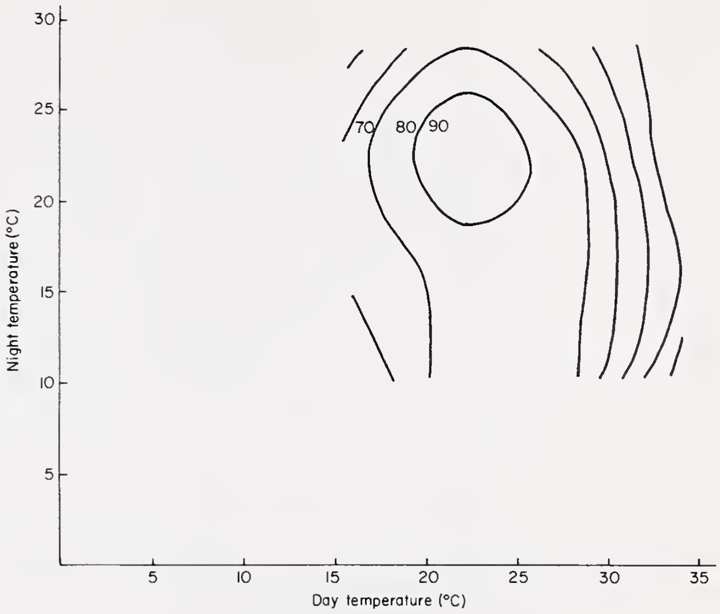
Species: *Picea engelmannii*
Growth Parameter: Height
Maximum Size (= 100%): 165mm
Seed Source: Larimer County Colo., 10,300 feet (3,140m)
Coefficient of Variability: Not available
Authority: Hellmers et al. (1970)



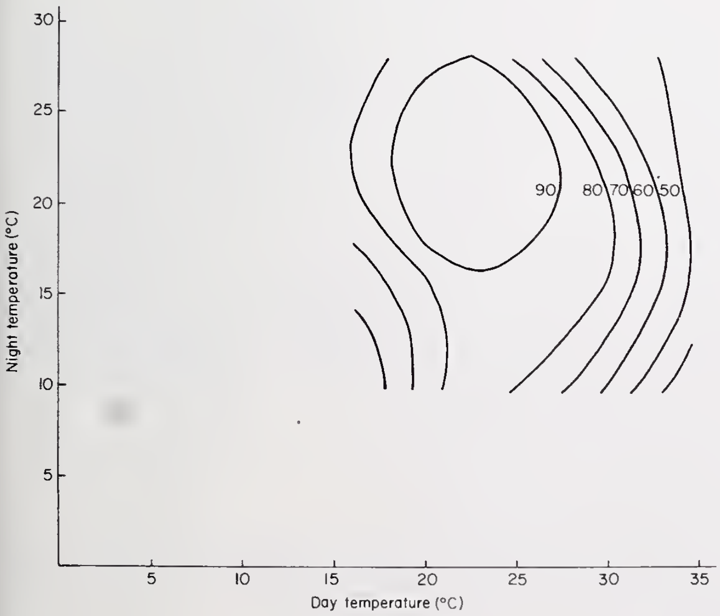
Species: *Picea engelmannii*
Growth Parameter: Dry weight
Maximum Size (= 100%): 8.3gm
Seed Source: Larimer County Colo., 10,300 feet (3,140m)
Coefficient of Variability: 17% ±
Authority: Hellmers et al. (1970)



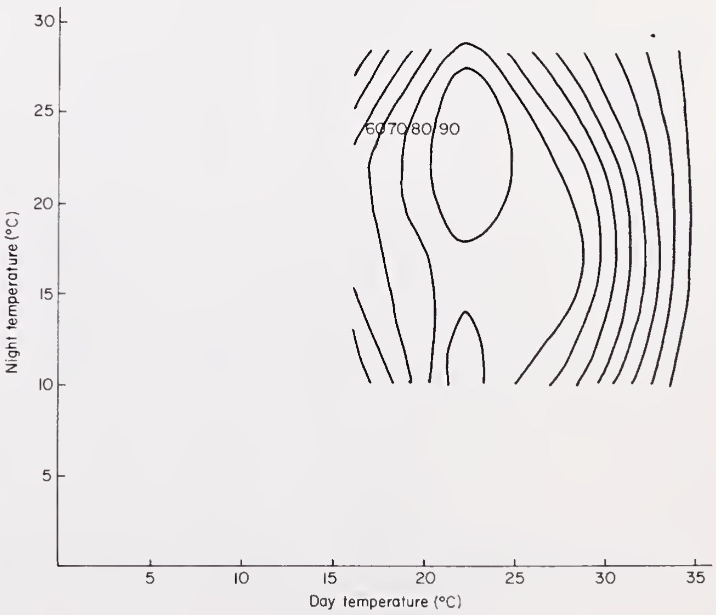
Species: *Picea glauca*
Growth Parameter: Caliper
Maximum Size (= 100%): 2.0mm
Seed Source: Kenai, Alaska, L-224
Coefficient of Variability: 6.8%
Authority: Tinus (1976)



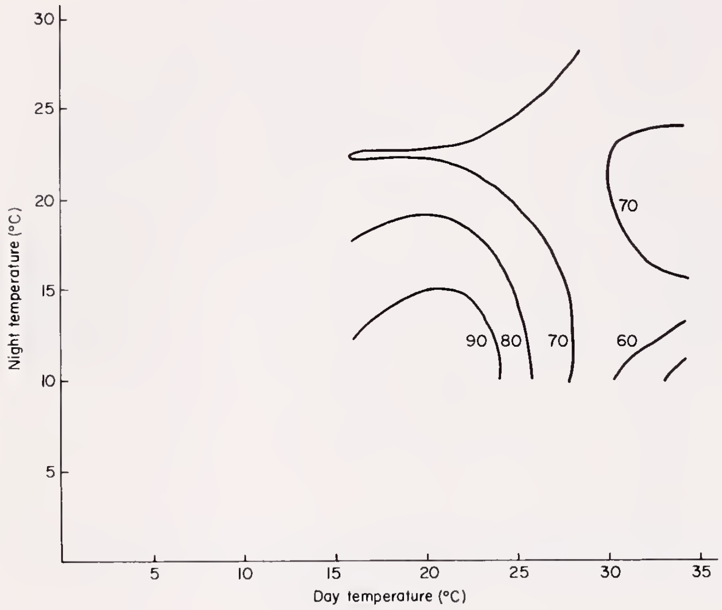
Species: *Picea glauca*
Growth Parameter: Height
Maximum Size (= 100%): 100mm
Seed Source: Kenai, Alaska, L-224
Coefficient of Variability: 9.9%
Authority: Tinus (1976)



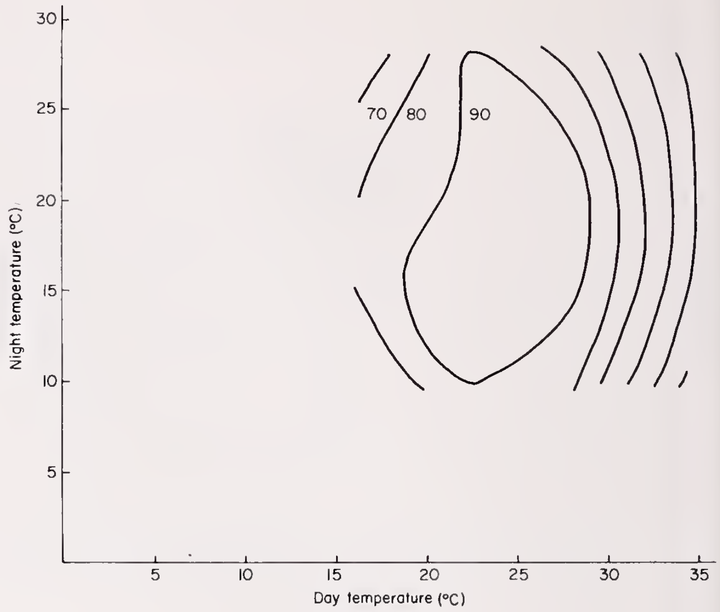
Species: *Picea glauca*
Growth Parameter: Dry weight
Maximum Size (= 100%): 0.43gm
Seed Source: Kenai, Alaska, L-224
Coefficient of Variability: 19.7%
Authority: Tinus (1976)



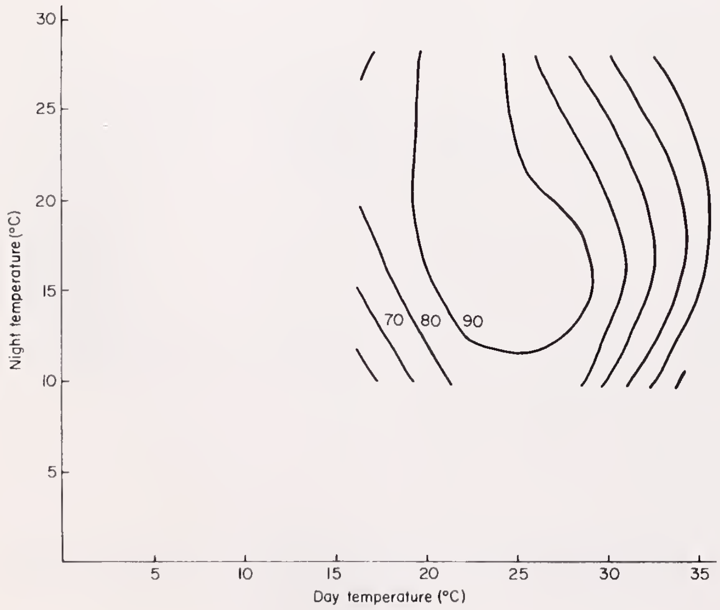
Species: *Picea glauca*
Growth Parameter: Root/shoot ratio (dry weight)
Maximum Size (= 100%): 0.33
Seed Source: Kenai, Alaska, L-224
Coefficient of Variability: Not available
Authority: Tinus (1976)



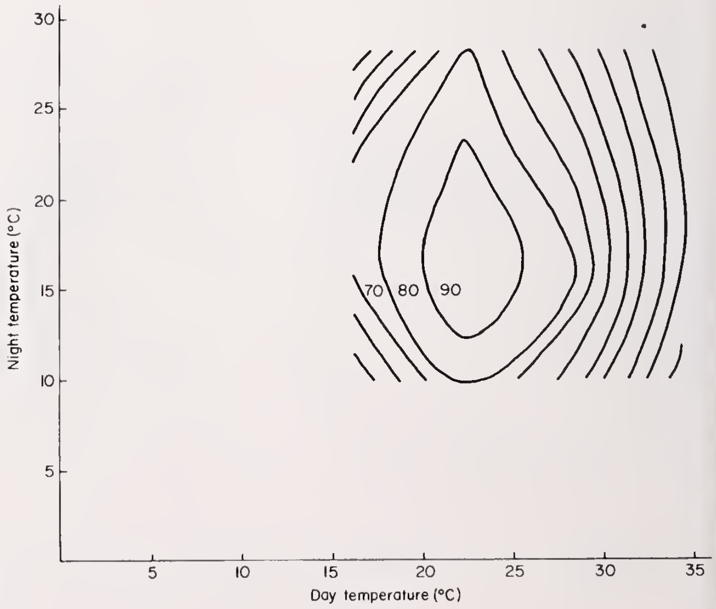
Species: *Picea glauca*
Growth Parameter: Caliper
Maximum Size (= 100%): 1.7mm
Seed Source: Fairbanks, Alaska, L-274
Coefficient of Variability: 3.6%
Authority: Tinus (1976)



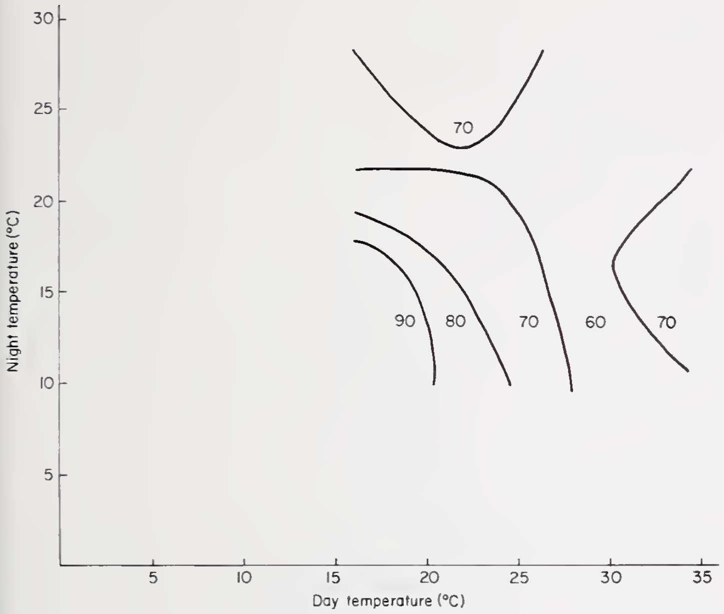
Species: *Picea glauca*
Growth Parameter: Height
Maximum Size (= 100%): 115mm
Seed Source: Fairbanks, Alaska, L-274
Coefficient of Variability: 3.5%
Authority: Tinus (1976)



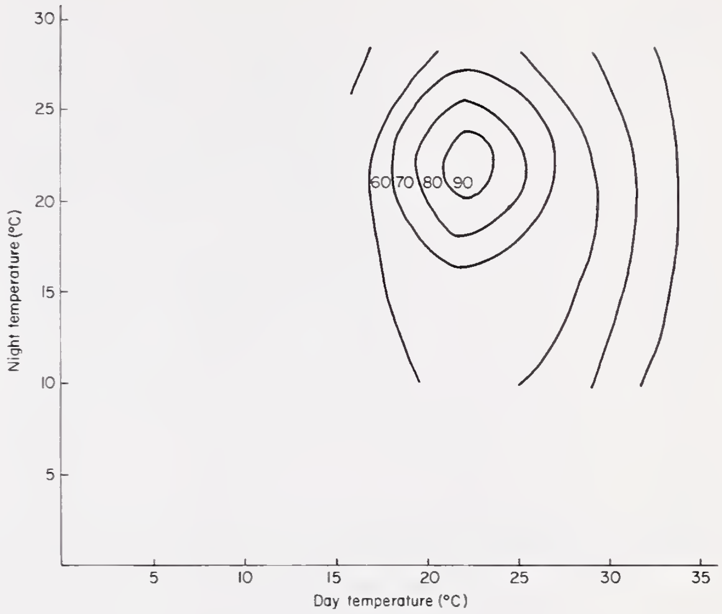
Species: *Picea glauca*
Growth Parameter: Dry weight
Maximum Size (= 100%): 0.39gm
Seed Source: Fairbanks, Alaska, L-274
Coefficient of Variability: 8.7%
Authority: Tinus (1976)



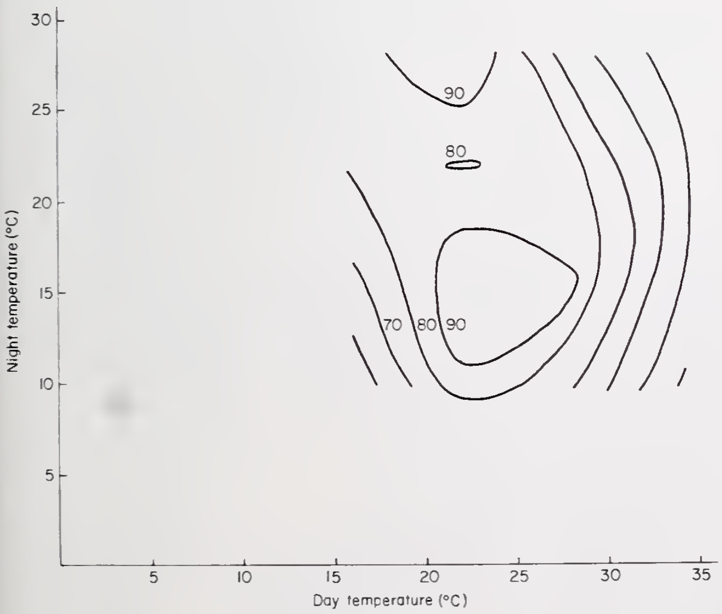
Species: *Picea glauca*
Growth Parameter: Root/shoot ratio (dry weight)
Maximum Size (= 100%): 0.35
Seed Source: Fairbanks, Alaska, L-274
Coefficient of Variability: Not available
Authority: Tinus (1976)



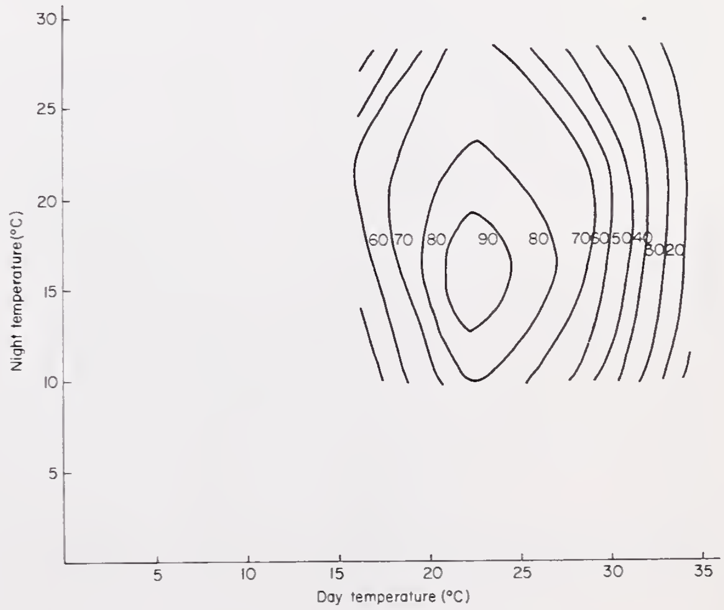
Species: *Picea glauca*
Growth Parameter: Caliper
Maximum Size (= 100%): 2.2mm
Seed Source: Central Alberta, DG-7986
Coefficient of Variability: 4.8%
Authority: Tinus (1976)



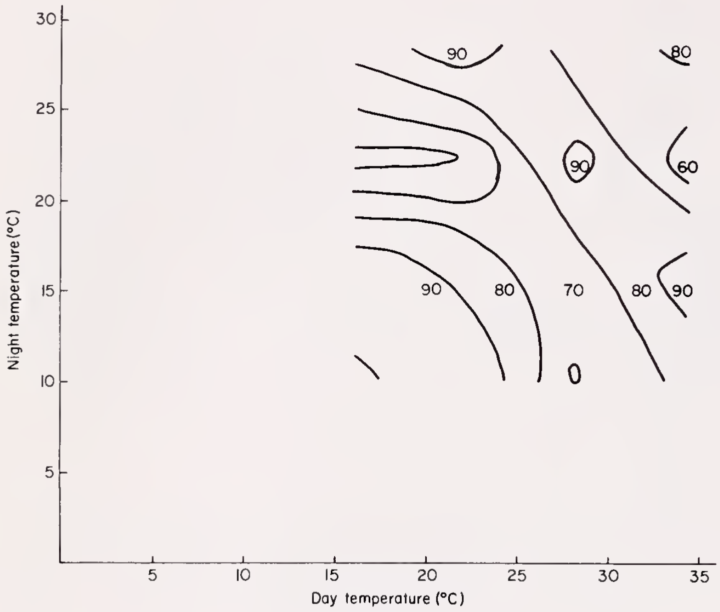
Species: *Picea glauca*
Growth Parameter: Height
Maximum Size (= 100%): 100mm
Seed Source: Central Alberta, DG-7986
Coefficient of Variability: 5.0%
Authority: Tinus (1976)



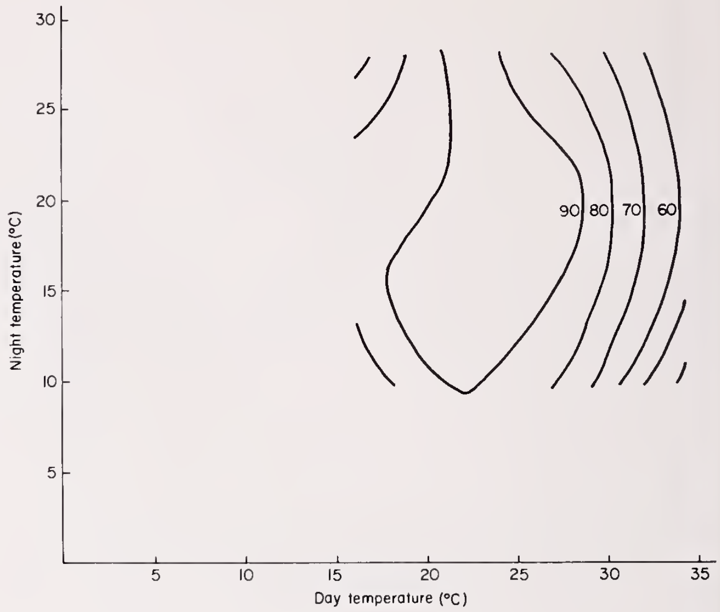
Species: *Picea glauca*
Growth Parameter: Dry weight
Maximum Size (= 100%): 0.36 gm
Seed Source: Central Alberta, DG-7936
Coefficient of Variability: 11.1%
Authority: Tinus (1976)



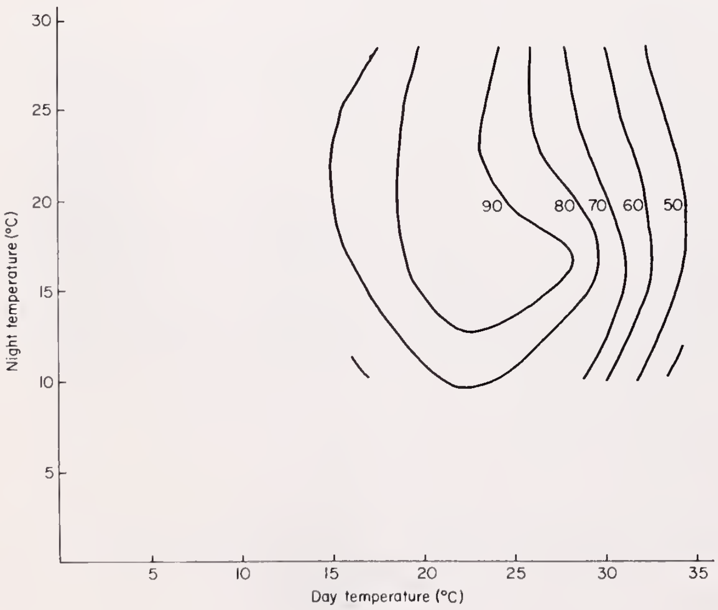
Species: *Picea glauca*
Growth Parameter: Root/shoot ratio (dry weight)
Maximum Size (= 100%): 0.21
Seed Source: Central Alberta, DG-7986
Coefficient of Variability: Not available
Authority: Tinus (1976)



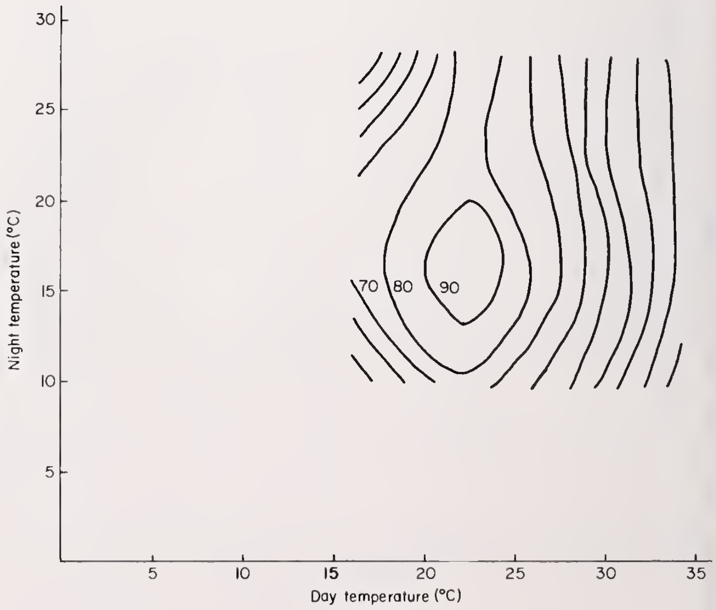
Species: *Picea glauca*
Growth Parameter: Caliper
Maximum Size (= 100%): 1.6mm
Seed Source: Central Alberta, DR-46135
Coefficient of Variability: 4.1%
Authority: Tinus (1976)



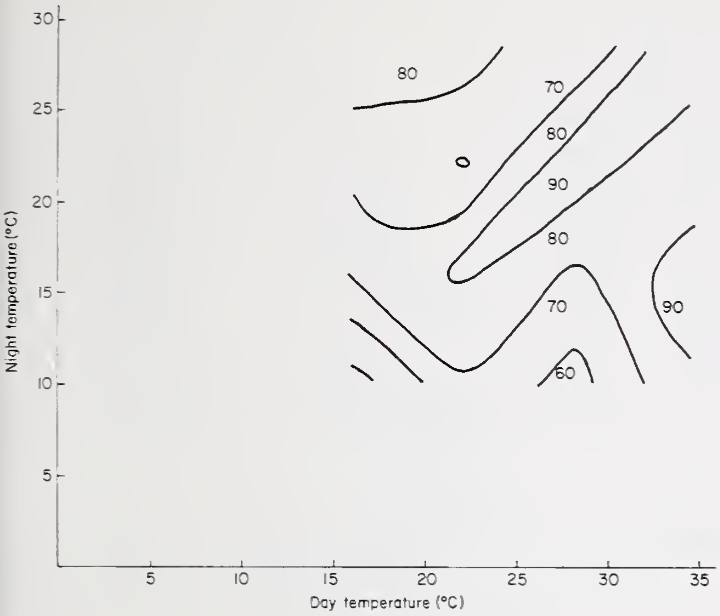
Species: *Picea glauca*
Growth Parameter: Height
Maximum Size (= 100%): 94mm
Seed Source: Central Alberta, DR-46135
Coefficient of Variability: 4.3%
Authority: Tinus (1976)



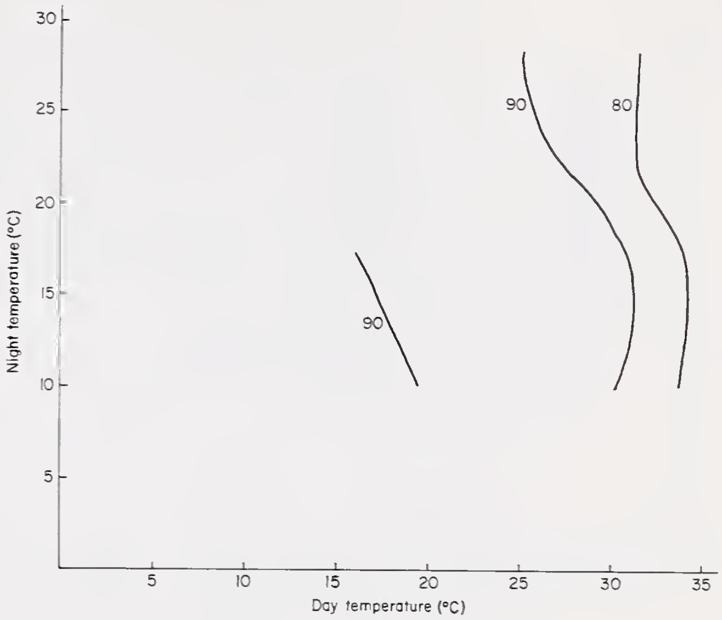
Species: *Picea glauca*
Growth Parameter: Dry weight
Maximum Dize (= 100%): 0.37gm
Seed Source: Central Alberta, DR-46135
Coefficient of Variability: 10.6%
Authority: Tinus (1976)



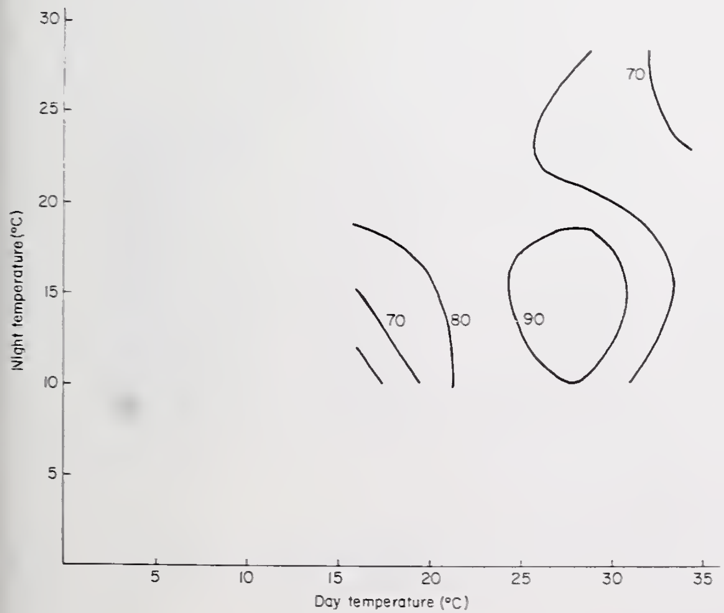
Species: *Picea glauca*
Growth Parameter: Root/shoot ratio (dry weight)
Maximum Size (= 100%): 0.23
Seed Source: Central Alberta , DR-46135
Coefficient of Variability: Not available
Authority: Tinus (1976)



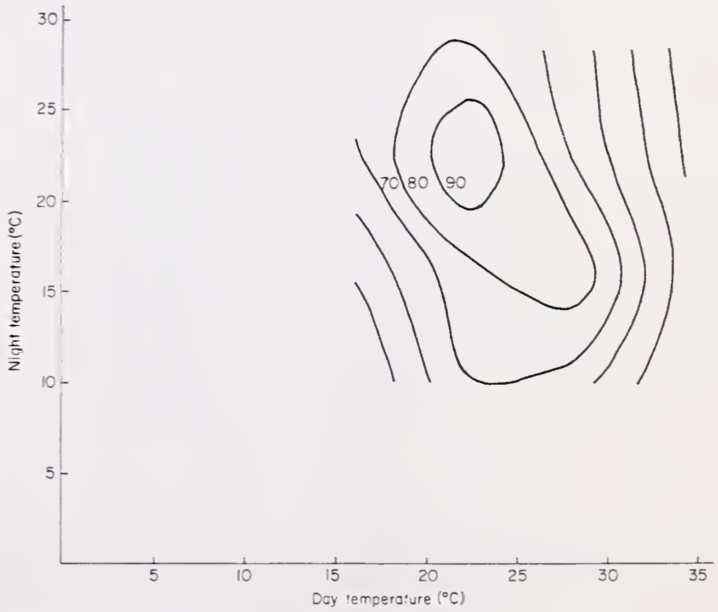
Species: *Picea glauca*
Growth Parameter: Caliper
Maximum Size (= 100%): 1.8mm
Seed Source: Central Alberta, DP-8796
Coefficient of Variability: 2.7%
Authority: Tinus (1976)



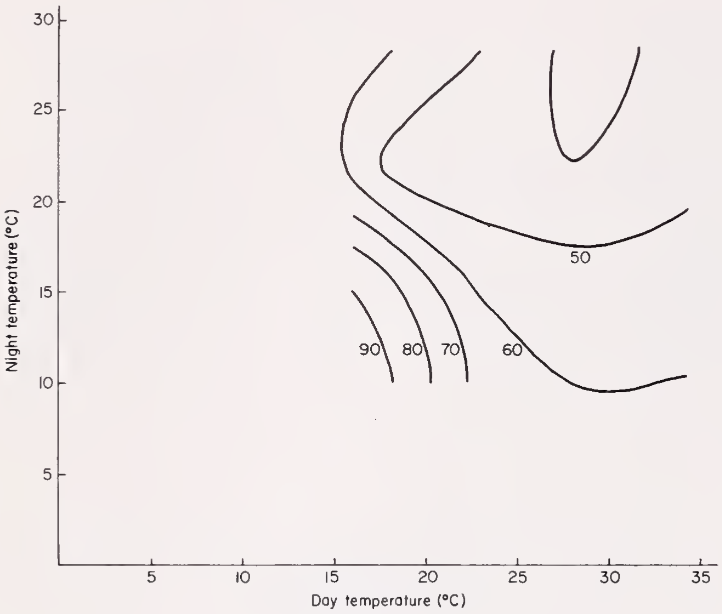
Species: *Picea glauca*
Growth Parameter: Height
Maximum Size (= 100%): 124mm
Seed Source: Central Alberta, DP-8796
Coefficient of Variability: 3.9%
Authority: Tinus (1976)



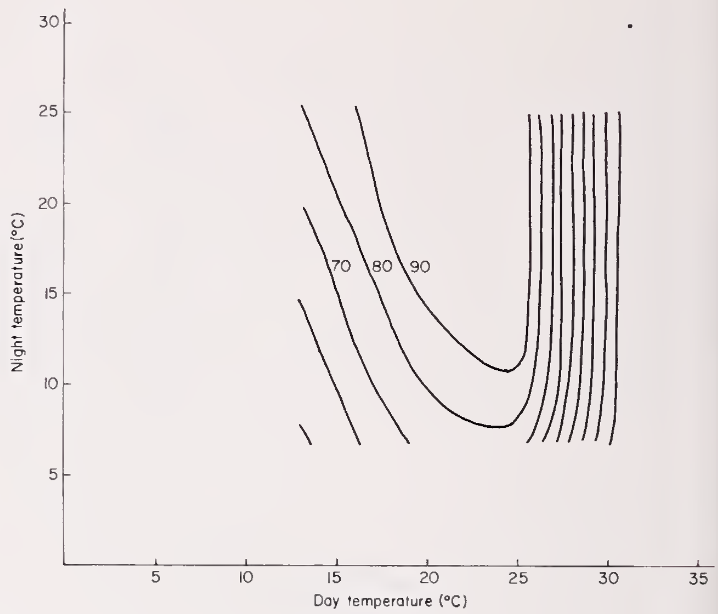
Species: *Picea glauca*
Growth Parameter: Dry weight
Maximum Size (= 100%): 0.56gm
Seed Source: Central Alberta, DP-8796
Coefficient of Variability: 6.6%
Authority: Tinus (1976)



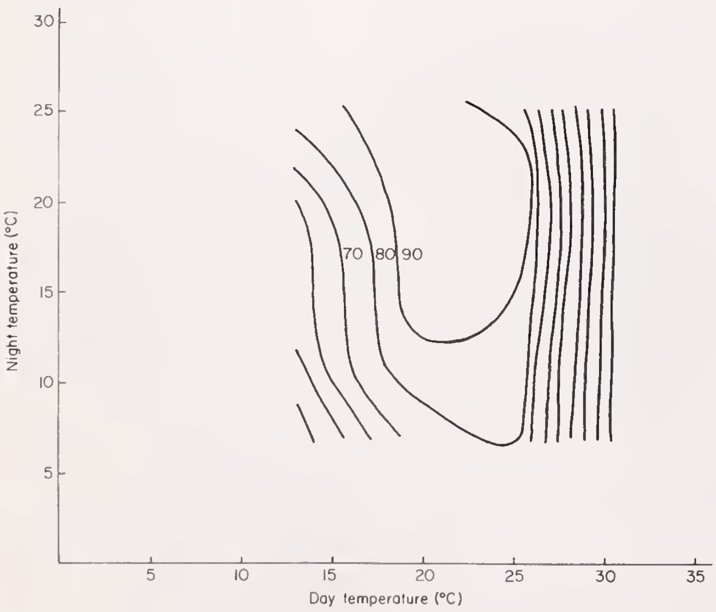
Species: *Picea glauca*
Growth Parameter: Root/shoot ratio (dry weight)
Maximum Size (= 100%): 0.43
Seed Source: Central Alberta, DP-8796
Coefficient of Variability: Not available
Authority: Tinus (1976)



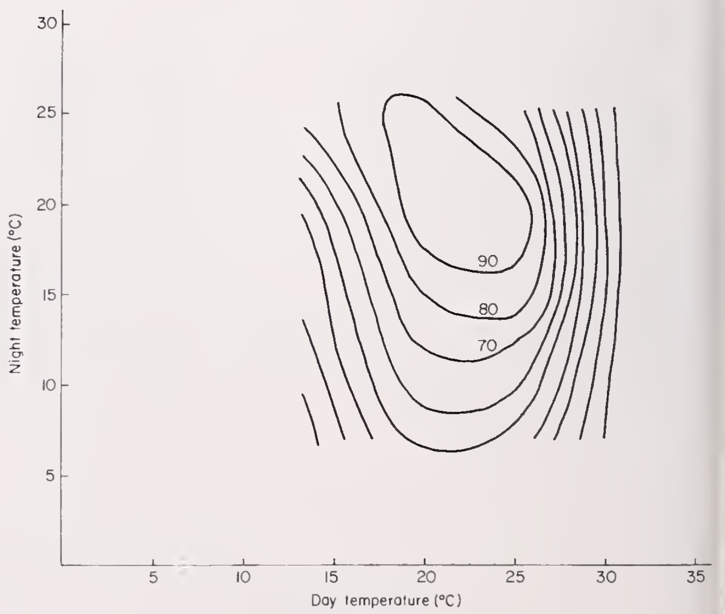
Species: *Picea pungens*
Growth Parameter: Caliper
Maximum Size (= 100%): 5.5mm
Seed Source: Indian Head, Sask. (origin unknown)
Coefficient of Variability: Not available
Authority: Tinus (1971)



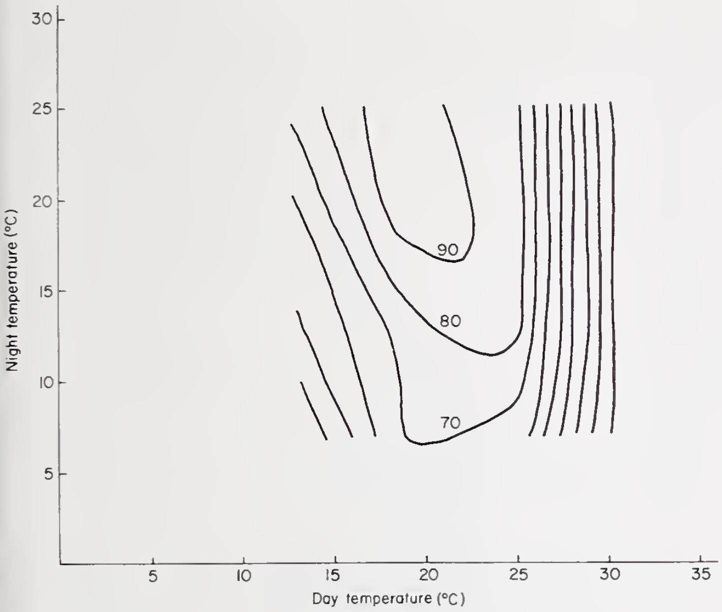
Species: *Picea pungens*
Growth Parameter: Height
Maximum Size (= 100%): 264mm
Seed Source: Indian Head, Sask. (origin unknown)
Coefficient of Variability: Not available
Authority: Tinus (1971)



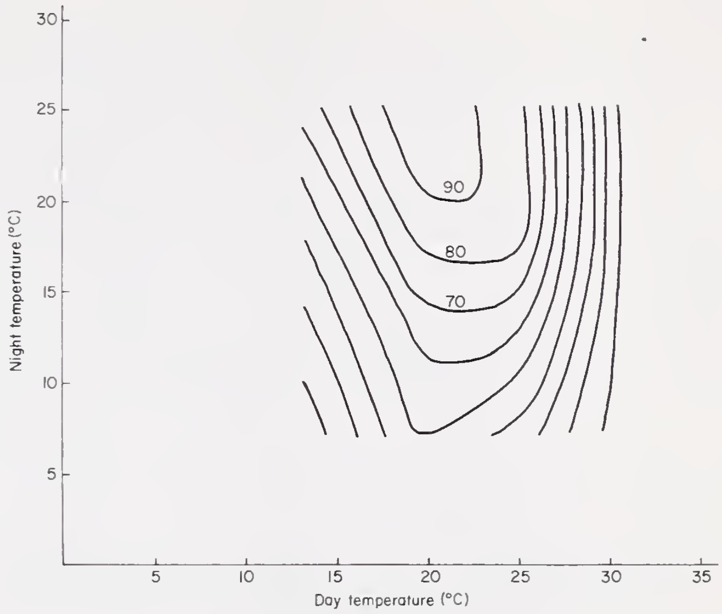
Species: *Picea pungens*
Growth Parameter: Dry weight
Maximum Size (= 100%): 8.9gm
Seed Source: Indian Head, Sask. (origin unknown)
Coefficient of Variability: Not available
Authority: Tinus (1971)



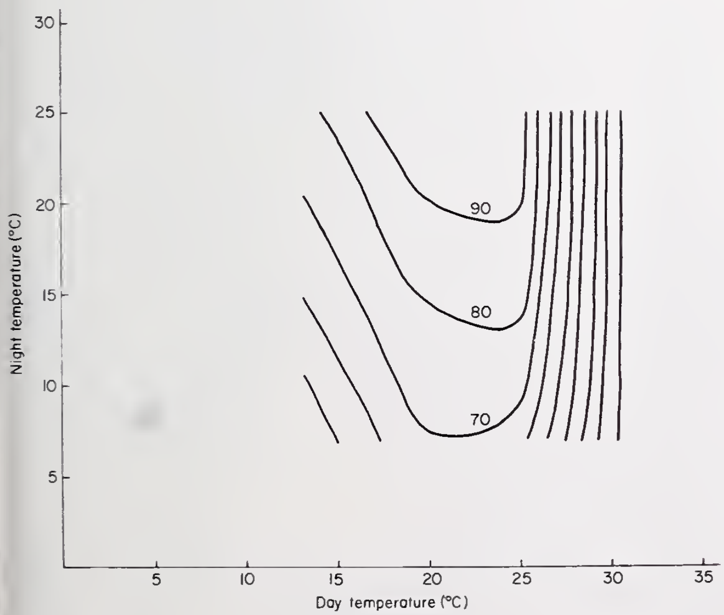
Species: *Picea pungens*
Growth Parameter: Height
Maximum Size (= 100%): 274mm
Seed Source: Fort Collins, Colo.
Coefficient of Variability: Not available
Authority: Tinus (unpublished)



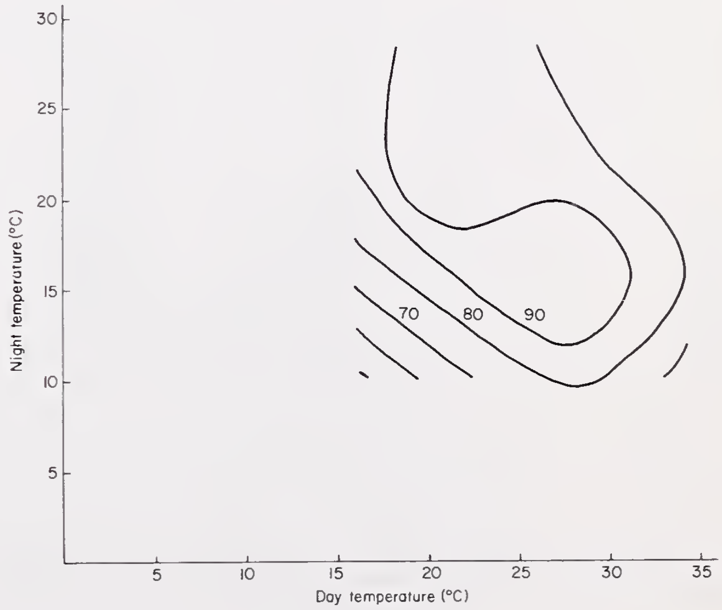
Species: *Picea pungens*
Growth Parameter: Dry weight
Maximum Size (= 100%): 9.4gm
Seed Source: Fort Collins, Colo.
Coefficient of Variability: Not available
Authority: Tinus (unpublished)



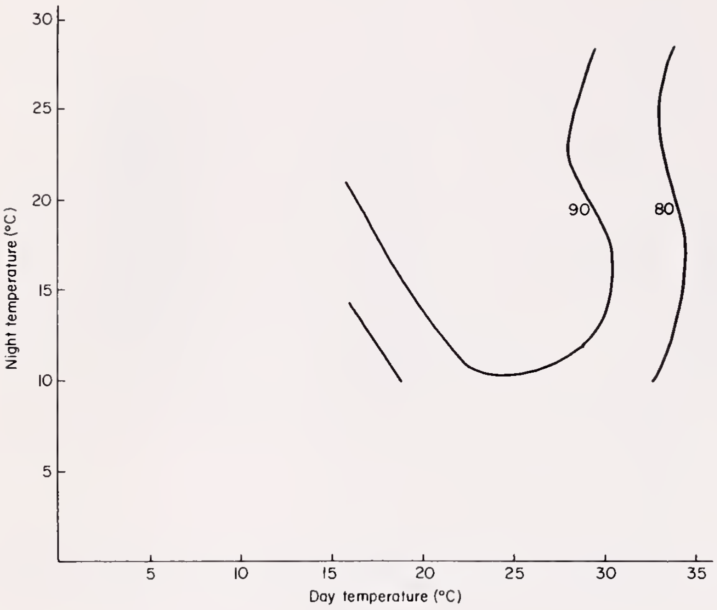
Species: *Picea pungens*
Growth Parameter: Caliper
Maximum Size (= 100%): 5.6mm
Seed Source: Fort Collins, Colo.
Coefficient of Variability: Not available
Authority: Tinus (unpublished)



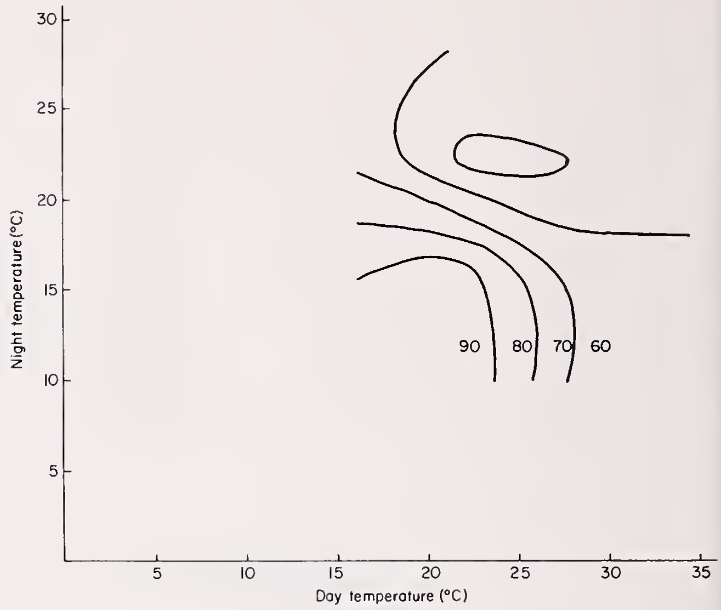
Species: *Pinus contorta*
Growth Parameter: Height
Maximum Size (= 100%): 113mm
Seed Source: Central Alberta, DB-655
Coefficient of Variability: 3.8%
Authority: Tinus (1976)



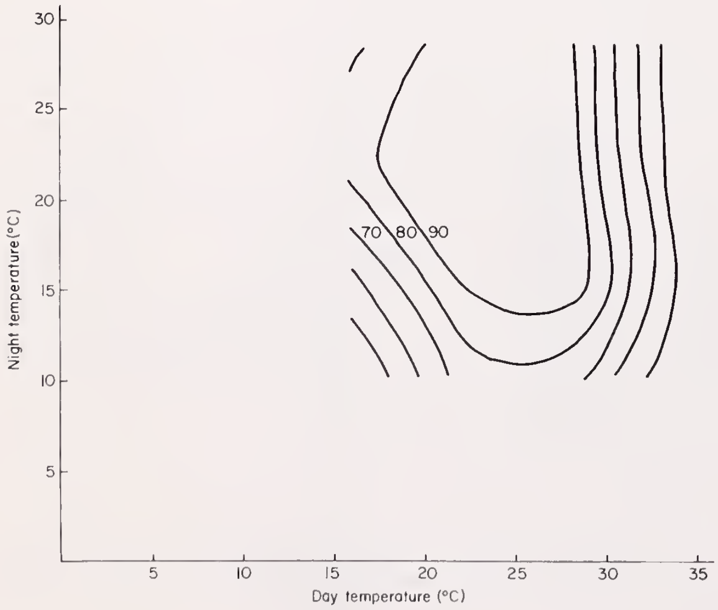
Species: *Pinus contorta*
Growth Parameter: Caliper
Maximum Size (= 100%): 1.8
Seed Source: Central Alberta, DB-655
Coefficient of Variability: 3.2%
Authority: Tinus (1976)



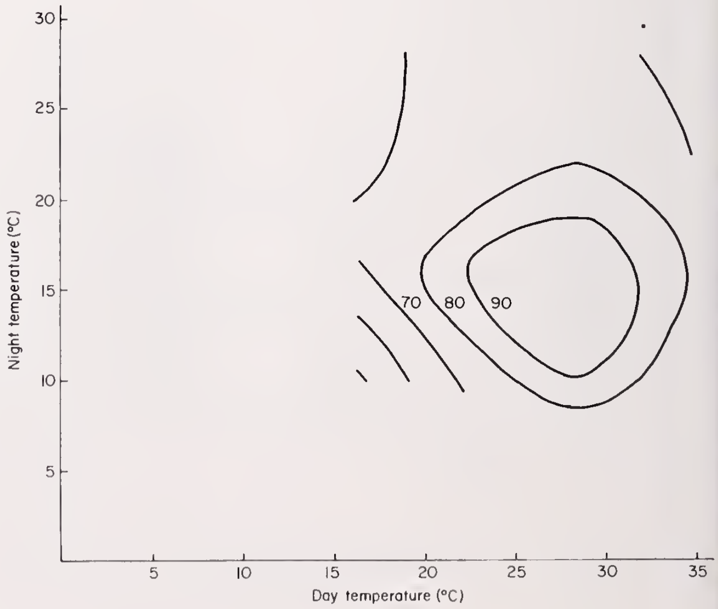
Species: *Pinus contorta*
Growth Parameter: Root/shoot ratio (dry weight)
Maximum Size (= 100%): 0.37
Seed Source: Central Alberta, DB-655
Coefficient of Variability: Not available
Authority: Tinus (1976)



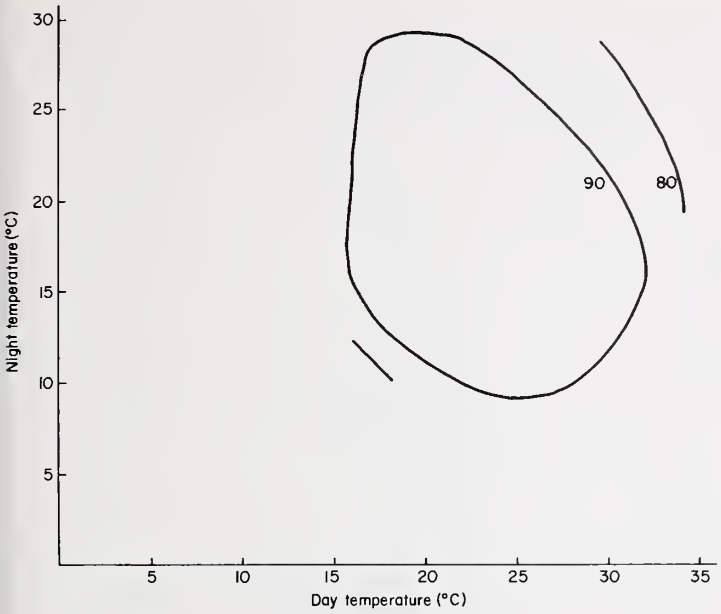
Species: *Pinus contorta*
Growth Parameter: Dry weight
Maximum Size (= 100%): 0.38gm
Seed Source: Central Alberta, DB-655
Coefficient of Variability: 7.0%
Authority: Tinus (1976)



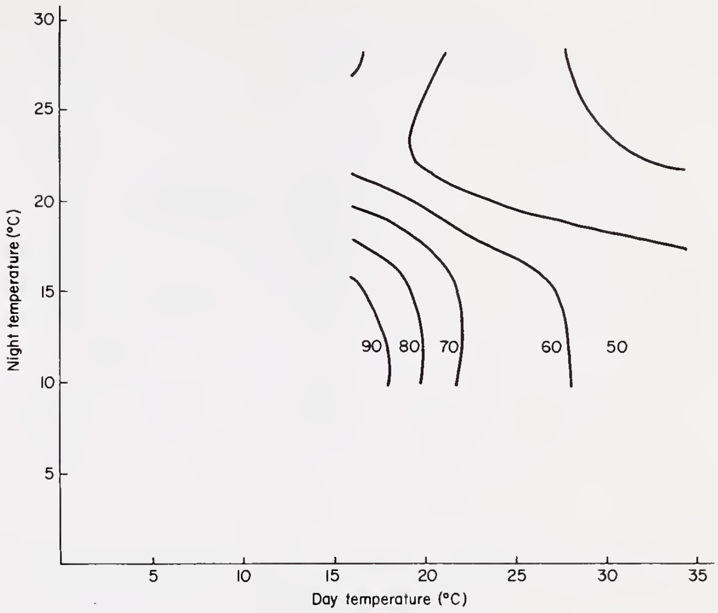
Species: *Pinus contorta*
Growth Parameter: Height
Maximum Size (= 100%): 117mm
Seed Source: Whitehorse, Y.T., L-236
Coefficient of Variability: 4.7%
Authority: Tinus (1976)



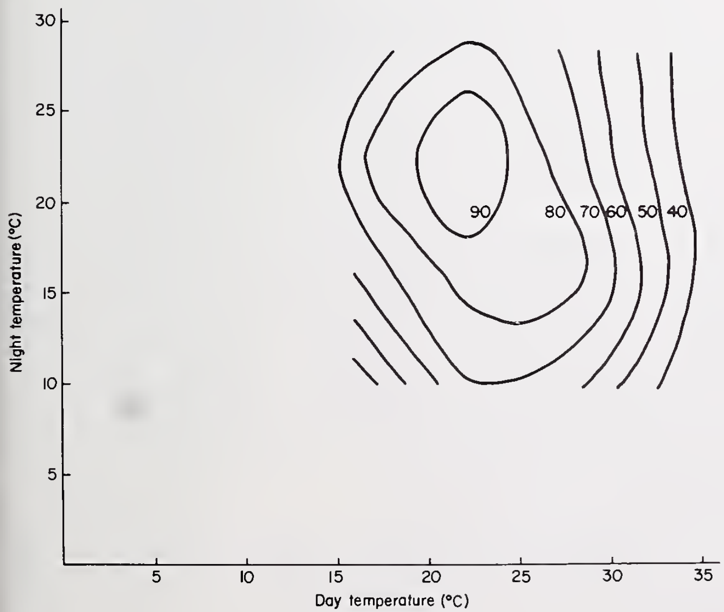
Species: *Pinus cortorta*
Growth Parameter: Caliper
Maximum Size (= 100%): 1.8mm
Seed Source: Whitehorse, Y.T., L-236
Coefficient of Variability: 3.6%
Authority: Tinus (1976)



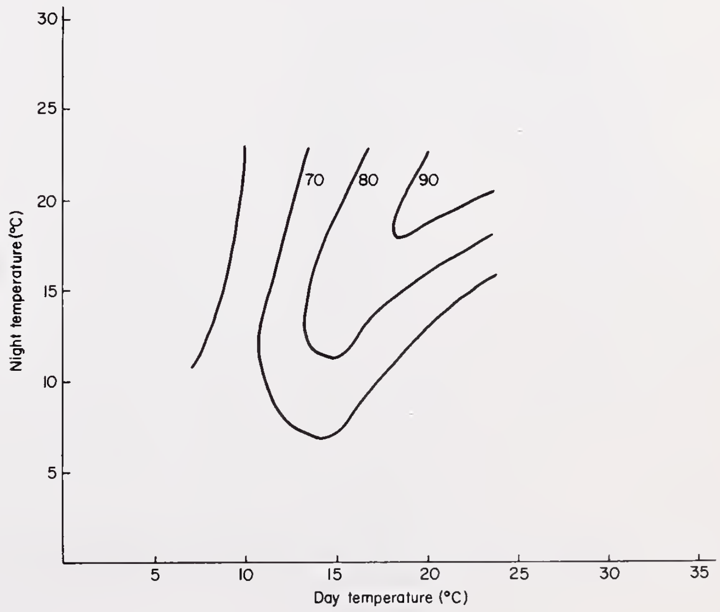
Species: *Pinus contorta*
Growth Parameter: Root/Shoot ratio (dry weight)
Maximum Size (= 100%): 0.54
Seed Source: Whitehorse, Y.T. L-236
Coefficient of Variability: Not available
Authority: Tinus (1976)



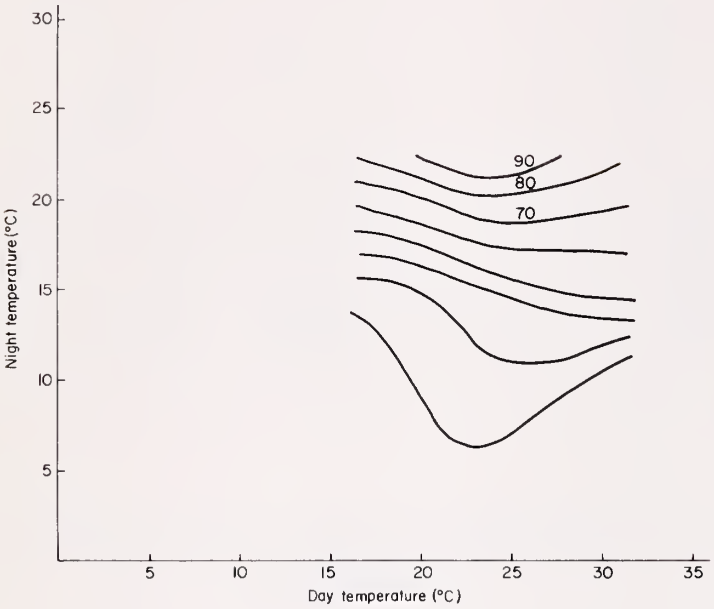
Species: *Pinus contorta*
Growth Parameter: Dry weight
Maximum Size (= 100%): 0.50gm
Seed Source: Whitehorse, Y.T., L-236
Coefficient of Variability: 8.5%
Authority: Tinus (1976)



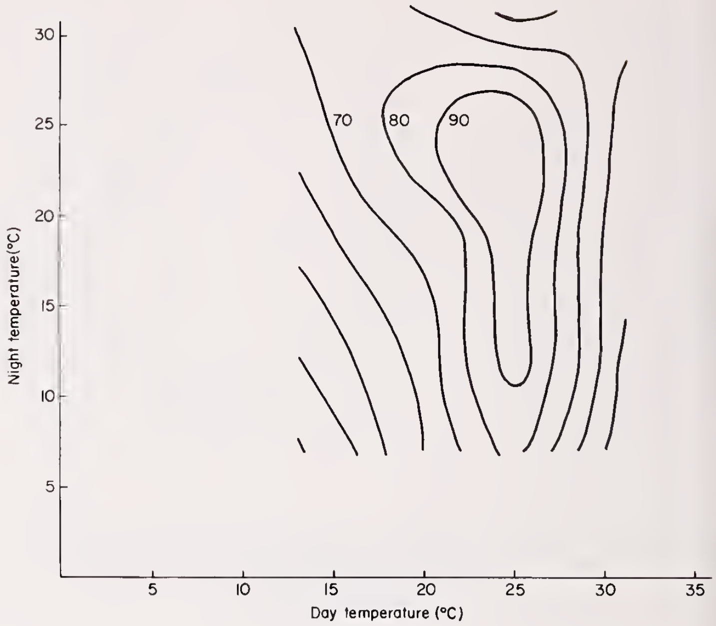
Species: *Pinus ponderosa*
Growth Parameter: Dry weight
Maximum Size (= 100%): 0.102gm
Seed Source: Black Hills, S. Dak.
Coefficient of Variability: Not available
Authority: Larson (1967)



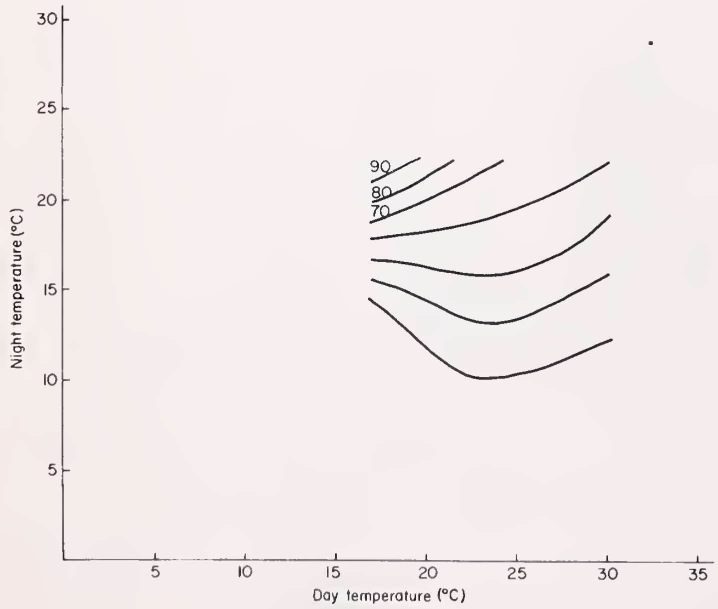
Species: *Pinus ponderosa*
Growth Parameter: Height
Maximum Size (= 100%): 43mm
Seed Source: Moon, S. Dak.
Coefficient of Variability: 20%
Authority: Callaham (1962)



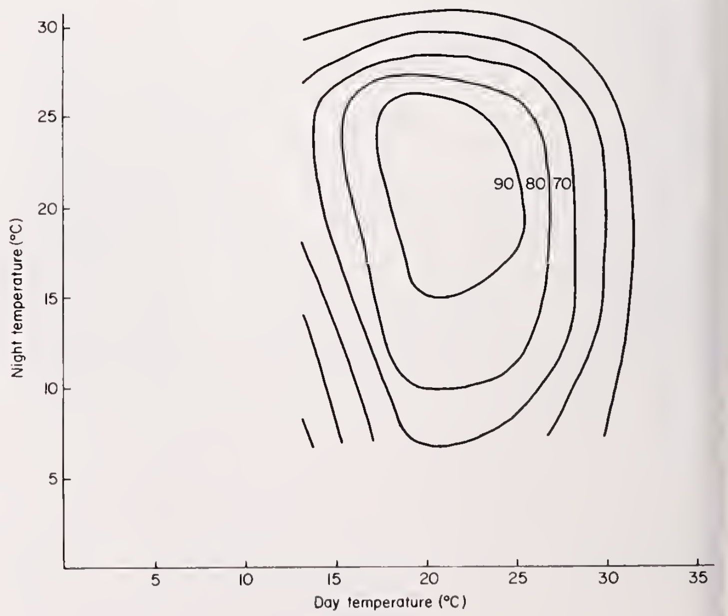
Species: *Pinus ponderosa*
Growth Parameter: Height
Maximum Size (= 100%): 147mm
Seed Source: Valentine, Nebr.
Coefficient of Variability: 5.4%
Authority: Tinus (1971)



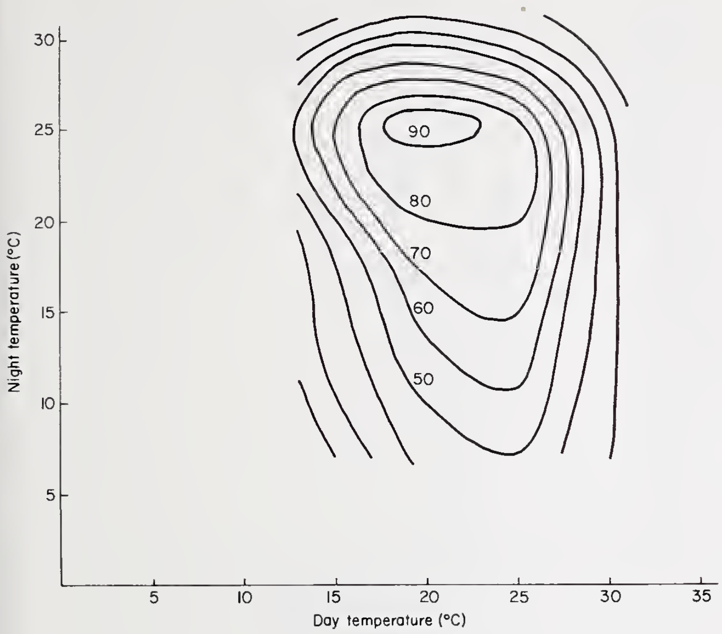
Species: *Pinus ponderosa*
Growth Parameter: Height
Maximum Size (= 100%): 67mm
Seed Source: Safford, Ariz.
Coefficient of Variability: 14%
Authority: Callaham (1962)



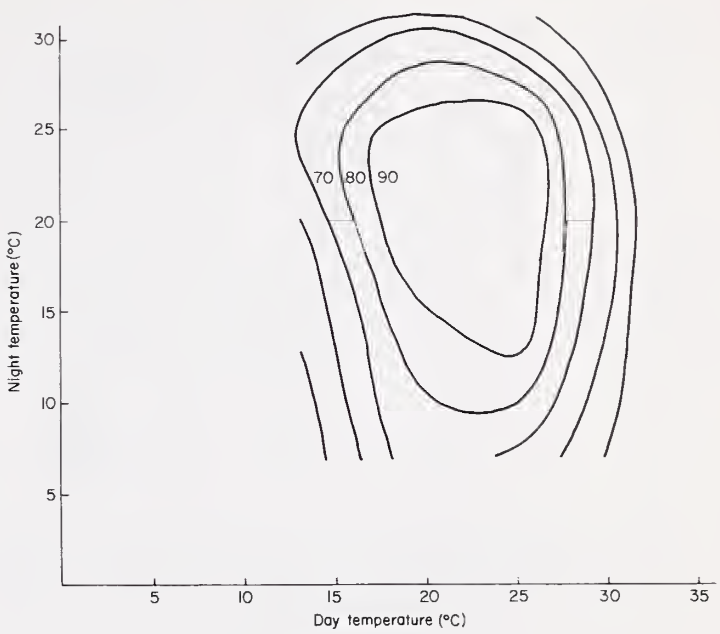
Species: *Pinus ponderosa*
Growth Parameter: Caliper
Maximum Size (= 100%): 7.6mm
Seed Source: Valentine, Nebr.
Coefficient of Variability: 4.3%
Authority: Tinus (1971)



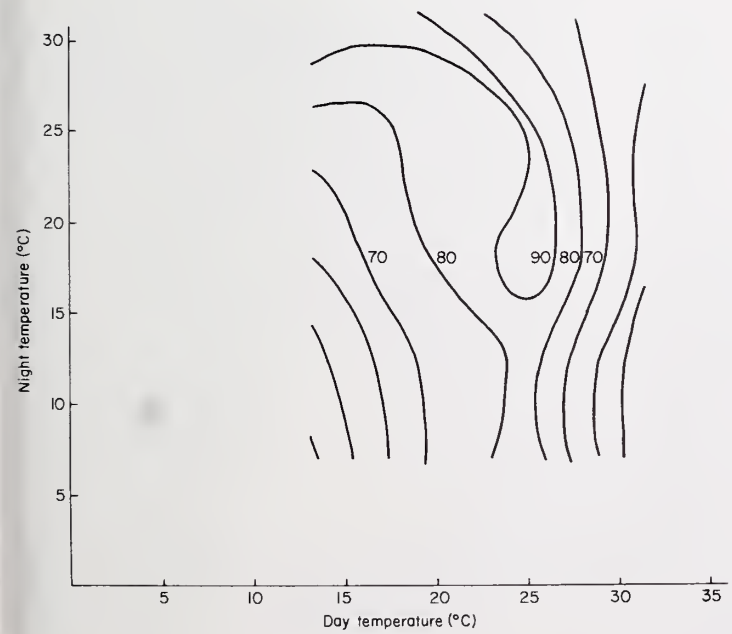
Species: *Pinus ponderosa*
Growth Parameter: Dry weight
Maximum Size (= 100%): 16.2gm
Seed Source: Valentine, Nebr.
Coefficient of Variability: 9.6%
Authority: Tinus (1971)



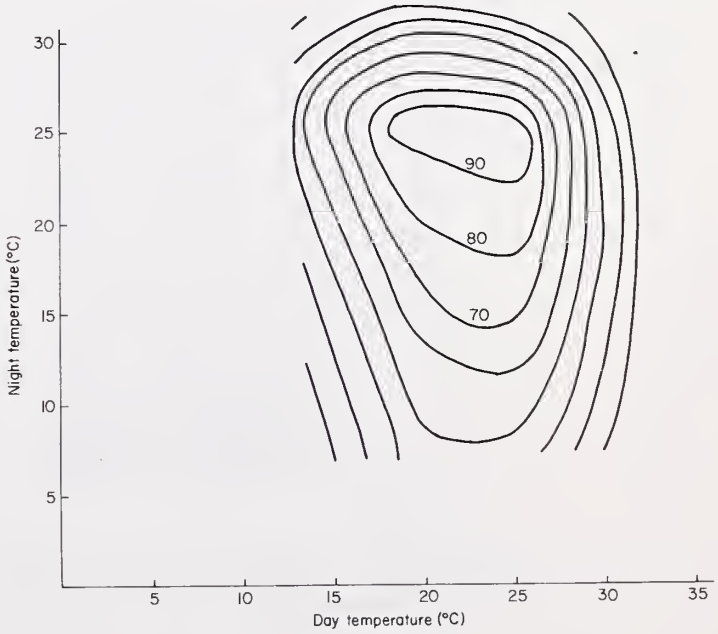
Species: *Pinus ponderosa*
Growth Parameter: Caliper
Maximum Size (= 100%): 8.7mm
Seed Source: Ruidoso, N. Mex.
Coefficient of Variability: 4.5%
Authority: Tinus (1971)



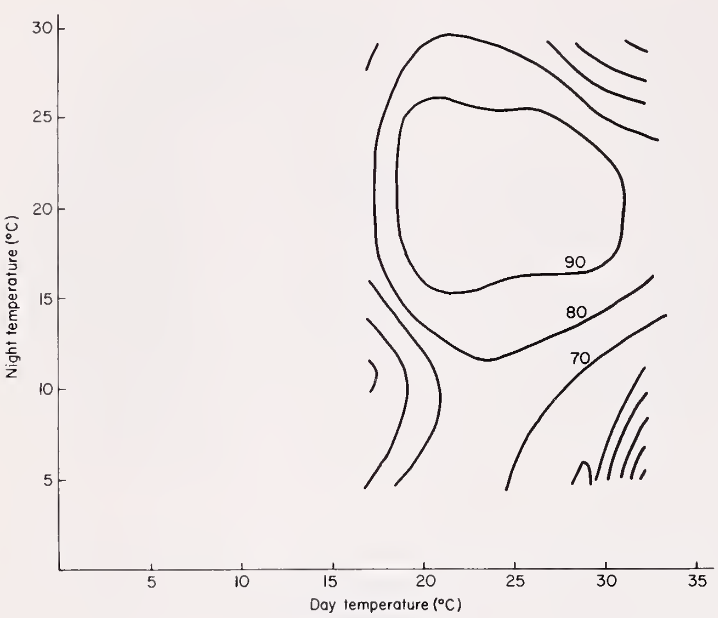
Species: *Pinus ponderosa*
Growth Parameter: Height
Maximum Size (= 100%): 154mm
Seed Source: Ruidoso, N. Mex.
Coefficient of Variability: 5.5%
Authority: Tinus (1971)



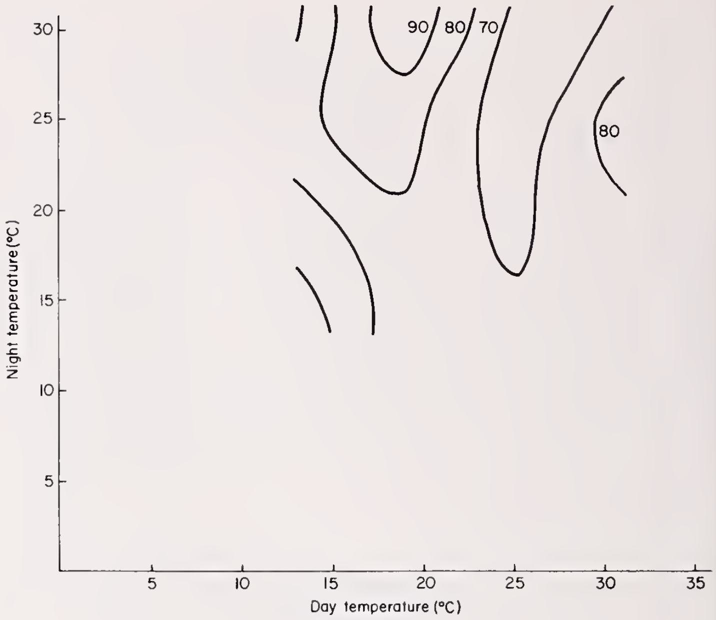
Species: *Pinus ponderosa*
Growth Parameter: Dry weight
Maximum Size (= 100%): 19.1gm
Seed Source: Ruidoso, N. Mex.
Coefficient of Variability: 8.4%
Authority: Tinus (1971)



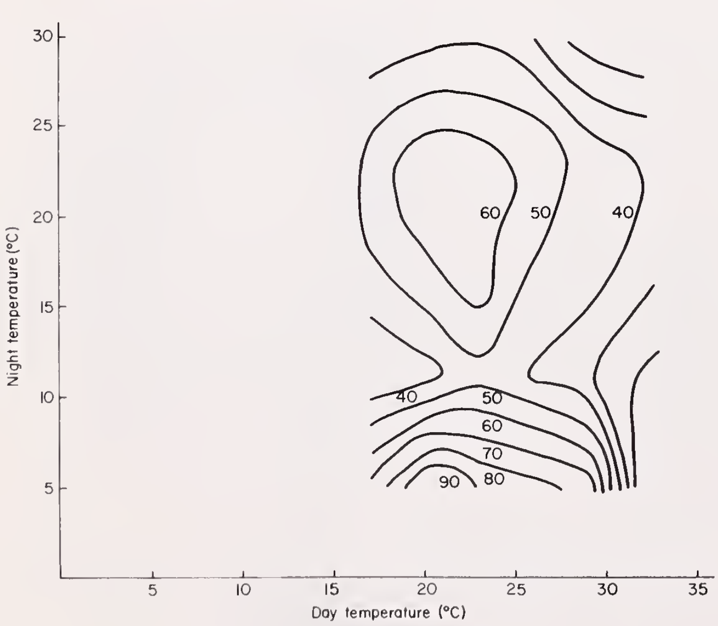
Species: *Pinus radiata*
Growth Parameter: Height
Maximum Size (= 100%): 386mm
Seed Source: Tallaganda Seed Orchard, Canberra
Coefficient of Variability: Not available
Authority: Cremer (1968)



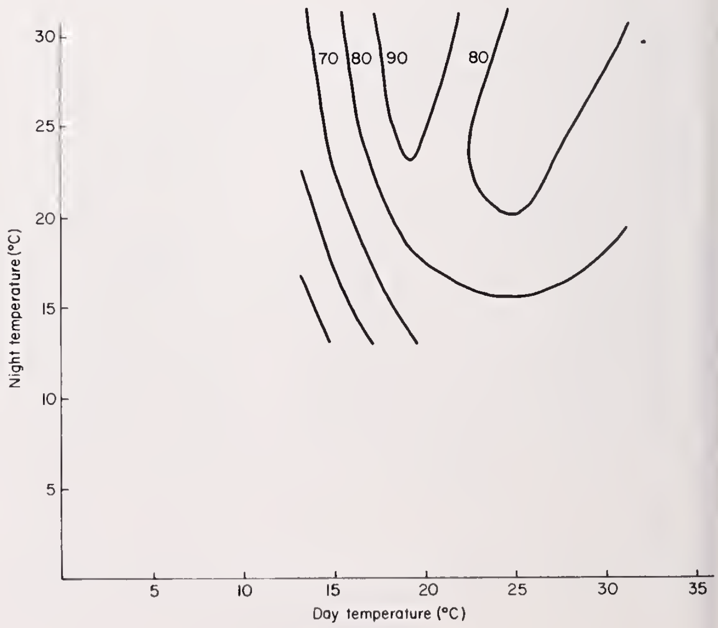
Species: *Pinus sylvestris*
Growth Parameter: Height
Maximum Size (= 100%): 191mm
Seed Source: Denbigh N. Dak. (Russian origin 645-21)
Coefficient of Variability: 5.5%
Authority: Tinus (unpublished)



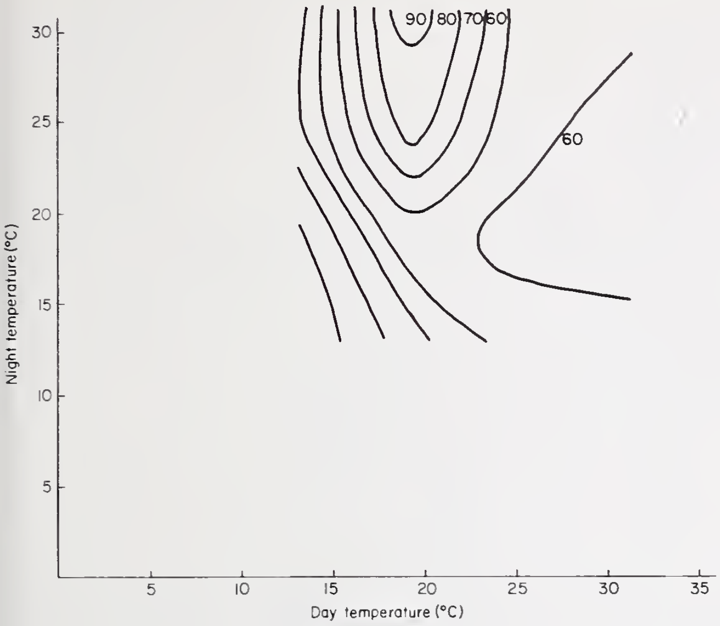
Species: *Pinus radiata*
Growth Parameter: Dry weight
Maximum Size (= 100%): 12.9gm
Seed Source: Tallaganda Seed Orchard, Canberra
Coefficient of Variability: Not available
Authority: Cremer (1968)



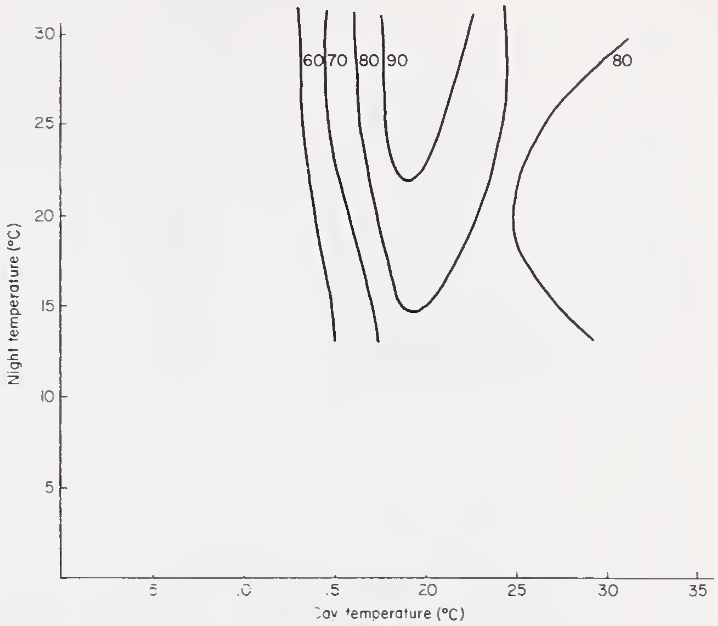
Species: *Pinus sylvestris*
Growth Parameter: Caliper
Maximum Size (= 100%): 5.6mm
Seed Source: Denbigh, N. Dak. (Russian origin 645-21)
Coefficient of Variability: 3.7%
Authority: Tinus (unpublished)



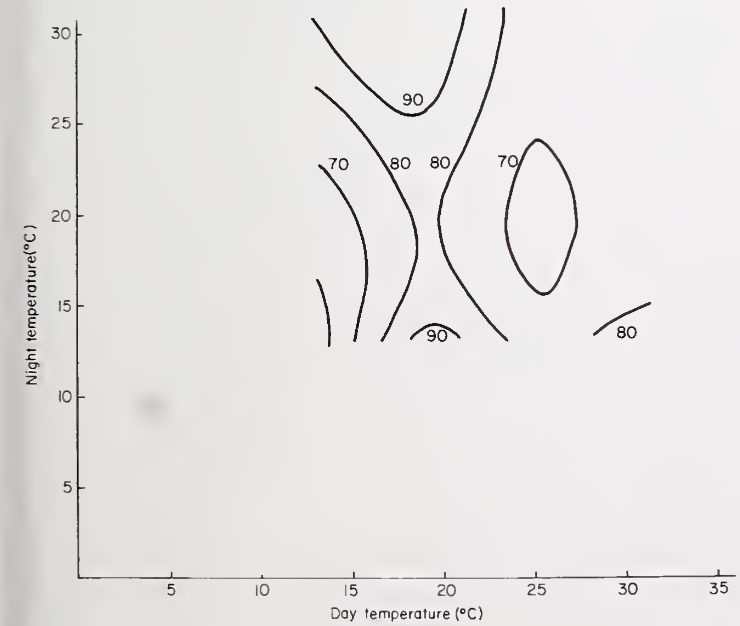
Species: *Pinus sylvestris*
Growth Parameter: Dry weight
Maximum Size (= 100%): 9.1gm
Seed Source: Denbigh, N. Dak. (Russian origin 645-21)
Coefficient of Variability: 9.8%
Authority: Tinus (unpublished)



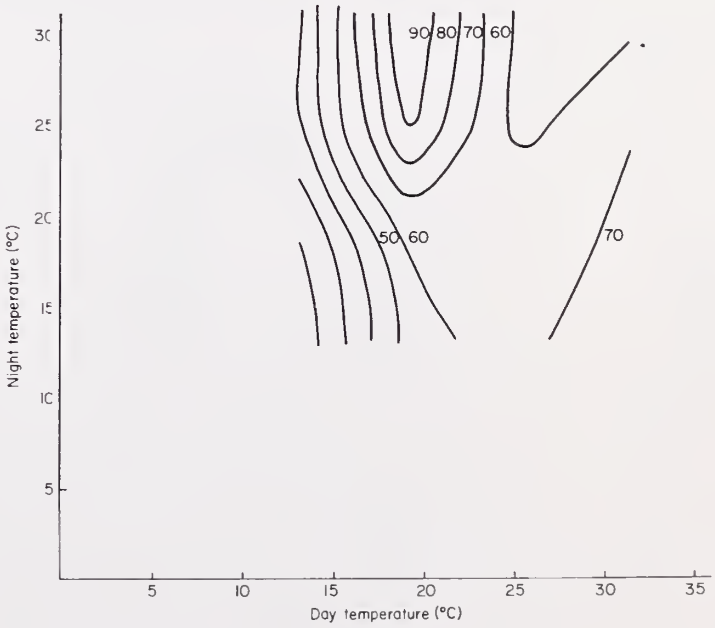
Species: *Pinus sylvestris*
Growth Parameter: Caliper
Maximum Size (= 100%): 5.1mm
Seed Source: Denbigh, N. Dak. (Russian origin 1940-21)
Coefficient of Variability: 4.1%
Authority: Tinus (unpublished)



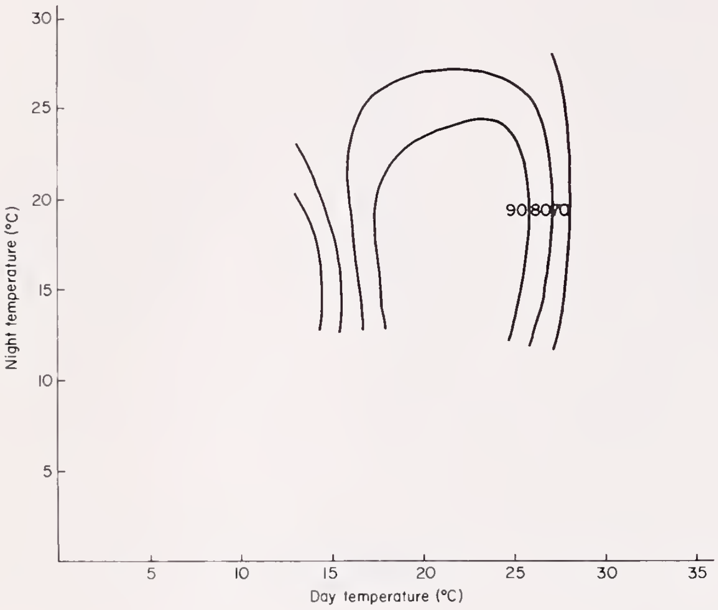
Species: *Pinus sylvestris*
Growth Parameter: Height
Maximum Size (= 100%): 158mm
Seed Source: Denbigh N. Dak. (Russian origin 1940-21)
Coefficient of Variability: 5.5%
Authority: Tinus (unpublished)



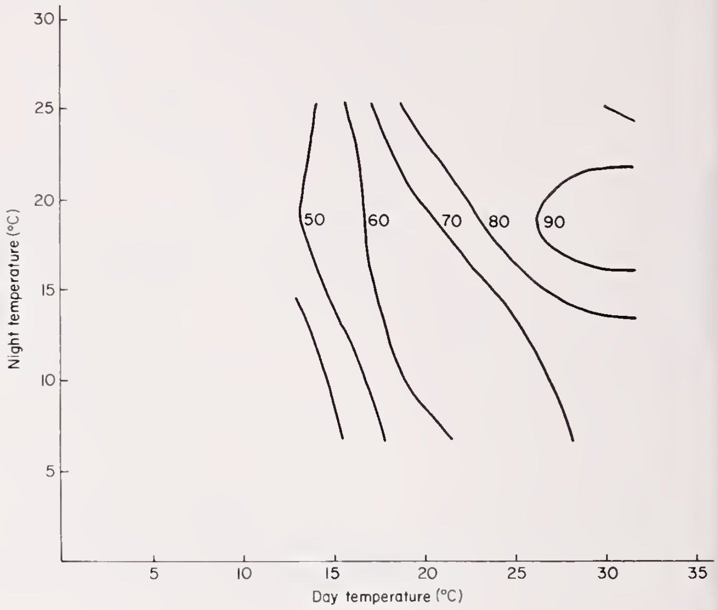
Species: *Pinus sylvestris*
Growth Parameter: Dry weight
Maximum Size (= 100%): 7.1gm
Seed Source: Denbigh, N. Dak. (Russian origin 1940-21)
Coefficient of Variability: 7.8%
Authority: Tinus (unpublished)



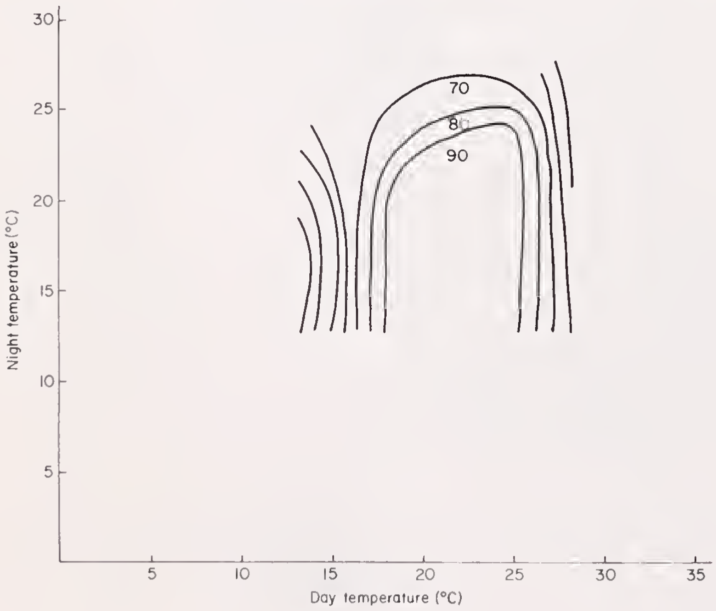
Species: *Pseudotsuga menziesii*
Growth Parameter: Height
Maximum Size (= 100%): 170mm
Seed Source: Lake Cowichan District, Vancouver Island
Coefficient of Variability: Not available
Authority: Brix (1971)



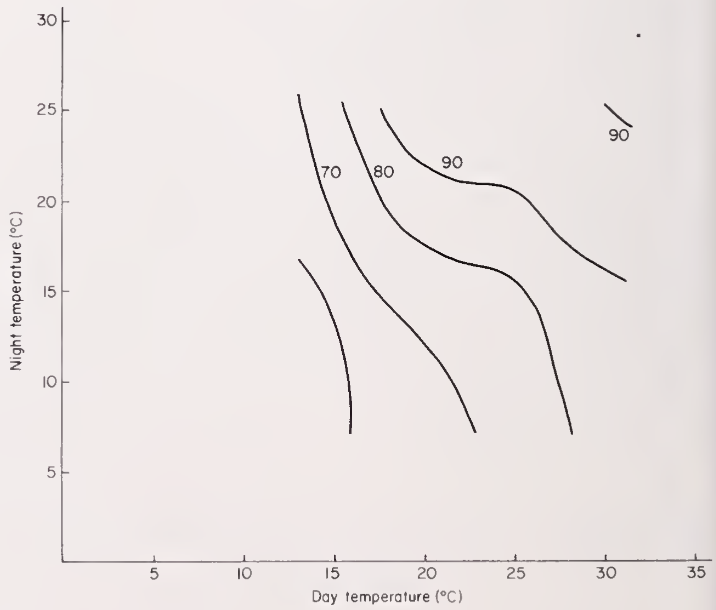
Species: *Quercus macrocarpa*
Growth Parameter: Height
Maximum Size (= 100%): 354mm
Seed Source: Devils Lake, N. Dak.
Coefficient of Variability: 5.6%
Authority: Tinus (1974)



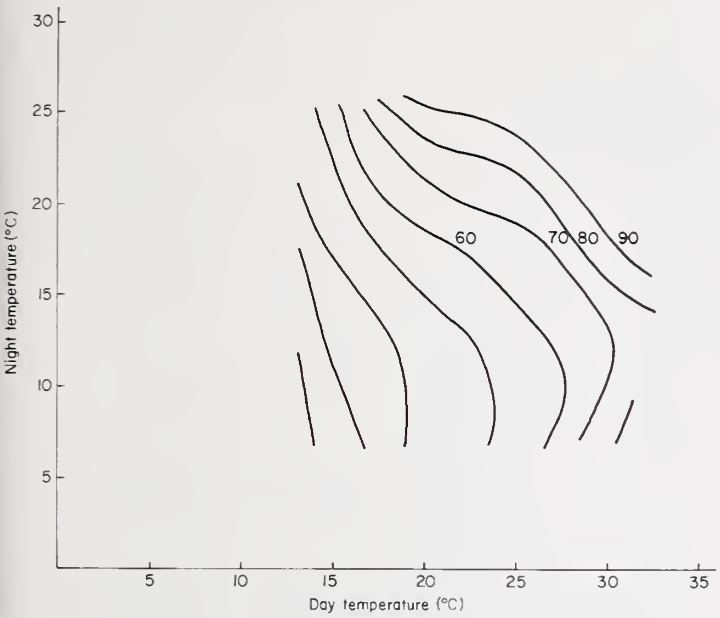
Species: *Pseudotsuga menziesii*
Growth Parameter: Dry weight
Maximum Size (= 100%): 2.4gm
Seed Source: Lake Cowichan District, Vancouver Island
Coefficient of Variability: Not available
Authority: Brix (1971)



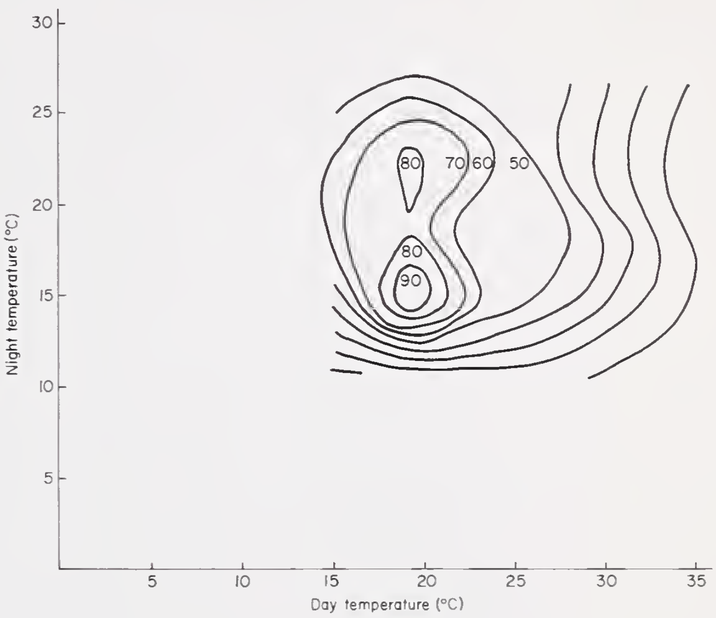
Species: *Quercus macrocarpa*
Growth Parameter: Caliper
Maximum Size (= 100%): 5.1mm
Seed Source: Devils Lake, N. Dak.
Coefficient of Variability: 5.5%
Authority: Tinus (1974)



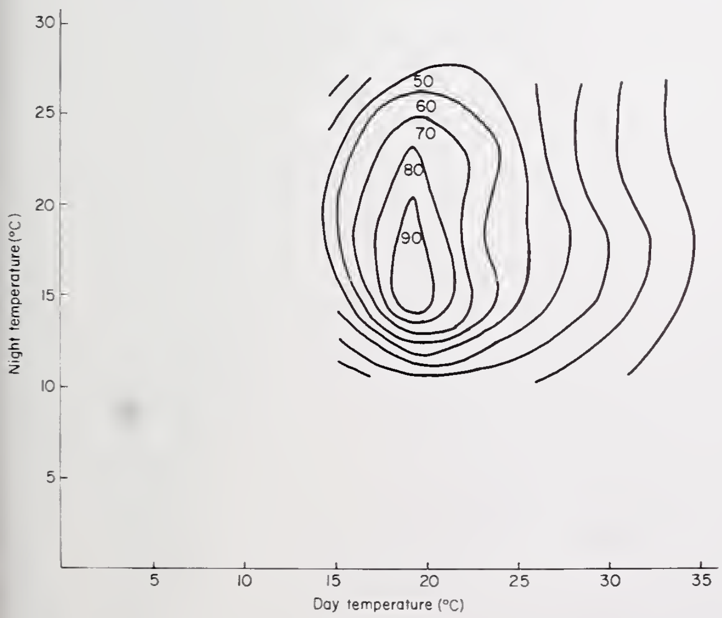
Species: *Quercus macrocarpa*
Growth Parameter: Dry weight
Maximum Size (= 100%): 7.2gm
Seed Source: Devils Lake, N. Dak.
Coefficient of Variability: 13.5%
Authority: Tinus (1974)



Species: *Sequoia sempervirens*
Growth Parameter: Dry weight
Maximum Size (= 100%): 29gm
Seed Source: Klamath, Calif.
Coefficient of Variability: 14%
Authority: Helmers (1966)



Species: *Sequoia sempervirens*
Growth Parameter: Height
Maximum size (= 100%): 810mm
Seed Source: Klamath, Calif.
Coefficient of Variability: 10%
Authority: Helmers (1966)



Appendix 2

Growing schedules were developed for a number of nurseries. These may be useful as a starting point for other nurseries to formulate their own growing schedules, but unless circumstances match closely, they should not be used without appropriate modification. The schedules are arranged in the following order:

Species	Container Size *(cu. in.)*	Nursery location	Outplanting time
Blue spruce	30	Fort Collins, Colo.	Spring
Douglas-fir	30	Fort Collins, Colo.	Spring
Engelmann spruce	30	Denver, Colo.	Spring
White spruce	10	Palmer, Alaska	Spring
Ponderosa pine	4	Bozeman, Mont.	Spring/Fall
Ponderosa pine	4	Bozeman, Mont.	Spring
Ponderosa pine	10	Salt Lake City, Utah	Spring
Scots pine	10	Salt Lake City, Utah	Spring
Austrian pine	10	Salt Lake City, Utah	Spring
Ponderosa pine	10	Salt Lake City, Utah	Spring/Fall
Scots pine	10	Salt Lake City, Utah	Spring/Fall
Austrian pine	10	Salt Lake City, Utah	Spring/Fall
Ponderosa pine	30	McNary, Ariz.	July-September
Rocky Mountain juniper	30	Manhattan, Kans.	Spring/Fall
Eastern redcedar	30	Manhattan, Kans.	Spring/Fall
Austrian pine	30	Manhattan, Kans.	Spring/Fall
Ponderosa pine	30	Manhattan, Kans.	Spring/Fall
Black walnut	30	Manhattan, Kans.	Spring/Fall
Black walnut	30	Carbondale, Ill.	Spring/Summer/Fall
Bur oak	30	Bismarck, N. Dak.	Spring
Slash pine	4	Pineville, La.	Spring/Summer/Fall
Loblolly pine			
Longleaf pine			
Douglas fir	3-10	Corvallis, Oreg.	Fall/Winter/Spring

Species Blue spruce & Douglas-fir **Container** 30 cubic inches **Outplanting** Spring **Location** Fort Collins, Colo. **Cycle** Summer (1/yr.) Info. Grade A

Source Colo.

Season		APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.
Growth stage		Germination	Juvenile growth	Exponential growth			Spruce 6-8'' tall		Spruce 12-16'' tall	Stage I Bud set	Hardening Caliper growth	Stage II Cold hardening Meet chilling requirements	Maintain dormancy and hardiness	
Day temp (°F)	**Optimum**	70	72	72							65	34	34	
	Permissible	65-75	64-77	64-77							55-70	30-50	30-60	
Night temp (°F)	**Optimum**	70	66	66							55	34	34	
	Permissible	65-75	63-73	63-73							50-60	30-45	30-45	
Rel. Hum. (%)	**Optimum**	80	60	60							50		50	
	Permissible	60-90	50-80	50-80							40-70		40-70	
Daylight		75% Sunlight. Add shade if necessary to keep temp below 85°								75% Sunlight. Add shade if needed to maintain temperature.			30% Sunlight	
Supplemental light		10 watts/ft² incandescent or equivalent at least 6% of the time at night. No dark period over 15 min.								None				
Water		Frequent, light, surface always wet.	As needed. Water in excess each time. Surface should dry between waterings. Keep rootball near field capacity.							Leach with water. Dry to wilting.	As needed as before.			
Fertilizer		None	Complete, high N, pH 5.5-6.0, EC 1,800 ±300 μmhos. Rinse foliage.							None	Complete, low N, high PK. Rinse foliage.			
CO_2 level		Normal atmos.	1,000-1,500 ppm whenever vents are closed during daylight hours.									Normal atmosphere		
Operations		Fill, seed, load ghs.	Apply fungicide if needed.	Thin Do not transplant spruce.									Move to shadehouse.	Ship anytime (arrow)

Species Engelmann spruce **Container** 30 cubic inches **Outplanting** Spring (in mts.) **Location** Denver, Colo. **Cycle** Summer (1/yr.) Info. Grade A

Source Central Colo.

Season	MAR.	MAR.	APR.	MAY–JUL.	JUL.–AUG.	AUG.	SEPT.–OCT.	NOV.	DEC.	JAN.–MAR.
Growth stage		Germination	Juvenile growth	Exponential growth	Trees 12-16'' tall	Bud set	Natural hardening Caliper growth	Cold hardening	Chilling requirements met	Maintain dormancy and hardiness
Day temp (°F) Optimum		70	66	66			66	34		34
Day temp (°F) Permissible		65-75	63-74	63-74			60-75	30-50		30-60
Night temp (°F) Optimum		70	73	73			60	34		34
Night temp (°F) Permissible		65-75	71-75	71-75			50-65	30-45		20-45
Rel. Hum. (%) Optimum		80	60	60			60			
Rel. Hum. (%) Permissible		60-90	50-80	50-80			50-80			
Daylight		30% Sunlight (2 layers poly, 1 shade cloth)		60% Sunlight (2 layers poly.) Increase shade to hold temp. or if chlorosis appears.		50% Sunlight (shadehouse)				Bright skylight desirable. Direct sun or total darkness not desirable.
Supplemental light		8 watts/ft² incandescent or equivalent at least 6% of the time at night. No dark period over 15 min.				None				
Water		Frequent light, surface always wet.	As needed with nutrient solution. Water in excess each time. Surface should dry between waterings. Keep rootball near field capacity.		Leach with water. Do not dry	← →	As needed as before.			
Fertilizer		None	Complete, high N, pH 5.5-6.0, EC 1,800 ±300 µmhos.			None	Complete, low N, high PK.			
CO_2 level		None	1,000-1,500 ppm whenever vents are closed during daylight hours.			None				
Operations	Fill, seed, load ghs.	← Apply fungicide if needed. →		← → Thin Do **not** transplant.		← →	Move to shadehouse. Mulch with sawdust.		May be moved to ranger district and mulched anytime after Dec. 1, or remain in shadehouse.	

Species White spruce Container 10 cubic inches Outplanting Spring Location Palmer, Alaska Cycle Summer (1/yr.) Info. Grade B

Source Fairbanks, Alaska

Season	MAR. (early)	MAR. (late)	APR. – mid-MAY	mid-MAY – mid-AUG.	mid-AUG. – early SEPT.	SEPT. – MAR.
Growth stage	Sow	Germination	Juvenile growth	Exponential growth	Natural hardening	Natural hardening; Maintain dormancy
Day temp (°F) Optimum		70	72	72	65 (declining with the season)	65 (declining with the season)
Day temp (°F) Permissible		65-75	68-75	68-75	55-70	55-70
Night temp (°F) Optimum		70	61	61	55	55
Night temp (°F) Permissible		65-75	56-72	56-72	50-70	50-70
Rel. Hum. (%) Optimum		80	60	60		
Rel. Hum. (%) Permissible		60-90	50-70	50-70		
Daylight		75% Sunlight (unshaded 2 layer ghs.)	75% Sunlight (unshaded 2 layer ghs.)	75% Sunlight (unshaded 2 layer ghs.)	50% Sunlight (shadehouse)	50% Sunlight (shadehouse)
Supplemental light		8 watts/ft² incandescent light at least 6% of the dark period. No dark period over 15 min.	8 watts/ft² incandescent light at least 6% of the dark period. No dark period over 15 min.	8 watts/ft² incandescent light at least 6% of the dark period. No dark period over 15 min.	None	None
Water		Frequent, light, surface always wet	Frequent, light, surface always wet / As needed with nutrient solution. Surface should dry. Rootball always near field capacity.	As needed with nutrient solution. Surface should dry. Rootball always near field capacity.	Leach with water. Dry to wilting.	As needed. Treat as before.
Fertilizer		None	Complete, high N, pH 5.5-6.0, EC 1,500-2,000 μmhos. Water in excess each time. Rinse foliage with water.	Complete, high N, pH 5.5-6.0, EC 1,500-2,000 μmhos. Water in excess each time. Rinse foliage with water.	None	Complete, low N, high PK. Otherwise, as before.
CO_2 level		Normal atmos.	1,000-1,500 ppm whenever vents are closed during daylight hours.	1,000-1,500 ppm whenever vents are closed during daylight hours.	None (Normal atmosphere)	None (Normal atmosphere)
Operations	Fill, seed, load ghs.		Thin (mid-Apr. – early May)		Move trees to shadehouse.	Ship May 1

Species Ponderosa pine **Container** 4 cubic inches **Outplanting** Spring/Fall **Location** Bozeman, Mont. **Cycle** Summer (2/yrs.) Info. Grade B

Source E. Mont.

Season		APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.
Growth stage		Germin-ation	Juvenile growth	Mature foliage appears	Multiple flushing	Bud set	Natural hardening Caliper growth			Maintain dormancy and hardiness.				
Day temp (°F)	**Optimum**	70	72		72		65 (declining with the season)				34			
	Permissible	65-75	68-77		68-77		60-75				20-60			
Night temp (°F)	**Optimum**	70	75		75		55				34			
	Permissible	65-75	68-77		68-77		50-65				20-45			
Rel. Hum. (%)	**Optimum**	80		60			60							
	Permissible	60-90		50-80			50-80							
Daylight		50% Sunlight	75-90% Sunlight			30-50% Sunlight				Bright skylight only.				
Supplemental light		None	8 watts/ft² incandescent or equivalent at least 3% of the night time. No dark period over 30 min.			None								
Water		Frequent, light, surface always wet	As needed. Surface should dry. Water in excess. Keep rootball near field capacity.		Leach with water. Dry to wilting.	As needed as before.								
Fertilizer		None	Complete, high N, pH 5.5-6.0, EC 1,800±300 μmhos. Rinse foliage.			None	Complete, low N, high PK, pH 5.5-6.0, EC 1,800±300 μmhos. Rinse foliage.							
CO_2 level		Normal atmos.	1,000-1,500 ppm whenever vents are closed during daylight hours.			Normal atmosphere								
Operations		Load ghs. Apply fungicide if needed.	Thin		Move to shade-house.		Ship for fall planting							Ship and outplant

Species Ponderosa pine **Container** 4 cubic inches **Outplanting** Spring **Location** Bozeman, Mont. **Cycle** Winter (2/yr.) Info. Grade B

Source E. Mont.

Season	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.
Growth stage	Germination	Juvenile growth	Mature foliage appears	Multiple flushing			Stage I Hardening Bud set Caliper growth	Stage II Cold hardening Meet chilling requirement	Maintain dormancy and hardiness.				
								(Frost o.k., but not a frozen rootball.)					
Day temp (°F) Optimum	70	72		72			65	34	34				
Day temp (°F) Permissible	65-75	68-77		68-77			60-68	30-50	30-60				
Night temp (°F) Optimum	70	75		75			55	34	34				
Night temp (°F) Permissible	65-75	68-77		68-77			50-65	30-45	30-45				
Rel. Hum. (%) Optimum	80	60		60			60						
Rel. Hum. (%) Permissible	60-90	50-80		50-80			50-80						
Daylight	50% Sunlight	75-90% Sunlight					75-90% Sunlight (Shade only to maintain temperature)		Bright skylight Sun not needed.				
Supplemental light	None	8 watts/ft² incandescent or equivalent at least 3% of the night time. No dark period over 30 min.					None		None				
Water	Frequent, light, surface always wet	As needed. Water in excess each time. Surface should dry between waterings. Keep rootball near field capacity.				Leach with water. Dry to wilting.	As needed as before.						
Fertilizer	None	Complete, high N, pH 5.5-6.0, EC 1,800±300 μmhos. Rinse foliage.					None; Complete, low N, high PK Rinse foliage.			Water with high N just before shipment			
CO_2 level	Normal atmos.	1,000-1,500 ppm whenever vents are closed during daylight hours.					None						
Operations	Load ghs.; Apply fungicide if needed.	Thin						Move to shadehouse.	Ship and outplant				

Species Ponderosa pine, Scots pine, Austrian pine **Container** 10 cubic inches **Outplanting** Spring **Location** Salt Lake City, Utah **Cycle** Winter (2/yr.) Info. Grade B

Source ______

Season		AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.
Growth stage		Germination	Juvenile growth	Mature foliage appears	Multiple flushing			Stage I Hardening Bud set Caliper growth	Stage II Cold hardening Meet chilling requirements	Maintain dormancy and hardiness.		Top flush after outplanting		
Day temp (°F)	Optimum	70	72		72			65	34	34				
	Permissible	65-75	65-80		65-85			60-70	33-50	20-60				
Night temp (°F)	Optimum	70	75		75			55	34	34				
	Permissible	65-75	68-77		68-77			50-65	33-40	20-45				
Rel. Hum. (%)	Optimum	80	60		60			60	60	60				
	Permissible	60-90	50-80		50-80			50-80	50-80	50-80				
Daylight		40-50% Sunlight			75-90% Sunlight				30% Sunlight or bright skylight	Skylight only (can do without any)		Partial shade if available.		
Supplemental light		None	8 watts/ft² incandescent or equivalent at least 3% of the time. No dark period over 30 min.				None		None	None				
Water		Frequent, light, surface always wet	As needed. Surface should dry. Water in excess each time. Keep rootball near field capacity.				Leach with water. Dry to wilting.	As needed treat as before.						
Fertilizer		None	Complete, high N, pH 5.5-6.0, EC 1,800±300 μmhos. Rinse foliage.				None	Complete, low N, high PK Rinse foliage.		Water with high N just before shipment				
CO_2 level		Normal atmos.	1,000-1,500 ppm whenever vents are closed during daylight hours.						Normal atmosphere					
Operations		Load ghs.	← Thin →				Begin Stage I hardening when trees are as tall as desired. No later than Jan. 24.			← → Move crop to shadehouse. or cooler. ← Ship and outplant →				

Species Ponderosa pine, Scots pine, Austrian pine **Container** 10 cubic inches **Outplanting** Spring/Fall **Location** Salt Lake City, Utah **Cycle** ____

Source ____

Season		APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.
Growth stage		Germination	Juvenile growth	Mature foliage appears	Multiple flushing	Bud set	Natural hardening: Caliper growth	Cold hardening	Chilling requirements met			Maintain dormancy and hardiness.		
Day temp (°F)	Optimum	70	72	72		65	(declining with the season)						34	
	Permissible	65-75	65-80	65-85		50-80					(Minimum rootball temp. 0° F)		10-50	
Night temp (°F)	Optimum	70	75	75		60							34	
	Permissible	65-75	68-77	68-77		40-65							10-45	
Rel. Hum. (%)	Optimum	80	60	60			Same							
	Permissible	60-90	50-80	50-80										
Daylight		40-50% Sunlight	75-90% Sunlight				50% Sunlight							
Supplemental light		None	8 watts/ft² incandescent or equivalent at least 3% of the night time. No dark period over 30 min.			None								
Water		Frequent, light, surface always wet	As needed. Surface should dry. Water in excess each time. Keep rootball near field capacity.			Fall planting: Leach with water. Dry to wilting. Spring planting: Omit drydown. As needed. Treat as before.								
Fertilizer		None	Complete, high N at each watering. Rinse foliage.			None	Complete, low N, high PK							
CO_2 level		Normal atmos.	1,000-1,500 ppm whenever vents are closed during daylight hours.				Normal atmosphere							
Operations		Load ghs.; Apply fungicide if needed	Thin			Move to shadehouse. Mulch with sawdust	Ship for fall planting		Protect crop from excessive winter rain				Move to a cooler to prevent budbreak. Ship for spring planting.	

Species Ponderosa pine **Container** 30 cubic inches **Outplanting** July-Sept. **Location** McNary, Ariz. **Cycle** Spring (1/yr.) Info. Grade A

Source Central Ariz.

Season	JAN.	JAN.–FEB.	MAR.–MAY	JUN.	JUL.–JAN.
Growth stage	Germination	Juvenile growth	Mature foliage appears; Multiple flushing	Stage I Hardening: Bud set; Caliper growth	Root growth after outplanting. Terminal growth unlikely
Day temp (°F) Optimum	70	72	72	70	
Day temp (°F) Permissible	60-78	65-80	65-80	50-80	
Night temp (°F) Optimum	70	72	75	60	
Night temp (°F) Permissible	60-75	55-75	64-77	50-65	
Rel. Hum. (%) Optimum	80	60	60	60	
Rel. Hum. (%) Permissible	60-90	50-80	50-80	30-80	
Daylight	75% Sunlight Shade if necessary		75-90% Sunlight, shade only if necessary to maintain permissible temperatures.	Bright skylight or 30% Sunlight	
Supplemental light	None	8 watts/ft² incandescent light or equivalent at least 3% of the night time. No dark period over 30 min.		None	
Water	Frequent, light, surface always wet	As needed. Surface should dry. Water with nutrient solution in excess each time. Keep rootball near field capacity.	Leach with water. Dry to wilting.	As needed treat as before.	
Fertilizer	None	Complete, high N, pH 5.5-6.0, EC 1,800±300 μmhos. Rinse foliage.		None; Complete, low N, high PK	Water with high N just before shipment.
CO_2 level	Normal atmos.	1,000-1,500 ppm whenever vents are closed during daylight hours.		Normal atmosphere	
Operations	Load ghs.	Apply fungicide if needed. Thin	Move to shade-house.		Ship and outplant

Species Rocky Mtn. juniper, Eastern redcedar; Austrian pine; Ponderosa pine; Black walnut **Container** 30 cubic inches **Outplanting** Spring/Fall **Location** Manhattan, Kans. **Cycle** Initial 1st and 2nd Info. Grade B

Source

Season	NOV. – DEC.	DEC./JAN. – JUL.	JUL. – NOV.
Growth stage	Germination: Juniper; Walnut, Pine	Walnut full size	Stage I Hardening pine, juniper. Walnut continues growth.
Day temp (°F) Optimum	75	78 (Greenhouse same)	75
Day temp (°F) Permissible	65-80	70-85	65-85
Night temp (°F) Optimum	50	72	60
Night temp (°F) Permissible	45-60	65-75	50-65
Rel. Hum. (%) Optimum	80	60	50
Rel. Hum. (%) Permissible	60-90	50-80	30-80
Daylight	50% Sunlight	75-90% Sunlight	50% Sunlight (Sunlight shadehouse)
Supplemental light	10 watts/ft² incandescent or equivalent at least 1 part in 15 throughout the night. Dark periods longer than 15 min.		None
Water	Frequent, light, surface always moist	As needed, according to species. Water in excess each time. Surface should dry between waterings. Keep rootball near field capacity.	Leach pine and juniper with water. As needed as before.
Fertilizer	None	Juniper only; Pine, Walnut: Complete, high N, pH 5.5-6.0, EC 1,800±300 µmhos. Rinse foliage.	None; Complete, low N. Rinse foliage.
CO_2 level	Normal atmosphere	1,000-1,500 ppm whenever vents are closed during daylight hours.	Normal atmosphere
Operations	X-Plant juniper; X-Plant pine and walnut; Apply fungicide if needed	Thin pine and juniper. Walnut options: A. Keep in greenhouse B. Move Crop #1 to heated storage. X Start Crop #2. Move walnut Crops 1 and 2 to shadehouse and ship.	Move pine, juniper to shadehouse. X Plant walnut Crop #3. Move walnut Crop #3 to shadehouse. Ship for fall planting or hold for spring planting.

Species Black walnut Container 30 cubic inch Outplanting Spring/ Summer/Fall Location Carbondale, Ill Cycle

Source

Season		MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
Growth stage		Crop #1 X-Germinate seed X-Plant germinants	Crop #2 X-Germinate seed X-Plant germinants		Crop #3 X-Germinate seed X-Plant germinants	Crop #4 X-Germinate seed X-Plant germinants		Crop #5 X-Germinate seed X-Plant germinants		Crop #6 X-Germinate seed X-Plant germinants				Crop #1 X-Germinate seed X-Plant germinants
Day temp (°F)	**Optimum**		82								68	50	34	
	Permissible		79-86								65-77	33-60	30-50	
Night temp (°F)	**Optimum**		72								59	37	34	
	Permissible		66-82								55-66	33-41	30-37	
Rel. Hum. (%)	**Optimum**		60									60		
	Permissible		50-80									50-80		
Daylight		50-90% of full sunlight (2 layers polyethylene, no shade)			Same, but add 30%shade if needed to stay under maximum day temperature.			Same, but no shade			Same, but shade as needed to stay under maximum day temperature.			
Supplemental light		8 watts/ft² incandescent light on 1 min. out of every 15 min. (or 6% of the time, provided no dark period is longer than 30 min.) throughout the night.									None			
Water		As needed. Surface should dry between waterings. Fertilize and water in excess at every watering. Maintain rootball moisture stress at 0.5-3 bars.									Leach well Dry to wilting	As needed, as before.		
Fertilizer		Complete, high N, pH 6.0-6.5, Conductivity 1,800 ±300 μmhos. Rinse foliage and piping.									None	Complete, low N, high PK. Otherwise, same as before.		
CO_2 level		1,000-1,500 ppm whenever vents are closed during daylight hours.									Normal atmosphere.			
Operations			X-Move Crop #1 to shadehouse	X-Ship & plant Crop #1	X-Move Crop #2 to shadehouse	X-Ship Crop #2	X-Move Crop #3 to shadehouse X-Ship Crop #3	X-Move Crop #4 to shadehouse	X-Ship Crop #4 X-Crop #5 to shadehouse	X-Ship Crop #5				X-Crop #6 to shadehouse or X-Ship & plant

Species Bur oak **Container** 30 cubic inches **Outplanting** Spring **Location** Bismark, N. Dak. **Cycle** 2 crops per year. Info. Grade A

Source ______

Season		MAR.	APR.–MAY	JUN.	JUL.–SEPT.	OCT.	NOV.	DEC.–MAR.
Growth stage		Germination	Juvenile growth; Multiple flushing	Crop #1 Bud set; Germinate Crop #2 Juvenile growth	Multiple flushing	Natural hardening Bud set, leaf fall	Cold hardening meet chilling requirements	Maintain dormancy
Day temp (°F)	Optimum	70	90	Crop #2 70	Crop #2 90	70	34	34
	Permissible	68-80	80-95	68-80	80-95	60-80	32-40	28-50 (Rootball should not remain continuously frozen)
Night temp (°F)	Optimum	70	72	70	72	55	34	34
	Permissible	68-80	66-80	68-80	66-80	45-70	32-40	28-40
Rel. Hum. (%)	Optimum	70	70	70	70	Same	Same	Same
	Permissible	50-90	50-90	50-90	50-90	Same	Same	Same
Daylight		50-90% of full Sunlight		Same	Same	Same	Same	
Supplemental light		None	8 watts/ft² incandescent light on 1 min. out of every 15 min. (or 6% of the time, provided no dark period is longer than 30 min.) throughout the night.			None		
Water		As needed. Surface should dry between waterings. Maintain rootball moisture stress at 0.5-3 bars. Fertilize (except during germination) and water in excess at every watering.				Same		
Fertilizer		None	Complete, high N, pH 5.8-6.8, conductivity 1,800 ±300 μmhos.	Crop #1: As before using low N, high PK. Crop #2: As before using high N.		Both crops receive low N, high PK.		
CO_2 level		Normal atmos.	1,000-1,200 ppm whenever vents are closed during daylight hours.	Normal atmos.	Crop #2: 1,000-1,200 ppm whenever vents are closed during daylight hours.	Normal atmosphere		
Operations		Germinate seed; Plant seed		Move Crop #1 to shadehouse	Collect seed		Mulch Crop #1	Move Crop #2 to shadehouse

Species: Slash, Loblolly, Longleaf pine — Container: 4 cubic inches — Outplanting: Spring/Summer/Fall — Location: Central La. — Cycle: 3 crops, 1 year — Info. Grade B

Source: Courtesy of James P. Barnett, Researcher Forester, Southern For. Exp. Stn. Pineville, La.

Season	OCT.	OCT.–NOV.	NOV.–DEC.	DEC.–JAN.	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL. – AUG. – SEPT.
Growth stage	Germination Crop #1	Juvenile growth	Exponential growth	Greenhouse hardening	Germination Crop #2	Juvenile growth	Exponential growth	Germination Crop #3	Juvenile growth	Exponential growth	
Day temp (°F) Optimum	72	75	70	65	72	75	78	72	75	78	
Day temp (°F) Permissible	65-80	65-85	72-85	55-70	65-80	65-85	72-85	65-80	65-85	72-85	
Night temp (°F) Optimum	72	72	75	55	72	72	75	72	72	75	
Night temp (°F) Permissible	65-80	65-80	72-85	50-65	65-80	65-80	72-85	65-80	65-80	72-85	
Rel. Hum. (%) Optimum	80	60			80	60		80	60		
Rel. Hum. (%) Permissible	60-90	50-80			60-90	50-80		60-90	50-80		
Daylight	50% Sunlight	55-70% Sunlight			50% Sunlight	55-70% Sunlight		50% Sunlight	55-70% Sunlight		
Supplemental light	None	8 watts/ft² incandescent or equivalent at least 3% of the time, no dark period over 30 min.		None		8 watts/ft² incandescent or equivalent at least 3% of the time, no dark period over 30 min.		None	8 watts/ft² incandescent or equivalent at least 3% of the time, no dark period over 30 min.		
Water	Frequent, light, surface kept wet.	As needed, surface should dry. Water in excess. Keep rootball near field cap.		As needed. Dry to wilting	Frequent, light, surface kept wet.	As needed, surface should dry. Water in excess. Keep rootball near field cap. Stress		Frequent, light, surface wet.	As needed, surface should dry. Water in excess. Keep rootball near field capacity.		
Fertilizer	None	Complete, high N, pH 5.0-5.5		Low N, high P	None	Complete, high N, pH 5.0-5.5		None	Complete, high N, pH 5.0-5.5		
CO_2 level	Normal atmos.	1,000-1,500 ppm whenever vents are closed in daylight hours.		Normal atmos.	Normal atmos.	1,000-1,500 ppm whenever vents are closed in daylight hours.		Normal atmos.	Normal atmos., CO_2 at higher levels not usually feasible because of venting needs		

Operations:

- Leach Crop #1
- Apply fungicide
- Thin
- Move to lathhouse. Load Crop #2
- Harden Crop #1 in lathhouse
- Fungicide
- Thin
- Ship Crop #1 for outplanting
- Move Crop #2 to lathhouse.
- Load Crop #3
- Fungicide
- Thin
- Harden Crop #2 in lathhouse
- Ship Crop #2 for outplanting
- Move Crop #3 to lathhouse.
- Temperatures usually too high for greenhouse production
- Harden or ship for outplanting

Species Douglas–fir **Container** 3-10 cubic inches **Outplanting** Fall/ Winter/Spring **Location** Corvallis, Oreg. **Cycle** Summer Info. Grade A, B

Source West Coast (Courtesy of Peyton W. Owston, Pac. Northwest For. and Range Exp. Stn., Corvallis, Oreg.)

Season		MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.
Growth stage		Sowing	Germin-ation	Juvenile growth	Height			Natural hardening Bud set Caliper growth		Cold hardening		Maintain dormancy and hardiness		
Day temp (°F)	**Optimum**		75-85	75-85	70-80			76-70	45-55	35-40		35-40		
	Permissible		70-85	70-90	65-90			50-85	40-70	30-40		25-50		
Night temp (°F)	**Optimum**		65-70	55-60	55-60			55-60	40-50	33-36		33-36		
	Permissible		60-80	50-65	50-65			45-65	35-60	25-45		25-40		
Rel. Hum. (%)	**Optimum**		65-80	50-70	50-70	Same								
	Permissible		55-90	40-80	40-80									
Daylight			50-75% Sunlight	65-80% Sunlight			100% Sun-light		50-100% Sunlight					
Supplemental light			None	None					None					
Water			Frequent light, surface always wet	As needed. Surface should dry, water in excess each time 5-6 bars tension is reached			Leach w/H_2O Dry to 22 bars PMS	As needed. Surface should dry, water in excess each time 0.5-3 bars tension is reached						
Fertilizer			None	Complete high N. pH 5.5-5.0. Rinse foliage			Leach w/H_2O Dry to 22 bars PMS	Complete, low N, high PK.						
CO_2 level			Normal atmosphere											
Operations		Fill, seed, load, ghs.		Thin to one per pot. Apply fungicide if needed.				NOTE: Trees in greenhouse all winter, or in shadehouse if minimum air temp. is usually above freezing. Brief periods down to 25° F are acceptable.				Perhaps move to cooler to prevent bud break anytime after Jan. 1.		
										Outplant anytime site conditions are favorable.				

Appendix 3

Probability tables for determining the proportion of containers expected to have a certain number of seedlings, giving the number of seeds sown and the germination percent (Balmer and Space 1976).

TABLE 1 2 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES
1	.98010	.01980	.00010
2	.96040	.03920	.00040
3	.94090	.05820	.00090
4	.92160	.07680	.00160
5	.90250	.09500	.00250
6	.88360	.11280	.00360
7	.86490	.13020	.00490
8	.84640	.14720	.00640
9	.82810	.16380	.00810
10	.81000	.18000	.01000
11	.79210	.19580	.01210
12	.77440	.21120	.01440
13	.75690	.22620	.01690
14	.73960	.24080	.01960
15	.72250	.25500	.02250
16	.70560	.26880	.02560
17	.68890	.28220	.02890
18	.67240	.29520	.03240
19	.65610	.30780	.03610
20	.64000	.32000	.04000
21	.62410	.33180	.04410
22	.60840	.34320	.04840
23	.59290	.35420	.05290
24	.57760	.36480	.05760
25	.56250	.37500	.06250
26	.54760	.38480	.06760
27	.53290	.39420	.07290
28	.51840	.40320	.07840
29	.50410	.41180	.08410
30	.49000	.42000	.09000
31	.47610	.42780	.09610
32	.46240	.43520	.10240
33	.44890	.44220	.10890
34	.43560	.44880	.11560
35	.42250	.45500	.12250
36	.40960	.46080	.12960
37	.39690	.46620	.13690
38	.38440	.47120	.14440
39	.37210	.47580	.15210
40	.36000	.48000	.16000
41	.34810	.48380	.16810
42	.33640	.48720	.17640
43	.32490	.49020	.18490
44	.31360	.49280	.19360
45	.30250	.49500	.20250
46	.29160	.49680	.21160
47	.28090	.49820	.22090
48	.27040	.49920	.23040
49	.26010	.49980	.24010
50	.25000	.50000	.25000

TABLE 1 2 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES
51	.24010	.49980	.26010
52	.23040	.49920	.27040
53	.22090	.49820	.28090
54	.21160	.49680	.29160
55	.20250	.49500	.30250
56	.19360	.49280	.31360
57	.18490	.49020	.32490
58	.17640	.48720	.33640
59	.16810	.48380	.34810
60	.16000	.48000	.36000
61	.15210	.47580	.37210
62	.14440	.47120	.38440
63	.13690	.46620	.39690
64	.12960	.46080	.40960
65	.12250	.45500	.42250
66	.11560	.44880	.43560
67	.10890	.44220	.44890
68	.10240	.43520	.46240
69	.09610	.42780	.47610
70	.09000	.42000	.49000
71	.08410	.41180	.50410
72	.07840	.40320	.51840
73	.07290	.39420	.53290
74	.06760	.38480	.54760
75	.06250	.37500	.56250
76	.05760	.36480	.57760
77	.05290	.35420	.59290
78	.04840	.34320	.60840
79	.04410	.33180	.62410
80	.04000	.32000	.64000
81	.03610	.30780	.65610
82	.03240	.29520	.67240
83	.02890	.28220	.68890
84	.02560	.26880	.70560
85	.02250	.25500	.72250
86	.01960	.24080	.73960
87	.01690	.22620	.75690
88	.01440	.21120	.77440
89	.01210	.19580	.79210
90	.01000	.18000	.81000
91	.00810	.16380	.82810
92	.00640	.14720	.84640
93	.00490	.13020	.86490
94	.00360	.11280	.88360
95	.00250	.09500	.90250
96	.00160	.07680	.92160
97	.00090	.05820	.94090
98	.00040	.03920	.96040
99	.00010	.01980	.98010

TABLE 2 3 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES
1	.97030	.02940	.00030	.00000
2	.94119	.05762	.00118	.00001
3	.91267	.08468	.00262	.00003
4	.88474	.11059	.00461	.00006
5	.85737	.13537	.00712	.00012
6	.83058	.15905	.01015	.00022
7	.80436	.18163	.01367	.00034
8	.77869	.20314	.01766	.00051
9	.75357	.22359	.02211	.00073
10	.72900	.24300	.02700	.00100
11	.70497	.26139	.03231	.00133
12	.68147	.27878	.03802	.00173
13	.65850	.29519	.04411	.00220
14	.63606	.31063	.05057	.00274
15	.61412	.32512	.05737	.00337
16	.59270	.33869	.06451	.00410
17	.57179	.35134	.07196	.00491
18	.55137	.36310	.07970	.00583
19	.53144	.37398	.08772	.00686
20	.51200	.38400	.09600	.00800
21	.49304	.39318	.10452	.00926
22	.47455	.40154	.11326	.01065
23	.45653	.40910	.12220	.01217
24	.43898	.41587	.13133	.01382
25	.42188	.42188	.14063	.01563
26	.40522	.42713	.15007	.01758
27	.38902	.43165	.15965	.01968
28	.37325	.43546	.16934	.02195
29	.35791	.43857	.17913	.02439
30	.34300	.44100	.18900	.02700
31	.32851	.44277	.19893	.02979
32	.31443	.44390	.20890	.03277
33	.30076	.44441	.21889	.03594
34	.28750	.44431	.22889	.03930
35	.27462	.44362	.23887	.04287
36	.26214	.44237	.24883	.04666
37	.25005	.44056	.25874	.05065
38	.23833	.43822	.26858	.05487
39	.22698	.43536	.27834	.05932
40	.21600	.43200	.28800	.06400
41	.20538	.42816	.29754	.06892
42	.19511	.42386	.30694	.07409
43	.18519	.41912	.31618	.07951
44	.17562	.41395	.32525	.08518
45	.16637	.40837	.33412	.09112
46	.15746	.40241	.34279	.09734
47	.14888	.39607	.35123	.10382
48	.14061	.38938	.35942	.11059
49	.13265	.38235	.36735	.11765
50	.12500	.37500	.37500	.12500

TABLE 2 3 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES
51	.11765	.36735	.38235	.13265
52	.11059	.35942	.38938	.14061
53	.10382	.35123	.39607	.14888
54	.09734	.34279	.40241	.15746
55	.09112	.33412	.40837	.16637
56	.08518	.32525	.41395	.17562
57	.07951	.31618	.41912	.18519
58	.07409	.30694	.42386	.19511
59	.06892	.29754	.42816	.20538
60	.06400	.28800	.43200	.21600
61	.05932	.27834	.43536	.22698
62	.05487	.26858	.43822	.23833
63	.05065	.25874	.44056	.25005
64	.04666	.24883	.44237	.26214
65	.04287	.23887	.44362	.27462
66	.03930	.22889	.44431	.28750
67	.03594	.21889	.44441	.30076
68	.03277	.20890	.44390	.31443
69	.02979	.19893	.44277	.32851
70	.02700	.18900	.44100	.34300
71	.02439	.17913	.43857	.35791
72	.02195	.16934	.43546	.37325
73	.01968	.15965	.43165	.38902
74	.01758	.15007	.42713	.40522
75	.01563	.14063	.42188	.42188
76	.01382	.13133	.41587	.43898
77	.01217	.12220	.40910	.45653
78	.01065	.11326	.40154	.47455
79	.00926	.10452	.39318	.49304
80	.00800	.09600	.38400	.51200
81	.00686	.08772	.37398	.53144
82	.00583	.07970	.36310	.55137
83	.00491	.07196	.35134	.57179
84	.00410	.06451	.33869	.59270
85	.00337	.05737	.32512	.61412
86	.00274	.05057	.31063	.63606
87	.00220	.04411	.29519	.65850
88	.00173	.03802	.27878	.68147
89	.00133	.03231	.26139	.70497
90	.00100	.02700	.24300	.72900
91	.00073	.02211	.22359	.75357
92	.00051	.01766	.20314	.77869
93	.00034	.01367	.18163	.80436
94	.00022	.01015	.15905	.83058
95	.00012	.00712	.13537	.85737
96	.00006	.00461	.11059	.88474
97	.00003	.00262	.08468	.91267
98	.00001	.00118	.05762	.94119
99	.00000	.00030	.02940	.97030

TABLE 3 — 4 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES
1	.96060	.03881	.00059	.00000	.00000
2	.92237	.07530	.00230	.00003	.00000
3	.88529	.10952	.00508	.00010	.00000
4	.84935	.14156	.00885	.00025	.00000
5	.81451	.17147	.01354	.00047	.00001
6	.78075	.19934	.01909	.00081	.00001
7	.74805	.22522	.02543	.00128	.00002
8	.71639	.24918	.03250	.00188	.00004
9	.68575	.27129	.04025	.00265	.00007
10	.65610	.29160	.04860	.00360	.00010
11	.62742	.31019	.05751	.00474	.00015
12	.59970	.32711	.06691	.00608	.00021
13	.57290	.34242	.07675	.00765	.00029
14	.54701	.35619	.08698	.00944	.00038
15	.52201	.36847	.09754	.01147	.00051
16	.49787	.37933	.10838	.01376	.00066
17	.47458	.38882	.11946	.01631	.00084
18	.45212	.39698	.13071	.01913	.00105
19	.43047	.40390	.14211	.02222	.00130
20	.40960	.40960	.15360	.02560	.00160
21	.38950	.41415	.16514	.02926	.00194
22	.37015	.41761	.17668	.03322	.00234
23	.35153	.42001	.18819	.03747	.00280
24	.33362	.42142	.19962	.04202	.00332
25	.31641	.42188	.21094	.04688	.00391
26	.29987	.42143	.22211	.05202	.00457
27	.28398	.42014	.23309	.05747	.00531
28	.26874	.41804	.24386	.06322	.00615
29	.25412	.41518	.25437	.06926	.00707
30	.24010	.41160	.26460	.07560	.00810
31	.22667	.40735	.27452	.08222	.00924
32	.21381	.40247	.28410	.08913	.01049
33	.20151	.39701	.29331	.09631	.01186
34	.18975	.39099	.30213	.10376	.01336
35	.17851	.38447	.31054	.11147	.01501
36	.16777	.37749	.31850	.11944	.01680
37	.15753	.37007	.32601	.12765	.01874
38	.14776	.36226	.33304	.13608	.02085
39	.13846	.35409	.33958	.14474	.02313
40	.12960	.34560	.34560	.15360	.02560
41	.12117	.33682	.35109	.16265	.02826
42	.11316	.32779	.35605	.17188	.03112
43	.10556	.31853	.36044	.18128	.03419
44	.09834	.30908	.36428	.19081	.03748
45	.09151	.29947	.36754	.20047	.04101
46	.08503	.28973	.37022	.21025	.04477
47	.07890	.27989	.37230	.22010	.04880
48	.07312	.26997	.37380	.23003	.05308
49	.06765	.26000	.37470	.24000	.05765
50	.06250	.25000	.37500	.25000	.06250

TABLE 3 — 4 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES
51	.05765	.24000	.37470	.26000	.06765
52	.05308	.23003	.37380	.26997	.07312
53	.04880	.22010	.37230	.27989	.07890
54	.04477	.21025	.37022	.28973	.08503
55	.04101	.20047	.36754	.29947	.09151
56	.03748	.19081	.36428	.30908	.09834
57	.03419	.18128	.36044	.31853	.10556
58	.03112	.17188	.35605	.32779	.11316
59	.02826	.16265	.35109	.33682	.12117
60	.02560	.15360	.34560	.34560	.12960
61	.02313	.14474	.33958	.35409	.13846
62	.02085	.13608	.33304	.36226	.14776
63	.01874	.12765	.32601	.37007	.15753
64	.01680	.11944	.31850	.37749	.16777
65	.01501	.11147	.31054	.38447	.17851
66	.01336	.10376	.30213	.39099	.18975
67	.01186	.09631	.29331	.39701	.20151
68	.01049	.08913	.28410	.40247	.21381
69	.00924	.08222	.27452	.40735	.22667
70	.00810	.07560	.26460	.41160	.24010
71	.00707	.06926	.25437	.41518	.25412
72	.00615	.06322	.24386	.41804	.26874
73	.00531	.05747	.23309	.42014	.28398
74	.00457	.05202	.22211	.42143	.29987
75	.00391	.04688	.21094	.42188	.31641
76	.00332	.04202	.19962	.42142	.33362
77	.00280	.03747	.18819	.42001	.35153
78	.00234	.03322	.17668	.41761	.37015
79	.00194	.02926	.16514	.41415	.38950
80	.00160	.02560	.15360	.40960	.40960
81	.00130	.02222	.14211	.40390	.43047
82	.00105	.01913	.13071	.39698	.45212
83	.00084	.01631	.11946	.38882	.47458
84	.00066	.01376	.10838	.37933	.49787
85	.00051	.01147	.09754	.36847	.52201
86	.00038	.00944	.08698	.35619	.54701
87	.00029	.00765	.07675	.34242	.57290
88	.00021	.00608	.06691	.32711	.59970
89	.00015	.00474	.05751	.31019	.62742
90	.00010	.00360	.04860	.29160	.65610
91	.00007	.00265	.04025	.27129	.68575
92	.00004	.00188	.03250	.24918	.71639
93	.00002	.00128	.02543	.22522	.74805
94	.00001	.00081	.01909	.19934	.78075
95	.00001	.00047	.01354	.17147	.81451
96	.00000	.00025	.00885	.14156	.84935
97	.00000	.00010	.00508	.10952	.88529
98	.00000	.00003	.00230	.07530	.92237
99	.00000	.00000	.00059	.03881	.96060

TABLE 4 5 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES
1	.95099	.04803	.00097	.00001	.00000	.00000
2	.90392	.09224	.00376	.00008	.00000	.00000
3	.85873	.13279	.00821	.00025	.00000	.00000
4	.81537	.16987	.01416	.00059	.00001	.00000
5	.77378	.20363	.02143	.00113	.00003	.00000
6	.73390	.23422	.02990	.00191	.00006	.00000
7	.69569	.26182	.03941	.00297	.00011	.00000
8	.65908	.28656	.04984	.00433	.00019	.00000
9	.62403	.30859	.06104	.00604	.00030	.00001
10	.59049	.32805	.07290	.00810	.00045	.00001
11	.55841	.34508	.08530	.01054	.00065	.00002
12	.52773	.35982	.09813	.01338	.00091	.00002
13	.49842	.37238	.11129	.01663	.00124	.00004
14	.47043	.38291	.12467	.02029	.00165	.00005
15	.44371	.39150	.13818	.02438	.00215	.00008
16	.41821	.39830	.15173	.02890	.00275	.00010
17	.39390	.40340	.16525	.03385	.00347	.00014
18	.37074	.40691	.17864	.03921	.00430	.00019
19	.34868	.40894	.19185	.04500	.00528	.00025
20	.32768	.40960	.20480	.05120	.00640	.00032
21	.30771	.40898	.21743	.05780	.00768	.00041
22	.28872	.40717	.22968	.06478	.00914	.00052
23	.27068	.40426	.24151	.07214	.01077	.00064
24	.25355	.40035	.25285	.07985	.01261	.00080
25	.23730	.39551	.26367	.08789	.01465	.00098
26	.22190	.38983	.27393	.09625	.01691	.00119
27	.20731	.38338	.28359	.10489	.01940	.00143
28	.19349	.37623	.29263	.11380	.02213	.00172
29	.18042	.36847	.30100	.12294	.02511	.00205
30	.16807	.36015	.30870	.13230	.02835	.00243
31	.15640	.35134	.31570	.14183	.03186	.00286
32	.14539	.34210	.32198	.15152	.03565	.00336
33	.13501	.33249	.32753	.16132	.03973	.00391
34	.12523	.32257	.33235	.17121	.04410	.00454
35	.11603	.31239	.33642	.18115	.04877	.00525
36	.10737	.30199	.33974	.19110	.05375	.00605
37	.09924	.29143	.34231	.20104	.05904	.00693
38	.09161	.28075	.34415	.21093	.06464	.00792
39	.08446	.26999	.34524	.22073	.07056	.00902
40	.07776	.25920	.34560	.23040	.07680	.01024
41	.07149	.24841	.34524	.23991	.08336	.01159
42	.06564	.23765	.34418	.24923	.09024	.01307
43	.06017	.22695	.34242	.25832	.09744	.01470
44	.05507	.21636	.33999	.26714	.10495	.01649
45	.05033	.20589	.33691	.27565	.11277	.01845
46	.04592	.19557	.33319	.28383	.12089	.02060
47	.04182	.18543	.32887	.29164	.12931	.02293
48	.03802	.17548	.32396	.29904	.13802	.02548
49	.03450	.16575	.31850	.30601	.14700	.02825
50	.03125	.15625	.31250	.31250	.15625	.03125

TABLE 4 5 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES
51	.02825	.14700	.30601	.31850	.16575	.03450
52	.02548	.13802	.29904	.32396	.17548	.03802
53	.02293	.12931	.29164	.32887	.18543	.04182
54	.02060	.12089	.28383	.33319	.19557	.04592
55	.01845	.11277	.27565	.33691	.20589	.05033
56	.01649	.10495	.26714	.33999	.21636	.05507
57	.01470	.09744	.25832	.34242	.22695	.06017
58	.01307	.09024	.24923	.34418	.23765	.06564
59	.01159	.08336	.23991	.34524	.24841	.07149
60	.01024	.07680	.23040	.34560	.25920	.07776
61	.00902	.07056	.22073	.34524	.26999	.08446
62	.00792	.06464	.21093	.34415	.28075	.09161
63	.00693	.05904	.20104	.34231	.29143	.09924
64	.00605	.05375	.19110	.33974	.30199	.10737
65	.00525	.04877	.18115	.33642	.31239	.11603
66	.00454	.04410	.17121	.33235	.32257	.12523
67	.00391	.03973	.16132	.32753	.33249	.13501
68	.00336	.03565	.15152	.32198	.34210	.14539
69	.00286	.03186	.14183	.31570	.35134	.15640
70	.00243	.02835	.13230	.30870	.36015	.16807
71	.00205	.02511	.12294	.30100	.36847	.18042
72	.00172	.02213	.11380	.29263	.37623	.19349
73	.00143	.01940	.10489	.28359	.38338	.20731
74	.00119	.01691	.09625	.27393	.38983	.22190
75	.00098	.01465	.08789	.26367	.39551	.23730
76	.00080	.01261	.07985	.25285	.40035	.25355
77	.00064	.01077	.07214	.24151	.40426	.27068
78	.00052	.00914	.06478	.22968	.40717	.28872
79	.00041	.00768	.05780	.21743	.40898	.30771
80	.00032	.00640	.05120	.20480	.40960	.32768
81	.00025	.00528	.04500	.19185	.40894	.34868
82	.00019	.00430	.03921	.17864	.40691	.37074
83	.00014	.00347	.03385	.16525	.40340	.39390
84	.00010	.00275	.02890	.15173	.39830	.41821
85	.00008	.00215	.02438	.13818	.39150	.44371
86	.00005	.00165	.02029	.12467	.38291	.47043
87	.00004	.00124	.01663	.11129	.37238	.49842
88	.00002	.00091	.01338	.09813	.35982	.52773
89	.00002	.00065	.01054	.08530	.34508	.55841
90	.00001	.00045	.00810	.07290	.32805	.59049
91	.00001	.00030	.00604	.06104	.30859	.62403
92	.00000	.00019	.00433	.04984	.28656	.65908
93	.00000	.00011	.00297	.03941	.26182	.69569
94	.00000	.00006	.00191	.02990	.23422	.73390
95	.00000	.00003	.00113	.02143	.20363	.77378
96	.00000	.00001	.00059	.01416	.16987	.81537
97	.00000	.00000	.00025	.00821	.13279	.85873
98	.00000	.00000	.00008	.00376	.09224	.90392
99	.00000	.00000	.00001	.00097	.04803	.95099

TABLE 5 6 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES
1	.94148	.05706	.00144	.00002	.00000	.00000	.00000
2	.88584	.10847	.00553	.00015	.00000	.00000	.00000
3	.83297	.15457	.01195	.00049	.00001	.00000	.00000
4	.78276	.19569	.02038	.00113	.00004	.00000	.00000
5	.73509	.23213	.03054	.00214	.00008	.00000	.00000
6	.68987	.26421	.04216	.00359	.00017	.00000	.00000
7	.64699	.29219	.05498	.00552	.00031	.00001	.00000
8	.60635	.31636	.06877	.00797	.00052	.00002	.00000
9	.56787	.33698	.08332	.01099	.00081	.00003	.00000
10	.53144	.35429	.09841	.01458	.00121	.00005	.00000
11	.49698	.36855	.11388	.01877	.00174	.00009	.00000
12	.46440	.37997	.12953	.02355	.00241	.00013	.00000
13	.43363	.38877	.14523	.02893	.00324	.00019	.00000
14	.40457	.39516	.16082	.03491	.00426	.00028	.00001
15	.37715	.39933	.17618	.04145	.00549	.00039	.00001
16	.35130	.40148	.19118	.04855	.00694	.00053	.00002
17	.32694	.40178	.20573	.05618	.00863	.00071	.00002
18	.30401	.40040	.21973	.06431	.01059	.00093	.00003
19	.28243	.39749	.23310	.07290	.01283	.00120	.00005
20	.26214	.39322	.24576	.08192	.01536	.00154	.00006
21	.24309	.38771	.25765	.09132	.01821	.00194	.00009
22	.22520	.38111	.26873	.10106	.02138	.00241	.00011
23	.20842	.37354	.27894	.11109	.02489	.00297	.00015
24	.19270	.36512	.28825	.12137	.02875	.00363	.00019
25	.17798	.35596	.29663	.13184	.03296	.00439	.00024
26	.16421	.34617	.30406	.14244	.03754	.00528	.00031
27	.15133	.33584	.31053	.15314	.04248	.00628	.00039
28	.13931	.32507	.31604	.16387	.04780	.00743	.00048
29	.12810	.31394	.32057	.17458	.05348	.00874	.00059
30	.11765	.30253	.32413	.18522	.05953	.01021	.00073
31	.10792	.29091	.32675	.19573	.06595	.01185	.00089
32	.09887	.27916	.32842	.20607	.07273	.01369	.00107
33	.09046	.26732	.32917	.21617	.07985	.01573	.00129
34	.08265	.25548	.32902	.22599	.08732	.01799	.00154
35	.07542	.24366	.32801	.23549	.09510	.02048	.00184
36	.06872	.23193	.32615	.24461	.10320	.02322	.00218
37	.06252	.22032	.32349	.25331	.11158	.02621	.00257
38	.05680	.20888	.32006	.26155	.12023	.02948	.00301
39	.05152	.19764	.31589	.26929	.12912	.03302	.00352
40	.04666	.18662	.31104	.27648	.13824	.03686	.00410
41	.04218	.17587	.30554	.28310	.14755	.04101	.00475
42	.03807	.16540	.29943	.28911	.15702	.04548	.00549
43	.03430	.15524	.29277	.29448	.16662	.05028	.00632
44	.03084	.14539	.28559	.29919	.17631	.05541	.00726
45	.02768	.13589	.27795	.30322	.18607	.06089	.00830
46	.02479	.12673	.26989	.30654	.19584	.06673	.00947
47	.02216	.11793	.26145	.30914	.20561	.07293	.01078
48	.01977	.10950	.25269	.31100	.21531	.07950	.01223
49	.01760	.10144	.24365	.31213	.22491	.08644	.01384
50	.01563	.09375	.23438	.31250	.23438	.09375	.01563

TABLE 5 6 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES
51	.01384	.08644	.22491	.31213	.24365	.10144	.01760
52	.01223	.07950	.21531	.31100	.25269	.10950	.01977
53	.01078	.07293	.20561	.30914	.26145	.11793	.02216
54	.00947	.06673	.19584	.30654	.26989	.12673	.02479
55	.00830	.06089	.18607	.30322	.27795	.13589	.02768
56	.00726	.05541	.17631	.29919	.28559	.14539	.03084
57	.00632	.05028	.16662	.29448	.29277	.15524	.03430
58	.00549	.04548	.15702	.28911	.29943	.16540	.03807
59	.00475	.04101	.14755	.28310	.30554	.17587	.04218
60	.00410	.03686	.13824	.27648	.31104	.18662	.04666
61	.00352	.03302	.12912	.26929	.31589	.19764	.05152
62	.00301	.02948	.12023	.26155	.32006	.20888	.05680
63	.00257	.02621	.11158	.25331	.32349	.22032	.06252
64	.00218	.02322	.10320	.24461	.32615	.23193	.06872
65	.00184	.02048	.09510	.23549	.32801	.24366	.07542
66	.00154	.01799	.08732	.22599	.32902	.25548	.08265
67	.00129	.01573	.07985	.21617	.32917	.26732	.09046
68	.00107	.01369	.07273	.20607	.32842	.27916	.09887
69	.00089	.01185	.06595	.19573	.32675	.29091	.10792
70	.00073	.01021	.05953	.18522	.32413	.30253	.11765
71	.00059	.00874	.05348	.17458	.32057	.31394	.12810
72	.00048	.00743	.04780	.16387	.31604	.32507	.13931
73	.00039	.00628	.04248	.15314	.31053	.33584	.15133
74	.00031	.00528	.03754	.14244	.30406	.34617	.16421
75	.00024	.00439	.03296	.13184	.29663	.35596	.17798
76	.00019	.00363	.02875	.12137	.28825	.36512	.19270
77	.00015	.00297	.02489	.11109	.27894	.37354	.20842
78	.00011	.00241	.02138	.10106	.26873	.38111	.22520
79	.00009	.00194	.01821	.09132	.25765	.38771	.24309
80	.00006	.00154	.01536	.08192	.24576	.39322	.26214
81	.00005	.00120	.01283	.07290	.23310	.39749	.28243
82	.00003	.00093	.01059	.06431	.21973	.40040	.30401
83	.00002	.00071	.00863	.05618	.20573	.40178	.32694
84	.00002	.00053	.00694	.04855	.19118	.40148	.35130
85	.00001	.00039	.00549	.04145	.17618	.39933	.37715
86	.00001	.00028	.00426	.03491	.16082	.39516	.40457
87	.00000	.00019	.00324	.02893	.14523	.38877	.43363
88	.00000	.00013	.00241	.02355	.12953	.37997	.46440
89	.00000	.00009	.00174	.01877	.11388	.36855	.49698
90	.00000	.00005	.00121	.01458	.09841	.35429	.53144
91	.00000	.00003	.00081	.01099	.08332	.33698	.56787
92	.00000	.00002	.00052	.00797	.06877	.31636	.60635
93	.00000	.00001	.00031	.00552	.05498	.29219	.64699
94	.00000	.00000	.00017	.00359	.04216	.26421	.68987
95	.00000	.00000	.00008	.00214	.03054	.23213	.73509
96	.00000	.00000	.00004	.00113	.02038	.19569	.78276
97	.00000	.00000	.00001	.00049	.01195	.15457	.83297
98	.00000	.00000	.00000	.00015	.00553	.10847	.88584
99	.00000	.00000	.00000	.00002	.00144	.05706	.94148

TABLE 6 7 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES
1	.93207	.06590	.00200	.00003	.00000	.00000	.00000	.00000
2	.86813	.12402	.00759	.00026	.00001	.00000	.00000	.00000
3	.80798	.17492	.01623	.00084	.00003	.00000	.00000	.00000
4	.75145	.21917	.02740	.00190	.00008	.00000	.00000	.00000
5	.69834	.25728	.04062	.00356	.00019	.00001	.00000	.00000
6	.64848	.28975	.05548	.00590	.00038	.00001	.00000	.00000
7	.60170	.31703	.07159	.00898	.00068	.00003	.00000	.00000
8	.55785	.33956	.08858	.01284	.00112	.00006	.00000	.00000
9	.51676	.35776	.10615	.01750	.00173	.00010	.00000	.00000
10	.47830	.37201	.12400	.02296	.00255	.00017	.00001	.00000
11	.44231	.38268	.14189	.02923	.00361	.00027	.00001	.00000
12	.40868	.39010	.15959	.03627	.00495	.00040	.00002	.00000
13	.37725	.39460	.17689	.04405	.00658	.00059	.00003	.00000
14	.34793	.39648	.19363	.05253	.00855	.00084	.00005	.00000
15	.32058	.39601	.20965	.06166	.01088	.00115	.00007	.00000
16	.29509	.39345	.22483	.07137	.01360	.00155	.00010	.00000
17	.27136	.38906	.23906	.08161	.01671	.00205	.00014	.00000
18	.24929	.38305	.25225	.09229	.02026	.00267	.00020	.00001
19	.22877	.37563	.26433	.10334	.02424	.00341	.00027	.00001
20	.20972	.36700	.27525	.11469	.02867	.00430	.00036	.00001
21	.19204	.35734	.28497	.12625	.03356	.00535	.00047	.00002
22	.17566	.34681	.29345	.13795	.03891	.00658	.00062	.00002
23	.16049	.33556	.30070	.14970	.04471	.00801	.00080	.00003
24	.14645	.32374	.30670	.16142	.05097	.00966	.00102	.00005
25	.13348	.31146	.31146	.17303	.05768	.01154	.00128	.00006
26	.12151	.29886	.31501	.18447	.06481	.01366	.00160	.00008
27	.11047	.28602	.31737	.19564	.07236	.01606	.00198	.00010
28	.10031	.27306	.31856	.20648	.08030	.01874	.00243	.00013
29	.09095	.26004	.31864	.21692	.08860	.02171	.00296	.00017
30	.08235	.24706	.31765	.22689	.09724	.02500	.00357	.00022
31	.07446	.23418	.31564	.23635	.10618	.02862	.00429	.00028
32	.06723	.22146	.31265	.24522	.11540	.03258	.00511	.00034
33	.06061	.20896	.30876	.25346	.12484	.03689	.00606	.00043
34	.05455	.19672	.30402	.26102	.13447	.04156	.00714	.00053
35	.04902	.18478	.29848	.26787	.14424	.04660	.00836	.00064
36	.04398	.17317	.29223	.27397	.15411	.05201	.00975	.00078
37	.03939	.16194	.28532	.27928	.16402	.05780	.01131	.00095
38	.03522	.15109	.27781	.28378	.17393	.06396	.01307	.00114
39	.03143	.14065	.26977	.28746	.18379	.07050	.01503	.00137
40	.02799	.13064	.26127	.29030	.19354	.07741	.01720	.00164
41	.02489	.12106	.25238	.29230	.20312	.08469	.01962	.00195
42	.02208	.11192	.24314	.29345	.21250	.09233	.02229	.00231
43	.01955	.10323	.23363	.29375	.22160	.10030	.02522	.00272
44	.01727	.09499	.22391	.29321	.23038	.10861	.02844	.00319
45	.01522	.08719	.21402	.29185	.23878	.11722	.03197	.00374
46	.01339	.07984	.20403	.28968	.24676	.12612	.03581	.00436
47	.01175	.07292	.19400	.28672	.25427	.13529	.03999	.00507
48	.01028	.06643	.18396	.28301	.26124	.14469	.04452	.00587
49	.00897	.06036	.17397	.27857	.26765	.15429	.04941	.00678
50	.00781	.05469	.16406	.27344	.27344	.16406	.05469	.00781

TABLE 6 7 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES
51	.00678	.04941	.15429	.26765	.27857	.17397	.06036	.00897
52	.00587	.04452	.14469	.26124	.28301	.18396	.06643	.01028
53	.00507	.03999	.13529	.25427	.28672	.19400	.07292	.01175
54	.00436	.03581	.12612	.24676	.28968	.20403	.07984	.01339
55	.00374	.03197	.11722	.23878	.29185	.21402	.08719	.01522
56	.00319	.02844	.10861	.23038	.29321	.22391	.09499	.01727
57	.00272	.02522	.10030	.22160	.29375	.23363	.10323	.01955
58	.00231	.02229	.09233	.21250	.29345	.24314	.11192	.02208
59	.00195	.01962	.08469	.20312	.29230	.25238	.12106	.02489
60	.00164	.01720	.07741	.19354	.29030	.26127	.13064	.02799
61	.00137	.01503	.07050	.18379	.28746	.26977	.14065	.03143
62	.00114	.01307	.06396	.17393	.28378	.27781	.15109	.03522
63	.00095	.01131	.05780	.16402	.27928	.28532	.16194	.03939
64	.00078	.00975	.05201	.15411	.27397	.29223	.17317	.04398
65	.00064	.00836	.04660	.14424	.26787	.29848	.18478	.04902
66	.00053	.00714	.04156	.13447	.26102	.30402	.19672	.05455
67	.00043	.00606	.03689	.12484	.25346	.30876	.20896	.06061
68	.00034	.00511	.03258	.11540	.24522	.31265	.22146	.06723
69	.00028	.00429	.02862	.10618	.23635	.31564	.23418	.07446
70	.00022	.00357	.02500	.09724	.22689	.31765	.24706	.08235
71	.00017	.00296	.02171	.08860	.21692	.31864	.26004	.09095
72	.00013	.00243	.01874	.08030	.20648	.31856	.27306	.10031
73	.00010	.00198	.01606	.07236	.19564	.31737	.28602	.11047
74	.00008	.00160	.01366	.06481	.18447	.31501	.29886	.12151
75	.00006	.00128	.01154	.05768	.17303	.31146	.31146	.13348
76	.00005	.00102	.00966	.05097	.16142	.30670	.32374	.14645
77	.00003	.00080	.00801	.04471	.14970	.30070	.33556	.16049
78	.00002	.00062	.00658	.03891	.13795	.29345	.34681	.17566
79	.00002	.00047	.00535	.03356	.12625	.28497	.35734	.19204
80	.00001	.00036	.00430	.02867	.11469	.27525	.36700	.20972
81	.00001	.00027	.00341	.02424	.10334	.26433	.37563	.22877
82	.00001	.00020	.00267	.02026	.09229	.25225	.38305	.24929
83	.00000	.00014	.00205	.01671	.08161	.23906	.38906	.27136
84	.00000	.00010	.00155	.01360	.07137	.22483	.39345	.29509
85	.00000	.00007	.00115	.01088	.06166	.20965	.39601	.32058
86	.00000	.00005	.00084	.00855	.05253	.19363	.39648	.34793
87	.00000	.00003	.00059	.00658	.04405	.17689	.39460	.37725
88	.00000	.00002	.00040	.00495	.03627	.15959	.39010	.40868
89	.00000	.00001	.00027	.00361	.02923	.14189	.38268	.44231
90	.00000	.00001	.00017	.00255	.02296	.12400	.37201	.47830
91	.00000	.00000	.00010	.00173	.01750	.10615	.35776	.51676
92	.00000	.00000	.00006	.00112	.01284	.08858	.33956	.55785
93	.00000	.00000	.00003	.00068	.00898	.07159	.31703	.60170
94	.00000	.00000	.00001	.00038	.00590	.05548	.28975	.64848
95	.00000	.00000	.00001	.00019	.00356	.04062	.25728	.69834
96	.00000	.00000	.00000	.00008	.00190	.02740	.21917	.75145
97	.00000	.00000	.00000	.00003	.00084	.01623	.17492	.80798
98	.00000	.00000	.00000	.00001	.00026	.00759	.12402	.86813
99	.00000	.00000	.00000	.00000	.00003	.00200	.06590	.93207

TABLE 7 8 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES
1	.92274	.07457	.00264	.00005	.00000	.00000	.00000	.00000	.00000
2	.85076	.13890	.00992	.00040	.00001	.00000	.00000	.00000	.00000
3	.78374	.19392	.02099	.00130	.00005	.00000	.00000	.00000	.00000
4	.72139	.24046	.03507	.00292	.00015	.00001	.00000	.00000	.00000
5	.66342	.27933	.05146	.00542	.00036	.00002	.00000	.00000	.00000
6	.60957	.31127	.06954	.00888	.00071	.00004	.00000	.00000	.00000
7	.55958	.33695	.08877	.01336	.00126	.00008	.00000	.00000	.00000
8	.51322	.35702	.10866	.01890	.00205	.00014	.00001	.00000	.00000
9	.47025	.37207	.12879	.02548	.00315	.00025	.00001	.00000	.00000
10	.43047	.38264	.14880	.03307	.00459	.00041	.00002	.00000	.00000
11	.39366	.38924	.16838	.04162	.00643	.00064	.00004	.00000	.00000
12	.35963	.39233	.18725	.05107	.00870	.00095	.00006	.00000	.00000
13	.32821	.39234	.20519	.06132	.01145	.00137	.00010	.00000	.00000
14	.29922	.38968	.22203	.07229	.01471	.00192	.00016	.00001	.00000
15	.27249	.38469	.23760	.08386	.01850	.00261	.00023	.00001	.00000
16	.24788	.37772	.25181	.09593	.02284	.00348	.00033	.00002	.00000
17	.22523	.36905	.26456	.10837	.02775	.00455	.00047	.00003	.00000
18	.20441	.35897	.27579	.12108	.03322	.00583	.00064	.00004	.00000
19	.18530	.34773	.28548	.13393	.03927	.00737	.00086	.00006	.00000
20	.16777	.33554	.29360	.14680	.04588	.00918	.00115	.00008	.00000
21	.15171	.32263	.30016	.15958	.05303	.01128	.00150	.00011	.00000
22	.13701	.30915	.30519	.17216	.06070	.01370	.00193	.00016	.00001
23	.12357	.29529	.30872	.18443	.06886	.01646	.00246	.00021	.00001
24	.11130	.28119	.31079	.19629	.07748	.01957	.00309	.00028	.00001
25	.10011	.26697	.31146	.20764	.08652	.02307	.00385	.00037	.00002
26	.08992	.25275	.31081	.21841	.09592	.02696	.00474	.00048	.00002
27	.08065	.23862	.30890	.22850	.10564	.03126	.00578	.00061	.00003
28	.07222	.22469	.30582	.23786	.11563	.03597	.00699	.00078	.00004
29	.06458	.21101	.30165	.24642	.12581	.04111	.00840	.00098	.00005
30	.05765	.19765	.29648	.25412	.13614	.04668	.01000	.00122	.00007
31	.05138	.18467	.29039	.26093	.14653	.05267	.01183	.00152	.00009
32	.04572	.17211	.28347	.26680	.15694	.05908	.01390	.00187	.00011
33	.04061	.16000	.27583	.27171	.16728	.06591	.01623	.00228	.00014
34	.03600	.14838	.26753	.27564	.17750	.07315	.01884	.00277	.00018
35	.03186	.13726	.25869	.27859	.18751	.08077	.02175	.00335	.00023
36	.02815	.12666	.24937	.28054	.19725	.08876	.02497	.00401	.00028
37	.02482	.11659	.23967	.28151	.20667	.09710	.02851	.00478	.00035
38	.02183	.10706	.22965	.28151	.21567	.10575	.03241	.00568	.00043
39	.01917	.09805	.21941	.28056	.22422	.11468	.03666	.00670	.00054
40	.01680	.08958	.20902	.27869	.23224	.12386	.04129	.00786	.00066
41	.01468	.08163	.19854	.27593	.23969	.13325	.04630	.00919	.00080
42	.01281	.07419	.18803	.27232	.24649	.14280	.05170	.01070	.00097
43	.01114	.06725	.17756	.26790	.25262	.15246	.05751	.01239	.00117
44	.00967	.06079	.16718	.26272	.25802	.16219	.06372	.01430	.00140
45	.00837	.05481	.15695	.25683	.26266	.17192	.07033	.01644	.00168
46	.00723	.04927	.14690	.25028	.26650	.18162	.07736	.01883	.00200
47	.00623	.04417	.13709	.24314	.26952	.19121	.08478	.02148	.00238
48	.00535	.03948	.12754	.23547	.27169	.20063	.09260	.02442	.00282
49	.00458	.03518	.11830	.22731	.27300	.20984	.10080	.02767	.00332
50	.00391	.03125	.10938	.21875	.27344	.21875	.10938	.03125	.00391

TABLE 7 8 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES
51	.00332	.02767	.10080	.20984	.27300	.22731	.11830	.03518	.00458
52	.00282	.02442	.09260	.20063	.27169	.23547	.12754	.03948	.00535
53	.00238	.02148	.08478	.19121	.26952	.24314	.13709	.04417	.00623
54	.00200	.01883	.07736	.18162	.26650	.25028	.14690	.04927	.00723
55	.00168	.01644	.07033	.17192	.26266	.25683	.15695	.05481	.00837
56	.00140	.01430	.06372	.16219	.25802	.26272	.16718	.06079	.00967
57	.00117	.01239	.05751	.15246	.25262	.26790	.17756	.06725	.01114
58	.00097	.01070	.05170	.14280	.24649	.27232	.18803	.07419	.01281
59	.00080	.00919	.04630	.13325	.23969	.27593	.19854	.08163	.01468
60	.00066	.00786	.04129	.12386	.23224	.27869	.20902	.08958	.01680
61	.00054	.00670	.03666	.11468	.22422	.28056	.21941	.09805	.01917
62	.00043	.00568	.03241	.10575	.21567	.28151	.22965	.10706	.02183
63	.00035	.00478	.02851	.09710	.20667	.28151	.23967	.11659	.02482
64	.00028	.00401	.02497	.08876	.19725	.28054	.24937	.12666	.02815
65	.00023	.00335	.02175	.08077	.18751	.27859	.25869	.13726	.03186
66	.00018	.00277	.01884	.07315	.17750	.27564	.26753	.14838	.03600
67	.00014	.00228	.01623	.06591	.16728	.27171	.27583	.16000	.04061
68	.00011	.00187	.01390	.05908	.15694	.26680	.28347	.17211	.04572
69	.00009	.00152	.01183	.05267	.14653	.26093	.29039	.18467	.05138
70	.00007	.00122	.01000	.04668	.13614	.25412	.29648	.19765	.05765
71	.00005	.00098	.00840	.04111	.12581	.24642	.30165	.21101	.06458
72	.00004	.00078	.00699	.03597	.11563	.23786	.30582	.22469	.07222
73	.00003	.00061	.00578	.03126	.10564	.22850	.30890	.23862	.08065
74	.00002	.00048	.00474	.02696	.09592	.21841	.31081	.25275	.08992
75	.00002	.00037	.00385	.02307	.08652	.20764	.31146	.26697	.10011
76	.00001	.00028	.00309	.01957	.07748	.19629	.31079	.28119	.11130
77	.00001	.00021	.00246	.01646	.06886	.18443	.30872	.29529	.12357
78	.00001	.00016	.00193	.01370	.06070	.17216	.30519	.30915	.13701
79	.00000	.00011	.00150	.01128	.05303	.15958	.30016	.32263	.15171
80	.00000	.00008	.00115	.00918	.04588	.14680	.29360	.33554	.16777
81	.00000	.00006	.00086	.00737	.03927	.13393	.28548	.34773	.18530
82	.00000	.00004	.00064	.00583	.03322	.12108	.27579	.35897	.20441
83	.00000	.00003	.00047	.00455	.02775	.10837	.26456	.36905	.22523
84	.00000	.00002	.00033	.00348	.02284	.09593	.25181	.37772	.24788
85	.00000	.00001	.00023	.00261	.01850	.08386	.23760	.38469	.27249
86	.00000	.00001	.00016	.00192	.01471	.07229	.22203	.38968	.29922
87	.00000	.00000	.00010	.00137	.01145	.06132	.20519	.39234	.32821
88	.00000	.00000	.00006	.00095	.00870	.05107	.18725	.39233	.35963
89	.00000	.00000	.00004	.00064	.00643	.04162	.16838	.38924	.39366
90	.00000	.00000	.00002	.00041	.00459	.03307	.14880	.38264	.43047
91	.00000	.00000	.00001	.00025	.00315	.02548	.12879	.37207	.47025
92	.00000	.00000	.00001	.00014	.00205	.01890	.10866	.35702	.51322
93	.00000	.00000	.00000	.00008	.00126	.01336	.08877	.33695	.55958
94	.00000	.00000	.00000	.00004	.00071	.00888	.06954	.31127	.60957
95	.00000	.00000	.00000	.00002	.00036	.00542	.05146	.27933	.66342
96	.00000	.00000	.00000	.00001	.00015	.00292	.03507	.24046	.72139
97	.00000	.00000	.00000	.00000	.00005	.00130	.02099	.19392	.78374
98	.00000	.00000	.00000	.00000	.00001	.00040	.00992	.13890	.85076
99	.00000	.00000	.00000	.00000	.00000	.00005	.00264	.07457	.92274

TABLE 8 9 SEEDS PER CONTAINER

GERMINATION PERCENT	0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES
	PROBABILITY OF OCCURANCE									
1	.91352	.08305	.00336	.00008	.00000	.00000	.00000	.00000	.00000	.00000
2	.83375	.15314	.01250	.00060	.00002	.00000	.00000	.00000	.00000	.00000
3	.76023	.21161	.02618	.00189	.00009	.00000	.00000	.00000	.00000	.00000
4	.69253	.25970	.04328	.00421	.00026	.00001	.00000	.00000	.00000	.00000
5	.63025	.29854	.06285	.00772	.00061	.00003	.00000	.00000	.00000	.00000
6	.57299	.32917	.08404	.01252	.00120	.00008	.00000	.00000	.00000	.00000
7	.52041	.35254	.10614	.01864	.00210	.00016	.00001	.00000	.00000	.00000
8	.47216	.36952	.12853	.02608	.00340	.00030	.00002	.00000	.00000	.00000
9	.42793	.38090	.15069	.03477	.00516	.00051	.00003	.00000	.00000	.00000
10	.38742	.38742	.17219	.04464	.00744	.00083	.00006	.00000	.00000	.00000
11	.35036	.38972	.19267	.05556	.01030	.00127	.00010	.00001	.00000	.00000
12	.31648	.38841	.21186	.06741	.01379	.00188	.00017	.00001	.00000	.00000
13	.28554	.38401	.22952	.08002	.01794	.00268	.00027	.00002	.00000	.00000
14	.25733	.37701	.24550	.09325	.02277	.00371	.00040	.00003	.00000	.00000
15	.23162	.36786	.25967	.10692	.02830	.00499	.00059	.00004	.00000	.00000
16	.20822	.35694	.27196	.12087	.03453	.00658	.00084	.00007	.00000	.00000
17	.18694	.34460	.28232	.13493	.04145	.00849	.00116	.00010	.00001	.00000
18	.16762	.33115	.29077	.14893	.04904	.01076	.00158	.00015	.00001	.00000
19	.15009	.31687	.29731	.16272	.05725	.01343	.00210	.00021	.00001	.00000
20	.13422	.30199	.30199	.17616	.06606	.01652	.00275	.00029	.00002	.00000
21	.11985	.28673	.30488	.18910	.07540	.02004	.00355	.00040	.00003	.00000
22	.10687	.27128	.30606	.20143	.08522	.02404	.00452	.00055	.00004	.00000
23	.09515	.25580	.30563	.21301	.09544	.02851	.00568	.00073	.00005	.00000
24	.08459	.24042	.30368	.22377	.10599	.03347	.00705	.00095	.00008	.00000
25	.07508	.22525	.30034	.23360	.11680	.03893	.00865	.00124	.00010	.00000
26	.06654	.21041	.29571	.24243	.12777	.04489	.01052	.00158	.00014	.00001
27	.05887	.19597	.28993	.25021	.13882	.05134	.01266	.00201	.00019	.00001
28	.05200	.18200	.28310	.25689	.14985	.05828	.01511	.00252	.00024	.00001
29	.04585	.16854	.27536	.26244	.16079	.06567	.01788	.00313	.00032	.00001
30	.04035	.15565	.26683	.26683	.17153	.07351	.02100	.00386	.00041	.00002
31	.03545	.14335	.25761	.27006	.18200	.08177	.02449	.00472	.00053	.00003
32	.03109	.13166	.24784	.27213	.19209	.09040	.02836	.00572	.00067	.00004
33	.02721	.12060	.23760	.27307	.20174	.09937	.03263	.00689	.00085	.00005
34	.02376	.11017	.22702	.27288	.21087	.10863	.03731	.00824	.00106	.00006
35	.02071	.10037	.21619	.27162	.21939	.11813	.04241	.00979	.00132	.00008
36	.01801	.09120	.20520	.26932	.22724	.12782	.04793	.01156	.00162	.00010
37	.01563	.08264	.19413	.26603	.23436	.13764	.05389	.01356	.00199	.00013
38	.01354	.07467	.18307	.26181	.24069	.14752	.06028	.01583	.00243	.00017
39	.01169	.06729	.17208	.25672	.24619	.15740	.06709	.01838	.00294	.00021
40	.01008	.06047	.16124	.25082	.25082	.16722	.07432	.02123	.00354	.00026
41	.00866	.05418	.15060	.24420	.25455	.17689	.08195	.02441	.00424	.00033
42	.00743	.04841	.14022	.23692	.25734	.18635	.08996	.02792	.00505	.00041
43	.00635	.04312	.13013	.22905	.25919	.19553	.09834	.03179	.00600	.00050
44	.00542	.03830	.12037	.22068	.26009	.20436	.10704	.03605	.00708	.00062
45	.00461	.03391	.11099	.21188	.26004	.21276	.11605	.04069	.00832	.00076
46	.00390	.02993	.10199	.20273	.25904	.22067	.12532	.04575	.00974	.00092
47	.00330	.02634	.09342	.19330	.25712	.22801	.13480	.05123	.01136	.00112
48	.00278	.02309	.08527	.18366	.25430	.23474	.14446	.05715	.01319	.00135
49	.00233	.02018	.07757	.17390	.25061	.24079	.15423	.06351	.01525	.00163
50	.00195	.01758	.07031	.16406	.24609	.24609	.16406	.07031	.01758	.00195

TABLE 8 9 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES
51	.00163	.01525	.06351	.15423	.24079	.25061	.17390	.07757	.02018	.00233
52	.00135	.01319	.05715	.14446	.23474	.25430	.18366	.08527	.02309	.00278
53	.00112	.01136	.05123	.13480	.22801	.25712	.19330	.09342	.02634	.00330
54	.00092	.00974	.04575	.12532	.22067	.25904	.20273	.10199	.02993	.00390
55	.00076	.00832	.04069	.11605	.21276	.26004	.21188	.11099	.03391	.00461
56	.00062	.00708	.03605	.10704	.20436	.26009	.22068	.12037	.03830	.00542
57	.00050	.00600	.03179	.09834	.19553	.25919	.22905	.13013	.04312	.00635
58	.00041	.00505	.02792	.08996	.18635	.25734	.23692	.14022	.04841	.00743
59	.00033	.00424	.02441	.08195	.17689	.25455	.24420	.15060	.05418	.00866
60	.00026	.00354	.02123	.07432	.16722	.25082	.25082	.16124	.06047	.01008
61	.00021	.00294	.01838	.06709	.15740	.24619	.25672	.17208	.06729	.01169
62	.00017	.00243	.01583	.06028	.14752	.24069	.26181	.18307	.07467	.01354
63	.00013	.00199	.01356	.05389	.13764	.23436	.26603	.19413	.08264	.01563
64	.00010	.00162	.01156	.04793	.12782	.22724	.26932	.20520	.09120	.01801
65	.00008	.00132	.00979	.04241	.11813	.21939	.27162	.21619	.10037	.02071
66	.00006	.00106	.00824	.03731	.10863	.21087	.27288	.22702	.11017	.02376
67	.00005	.00085	.00689	.03263	.09937	.20174	.27307	.23760	.12060	.02721
68	.00004	.00067	.00572	.02836	.09040	.19209	.27213	.24784	.13166	.03109
69	.00003	.00053	.00472	.02449	.08177	.18200	.27006	.25761	.14335	.03545
70	.00002	.00041	.00386	.02100	.07351	.17153	.26683	.26683	.15565	.04035
71	.00001	.00032	.00313	.01788	.06567	.16079	.26244	.27536	.16854	.04585
72	.00001	.00024	.00252	.01511	.05828	.14985	.25689	.28310	.18200	.05200
73	.00001	.00019	.00201	.01266	.05134	.13882	.25021	.28993	.19597	.05887
74	.00001	.00014	.00158	.01052	.04489	.12777	.24243	.29571	.21041	.06654
75	.00000	.00010	.00124	.00865	.03893	.11680	.23360	.30034	.22525	.07508
76	.00000	.00008	.00095	.00705	.03347	.10599	.22377	.30368	.24042	.08459
77	.00000	.00005	.00073	.00568	.02851	.09544	.21301	.30563	.25580	.09515
78	.00000	.00004	.00055	.00452	.02404	.08522	.20143	.30606	.27128	.10687
79	.00000	.00003	.00040	.00355	.02004	.07540	.18910	.30488	.28673	.11985
80	.00000	.00002	.00029	.00275	.01652	.06606	.17616	.30199	.30199	.13422
81	.00000	.00001	.00021	.00210	.01343	.05725	.16272	.29731	.31687	.15009
82	.00000	.00001	.00015	.00158	.01076	.04904	.14893	.29077	.33115	.16762
83	.00000	.00001	.00010	.00116	.00849	.04145	.13493	.28232	.34460	.18694
84	.00000	.00000	.00007	.00084	.00658	.03453	.12087	.27196	.35694	.20822
85	.00000	.00000	.00004	.00059	.00499	.02830	.10692	.25967	.36786	.23162
86	.00000	.00000	.00003	.00040	.00371	.02277	.09325	.24550	.37701	.25733
87	.00000	.00000	.00002	.00027	.00268	.01794	.08002	.22952	.38401	.28554
88	.00000	.00000	.00001	.00017	.00188	.01379	.06741	.21186	.38841	.31648
89	.00000	.00000	.00001	.00010	.00127	.01030	.05556	.19267	.38972	.35036
90	.00000	.00000	.00000	.00006	.00083	.00744	.04464	.17219	.38742	.38742
91	.00000	.00000	.00000	.00003	.00051	.00516	.03477	.15069	.38090	.42793
92	.00000	.00000	.00000	.00002	.00030	.00340	.02608	.12853	.36952	.47216
93	.00000	.00000	.00000	.00001	.00016	.00210	.01864	.10614	.35254	.52041
94	.00000	.00000	.00000	.00000	.00008	.00120	.01252	.08404	.32917	.57299
95	.00000	.00000	.00000	.00000	.00003	.00061	.00772	.06285	.29854	.63025
96	.00000	.00000	.00000	.00000	.00001	.00026	.00421	.04328	.25970	.69253
97	.00000	.00000	.00000	.00000	.00000	.00009	.00189	.02618	.21161	.76023
98	.00000	.00000	.00000	.00000	.00000	.00002	.00060	.01250	.15314	.83375
99	.00000	.00000	.00000	.00000	.00000	.00000	.00008	.00336	.08305	.91352

TABLE 9 10 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES	10 TREES
1	.90438	.09135	.00415	.00011	.00000	.00000	.00000	.00000	.00000	.00000	.00000
2	.81707	.16675	.01531	.00083	.00003	.00000	.00000	.00000	.00000	.00000	.00000
3	.73742	.22807	.03174	.00262	.00014	.00001	.00000	.00000	.00000	.00000	.00000
4	.66483	.27701	.05194	.00577	.00042	.00002	.00000	.00000	.00000	.00000	.00000
5	.59874	.31512	.07463	.01048	.00096	.00006	.00000	.00000	.00000	.00000	.00000
6	.53862	.34380	.09875	.01681	.00188	.00014	.00001	.00000	.00000	.00000	.00000
7	.48398	.36429	.12339	.02477	.00326	.00029	.00002	.00000	.00000	.00000	.00000
8	.43439	.37773	.14781	.03427	.00522	.00054	.00004	.00000	.00000	.00000	.00000
9	.38942	.38514	.17141	.04521	.00782	.00093	.00008	.00000	.00000	.00000	.00000
10	.34868	.38742	.19371	.05740	.01116	.00149	.00014	.00001	.00000	.00000	.00000
11	.31182	.38539	.21435	.07065	.01528	.00227	.00023	.00002	.00000	.00000	.00000
12	.27850	.37977	.23304	.08474	.02022	.00331	.00038	.00003	.00000	.00000	.00000
13	.24842	.37121	.24960	.09946	.02601	.00466	.00058	.00005	.00000	.00000	.00000
14	.22130	.36026	.26391	.11457	.03264	.00638	.00086	.00008	.00000	.00000	.00000
15	.19687	.34743	.27590	.12983	.04010	.00849	.00125	.00013	.00001	.00000	.00000
16	.17490	.33315	.28555	.14504	.04835	.01105	.00175	.00019	.00001	.00000	.00000
17	.15516	.31780	.29291	.15998	.05734	.01409	.00241	.00028	.00002	.00000	.00000
18	.13745	.30172	.29804	.17446	.06702	.01765	.00323	.00041	.00003	.00000	.00000
19	.12158	.28518	.30102	.18829	.07729	.02176	.00425	.00057	.00005	.00000	.00000
20	.10737	.26844	.30199	.20133	.08808	.02642	.00551	.00079	.00007	.00000	.00000
21	.09468	.25169	.30107	.21342	.09928	.03167	.00702	.00107	.00011	.00001	.00000
22	.08336	.23511	.29841	.22445	.11078	.03750	.00881	.00142	.00015	.00001	.00000
23	.07327	.21885	.29417	.23431	.12248	.04390	.01093	.00187	.00021	.00001	.00000
24	.06429	.20302	.28850	.24295	.13426	.05088	.01339	.00242	.00029	.00002	.00000
25	.05631	.18771	.28157	.25028	.14600	.05840	.01622	.00309	.00039	.00003	.00000
26	.04924	.17301	.27354	.25629	.15758	.06644	.01945	.00391	.00051	.00004	.00000
27	.04298	.15895	.26456	.26094	.16889	.07496	.02310	.00488	.00068	.00006	.00000
28	.03744	.14560	.25479	.26423	.17982	.08392	.02720	.00604	.00088	.00008	.00000
29	.03255	.13296	.24439	.26619	.19027	.09326	.03174	.00741	.00113	.00010	.00000
30	.02825	.12106	.23347	.26683	.20012	.10292	.03676	.00900	.00145	.00014	.00001
31	.02446	.10990	.22219	.26620	.20930	.11284	.04225	.01085	.00183	.00018	.00001
32	.02114	.09948	.21066	.26436	.21771	.12294	.04821	.01296	.00229	.00024	.00001
33	.01823	.08978	.19899	.26136	.22528	.13315	.05465	.01538	.00284	.00031	.00002
34	.01568	.08079	.18729	.25729	.23195	.14339	.06156	.01812	.00350	.00040	.00002
35	.01346	.07249	.17565	.25222	.23767	.15357	.06891	.02120	.00428	.00051	.00003
36	.01153	.06485	.16416	.24623	.24239	.16361	.07669	.02465	.00520	.00065	.00004
37	.00985	.05785	.15288	.23943	.24608	.17343	.08488	.02848	.00627	.00082	.00005
38	.00839	.05144	.14188	.23189	.24872	.18293	.09343	.03272	.00752	.00102	.00006
39	.00713	.04561	.13121	.22371	.25030	.19203	.10231	.03738	.00896	.00127	.00008
40	.00605	.04031	.12093	.21499	.25082	.20066	.11148	.04247	.01062	.00157	.00010
41	.00511	.03552	.11107	.20582	.25030	.20873	.12087	.04800	.01251	.00193	.00013
42	.00431	.03120	.10166	.19630	.24876	.21617	.13044	.05398	.01466	.00236	.00017
43	.00362	.02731	.09271	.18651	.24623	.22290	.14013	.06041	.01709	.00286	.00022
44	.00303	.02383	.08426	.17655	.24275	.22888	.14986	.06728	.01982	.00346	.00027
45	.00253	.02072	.07630	.16648	.23837	.23403	.15957	.07460	.02289	.00416	.00034
46	.00211	.01796	.06885	.15639	.23314	.23832	.16918	.08235	.02631	.00498	.00042
47	.00175	.01551	.06189	.14635	.22713	.24170	.17861	.09051	.03010	.00593	.00053
48	.00145	.01334	.05543	.13644	.22040	.24413	.18779	.09906	.03429	.00703	.00065
49	.00119	.01144	.04945	.12670	.21302	.24560	.19664	.10796	.03890	.00830	.00080
50	.00098	.00977	.04395	.11719	.20508	.24609	.20508	.11719	.04395	.00977	.00098

TABLE 9 10 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES	10 TREES
51	.00080	.00830	.03890	.10796	.19664	.24560	.21302	.12670	.04945	.01144	.00119
52	.00065	.00703	.03429	.09906	.18779	.24413	.22040	.13644	.05543	.01334	.00145
53	.00053	.00593	.03010	.09051	.17861	.24170	.22713	.14635	.06189	.01551	.00175
54	.00042	.00498	.02631	.08235	.16918	.23832	.23314	.15639	.06885	.01796	.00211
55	.00034	.00416	.02289	.07460	.15957	.23403	.23837	.16648	.07630	.02072	.00253
56	.00027	.00346	.01982	.06728	.14986	.22888	.24275	.17655	.08426	.02383	.00303
57	.00022	.00286	.01709	.06041	.14013	.22290	.24623	.18651	.09271	.02731	.00362
58	.00017	.00236	.01466	.05398	.13044	.21617	.24876	.19630	.10166	.03120	.00431
59	.00013	.00193	.01251	.04800	.12087	.20873	.25030	.20582	.11107	.03552	.00511
60	.00010	.00157	.01062	.04247	.11148	.20066	.25082	.21499	.12093	.04031	.00605
61	.00008	.00127	.00896	.03738	.10231	.19203	.25030	.22371	.13121	.04561	.00713
62	.00006	.00102	.00752	.03272	.09343	.18293	.24872	.23189	.14188	.05144	.00839
63	.00005	.00082	.00627	.02848	.08488	.17343	.24608	.23943	.15288	.05785	.00985
64	.00004	.00065	.00520	.02465	.07669	.16361	.24239	.24623	.16416	.06485	.01153
65	.00003	.00051	.00428	.02120	.06891	.15357	.23767	.25222	.17565	.07249	.01346
66	.00002	.00040	.00350	.01812	.06156	.14339	.23195	.25729	.18729	.08079	.01568
67	.00002	.00031	.00284	.01538	.05465	.13315	.22528	.26136	.19899	.08978	.01823
68	.00001	.00024	.00229	.01296	.04821	.12294	.21771	.26436	.21066	.09948	.02114
69	.00001	.00018	.00183	.01085	.04225	.11284	.20930	.26620	.22219	.10990	.02446
70	.00001	.00014	.00145	.00900	.03676	.10292	.20012	.26683	.23347	.12106	.02825
71	.00000	.00010	.00113	.00741	.03174	.09326	.19027	.26619	.24439	.13296	.03255
72	.00000	.00008	.00088	.00604	.02720	.08392	.17982	.26423	.25479	.14560	.03744
73	.00000	.00006	.00068	.00488	.02310	.07496	.16889	.26094	.26456	.15895	.04298
74	.00000	.00004	.00051	.00391	.01945	.06644	.15758	.25629	.27354	.17301	.04924
75	.00000	.00003	.00039	.00309	.01622	.05840	.14600	.25028	.28157	.18771	.05631
76	.00000	.00002	.00029	.00242	.01339	.05088	.13426	.24295	.28850	.20302	.06429
77	.00000	.00001	.00021	.00187	.01093	.04390	.12248	.23431	.29417	.21885	.07327
78	.00000	.00001	.00015	.00142	.00881	.03750	.11078	.22445	.29841	.23511	.08336
79	.00000	.00001	.00011	.00107	.00702	.03167	.09928	.21342	.30107	.25169	.09468
80	.00000	.00000	.00007	.00079	.00551	.02642	.08808	.20133	.30199	.26844	.10737
81	.00000	.00000	.00005	.00057	.00425	.02176	.07729	.18829	.30102	.28518	.12158
82	.00000	.00000	.00003	.00041	.00323	.01765	.06702	.17446	.29804	.30172	.13745
83	.00000	.00000	.00002	.00028	.00241	.01409	.05734	.15998	.29291	.31780	.15516
84	.00000	.00000	.00001	.00019	.00175	.01105	.04835	.14504	.28555	.33315	.17490
85	.00000	.00000	.00001	.00013	.00125	.00849	.04010	.12983	.27590	.34743	.19687
86	.00000	.00000	.00000	.00008	.00086	.00638	.03264	.11457	.26391	.36026	.22130
87	.00000	.00000	.00000	.00005	.00058	.00466	.02601	.09946	.24960	.37121	.24842
88	.00000	.00000	.00000	.00003	.00038	.00331	.02022	.08474	.23304	.37977	.27850
89	.00000	.00000	.00000	.00002	.00023	.00227	.01528	.07065	.21435	.38539	.31182
90	.00000	.00000	.00000	.00001	.00014	.00149	.01116	.05740	.19371	.38742	.34868
91	.00000	.00000	.00000	.00000	.00008	.00093	.00782	.04521	.17141	.38514	.38942
92	.00000	.00000	.00000	.00000	.00004	.00054	.00522	.03427	.14781	.37773	.43439
93	.00000	.00000	.00000	.00000	.00002	.00029	.00326	.02477	.12339	.36429	.48398
94	.00000	.00000	.00000	.00000	.00001	.00014	.00188	.01681	.09875	.34380	.53862
95	.00000	.00000	.00000	.00000	.00000	.00006	.00096	.01048	.07463	.31512	.59874
96	.00000	.00000	.00000	.00000	.00000	.00002	.00042	.00577	.05194	.27701	.66483
97	.00000	.00000	.00000	.00000	.00000	.00001	.00014	.00262	.03174	.22807	.73742
98	.00000	.00000	.00000	.00000	.00000	.00000	.00003	.00083	.01531	.16675	.81707
99	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00011	.00415	.09135	.90438

TABLE 10 11 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES	10 TREES	11 TREES
1	.89534	.09948	.00502	.00015	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
2	.80073	.17976	.01834	.00112	.00005	.00000	.00000	.00000	.00000	.00000	.00000	.00000
3	.71530	.24335	.03763	.00349	.00022	.00001	.00000	.00000	.00000	.00000	.00000	.00000
4	.63824	.29253	.06094	.00762	.00063	.00004	.00000	.00000	.00000	.00000	.00000	.00000
5	.56880	.32931	.08666	.01368	.00144	.00011	.00001	.00000	.00000	.00000	.00000	.00000
6	.50630	.35549	.11345	.02173	.00277	.00025	.00002	.00000	.00000	.00000	.00000	.00000
7	.45010	.37267	.14025	.03167	.00477	.00050	.00004	.00000	.00000	.00000	.00000	.00000
8	.39964	.38226	.16620	.04336	.00754	.00092	.00008	.00000	.00000	.00000	.00000	.00000
9	.35437	.38552	.19064	.05656	.01119	.00155	.00015	.00001	.00000	.00000	.00000	.00000
10	.31381	.38355	.21308	.07103	.01578	.00246	.00027	.00002	.00000	.00000	.00000	.00000
11	.27752	.37730	.23316	.08645	.02137	.00370	.00046	.00004	.00000	.00000	.00000	.00000
12	.24508	.36762	.25065	.10254	.02797	.00534	.00073	.00007	.00000	.00000	.00000	.00000
13	.21613	.35525	.26541	.11898	.03556	.00744	.00111	.00012	.00001	.00000	.00000	.00000
14	.19032	.34080	.27740	.13547	.04411	.01005	.00164	.00019	.00002	.00000	.00000	.00000
15	.16734	.32484	.28663	.15174	.05356	.01323	.00233	.00029	.00003	.00000	.00000	.00000
16	.14692	.30783	.29317	.16752	.06382	.01702	.00324	.00044	.00004	.00000	.00000	.00000
17	.12878	.29015	.29714	.18258	.07479	.02145	.00439	.00064	.00007	.00000	.00000	.00000
18	.11271	.27215	.29870	.19670	.08636	.02654	.00583	.00091	.00010	.00001	.00000	.00000
19	.09848	.25410	.29801	.20971	.09838	.03231	.00758	.00127	.00015	.00001	.00000	.00000
20	.08590	.23622	.29528	.22146	.11073	.03876	.00969	.00173	.00022	.00002	.00000	.00000
21	.07480	.21872	.29070	.23182	.12325	.04587	.01219	.00232	.00031	.00003	.00000	.00000
22	.06502	.20173	.28449	.24072	.13579	.05362	.01512	.00305	.00043	.00004	.00000	.00000
23	.05642	.18537	.27684	.24808	.14820	.06198	.01851	.00395	.00059	.00006	.00000	.00000
24	.04886	.16972	.26798	.25388	.16034	.07089	.02239	.00505	.00080	.00008	.00001	.00000
25	.04224	.15486	.25810	.25810	.17207	.08030	.02677	.00637	.00106	.00012	.00001	.00000
26	.03644	.14083	.24740	.26077	.18324	.09014	.03167	.00795	.00140	.00016	.00001	.00000
27	.03137	.12764	.23605	.26191	.19374	.10032	.03711	.00980	.00181	.00022	.00002	.00000
28	.02696	.11531	.22422	.26159	.20346	.11077	.04308	.01197	.00233	.00030	.00002	.00000
29	.02311	.10384	.21207	.25986	.21228	.12139	.04958	.01447	.00295	.00040	.00003	.00000
30	.01977	.09322	.19975	.25682	.22013	.13208	.05661	.01733	.00371	.00053	.00005	.00000
31	.01688	.08342	.18738	.25256	.22694	.14274	.06413	.02058	.00462	.00069	.00006	.00000
32	.01437	.07441	.17508	.24718	.23264	.15327	.07213	.02424	.00570	.00089	.00008	.00000
33	.01221	.06617	.16295	.24078	.23719	.16355	.08056	.02834	.00698	.00115	.00011	.00001
34	.01035	.05866	.15108	.23349	.24057	.17350	.08938	.03289	.00847	.00145	.00015	.00001
35	.00875	.05183	.13955	.22542	.24276	.18300	.09854	.03790	.01020	.00183	.00020	.00001
36	.00738	.04566	.12841	.21669	.24377	.19197	.10798	.04339	.01220	.00229	.00026	.00001
37	.00621	.04009	.11771	.20740	.24362	.20031	.11764	.04935	.01449	.00284	.00033	.00002
38	.00520	.03508	.10751	.19768	.24232	.20793	.12744	.05579	.01710	.00349	.00043	.00002
39	.00435	.03060	.09783	.18764	.23993	.21476	.13730	.06270	.02004	.00427	.00055	.00003
40	.00363	.02661	.08868	.17737	.23649	.22072	.14715	.07007	.02336	.00519	.00069	.00004
41	.00302	.02305	.08009	.16698	.23207	.22577	.15689	.07788	.02706	.00627	.00087	.00006
42	.00250	.01990	.07206	.15655	.22673	.22986	.16645	.08609	.03117	.00752	.00109	.00007
43	.00206	.01712	.06459	.14618	.22055	.23293	.17572	.09469	.03572	.00898	.00136	.00009
44	.00170	.01468	.05767	.13594	.21362	.23498	.18463	.10362	.04071	.01066	.00168	.00012
45	.00139	.01254	.05129	.12590	.20602	.23598	.19308	.11284	.04616	.01259	.00206	.00015
46	.00114	.01067	.04544	.11612	.19783	.23594	.20098	.12229	.05209	.01479	.00252	.00020
47	.00093	.00904	.04009	.10666	.18916	.23485	.20826	.13192	.05849	.01729	.00307	.00025
48	.00075	.00763	.03523	.09755	.18010	.23274	.21484	.14165	.06538	.02012	.00371	.00031
49	.00061	.00642	.03082	.08885	.17072	.22964	.22063	.15141	.07274	.02330	.00448	.00039
50	.00049	.00537	.02686	.08057	.16113	.22559	.22559	.16113	.08057	.02686	.00537	.00049

TABLE 10 11 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES	10 TREES	11 TREES
51	.00039	.00448	.02330	.07274	.15141	.22063	.22964	.17072	.08885	.03082	.00642	.00061
52	.00031	.00371	.02012	.06538	.14165	.21484	.23274	.18010	.09755	.03523	.00763	.00075
53	.00025	.00307	.01729	.05849	.13192	.20826	.23485	.18916	.10666	.04009	.00904	.00093
54	.00020	.00252	.01479	.05209	.12229	.20098	.23594	.19783	.11612	.04544	.01067	.00114
55	.00015	.00206	.01259	.04616	.11284	.19308	.23598	.20602	.12590	.05129	.01254	.00139
56	.00012	.00168	.01066	.04071	.10362	.18463	.23498	.21362	.13594	.05767	.01468	.00170
57	.00009	.00136	.00898	.03572	.09469	.17572	.23293	.22055	.14618	.06459	.01712	.00206
58	.00007	.00109	.00752	.03117	.08609	.16645	.22986	.22673	.15655	.07206	.01990	.00250
59	.00006	.00087	.00627	.02706	.07788	.15689	.22577	.23207	.16698	.08009	.02305	.00302
60	.00004	.00069	.00519	.02336	.07007	.14715	.22072	.23649	.17737	.08868	.02661	.00363
61	.00003	.00055	.00427	.02004	.06270	.13730	.21476	.23993	.18764	.09783	.03060	.00435
62	.00002	.00043	.00349	.01710	.05579	.12744	.20793	.24232	.19768	.10751	.03508	.00520
63	.00002	.00033	.00284	.01449	.04935	.11764	.20031	.24362	.20740	.11771	.04009	.00621
64	.00001	.00026	.00229	.01220	.04339	.10798	.19197	.24377	.21669	.12841	.04566	.00738
65	.00001	.00020	.00183	.01020	.03790	.09854	.18300	.24276	.22542	.13955	.05183	.00875
66	.00001	.00015	.00145	.00847	.03289	.08938	.17350	.24057	.23349	.15108	.05866	.01035
67	.00001	.00011	.00115	.00698	.02834	.08056	.16355	.23719	.24078	.16295	.06617	.01221
68	.00000	.00008	.00089	.00570	.02424	.07213	.15327	.23264	.24718	.17508	.07441	.01437
69	.00000	.00006	.00069	.00462	.02058	.06413	.14274	.22694	.25256	.18738	.08342	.01688
70	.00000	.00005	.00053	.00371	.01733	.05661	.13208	.22013	.25682	.19975	.09322	.01977
71	.00000	.00003	.00040	.00295	.01447	.04958	.12139	.21228	.25986	.21207	.10384	.02311
72	.00000	.00002	.00030	.00233	.01197	.04308	.11077	.20346	.26159	.22422	.11531	.02696
73	.00000	.00002	.00022	.00181	.00980	.03711	.10032	.19374	.26191	.23605	.12764	.03137
74	.00000	.00001	.00016	.00140	.00795	.03167	.09014	.18324	.26077	.24740	.14083	.03644
75	.00000	.00001	.00012	.00106	.00637	.02677	.08030	.17207	.25810	.25810	.15486	.04224
76	.00000	.00001	.00008	.00080	.00505	.02239	.07089	.16034	.25388	.26798	.16972	.04886
77	.00000	.00000	.00006	.00059	.00395	.01851	.06198	.14820	.24808	.27684	.18537	.05642
78	.00000	.00000	.00004	.00043	.00305	.01512	.05362	.13579	.24072	.28449	.20173	.06502
79	.00000	.00000	.00003	.00031	.00232	.01219	.04587	.12325	.23182	.29070	.21872	.07480
80	.00000	.00000	.00002	.00022	.00173	.00969	.03876	.11073	.22146	.29528	.23622	.08590
81	.00000	.00000	.00001	.00015	.00127	.00758	.03231	.09838	.20971	.29801	.25410	.09848
82	.00000	.00000	.00001	.00010	.00091	.00583	.02654	.08636	.19670	.29870	.27215	.11271
83	.00000	.00000	.00000	.00007	.00064	.00439	.02145	.07479	.18258	.29714	.29015	.12878
84	.00000	.00000	.00000	.00004	.00044	.00324	.01702	.06382	.16752	.29317	.30783	.14692
85	.00000	.00000	.00000	.00003	.00029	.00233	.01323	.05356	.15174	.28663	.32484	.16734
86	.00000	.00000	.00000	.00002	.00019	.00164	.01005	.04411	.13547	.27740	.34080	.19032
87	.00000	.00000	.00000	.00001	.00012	.00111	.00744	.03556	.11898	.26541	.35525	.21613
88	.00000	.00000	.00000	.00000	.00007	.00073	.00534	.02797	.10254	.25065	.36762	.24508
89	.00000	.00000	.00000	.00000	.00004	.00046	.00370	.02137	.08645	.23316	.37730	.27752
90	.00000	.00000	.00000	.00000	.00002	.00027	.00246	.01578	.07103	.21308	.38355	.31381
91	.00000	.00000	.00000	.00000	.00001	.00015	.00155	.01119	.05656	.19064	.38552	.35437
92	.00000	.00000	.00000	.00000	.00000	.00008	.00092	.00754	.04336	.16620	.38226	.39964
93	.00000	.00000	.00000	.00000	.00000	.00004	.00050	.00477	.03167	.14025	.37267	.45010
94	.00000	.00000	.00000	.00000	.00000	.00002	.00025	.00277	.02173	.11345	.35549	.50630
95	.00000	.00000	.00000	.00000	.00000	.00001	.00011	.00144	.01368	.08666	.32931	.56880
96	.00000	.00000	.00000	.00000	.00000	.00000	.00004	.00063	.00762	.06094	.29253	.63824
97	.00000	.00000	.00000	.00000	.00000	.00000	.00001	.00022	.00349	.03763	.24335	.71530
98	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00005	.00112	.01834	.17976	.80073
99	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00015	.00502	.09948	.89534

TABLE 11 12 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES	10 TREES	11 TREES	12 TREES
1	.88638	.10744	.00597	.00020	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
2	.78472	.19218	.02157	.00147	.00007	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
3	.69384	.25751	.04380	.00452	.00031	.00002	.00000	.00000	.00000	.00000	.00000	.00000	.00000
4	.61271	.30635	.07021	.00975	.00091	.00006	.00000	.00000	.00000	.00000	.00000	.00000	.00000
5	.54036	.34128	.09879	.01733	.00205	.00017	.00001	.00000	.00000	.00000	.00000	.00000	.00000
6	.47592	.36453	.12797	.02723	.00391	.00040	.00003	.00000	.00000	.00000	.00000	.00000	.00000
7	.41860	.37809	.15652	.03927	.00665	.00080	.00007	.00000	.00000	.00000	.00000	.00000	.00000
8	.36767	.38365	.18349	.05318	.01041	.00145	.00015	.00001	.00000	.00000	.00000	.00000	.00000
9	.32248	.38272	.20818	.06863	.01527	.00242	.00028	.00002	.00000	.00000	.00000	.00000	.00000
10	.28243	.37657	.23013	.08523	.02131	.00379	.00049	.00005	.00000	.00000	.00000	.00000	.00000
11	.24699	.36632	.24902	.10259	.02853	.00564	.00081	.00009	.00001	.00000	.00000	.00000	.00000
12	.21567	.35292	.26469	.12031	.03691	.00805	.00128	.00015	.00001	.00000	.00000	.00000	.00000
13	.18803	.33716	.27709	.13801	.04640	.01109	.00193	.00025	.00002	.00000	.00000	.00000	.00000
14	.16367	.31974	.28628	.15534	.05690	.01482	.00281	.00039	.00004	.00000	.00000	.00000	.00000
15	.14224	.30122	.29236	.17198	.06828	.01928	.00397	.00060	.00007	.00001	.00000	.00000	.00000
16	.12341	.28208	.29551	.18763	.08041	.02451	.00545	.00089	.00011	.00001	.00000	.00000	.00000
17	.10689	.26272	.29595	.20206	.09312	.03052	.00729	.00128	.00016	.00001	.00000	.00000	.00000
18	.09242	.24345	.29392	.21506	.10622	.03731	.00955	.00180	.00025	.00002	.00000	.00000	.00000
19	.07977	.22453	.28967	.22649	.11954	.04486	.01228	.00247	.00036	.00004	.00000	.00000	.00000
20	.06872	.20616	.28347	.23622	.13288	.05315	.01550	.00332	.00052	.00006	.00000	.00000	.00000
21	.05909	.18849	.27558	.24419	.14605	.06212	.01926	.00439	.00073	.00009	.00001	.00000	.00000
22	.05071	.17165	.26628	.25035	.15887	.07170	.02359	.00570	.00101	.00013	.00001	.00000	.00000
23	.04344	.15571	.25580	.25470	.17118	.08181	.02851	.00730	.00136	.00018	.00002	.00000	.00000
24	.03713	.14072	.24440	.25726	.18279	.09236	.03403	.00921	.00182	.00026	.00002	.00000	.00000
25	.03168	.12671	.23229	.25810	.19358	.10324	.04015	.01147	.00239	.00035	.00004	.00000	.00000
26	.02696	.11369	.21969	.25729	.20340	.11434	.04687	.01412	.00310	.00048	.00005	.00000	.00000
27	.02290	.10165	.20678	.25493	.21215	.12555	.05417	.01717	.00397	.00065	.00007	.00000	.00000
28	.01941	.09057	.19372	.25112	.21973	.13672	.06203	.02068	.00503	.00087	.00010	.00001	.00000
29	.01641	.08043	.18069	.24600	.22608	.14775	.07041	.02465	.00629	.00114	.00014	.00001	.00000
30	.01384	.07118	.16779	.23970	.23114	.15850	.07925	.02911	.00780	.00149	.00019	.00001	.00000
31	.01165	.06279	.15515	.23235	.23488	.16884	.08850	.03408	.00957	.00191	.00026	.00002	.00000
32	.00977	.05520	.14287	.22411	.23729	.17866	.09809	.03957	.01164	.00243	.00034	.00003	.00000
33	.00818	.04836	.13101	.21510	.23837	.18785	.10795	.04557	.01403	.00307	.00045	.00004	.00000
34	.00683	.04223	.11966	.20547	.23816	.19630	.11798	.05210	.01677	.00384	.00059	.00006	.00000
35	.00569	.03675	.10885	.19537	.23669	.20392	.12810	.05912	.01990	.00476	.00077	.00008	.00000
36	.00472	.03188	.09862	.18491	.23402	.21062	.13822	.06664	.02343	.00586	.00099	.00010	.00000
37	.00391	.02755	.08899	.17422	.23022	.21633	.14823	.07462	.02739	.00715	.00126	.00013	.00001
38	.00323	.02373	.07999	.16342	.22536	.22100	.15802	.08302	.03180	.00866	.00159	.00018	.00001
39	.00265	.02036	.07161	.15261	.21953	.22457	.16751	.09180	.03668	.01042	.00200	.00023	.00001
40	.00218	.01741	.06385	.14189	.21284	.22703	.17658	.10090	.04204	.01246	.00249	.00030	.00002
41	.00178	.01484	.05671	.13135	.20538	.22835	.18513	.11027	.04789	.01479	.00308	.00039	.00002
42	.00145	.01259	.05016	.12107	.19725	.22854	.19308	.11984	.05424	.01746	.00379	.00050	.00003
43	.00118	.01065	.04418	.11110	.18857	.22761	.20032	.12953	.06107	.02048	.00463	.00064	.00004
44	.00095	.00897	.03876	.10150	.17944	.22558	.20678	.13926	.06839	.02388	.00563	.00080	.00005
45	.00077	.00752	.03385	.09233	.16996	.22250	.21238	.14895	.07617	.02770	.00680	.00101	.00007
46	.00061	.00628	.02944	.08361	.16025	.21841	.21706	.15849	.08438	.03195	.00816	.00126	.00009
47	.00049	.00523	.02550	.07537	.15038	.21338	.22076	.16780	.09300	.03665	.00975	.00157	.00012
48	.00039	.00433	.02198	.06764	.14047	.20747	.22343	.17678	.10199	.04184	.01159	.00194	.00015
49	.00031	.00357	.01886	.06041	.13060	.20077	.22505	.18533	.11129	.04752	.01370	.00239	.00019
50	.00024	.00293	.01611	.05371	.12085	.19336	.22559	.19336	.12085	.05371	.01611	.00293	.00024

TABLE 11 12 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES	10 TREES	11 TREES	12 TREES
51	.00019	.00239	.01370	.04752	.11129	.18533	.22505	.20077	.13060	.06041	.01886	.00357	.00031
52	.00015	.00194	.01159	.04184	.10199	.17678	.22343	.20747	.14047	.06764	.02198	.00433	.00039
53	.00012	.00157	.00975	.03665	.09300	.16780	.22076	.21338	.15038	.07537	.02550	.00523	.00049
54	.00009	.00126	.00816	.03195	.08438	.15849	.21706	.21841	.16025	.08361	.02944	.00628	.00061
55	.00007	.00101	.00680	.02770	.07617	.14895	.21238	.22250	.16996	.09233	.03385	.00752	.00077
56	.00005	.00080	.00563	.02388	.06839	.13926	.20678	.22558	.17944	.10150	.03876	.00897	.00095
57	.00004	.00064	.00463	.02048	.06107	.12953	.20032	.22761	.18857	.11110	.04418	.01065	.00118
58	.00003	.00050	.00379	.01746	.05424	.11984	.19308	.22854	.19725	.12107	.05016	.01259	.00145
59	.00002	.00039	.00308	.01479	.04789	.11027	.18513	.22835	.20538	.13135	.05671	.01484	.00178
60	.00002	.00030	.00249	.01246	.04204	.10090	.17658	.22703	.21284	.14189	.06385	.01741	.00218
61	.00001	.00023	.00200	.01042	.03668	.09180	.16751	.22457	.21953	.15261	.07161	.02036	.00265
62	.00001	.00018	.00159	.00866	.03180	.08302	.15802	.22100	.22536	.16342	.07999	.02373	.00323
63	.00001	.00013	.00126	.00715	.02739	.07462	.14823	.21633	.23022	.17422	.08899	.02755	.00391
64	.00000	.00010	.00099	.00586	.02343	.06664	.13822	.21062	.23402	.18491	.09862	.03188	.00472
65	.00000	.00008	.00077	.00476	.01990	.05912	.12810	.20392	.23669	.19537	.10885	.03675	.00569
66	.00000	.00006	.00059	.00384	.01677	.05210	.11798	.19630	.23816	.20547	.11966	.04223	.00683
67	.00000	.00004	.00045	.00307	.01403	.04557	.10795	.18785	.23837	.21510	.13101	.04836	.00818
68	.00000	.00003	.00034	.00243	.01164	.03957	.09809	.17866	.23729	.22411	.14287	.05520	.00977
69	.00000	.00002	.00026	.00191	.00957	.03408	.08850	.16884	.23488	.23235	.15515	.06279	.01165
70	.00000	.00001	.00019	.00149	.00780	.02911	.07925	.15850	.23114	.23970	.16779	.07118	.01384
71.	.00000	.00001	.00014	.00114	.00629	.02465	.07041	.14775	.22608	.24600	.18069	.08043	.01641
72	.00000	.00001	.00010	.00087	.00503	.02068	.06203	.13672	.21973	.25112	.19372	.09057	.01941
73	.00000	.00000	.00007	.00065	.00397	.01717	.05417	.12555	.21215	.25493	.20678	.10165	.02290
74	.00000	.00000	.00005	.00048	.00310	.01412	.04687	.11434	.20340	.25729	.21969	.11369	.02696
75	.00000	.00000	.00004	.00035	.00239	.01147	.04015	.10324	.19358	.25810	.23229	.12671	.03168
76	.00000	.00000	.00002	.00026	.00182	.00921	.03403	.09236	.18279	.25726	.24440	.14072	.03713
77	.00000	.00000	.00002	.00018	.00136	.00730	.02851	.08181	.17118	.25470	.25580	.15571	.04344
78	.00000	.00000	.00001	.00013	.00101	.00570	.02359	.07170	.15887	.25035	.26628	.17165	.05071
79	.00000	.00000	.00001	.00009	.00073	.00439	.01926	.06212	.14605	.24419	.27558	.18849	.05909
80	.00000	.00000	.00000	.00006	.00052	.00332	.01550	.05315	.13288	.23622	.28347	.20616	.06872
81	.00000	.00000	.00000	.00004	.00036	.00247	.01228	.04486	.11954	.22649	.28967	.22453	.07977
82	.00000	.00000	.00000	.00002	.00025	.00180	.00955	.03731	.10622	.21506	.29392	.24345	.09242
83	.00000	.00000	.00000	.00001	.00016	.00128	.00729	.03052	.09312	.20206	.29595	.26272	.10689
84	.00000	.00000	.00000	.00001	.00011	.00089	.00545	.02451	.08041	.18763	.29551	.28208	.12341
85	.00000	.00000	.00000	.00001	.00007	.00060	.00397	.01928	.06828	.17198	.29236	.30122	.14224
86	.00000	.00000	.00000	.00000	.00004	.00039	.00281	.01482	.05690	.15534	.28628	.31974	.16367
87	.00000	.00000	.00000	.00000	.00002	.00025	.00193	.01109	.04640	.13801	.27709	.33716	.18803
88	.00000	.00000	.00000	.00000	.00001	.00015	.00128	.00805	.03691	.12031	.26469	.35292	.21567
89	.00000	.00000	.00000	.00000	.00001	.00009	.00081	.00564	.02853	.10259	.24902	.36632	.24699
90	.00000	.00000	.00000	.00000	.00000	.00005	.00049	.00379	.02131	.08523	.23013	.37657	.28243
91	.00000	.00000	.00000	.00000	.00000	.00002	.00028	.00242	.01527	.06863	.20818	.38272	.32248
92	.00000	.00000	.00000	.00000	.00000	.00001	.00015	.00145	.01041	.05318	.18349	.38365	.36767
93	.00000	.00000	.00000	.00000	.00000	.00000	.00007	.00080	.00665	.03927	.15652	.37809	.41860
94	.00000	.00000	.00000	.00000	.00000	.00000	.00003	.00040	.00391	.02723	.12797	.36453	.47592
95	.00000	.00000	.00000	.00000	.00000	.00000	.00001	.00017	.00205	.01733	.09879	.34128	.54036
96	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00006	.00091	.00975	.07021	.30635	.61271
97	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00002	.00031	.00452	.04380	.25751	.69384
98	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00007	.00147	.02157	.19218	.78472
99	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00020	.00597	.10744	.88638

TABLE 12 13 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES	10 TREES	11 TREES	12 TREES	13 TREES
1	.87752	.11523	.00698	.00026	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
2	.76902	.20403	.02498	.00187	.00010	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
3	.67303	.27060	.05021	.00569	.00044	.00002	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
4	.58820	.31861	.07965	.01217	.00127	.00010	.00001	.00000	.00000	.00000	.00000	.00000	.00000	.00000
5	.51334	.35123	.11092	.02140	.00282	.00027	.00002	.00000	.00000	.00000	.00000	.00000	.00000	.00000
6	.44737	.37122	.14217	.03327	.00531	.00061	.00005	.00000	.00000	.00000	.00000	.00000	.00000	.00000
7	.38929	.38092	.17203	.04748	.00893	.00121	.00012	.00001	.00000	.00000	.00000	.00000	.00000	.00000
8	.33825	.38237	.19950	.06361	.01383	.00216	.00025	.00002	.00000	.00000	.00000	.00000	.00000	.00000
9	.29345	.37730	.22389	.08119	.02007	.00357	.00047	.00005	.00000	.00000	.00000	.00000	.00000	.00000
10	.25419	.36716	.24477	.09972	.02770	.00554	.00082	.00009	.00001	.00000	.00000	.00000	.00000	.00000
11	.21982	.35320	.26192	.11870	.03668	.00816	.00134	.00017	.00002	.00000	.00000	.00000	.00000	.00000
12	.18979	.33645	.27527	.13764	.04692	.01152	.00209	.00029	.00003	.00000	.00000	.00000	.00000	.00000
13	.16359	.31777	.28490	.15609	.05831	.01568	.00312	.00047	.00005	.00000	.00000	.00000	.00000	.00000
14	.14076	.29789	.29096	.17367	.07068	.02071	.00450	.00073	.00009	.00001	.00000	.00000	.00000	.00000
15	.12091	.27737	.29369	.19003	.08384	.02663	.00627	.00111	.00015	.00001	.00000	.00000	.00000	.00000
16	.10366	.25669	.29336	.20489	.09757	.03345	.00850	.00162	.00023	.00002	.00000	.00000	.00000	.00000
17	.08872	.23623	.29030	.21802	.11164	.04116	.01124	.00230	.00035	.00004	.00000	.00000	.00000	.00000
18	.07578	.21626	.28483	.22926	.12581	.04971	.01455	.00319	.00053	.00006	.00001	.00000	.00000	.00000
19	.06461	.19702	.27729	.23849	.13986	.05905	.01847	.00433	.00076	.00010	.00001	.00000	.00000	.00000
20	.05498	.17867	.26801	.24567	.15355	.06910	.02303	.00576	.00108	.00015	.00001	.00000	.00000	.00000
21	.04668	.16132	.25729	.25078	.16666	.07974	.02826	.00751	.00150	.00022	.00002	.00000	.00000	.00000
22	.03956	.14504	.24546	.25385	.17900	.09088	.03418	.00964	.00204	.00032	.00004	.00000	.00000	.00000
23	.03345	.12989	.23278	.25495	.19039	.10236	.04077	.01218	.00273	.00045	.00005	.00000	.00000	.00000
24	.02822	.11586	.21952	.25418	.20067	.11406	.04803	.01517	.00359	.00063	.00008	.00001	.00000	.00000
25	.02376	.10295	.20590	.25165	.20971	.12583	.05592	.01864	.00466	.00086	.00012	.00001	.00000	.00000
26	.01995	.09114	.19213	.24752	.21741	.13750	.06441	.02263	.00596	.00116	.00016	.00002	.00000	.00000
27	.01672	.08039	.17839	.24193	.22370	.14893	.07344	.02716	.00754	.00155	.00023	.00002	.00000	.00000
28	.01397	.07065	.16484	.23505	.22852	.15997	.08295	.03226	.00941	.00203	.00032	.00003	.00000	.00000
29	.01165	.06186	.15161	.22706	.23186	.17047	.09284	.03792	.01162	.00264	.00043	.00005	.00000	.00000
30	.00969	.05398	.13881	.21813	.23371	.18029	.10302	.04415	.01419	.00338	.00058	.00007	.00000	.00000
31	.00804	.04693	.12652	.20842	.23410	.18931	.11340	.05095	.01717	.00429	.00077	.00009	.00001	.00000
32	.00665	.04066	.11481	.19811	.23307	.19742	.12387	.05829	.02057	.00538	.00101	.00013	.00001	.00000
33	.00548	.03510	.10374	.18735	.23069	.20453	.13432	.06616	.02444	.00669	.00132	.00018	.00001	.00000
34	.00451	.03020	.09333	.17630	.22705	.21054	.14461	.07450	.02878	.00824	.00170	.00024	.00002	.00000
35	.00370	.02588	.08361	.16508	.22223	.21539	.15464	.08327	.03363	.01006	.00217	.00032	.00003	.00000
36	.00302	.02210	.07459	.15384	.21634	.21904	.16428	.09241	.03899	.01218	.00274	.00042	.00004	.00000
37	.00246	.01880	.06626	.14268	.20950	.22147	.17342	.10185	.04486	.01464	.00344	.00055	.00005	.00000
38	.00200	.01594	.05861	.13171	.20182	.22265	.18195	.11152	.05126	.01746	.00428	.00072	.00007	.00000
39	.00162	.01346	.05162	.12102	.19343	.22261	.18976	.12132	.05818	.02066	.00528	.00092	.00010	.00000
40	.00131	.01132	.04528	.11068	.18446	.22135	.19676	.13117	.06559	.02429	.00648	.00118	.00013	.00001
41	.00105	.00948	.03954	.10075	.17503	.21893	.20285	.14097	.07347	.02836	.00788	.00149	.00017	.00001
42	.00084	.00791	.03438	.09128	.16526	.21540	.20797	.15060	.08179	.03290	.00953	.00188	.00023	.00001
43	.00067	.00658	.02976	.08232	.15526	.21082	.21206	.15997	.09051	.03793	.01145	.00236	.00030	.00002
44	.00053	.00544	.02565	.07389	.14515	.20528	.21505	.16897	.09957	.04346	.01366	.00293	.00038	.00002
45	.00042	.00448	.02200	.06601	.13503	.19886	.21694	.17749	.10892	.04951	.01620	.00362	.00049	.00003
46	.00033	.00368	.01879	.05869	.12499	.19165	.21768	.18543	.11847	.05607	.01910	.00444	.00063	.00004
47	.00026	.00300	.01597	.05193	.11513	.18377	.21729	.19269	.12816	.06314	.02240	.00542	.00080	.00005
48	.00020	.00244	.01351	.04572	.10551	.17531	.21577	.19917	.13789	.07071	.02611	.00657	.00101	.00007
49	.00016	.00197	.01137	.04005	.09621	.16639	.21315	.20479	.14757	.07877	.03027	.00793	.00127	.00009
50	.00012	.00159	.00952	.03491	.08728	.15710	.20947	.20947	.15710	.08728	.03491	.00952	.00159	.00012

TABLE 12 13 SEEDS PER CONTAINER

GERMINATION PERCENT	PROBABILITY OF OCCURANCE 0 TREES	1 TREE	2 TREES	3 TREES	4 TREES	5 TREES	6 TREES	7 TREES	8 TREES	9 TREES	10 TREES	11 TREES	12 TREES	13 TREES
51	.00009	.00127	.00793	.03027	.07877	.14757	.20479	.21315	.16639	.09621	.04005	.01137	.00197	.00016
52	.00007	.00101	.00657	.02611	.07071	.13789	.19917	.21577	.17531	.10551	.04572	.01351	.00244	.00020
53	.00005	.00080	.00542	.02240	.06314	.12816	.19269	.21729	.18377	.11513	.05193	.01597	.00300	.00026
54	.00004	.00063	.00444	.01910	.05607	.11847	.18543	.21768	.19165	.12499	.05869	.01879	.00368	.00033
55	.00003	.00049	.00362	.01620	.04951	.10892	.17749	.21694	.19886	.13503	.06601	.02200	.00448	.00042
56	.00002	.00038	.00293	.01366	.04346	.09957	.16897	.21505	.20528	.14515	.07389	.02565	.00544	.00053
57	.00002	.00030	.00236	.01145	.03793	.09051	.15997	.21206	.21082	.15526	.08232	.02976	.00658	.00067
58	.00001	.00023	.00188	.00953	.03290	.08179	.15060	.20797	.21540	.16526	.09128	.03438	.00791	.00084
59	.00001	.00017	.00149	.00788	.02836	.07347	.14097	.20285	.21893	.17503	.10075	.03954	.00948	.00105
60	.00001	.00013	.00118	.00648	.02429	.06559	.13117	.19676	.22135	.18446	.11068	.04528	.01132	.00131
61	.00000	.00010	.00092	.00528	.02066	.05818	.12132	.18976	.22261	.19343	.12102	.05162	.01346	.00162
62	.00000	.00007	.00072	.00428	.01746	.05126	.11152	.18195	.22265	.20182	.13171	.05861	.01594	.00200
63	.00000	.00005	.00055	.00344	.01464	.04486	.10185	.17342	.22147	.20950	.14268	.06626	.01880	.00246
64	.00000	.00004	.00042	.00274	.01218	.03899	.09241	.16428	.21904	.21634	.15384	.07459	.02210	.00302
65	.00000	.00003	.00032	.00217	.01006	.03363	.08327	.15464	.21539	.22223	.16508	.08361	.02588	.00370
66	.00000	.00002	.00024	.00170	.00824	.02878	.07450	.14461	.21054	.22705	.17630	.09333	.03020	.00451
67	.00000	.00001	.00018	.00132	.00669	.02444	.06616	.13432	.20453	.23069	.18735	.10374	.03510	.00548
68	.00000	.00001	.00013	.00101	.00538	.02057	.05829	.12387	.19742	.23307	.19811	.11481	.04066	.00665
69	.00000	.00001	.00009	.00077	.00429	.01717	.05095	.11340	.18931	.23410	.20842	.12652	.04693	.00804
70	.00000	.00000	.00007	.00058	.00338	.01419	.04415	.10302	.18029	.23371	.21813	.13881	.05398	.00969
71	.00000	.00000	.00005	.00043	.00264	.01162	.03792	.09284	.17047	.23186	.22706	.15161	.06186	.01165
72	.00000	.00000	.00003	.00032	.00203	.00941	.03226	.08295	.15997	.22852	.23505	.16484	.07065	.01397
73	.00000	.00000	.00002	.00023	.00155	.00754	.02716	.07344	.14893	.22370	.24193	.17839	.08039	.01672
74	.00000	.00000	.00002	.00016	.00116	.00596	.02263	.06441	.13750	.21741	.24752	.19213	.09114	.01995
75	.00000	.00000	.00001	.00012	.00086	.00466	.01864	.05592	.12583	.20971	.25165	.20590	.10295	.02376
76	.00000	.00000	.00001	.00008	.00063	.00359	.01517	.04803	.11406	.20067	.25418	.21952	.11586	.02822
77	.00000	.00000	.00000	.00005	.00045	.00273	.01218	.04077	.10236	.19039	.25495	.23278	.12989	.03345
78	.00000	.00000	.00000	.00004	.00032	.00204	.00964	.03418	.09088	.17900	.25385	.24546	.14504	.03956
79	.00000	.00000	.00000	.00002	.00022	.00150	.00751	.02826	.07974	.16666	.25078	.25729	.16132	.04668
80	.00000	.00000	.00000	.00001	.00015	.00108	.00576	.02303	.06910	.15355	.24567	.26801	.17867	.05498
81	.00000	.00000	.00000	.00001	.00010	.00076	.00433	.01847	.05905	.13986	.23849	.27729	.19702	.06461
82	.00000	.00000	.00000	.00001	.00006	.00053	.00319	.01455	.04971	.12581	.22926	.28483	.21626	.07578
83	.00000	.00000	.00000	.00000	.00004	.00035	.00230	.01124	.04116	.11164	.21802	.29030	.23623	.08872
84	.00000	.00000	.00000	.00000	.00002	.00023	.00162	.00850	.03345	.09757	.20489	.29336	.25669	.10366
85	.00000	.00000	.00000	.00000	.00001	.00015	.00111	.00627	.02663	.08384	.19003	.29369	.27737	.12091
86	.00000	.00000	.00000	.00000	.00001	.00009	.00073	.00450	.02071	.07068	.17367	.29096	.29789	.14076
87	.00000	.00000	.00000	.00000	.00000	.00005	.00047	.00312	.01568	.05831	.15609	.28490	.31777	.16359
88	.00000	.00000	.00000	.00000	.00000	.00003	.00029	.00209	.01152	.04692	.13764	.27527	.33645	.18979
89	.00000	.00000	.00000	.00000	.00000	.00002	.00017	.00134	.00816	.03668	.11870	.26192	.35320	.21982
90	.00000	.00000	.00000	.00000	.00000	.00001	.00009	.00082	.00554	.02770	.09972	.24477	.36716	.25419
91	.00000	.00000	.00000	.00000	.00000	.00000	.00005	.00047	.00357	.02007	.08119	.22389	.37730	.29345
92	.00000	.00000	.00000	.00000	.00000	.00000	.00002	.00025	.00216	.01383	.06361	.19950	.38237	.33825
93	.00000	.00000	.00000	.00000	.00000	.00000	.00001	.00012	.00121	.00893	.04748	.17203	.38092	.38929
94	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00005	.00061	.00531	.03327	.14217	.37122	.44737
95	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00002	.00027	.00282	.02140	.11092	.35123	.51334
96	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00001	.00010	.00127	.01217	.07965	.31861	.58820
97	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00002	.00044	.00569	.05021	.27060	.67303
98	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00010	.00187	.02498	.20403	.76902
99	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00001	.00026	.00698	.11523	.87752

Appendix 4

Useful forms for greenhouse nursery record keeping.

1. Worksheet for calculation of fertilizer stock solutions.—See section 13.6 for instructions on how to use.

2. Fertilizer and irrigation record.—Fertilizing may or may not be done at each watering. EC and pH may or may not be taken at each fertilizing, although it is recommended that these readings be taken each time. Fertilizer type would be "high N," "low N," 15-10-30, etc. Several types of moisture sensor may be used, including a weighing scale, pressure bomb, bimetal probe, or educated finger. See section 6.56 for details.

3. Control settings.—This sheet should be posted where anyone who needs to know can tell quickly what greenhouse conditions are expected to be.

4. Growth record.—Seedlings should be sampled periodically during their growth. Measurements may be supplemented by pictures of seedlings or herbarium specimens.

5. Growing schedule.—Instructions for use and examples are in section 15, and additional examples are in appendix 2.

6. Daily Log (not shown).—This need not take any particular form, but should be a narrative of events and conditions as they occur. It will be most permanent if a bound log book is used.

WORKSHEET FOR CALCULATION OF FERTILIZER STOCK SOLUTION

Line 1	2	3	4	5	6	7	8	9	10	11
	Nutrient Elements (ppm)							Total	Stock soln. x ____	Cpd. com-pat.
	(NO_3) N	(NH_4) N	P	K	S	Ca	Mg	Cpd mg/l		
1. Target Conc.										
2. Water anal.										
3. Net to Add										
Cpds. used:	–	–	–	–	–	–	–	–	–	–
4.										
5.										
6.										
7.										
8.										
9.										
10. Total										
	Fe	Cl	B	Mn	Zn	Cu	Mo		x____	
11. Target Conc.										
12. Water anal.										
13. Net to Add										
14.										
15.										
16.										
17.										
18.										
19.										
20.										

FERTILIZER and IRRIGATION RECORD

Greenhouse No. ______ Crop ____________________

Mo./Yr. ______________ ____________________

Date	Moisture sensor reading	Water temp.	Length of watering time	Fertilizer type	Irrigation solution		Leachate		Remarks Initials
					pH	EC	pH	EC	
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									

CONTROL SETTINGS

Greenhouse No.

Crop ______________

	Day Temperature							Night Temperature											
	Cooling stage				Heating stage			Cooling stage				Heating stage							
Date	3	2	1	N	1	2	3	3	2	1	N	1	2	3	Rel. Hum.	CO_2	Light at night	Watering cycle	Comments Initials

GROWTH RECORD

Greenhouse No. ______ **Species** ____________________

Seed lot ____________________

Date	Height	Caliper	Weight	Comments

Species ______ Container ______ Outplanting ______ Location ______ Cycle ______ ______

Source ______

Season		
Growth stage		
Day temp (°F)	Optimum	
	Permissible	
Night temp (°F)	Optimum	
	Permissible	
Rel. Hum. (%)	Optimum	
	Permissible	
Daylight		
Supplemental light		
Water		
Fertilizer		
CO_2 level		
Operations		

Subject Index

Tinus, Richard W., and Stephen E. McDonald. 1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv. Gen. Tech. Rep. RM-60, 256 p. Rocky Mt. For. and Range Exp. Stn., For. Serv., U.S. Dep. Agric., Fort Collins, Colo. 80526.

This guide to development and operation of a greenhouse nursery for container grown forest tree seedlings will help managers decide if a nursery should be built and gives criteria for selecting site, building design and layout, hardware, controls, container, and growing medium. It discusses environmental factors that can be controlled, optimum conditions for growth, and how to achieve them. Growing schedules, greenhouse cultural practices, nursery management, and troubleshooting problems are also discussed.

Tinus, Richard W., and Stephen E. McDonald. 1979. How to grow tree seedlings in containers in greenhouses. USDA For. Serv. Gen. Tech. Rep. RM-60, 256 p. Rocky Mt. For. and Range Exp. Stn., For. Serv., U.S. Dep. Agric., Fort Collins, Colo. 80526.

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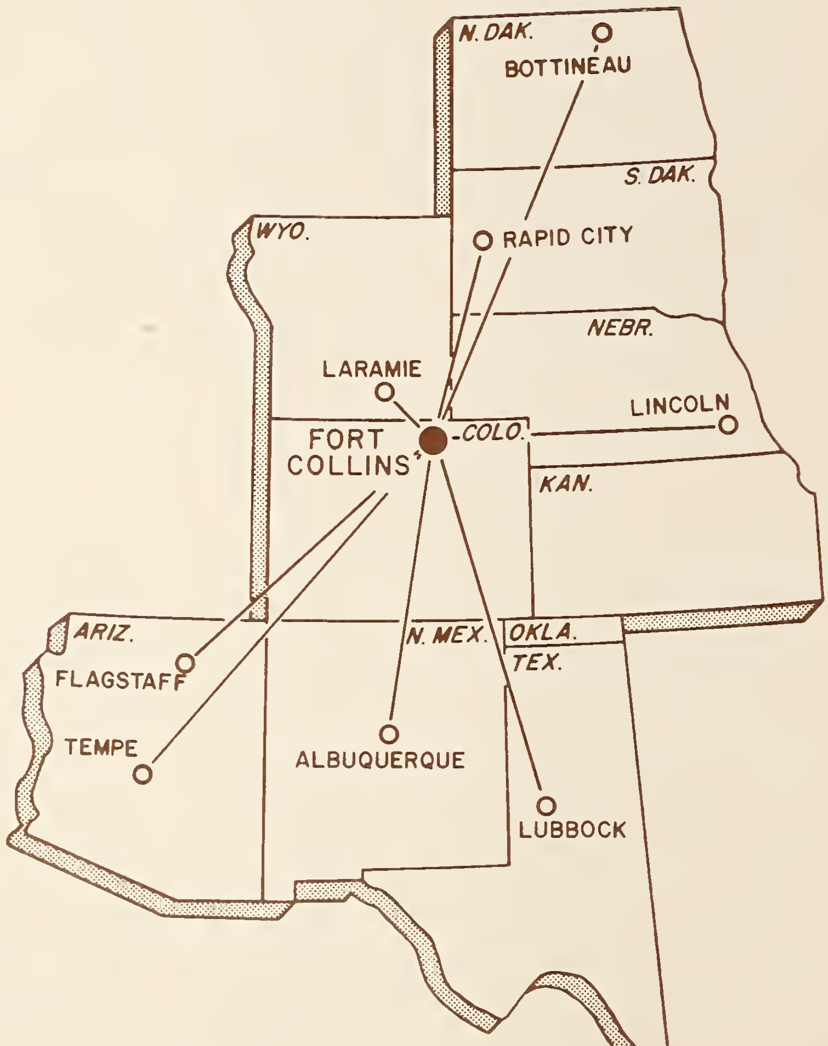
N. DAK.
BOTTINEAU
S. DAK.
WYO.
RAPID CITY
NEBR.
LARAMIE
LINCOLN
FORT COLLINS
COLO.
KAN.
ARIZ.
N. MEX.
OKLA.
TEX.
FLAGSTAFF
TEMPE
ALBUQUERQUE
LUBBOCK