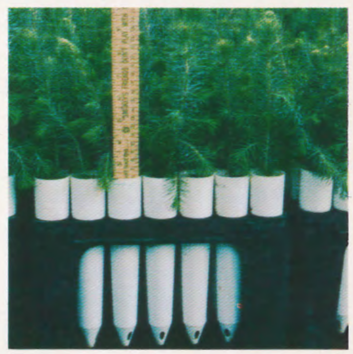
The Container Tree Nursery Manual • Volume One

Nursery Planning, Development, and Management



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The Container Tree Nursery Manual

Volume One
Nursery Planning, Development, and Management

Chapter 5
Nursery Management

Contents

1.5.1 Introduction

The final phase of nursery development begins when the construction is complete and it's time to plan for that first crop! The challenge of managing a container nursery can be intimidating to a new manager, and so the purpose of this chapter is to outline the various aspects of nursery management. Although individual management styles differ with personality types and specific objectives, there are several key aspects of every successful nursery: solid organization, professional personnel, a system of data collection and analysis, and an established system for solving problems. None of these are unique to container tree nurseries, and good general information on nursery management can be found in the general horticulture references listed in section 1.5.8.1.

1.5.2 Organization

If it is to succeed, the management of a nursery must have a structured organization that ensures that responsibilities are assigned and jobs get done. The responsibilities for a container tree nursery can be divided into four general categories (Nelson 1991):

1. **Production**—performing the day-to-day cultural operations of growing the crop.
2. **Engineering**—maintaining the physical plant and custom-building any special equipment.
3. **Marketing**—soliciting orders, delivering the crop, and providing whatever other customer services are needed.
4. **Business affairs**—keeping business records and accounting costs, bills, purchases, and payrolls.

In small nurseries, the manager may also be the owner and may also perform all, or nearly all, of these functions. As the nursery grows in size, the manager must delegate responsibilities for various parts of the job to assistants, which is the beginning of a hierarchical organization. Often, the first professional employee that a new nursery manager hires is a **grower.** This person acts as production manager, leaving the other general business duties to the nursery manager. Growers usually supervise the general laborers, but supervision is delegated to **crew leaders** in larger nurseries.

Regardless of the organizational structure, any successful nursery must have one characteristic: **unity of command.** Nursery managers must establish a clear assignment of responsibilities, together with the authority to carry them out. Raising a crop of container seedlings is not a simple procedure. Consequently, because nursery managers are most knowledgeable about day-to-day operations and will ultimately be held responsible, only they should direct nursery activities, make changes in growing schedules, and regulate the setting of environmental control equipment. In nurseries where there has not been a clear assignment of responsibility, trouble eventually develops.

1.5.3 Personnel and Supervision

1.5.3.1 Attributes of container nursery managers

One of the most difficult decisions that a nursery developer must make is hiring the nursery manager. The purpose of this section is to provide a brief glimpse of what to look for in nursery managers, and what makes them unique. Managers can be described as organizers, planners, people capable of great capacity for work, decision-makers, diplomats, problem solvers, firm believers that all activities must be for the betterment of the business, people of good judgment, and who are knowledgeable, honest, and forthright, and challenged by the accomplishment of the job (Nelson 1991).

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. Managers must be honest and be able to think and reason quickly and clearly. Problems will arise that will require solutions that can only be arrived at by careful analysis and deduction. Container nursery managers must know about propagation structures, seedling morphology and physiology, and the economics and management of a private business or government organization. They must have sufficient intellect and self-assurance to handle business management procedures, personnel management, physical facility management, crop rotations and scheduling, seedling culture, marketing, and delivery. If the nursery is part of a larger organization, staff and other managers may share these loads and help with these jobs. However, the nursery manager must see that overall management is coordinated.

1.5.3.2 Professional attitudes

Managing a container nursery facility is more than just growing a crop. Successful nursery managers must possess certain key professional attitudes that guide their daily work and provide an example for their employees.

Technical competence. Traditionally, forest nursery managers 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 seedling be a good one. However, foresters must learn to grow container tree seedlings by observation, trial and error, and studying technical publications. While this process for developing nursery managers has some drawbacks, the process has developed a stable core of nursery professionals. In recent years, more container nursery manager and grower positions are being filled by horticulturists.

Good nursery managers do not have to be foresters, horticulturists, or botanists. Regardless of their background or training, the key factor is that managers understand the daily operations of a container nursery and are able to grow tree seedlings. Managers and growers must have the knowledge-either from formal training or from experience-to understand how seedlings react to cultural treatments.

Clear managerial goals. Nursery managers must be allowed to grow the seedlings. Too often, especially at large government nurseries, they are buried by administrative details because they are the senior manager at the site. This is a waste of resources and poor management. Adequate support staff must be provided to allow nursery managers to do the real job they were hired to do.

The mission of the nursery must be kept foremost in the minds of managers and their staffs, and it is helpful to state that mission in terms of a concrete goal. For example, a goal might be "to grow high-quality seedlings at a reasonable cost." Often, the details of nursery development, personnel problems, maintenance work, or preoccupations with other related activities can unwittingly override the prime reason for the nursery. This is often directly attributable to the demands and priorities of higher management or owners, who often do not provide adequate technical and financial support to avoid compromising the primary goal of the nursery.

Relating to the crop. Nursery managers and their staffs must learn to "think like a seedling" (fig. 1.5.1). They should view nursery activity priorities from the standpoint of the biological requirements of the crop. The goal at the nursery usually is to grow good seedlings on an economical basis. Every member of the crew should have at least a rudimentary knowledge of the effects that their activities will have on the biological well-being of the seedlings. In recent years, the American Association of Nurserymen has been emphasizing basic horticultural training 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.

Figure 1.5.1—*A successful nursery manager must be able to "think like a seedling," an ability that results from proper training tempered by practical experience.*

Such education will often prevent disastrous errors on the part of container nursery workers who, for instance, might not understand the implications for the crop of turning down the heat in the propagation structure because "it is too hot to work comfortably." In the final analysis, managers are the prime trainers of the crew. Their knowledge and attitude toward the crop will largely determine how well their crew learns to "think like a seedling."

Commitment to the nursery. A container nursery cannot be run "by committee." Instead, one person always has to accept primary responsibility for the crop at any particular time. For example, if the photoperiod light system fails even for one night, the seedlings may lapse into bud dormancy and not begin shoot growth again until the following year. Even if seedlings can be forced to grow again, this one oversight means the crop will be seriously delayed and a growing contract may be lost. Problems always develop when there is no one person who conscientiously looks after the crop and the functioning of the nursery all the time.

Growing container seedlings involves precise control of the propagation environment, so that it is optimal for seedling growth. This is a great advantage, but at the same time, managers have more responsibilities for the well-being of the crop than do managers of bareroot nurseries. Nature provides buffers against plant damage in the bareroot nursery environment, including a large volume of soil to supply water and nutrients, and natural late summer conditioning of plants so that they are prepared for winter. A fully controlled greenhouse has few of these natural buffers and so there is little room for error. The price of rapid seedling growth in container nurseries is knowledge and constant vigilance.

Cleanliness. The cheapest insurance against disease, insect, mechanical, or seedling physiological problems in a container nursery is to keep everything clean and in good working order. Not only is cleanliness advised for sanitation, but it is also good business management. It is much easier to sell seedlings to visiting potential tree buyers or potential supporters within the organization if the nursery is clean, orderly, and well manicured. Visitors equate a clean, neat nursery with efficiency and good management; indeed, this usually proves to be correct.

The emphasis on cleanliness, neatness, and maintenance also affects the nursery workers. By emphasizing these things and providing a good example, nursery managers are saying "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-time employees, will respond with added pride in their work and feel they belong and have a stake in the nursery.

1.5.3.3 Supervision

Both Nelson (1991) and Hanan and others (1978) provide excellent sections in their texts on supervision, and there is a wealth of other literature on the subject. However, a few particular comments for nursery managers are appropriate here. First, the characteristics of a successful container nursery proceed directly from the nursery manager's example or, as Nelson (1991) puts it: "labor management begins with the management of oneself." Also, the wise supervisor makes sure that workers understand several things:

1. What the management structure of the organization is and who their immediate boss is.
2. What the goals of the nursery and/or parent organization are.
3. What their direct responsibilities are and how their authority relates to the remainder of the work force.
4. How their performance will be evaluated and what the monetary and professional rewards will be.

Successful supervision is also connected to the work environment, expectations, and opportunities for employee betterment. As mentioned earlier, a clean, orderly work environment combined with high product-quality standards not only provide employees with a better place to work but also generate pride in their work. High expectations for employees, in terms of work quality or quantity, generally will lead to a rise in personal expectations on the part of each worker and more self-esteem. Opportunities for advancement and education (on or off the job) have often proven just as important, or more so, than pay in motivating employees.

1.5.3.4 Safety programs

Greenhouses and other propagation structures have a number of inherent safety hazards that can be minimized by proper design and construction and by safe work habits (Goldsberry 1979). 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. Ungrounded tools or appliances of any kind should never be used in a container growing structure, unless they are double insulated. Power must be shut off first when electrical equipment is being repaired or adjusted.

Propagation structures contain many other hazards. Equipment, such as ventilation fans and conveyors, may start automatically without warning. For this reason, blades and other moving parts should be shielded so that no one can put fingers in them. Some structures have floor-mounted heaters, which should have their flues shielded so that they cannot be touched inadvertently. Pesticide storage areas must be properly designed, and all employees (not just applicators) must be given regular training on pesticide use in enclosed areas. (Pesticide storage and safety are discussed in detail in section 5.1.8 in volume five of this series.)

Many potential safety problems can be averted by maintaining a neat, clean work area. Tools and other equipment should never be left lying around, and hoses or cords should be coiled and placed out of traffic areas. Propagation areas are often humid, which makes floors slippery, especially if algae has been allowed to grow. Floors should be built to drain properly and should be cleaned as needed to prevent slippery conditions from developing.

Safety meetings should be held at the start of each major work period, such as sowing or grading and packing. These meetings are an excellent opportunity to inform new employees and remind returning workers of possible hazards and to show them the best ways to do tasks safely. Some tasks have proven to be particularly dangerous, such as pulling seedlings from their containers during packing, which often causes tendonitis and carpal tunnel syndrome (Wallersteiner 1988). Like most work-related injuries, however, they can be reduced by proper training and worker awareness (fig. 1.5.2).

Figure 1.5.2—*One of the obligations of a nursery manager is to instill a safety ethic by personal example, training, and frequent reminders.*

1.5.3.5 Operational planning

Operational planning is the advance work that brings all the non-structural requirements of nursery production (labor, supplies, equipment, etc.) together at key times of the production process. Operational planning is what allows seedling production to proceed smoothly and efficiently and is an important, but often neglected, part of container tree nursery management. Nursery managers often tend to concentrate on the daily details of growing seedlings while neglecting to plan for future needs. Operational planning is especially important in nurseries because of the seasonal nature of the work and requirements for labor and resources at specific, limited time periods, such as during the sowing and packing seasons.

For planning purposes, a container tree nursery can be visualized as a system that consists of a series of sequential processes (filling and sowing the containers), operations (placing a specified number of seeds per container), and the requirements (propagation structure, seeder equipment, labor, and supplies) to complete each process. Good managers assure that all processes are scheduled in the proper sequence and that all the requirements for a specific operation come together at the right time and place. (The requirements of a container nursery system are discussed in more detail in section 1.1.4.1, and the organizational framework is diagrammed in table 1.1.5.)

1.5.4 Data Collection and Analysis

The third important aspect of nursery management is the collection and analysis of information. The types of records and the methods of information collection and storage will vary considerably with the type, size, and complexity of the nursery. The purpose of this section is not to specify any particular record keeping method but rather to introduce the terms and concepts necessary to start managing a nursery and to impress on new nursery managers the importance of keeping good records right from the start. The types of records kept at a container nursery fall into two general categories: financial and production records, and cultural records.

1.5.4.1 Financial and production records

Financial records are kept to account for expenditures, to control the budget, and to provide the records necessary for improving procedures for conducting business in the future. Financial records also are kept to meet governmental requirements (including tax purposes) and as aids in obtaining credit.

A financial record keeping system should be designed to document three general classes of information: (1) expense data, (2) production data, and (3) unit-cost data. The data can be recorded by individual nursery operation (such as "sowing") but can also be used to analyze other production variables such as species, container size, and even customer. Information on seedling production costs should be organized to reflect different cost centers including supplies, utilities, services, and labor. Analysis of this information may show nursery managers where costs are excessive and help make management decisions, such as whether a winter crop can be financially justified (table 1.5.1). Because labor is such a large component of production costs, nursery managers should collect the number of hours spent on each task along with the number of seedlings processed. This information can then be analyzed and formatted to produce tables (table 1.5.2) that can be invaluable in making sound business decisions such as whether to invest in new labor-saving equipment.

Financial records should also include detailed production data regarding operational information such as "hours of labor spent filling containers" or "bags of fertilizer purchased" or "numbers of a certain species of tree seedlings shipped." Such production information, blended with the cost portions of financial records, is the basis for making many management decisions, especially regarding materials purchasing, next year's budget, or other operational, cultural, or maintenance activities. Ultimately such financial data are used to calculate unit output costs (dollars per thousand seedlings). This latter information is essential for setting accurate prices and estimating future production costs when bidding on seedling growing contracts.

The sophistication of financial record keeping will vary with the size and complexity of the facility. A small nursery may find it completely adequate to maintain written records in a log book, whereas this would be difficult for a larger facility. Modern computer-based record systems make record keeping much easier, especially the sorting of the data into different categories and displays for analysis. Many business and computer consultants and software packages are available to help the inexperienced manager. For example, a computer program called "Greenhouse Cost Accounting" enables the nursery manager to perform detailed cost accounting and calculate the profitability of container crops (Brumfield 1992). This software is particularly useful because it allows the user to allocate variable costs to any number of individual crops on an area basis, a task that would be extremely tedious without the benefit of a computer.

Needs change with size and sophistication of the nursery and so, at various points during the development of a nursery facility, the manager should check to see if the financial record system is still adequate to meet the needs of the nursery.

1.5.4.2 Cultural records

Cultural records are maintained to provide a plan for duplicating successful crops and give an accounting that can be used in (a) determining the cause of errors in the culture of the crop, (b) deciding on action taken on the current crop, and (c) making plans to avoid problems with future crops (Nelson 1991). The following is a general outline of the types of cultural records that should be made (a more detailed discussion will be given in volume six of this series).

Cultural records fall into three categories: growing schedules, environmental conditions in the propagation area, and crop development records.

Table 1.5.1—*Production costs for three different crops of spruce container seedlings in New Brunswick, Canada*

Cost center	Winter crop ($/1,000 seedlings)	First summer crop ($/1,000 seedlings)	Second summer crop ($/1,000 seedlings)	Average % of total cost
Propagation supplies				
Containers	$23.42	$23.42	$23.42	17.7
Growing media	1.66	1.66	1.66	1.2
Shadecloth	0.38	0.38	0.38	0.3
Seed	1.36	1.36	1.36	1.0
Seed covering	0.70	0.70	0.70	0.5
Fertilizer	0.60	0.77	0.63	0.5
Pesticides	0.43	0.43	0.43	0.3
Other supplies	17.96	17.96	17.96	13.5
Utilities				
Heating fuel	21.58	2.10	5.56	6.9
Electricity	2.84	0.82	1.66	1.3
Services and rentals	7.82	7.82	7.82	5.9
Labor				
Full-time	28.38	28.38	28.38	21.4
Part-time	37.79	37.79	37.79	28.5
Misc. expenses	1.23	1.23	1.23	1.0
Total cost per 1,000 seedlings	$146.15	$124.82	$128.98	100.0 %
Total cost per crop	$580,946.00	$496,175.00	$512,683.00	100.0 %

Based on a total production level of approximately 4.7 million seedlings of black spruce (*Picea mariana* (Mill.) B.S.P.) per crop, and a shippable seedling efficiency of 85%
Source: modified from Clements and Dominy (1990).

Growing schedules. These written plans of crop timing are essential to successful nursery management and are developed prior to sowing based on the best information and experience available. Growing schedules come in various degrees of sophistication and refinement. They may be only rough outlines of dates for key cultural processes, such as sowing, thinning, and harvesting, or they can provide considerable detail on each step of the process together with a record of actual accomplishment (Tinus and McDonald 1979). The best growing schedules include a variety of operational considerations related to crop timing, culture, and growing space utilization. They should include

1. Target specifications for the crop and the time of delivery.
2. Adequate allowance of time for seed stratification, if needed, prior to sowing and for a proper hardening period prior to shipment.
3. Placing species or container types with similar growth regimes in the same propagation environment.

Table 1.5.2—*Average nursery labor requirement and cost per process*

Process	Hours/1,000 seedlings	Cost/1,000 seedlings	Total cost per crop	% of total
Seed preparation	0.1	$0.60	$ 487.00	2.1
Sowing	1.2	6.40	5,409.00	23.6
Thinning	0.9	4.80	4,084.00	17.9
Cultural operations	0.3	1.50	1,235.00	5.4
Miscellaneous tasks	0.2	0.90	791.00	3.5
Maintenance	0.4	2.30	1,922.00	8.4
Grading & packing	1.9	10.50	8,952.00	39.1
Totals per crop	4.9	27.00	22,880.00	100.00

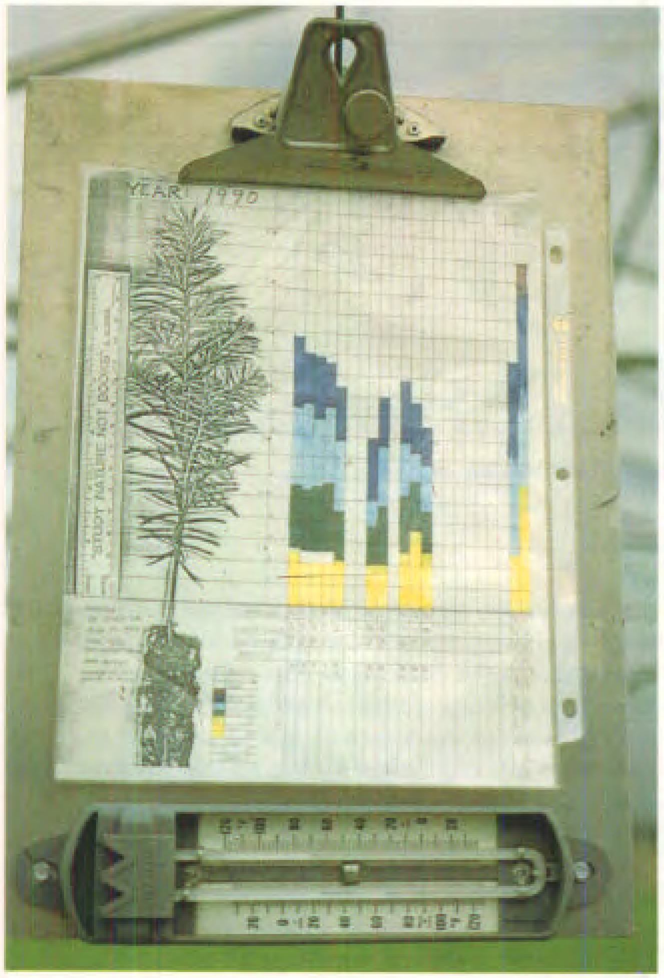
Based on 5 crop years, at a labor rate of $5.50 per hour, and a total production of 850,000 seedlings per crop.
Source: Wenny (1992).

4. Planning efficient use of space in the propagation environment to allow large blocks of similar trees to be sown at the same time and, if possible, placing seedlings to be removed first near the perimeter or doors for ease of handling.

Growing schedules should serve as a daily reminder to the nursery manager about the operations to be done and should, in aggregate for the various crops being grown, serve as the basis for work force and materials planning on a week-to-week basis. (Procedures on how to develop growing schedules and several examples will be provided in volume six, chapter 1, of this series.)

Environmental conditions. This set of culture-related records contains such things as temperatures inside and outside the propagation structure, solar radiation intensity, growing medium nutrient analysis, foliar nutrient analysis, occurrence of insect pests and disease, and other general observations (Nelson 1991). These records not only show the crop environment maintained but also will indicate various equipment failures and any involuntary deviations from the growing schedule. Abnormal crop conditions discovered later can often be related back to mechanical failures as indicated in the environmental records.

Daily or weekly records of environmental conditions and seedling growth can be charted by hand on clipboards mounted near the work area. This system has the advantage of being readily accessible and simple (fig. 1.5.3A). Record sheets can be 3-hole punched and assembled in a ring binder for late review and then filed. Hygrothermographs are handy ways to permanently record temperature and humidity. In recent years, environmental control computers are commonly used not only to control conditions in the propagation environment but also to provide a handy way to spot-check conditions throughout the growing area (fig. 1.5.3B). This weather information is constantly stored on disk and can be used to plot and analyze trends, which can help nursery managers spot problems quickly and take corrective action before serious growth loss occurs.



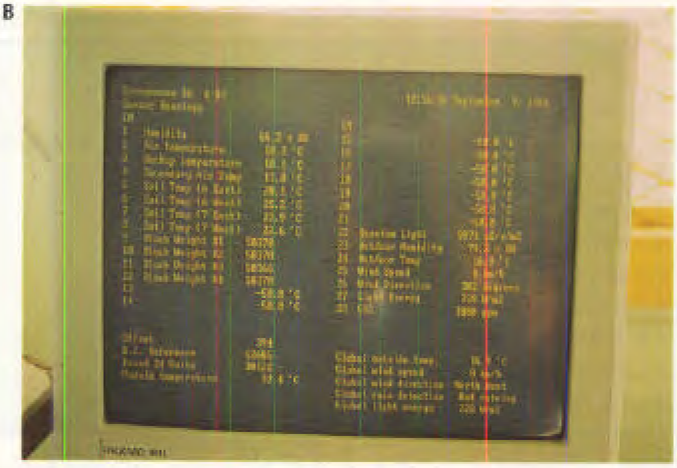


Figure 1.5.3—*Environmental conditions within the growing area can be recorded by hand along with notes about seedling growth* (**A**). *Nursery computer systems can monitor and record the full range of environmental variables* (**B**).

Ambient weather conditions should also be collected in a standard weather station, including daily temperature highs and lows, humidity, precipitation, and wind speed. Weather changes often are directly related to environmental conditions inside growing structures, and so these records can reveal problems with the environmental control system. Computers should be linked to outside weather sensors to provide a complete picture of the daily weather and seasonal climate trends, and the data can be automatically transferred directly to computers for permanent storage. Weather records are very valuable data that can tell the nursery manager how to design and operate propagation structures and how to acclimate crops, as well as provide a way of evaluating the risk of potentially damaging weather occurrences.

Crop development. All nurseries should keep some form of permanent records that monitor the growth and development of their crops over the growing season. Nursery managers should monitor significant events such as speed of germination and development of dormant buds, and also take periodic measurements of growth parameters including **shoot height** and **stem diameter (caliper).** Root growth is more difficult to monitor because small seedlings are damaged when removed from the container unless book containers (which are specifically designed to facilitate root monitoring) are used. Although it requires destructive sampling, seedling **ovendry weight** is a useful index of crop development and is necessary for the calculation of **shoot-to-root (S:R) ratios.**

It is best to appoint one person—the crop monitor—responsible for taking all seedling development and inventory measurements. This ensures that the measurements are taken the same way each time and, because they becomes intimately familiar with crop development, crop monitors are invaluable as a pest detection specialists. Seedling height can easily be taken with a ruler and stem diameter with calipers, and the data recorded on prepared data forms (fig. 1.5.4A). Digital calipers that are easier to read and can be linked to portable data recorders are now available (fig. 1.5.4B).

Figure 1.5.4—*Regular monitoring of seedling growth* **(A)** *provides information on the effectiveness of cultural practices, and also is a good time to check for pests. New digital calipers can be read with portable data recorders, making seedling growth monitoring quick and accurate* **(B)**.

Manually measured data can be entered into preprogrammed data recorders and then electronically downloaded into customized computer files. Nurseries with computer systems can merge this information with environmental and cultural records to generate sophisticated crop models and optimize growing schedules.

The growing media and the seedlings themselves can be chemically analyzed to determine the nutrient level of each of the mineral nutrients. Most nurseries collect representative samples of growing media or seedling foliage and send them to commercial testing laboratories. This information is valuable in helping nursery managers identify and correct nutrition problems, and in testing new fertilization regimes. For example, trials with black spruce—*Picea mariana* (Mill.) B.S.P.-showed that increasing the fertilizer rate by 50% improved the growth rate, but that doubling the rate caused a reduction in seedling quality (table 1.5.3). The total dry weight decreased and the shoots became too large, as reflected by the high shoot-to-root ratio. Foliar nitrogen content was too high for good survival and growth, and the high nitrate level in the growing medium could lead to undesirable agricultural pollution of runoff water. (See section 4.1.9 in volume four of this series for nutrient testing procedures and standards.)

Monitoring the target seedling. Successful nursery managers use the concept of the **target seedling** to describe the ideal morphological and physiological characteristics of a seedling that will survive and grow on a specific outplanting site (Rose and others 1990). The target seedling concept is a useful way for seedling users to describe what type of seedling they expect, and for nursery managers to describe what they can realistically produce. Because of differences between species and environmental conditions on the outplanting site, the target seedling will vary from customer to customer.

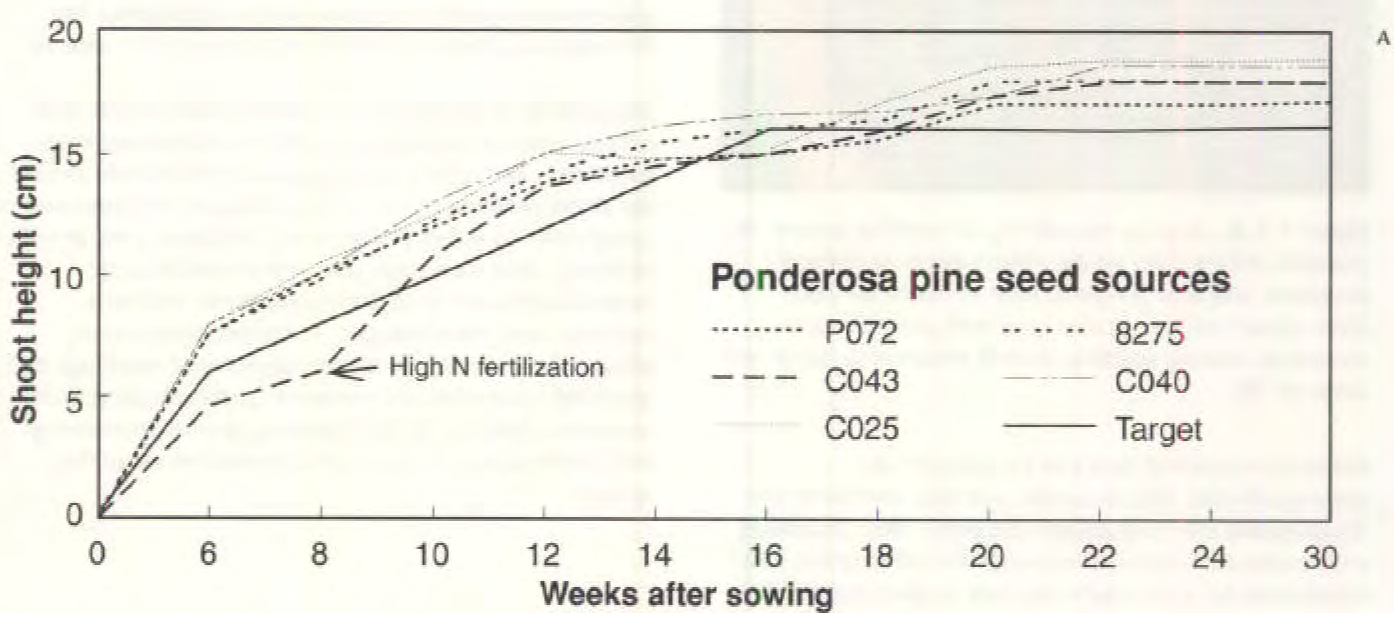
Morphological attributes-including shoot height, stem caliper, and root volume-are the most common measurements, but other physiological attributes help define the target seedling as well. Physiological attributes are categorized as either performance attributes (root growth potential, cold hardiness, and stress resistance) or material attributes (bud dormancy, water relations, nutrition, and morphology). These performance attributes are assessed by placing samples of seedlings into specified controlled environments and evaluating their responses (Ritchie 1984). (Seedling quality monitoring will be discussed in more detail in volume six of this series.)

Table 1.5.3—*Seedling growth data and foliar nutrient results can be very useful in detecting problems or testing new cultural practices*

Fertilizer treatment	Age (wks)	Total seedling dryweight (mg)	Shoot: root ratio	Growing media level* (ppm)	Foliar N content# (%)	Management analysis
Normal	13	175	4.3	2	2.75	Acceptable growth
1.5X	13	290	6.6	3	3.04	Better growth
2.0X	13	255	10.0	12	3.41	Inferior growth

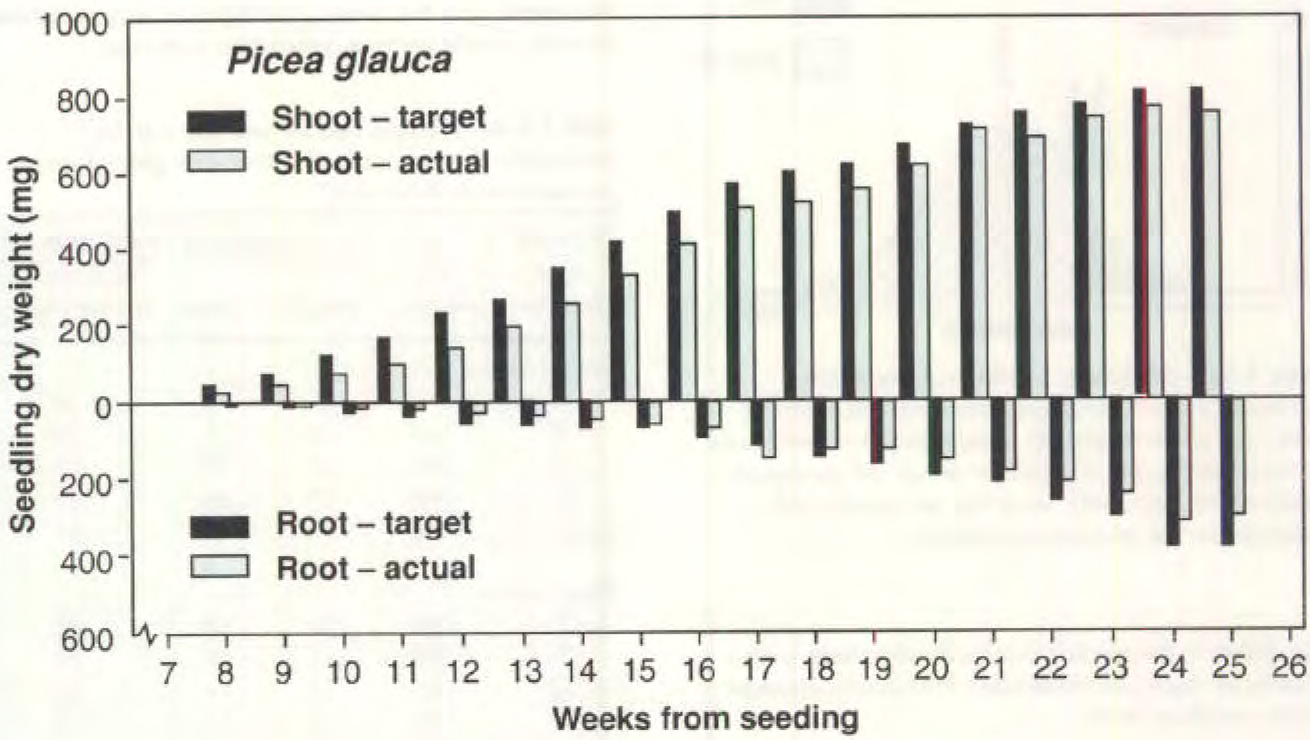
* = Nitrate-nitrogen.
\# = Total nitrogen.
Source: modified from Hallett (1982).

During the growing season, seedling growth trends can easily be visualized by graphing shoot height, caliper, and seedling dry weight over time (fig. 1.5.5A&B). Although they can be plotted by hand, computers make this process easy and the information can be stored for future analysis (fig. 1.5.5C). These growth charts are invaluable in monitoring crop development and adjusting environmental factors and cultural practices during the growing season. For example, if one seed lot shows slow growth compared to the target growth curve, the nitrogen fertilization rate can be increased to bring it up to expectations (fig. 1.5.5A). Without these charts, growth problems are difficult to identi fy early enough to be able to correct them. Accumulating growth records over several crops allows the nursery manager to reasonably predict seedling growth. Growth curves are the basis for refining growing schedules and predicting the time and resources necessary to produce the target seedling. The effects of unusual weather or other cultural factors on seedling quality or delivery time of a crop can also be projected.



Towards the end of the growing season, distribution curves of height and caliper can be used to illustrate how well a particular crop meets its target specifications. Then, the **grading (culling) standards** can be set based on the target seedling dimensions and the ability to the crop to meet these expectations. For shoot height, the **shippable seedlings** are usually clustered in a normal distribution around the target specification, with the culls distributed in both tails of the curve below the minimum and above the maximum height standards (fig. 1.5.6A).

The situation for caliper is different, however. Customers prefer seedlings with relatively large stem diameters and so will accept larger caliper stock as long as it does not exceed the maximum height standards. Therefore, seedlings are only graded to a minimum standard, and so for caliper, cull seedlings only occur on the small end of the curve (fig. 1.5.6B). Grading specifications will vary with species and stock type because larger seedlings are possible with larger containers and longer crop cycles (table 1.5.4). Because each growing season is a



B

Figure 1.5.5—*Graphing growth curves of height* **(A)**, *caliper, and dry weight* **(B)** *helps nursery managers monitor their crops in relation to their target seedling response. Computer programs make graphing of growth data and comparisons easy* **(C)**. *(A & C, courtesy of University of Idaho Forest Research Nursery, B, from Rose and others 1990.)*

C

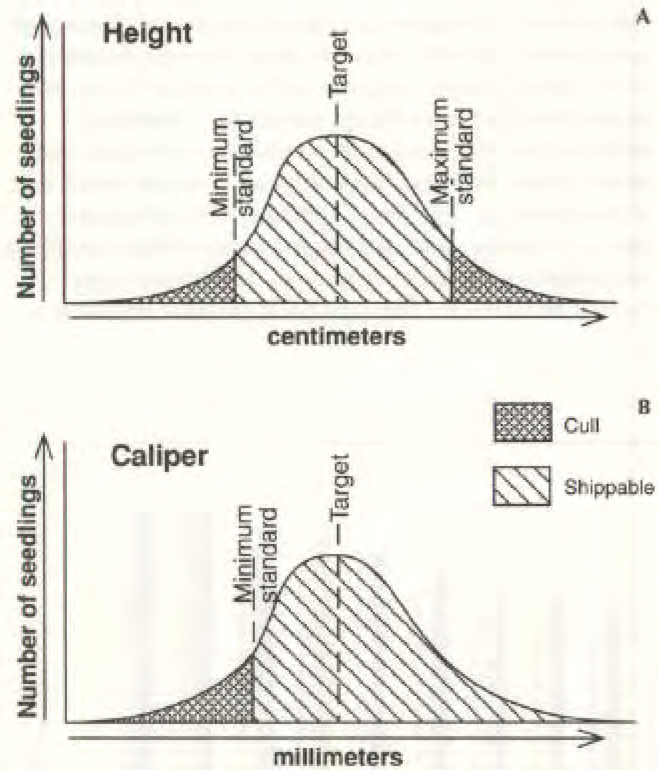


Figure 1.5.6—*Shippable seedlings are typically distributed around the target dimensions in a normal curve. For shoot height* **(A)**, *seedlings are culled below the minimum height standard or above the maximum standard; for caliper* **(B)**, *seedlings are usually only culled below the minimum standard.*

little different, the grading standards often have to be adjusted in negotiations between the nursery manager and the seedling buyer.

Sample size. The number of seedlings to be measured is usually a matter of convenience, although for the data to be statistically valid, the sample size should be determined by the following formula (Day *1979):*

$$X=S^2t^2/AE^2$$

where X = the required number of seedlings
S = the standard deviation
t = Student's t-value
AE = the allowable error

The required number of samples varies with species, type of propagation environment, and measurement parameter (table *1.5.4).* For a crop of white spruce—(*Picea glauca* (Moench) Voss)—and black spruce in eastern Canada, a sample size of *15* to *25* seedlings per seedlot would be sufficient when measuring height and caliper, but the number increased dramatically to over *60* to *90* samples if seedling weight was the parameter (Hallett *1982).* Obviously, this sample size is too large to be practical, but dry weights can be quite accurately predicted from caliper and height measurements using regression analysis. Regression equations must be determined for each species and nursery but, once calculated, give the nursery manager an easy-to-estimate ovendry weight without destructive sampling.

Table 1.5.4—*The required sample size can be statistically determined and varies with species and propagation environment**

Species and location	No. seedlings	Required sample size		
		Height	Caliper	Total seedling ovendry weight
White spruce				
A	180	26	16	89
B	180	21	16	74
C	180	20	17	76
D	180	17	16	77
Total	720	15	16	81
Black spruce				
E	180	20	18	82
F	180	21	19	81
G	180	12	14	61
H	180	16	12	79
Total	720	21	18	83

* Calculated with an allowable error of 10% and a 95% probability level.
Source: modified from Hallett (1982).

1.5.5 Nursery Problem Sowing

One of the most important aspects of nursery management is solving the day-to-day problems that come up. Although previous experience is the best weapon, even novice nursery managers can become proficient problem solvers by being prepared and following a set procedure (Landis 1984). Atypical problem solving procedures consists of five steps (fig. 1.5.7):

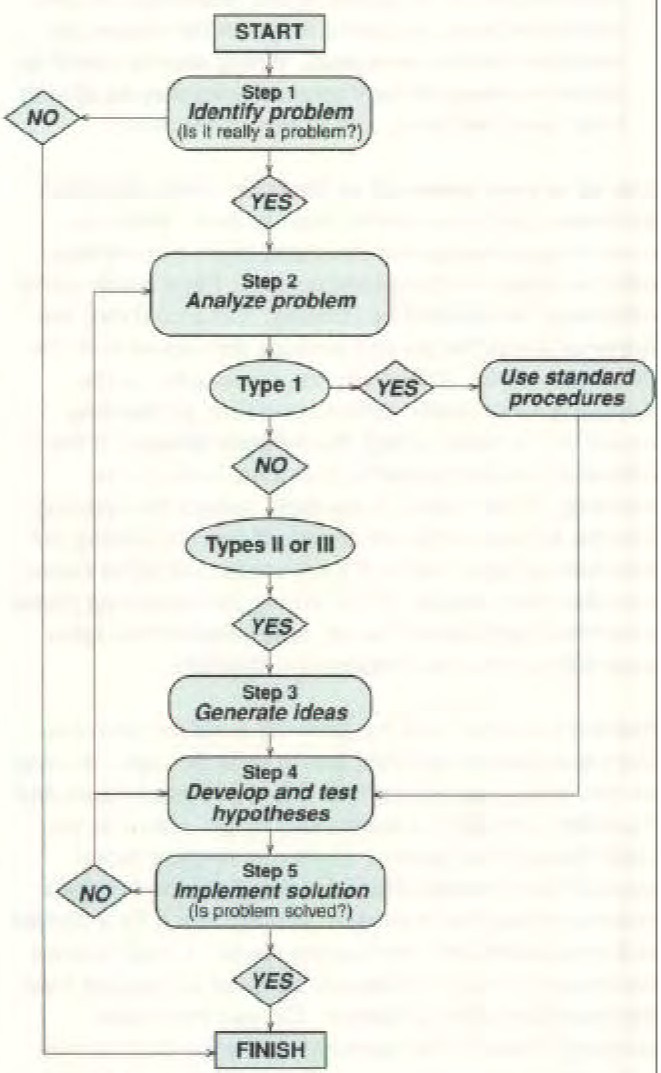


Figure 1.5.7—*Problem solving should be approached with a systematic process (Landis 1984).*

1. **Identifying the problem—**Problem identification requires knowledge and experience. In the early stages, however, many problems go unnoticed until the situation reaches a critical level. Nursery managers should make regular inspections of the crop and train their staff to be alert to possible problems.
2. **Analyzing the problem—**Efficient problem analysis begins with an accurate description of this situation, both what the problem is and what it is not. Try to observe with an open mind and to separate perceived problems from real ones.
3. **Generating ideas—**Even though new managers think that their situation is unique, the odds are that some one has faced this problem before. Information can be gathered from the nursery staff, other nurseries, and the published literature.
4. **Developing and testing the hypothesis—**Managers must keep an open mind during the evaluation process and consider all aspects of the situation. Nursery problems usually require prompt action, and so many decisions will have to be made on incomplete evidence.
5. **Implementing a solution—**All nurseries have constraints in funding, time, and personnel, and so managers must decide what solutions are practical under their own unique situation. A follow-up is required to make sure that the problem is really solved and so, whenever a corrective treatment is applied, control plots should always be left for comparison.

Nursery managers can become better problem solvers by visiting other nurseries, attending workshops and training sessions, and keeping up with the latest published literature (fig. 1.5.8).

Figure 1.5.8—*Novice nursery managers can gain valuable experience by visiting other nurseries, and discussing cultural regimes and production problems.*

1.5.5.1 Principles of crisis management

A crisis is a particularly severe problem that demands immediate attention. Some crises require corrective action within minutes; others may require a response on a time scale of hours to several days. The nursery manager must size up each situation and react accordingly. Overreacting can be just as harmful as not acting quickly enough, not only for the welfare of the crop, but also for the smooth running of the whole nursery. The timing of a crisis can never be predicted but, with proper management, the frequency of occurrence and the damage done can be minimized.

***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 nursery facility has certain standard operating procedures that represent the best information available. Therefore, changes in cultural procedures, equipment settings, or timing should be made with caution. A record of the change should be noted in the nursery log, and workers who will be affected should be informed.

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. Those items that may be needed in an emergency should be labeled to indicate where they go or what they fit. As these items are used, they must be restocked promptly.

Because the nursery manager cannot be available all of the time, more than one person should know what to do in an emergency. The following tips should be discussed with all responsible personnel and documented in the nursery operating manual:

1. **What conditions are normal—**This is necessary to recognize an abnormal situation that requires correction.
2. **What conditions require immediate attention and what can wait—**No one likes to be called out of bed in the middle of the night to fix something that could have waited until morning, but it is worse to be complacent about something that should be fixed immediately.
3. **How to fix what is wrong—**Everyone involved should be familiar with critical nursery repair procedures.
4. **Where the tools and spare parts are kept—**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—**Emergency phone numbers should be posted in the headhouse or other central location, including those for the electrician and other service personnel. It may also be useful to list the numbers of local growers who may be able to help, pest specialists, and nursery consultants.

***Use all of your senses all of the time*.** Many potential problems can be averted by staying alert. When approaching a propagation structure, 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 perhaps 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 covering. If the plastic is too tight, reduce the opening into the blower or blower speed. If you are visiting the structure at night, notice if the photoperiod lights come on when they should. If it is during the hardening phase, when the lights should be off, note whether any lights were left on near the propagation structure.

Make it a point to visit the growing areas on your way from one place to another, just to walk through. As soon as you enter, your senses will tell you if temperature and humidity are within a reasonable range. Listen as you walk through the nursery. 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. Loose or worn belts may be noisy and should be fixed so you can hear the sounds of other problems. Do you hear water running? Should it be running? Is the furnace running smoothly, or is combustion pulsing or uneven? Carbon dioxide generators make a high-pitched sound that is normal.

Use your nose. Does the air in the propagation structure smell as it should? Is the furnace properly tuned, or is combustion not complete? Has the house just been fumigated? If so, are the warning signs posted on the doors? Most nursery chemicals can be identified by their characteristic odor. Likewise, overheated or arcing motors have a distinctive smell. Some experienced growers are even able to detect the faint smell of gray mold, and so may be able to avert a disease outbreak.

Examine the seedlings closely. Is the morphology of the shoot correct and normal for their current stage of growth? In particular, watch for signs of premature bud set. Any signs of nutrient deficiencies or toxicities? Pick up a tray or block container. Does the weight feel about right? Is the root plug moisture at or close to field capacity? Are the roots healthy, or is there evidence of root rot? Is the foliage healthy, or are there signs of abnormal symptoms? Are insects present (on hardwoods look on the underside of the leaf)? If a problem develops later, it helps to know what potential pests have been in the growing area so that control treatment can be started immediately.

Each nursery is a little different, and it is hard to be specific about everything to look for. Nursery managers should make a checklist to use as a training aid to teach their staff how to be alert and what to look for, but there is no substitute for direct experience.

***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 knowing what constitutes the normal condition and being alert enough to recognize when something is out of place. Alarm devices can be very useful to call for help when no one is present. There should be a checklist posted in the headhouse or other central location indicating what the environmental control settings are, the condition of the crop, and other information necessary to help diagnose an abnormal situation.

Keeping a daily diary or log is also a good idea. It will help determine what is normal, and where there are departures from normal, it may give clues as to what is wrong. Check the hygrothermograph, environmental control computers, and other monitoring equipment regularly (at least daily) and record observations in the daily log. Weekly reviews of the log may help detect subtle problems or changes. Computer-based expert systems are now available that will not only collect and display the data, but analyze it and tell the grower when a problem occurs, and even predict future problems and recommend solutions.

The following examples demonstrate how hygrothermograph charts or computer data records can be used to solve problems:

- **The charts indicate that, although temperature control is satisfactory in the morning and late afternoon, it exceeds the setpoint during the hottest part of the day.** This trend indicates inadequate cooling capacity. Check all fans, evaporation pads, water pump, and vents for proper operation. If everything is working properly, then perhaps you are experiencing 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.
- **On a sunny day, the records show an abrupt rise in greenhouse temperature.** The most frequent cause is a power failure. On hot sunny days, these peak temperatures can be very damaging and call for immediate action (see section 1.5.5.2). Excessive temperature should trigger an alarm that will summon help but, without the temperature records, it would be impossible to determine whether damaging temperatures were reached and for how long.
- **The temperature falls well below the setpoint before the heater comes on.** This pattern is typical of a malfunctioning temperature sensor such as 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, the thermostat must be replaced.
- **Temperatures fluctuate widely around the setpoint.** This can be caused by several things. Are the temperature sensors in direct line with the heater or is heat circulation blocked in some way? If so, the sensors must be moved and the circulation problem corrected. This pattern can also be caused by a thermostat with too great a differential, either because it is improperly set or because it is wearing out. The thermostat must be readjusted or replaced.

1.5.5.2 Temperature crises

When the temperature becomes either too hot or too cold, succulent seedlings can be damaged within a very short time and so immediate action is required. Even in fully controlled propagation structures, failure of environmental control equipment for just a short period of time can cause seedling injury (fig. 1.5.9). Because emergency measures are sometimes damaging in themselves, the nursery manager must decide in each instance how fast to react and what actions represent the best alternative.

Unusual cold. There are two types of winter injury. When the temperature falls below the seedlings' cold tolerance, the resulting injury is from low temperature. When the tops of seedlings are exposed while the root systems are continuously frozen, the resulting injury is from desiccation. Nursery managers must determine which type of cold injury is most threatening because the type of response can be different.

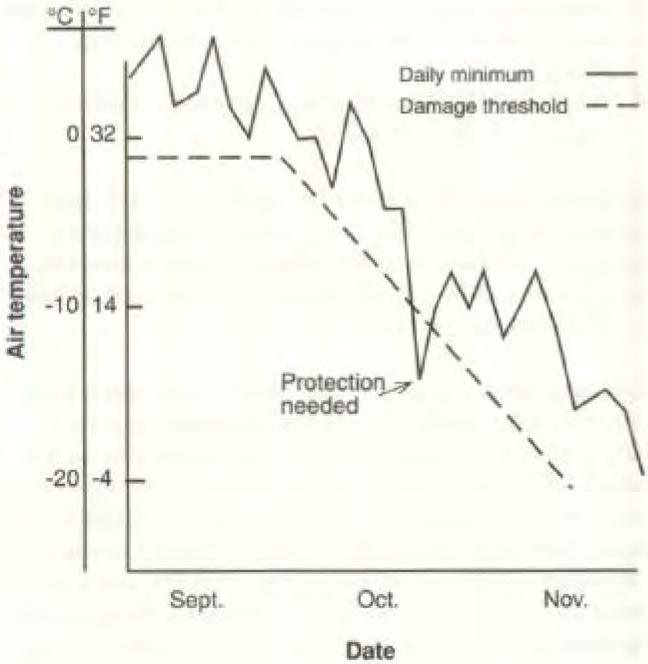
Figure 1.5.9—*Growers must remain alert to the possible failure of environmental control equipment, such as this vent that stuck open during cold weather, because seedling injury can occur quickly.*

Desiccation injury. In open growing compounds or shadehouses, physically covering the seedlings may be the best option for avoiding desiccation injury. Probably the cheapest covering that can be deployed quickly is polyethylene, preferably white, but clear or black will do in an emergency. Other, more effective plastic mesh coverings are also available, but they are more expensive. After the temperature has risen above the damage threshold, the covering should be removed promptly, especially in direct sunshine, because overheating can become a problem.

Covering the seedlings can also protect against cold injury, especially if insulated foam plastic sheets are used.

Frost protection with irrigation. Because water releases heat as it freezes, succulent seedlings can be protected from cold injury with irrigation under certain conditions. First, the need for protection depends on the seedlings' cold hardiness, which gradually increases during the late summer and fall as the crop goes into dormancy (fig. 1.5.10A). The dehardening curve in the late winter and early spring is much steeper, however, because plants lose their hardiness as soon as temperatures begin to warm. Therefore, before frost protection with irrigation is begun, the nursery manager should have an idea of how cold hardy the seedlings are. A well-designed growing schedule will allow time for an adequate hardening period and periodic cold hardiness tests can show how much cold the crops can tolerate at the moment and the rate at which they are hardening. The weather station at the nursery should be correlated with the local official weather station so that minimum temperatures at the nursery can be predicted from local forecasts. If the predicted minimum temperature is below the damage threshold for seedlings, then frost protection is warranted.

The next requirement is a proper irrigation system. A system designed for providing normal irrigation water demand may not be adequate for frost protection. An irrigation system designed for frost protection must supply a uniform, almost continuous film of water to the seedling foliage because the protection exists only as long as water continues to freeze and release heat. Boom irrigation systems may not move fast enough, and ice buildup would be a problem. Sprinkler irrigation systems designed to provide frost protection should include the following considerations (Pair and others 1983):



A

B

Figure 1.5.10—*Emergency protection from cold is needed only when the expected minimum temperature will be below the threshold of damage for the crop* **(A)**. *Seedlings can be frost protected with irrigation but growers must know the cold tolerance of their crops as well as current and forecasted weather conditions. In this crop of plug transplants, seedlings were damaged when an irrigation pump failed after wetting only those seedlings beyond the nozzle* **(B)**.

1. Sprinkler nozzles should have relatively small-diameter orifices, ranging from 1.6 to 4.8 mm (1/16 to 3/16 in).
2. Metal sprinklers are generally preferred because of the tendency for ice to build up on plastic heads.
3. The sprinkler heads should rotate at least one revolution per minute.
4. Sprinklers should not be spaced any further than 50% of their effective diameter.
5. Irrigation application rates of 2.5 mm (0.1 in) per hour have been effective under low wind conditions. At this rate, about 421 liters/min of water is required to cover 1 hectare of seedlings (= 45 gal/min ac).

Even with the proper irrigation system, the nursery manager must know when to start applying water for frost protection. Weather measurements with a psy-chrometer (wet bulb and dry bulb temperatures) are absolutely essential. The wet bulb temperature is important because, under low relative humidity conditions, the evaporative cooling effect can actually drive plant temperature lower than the air temperature when water first contacts the plant tissue (fig. 1.5.1 OB). Wind can cause the same effect, and so knowledge of wind speed must also be factored into the decision making process. Nursery managers who anticipate using irrigation for frost protection should become better informed by reading technical literature, for example, Began (1988) and section 4.2.7.4 in volume four of this series.

This is a good example of how the proper information, experience, and equipment are necessary to respond to crises. The inexperienced nursery manager who turns on the irrigation system for frost protection without having the necessary information can actually cause more damage than if nothing were done. (Symptoms and management of cold injury are covered in section 5.1.6 of volume five, and cold hardiness testing will be discussed in volume six.)

Heater failure. When it is very cold outside and the heating system fails, temperatures in a double-wall polyethylene greenhouse can fall at the rate of 0.5 °C (1 °F) per minute. This allows only 20 minutes between 10 °C (50 °F), which is a typical alarm temperature setting, and freezing. If the plant material is succulent, immediate action is required because even if the seedlings survive freezing, they may be thrown into irreversible dormancy. Much depends on the relative hardiness of the crop. If the seedlings have begun the hardening process, the potential for imposing dormancy is immaterial and, 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, shut off everything that is not essential in order not to overload the generator, and then start the emergency generator.
- **Heater off-Check** the fuel supply first. If it is adequate, check the furnace as 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, turn off the circuit breaker, 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 will not start, replace the motor. If the motor runs but there is little or no air flow, tighten or replace the belts. If it is direct drive, check set screws on the shaft. 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 will not stay lit, clean or replace the electric eye, faulty stack switch, or high limit sensor.
- **Cooling fan on-Check** for a stuck thermostat or the wrong setting. Shut fan off at circuit breaker if necessary.
- **Vents stuck open-Close** them manually and then oil them. Check for stuck thermostat or the wrong setting.
- **Hole in propagation structure covering-Patch or** cover seedlings with plastic.

If the heating system cannot be repaired quickly, then portable heaters must be moved into the propagation structure. Propane heaters should be used if possible because oil-burning models produce fumes that are toxic to both humans and plants.

Excessive heat. Unusually hot weather can cause heat injury in open compounds but the situation is particularly critical in propagation structures, especially in the spring when solar input is high and when young seedlings are succulent (fig. 1.5.11A). High heat levels can cause both direct and indirect injury. Intense sunlight can injure seedling stem tissue (fig. 1.5.11 B), and the resultant heat also increases transpirational losses, which can lead to indirect drought injury. (See section 5.1.5.3 in volume five of this series for symptoms and help in diagnosis.)

Excessive heat during the **rapid growth phase** is a relatively simple problem because immediate irrigation produces transpirational cooling, especially in low-humidity climates. The risk of damage from emergency irrigation is low, although some fertilizer may be leached out of the growing medium. Unseasonally warm temperatures are a more serious problem during the **hardening phase** or in unsheltered storage, however, because seedling dormancy may be affected. In the fall, temperatures above 10 °C (50 °F) can delay and possibly reverse hardening. In the late winter and spring, temperatures above 5 °C (40 °F) are likely to cause irreversible dehardening. Generally, these unseasonal episodes do not last long enough to cause problems, but if loss of seedling dormancy in the spring is a chronic problem, then refrigerated storage is the best solution.

An overheated greenhouse demands prompt action. The usual cause is a cooling system failure, and temperatures on a hot sunny day can rise at the rate of 1 °C (0.5 °F) per minute. Manually open all of the doors and vents in propagation structures. In a small structure, this can be quite effective, but it is of limited value in a large one. If a power outage has occurred, shut off everything that is not essential and switch to the emergency generator. 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

B

Figure 1.5.11—*Heat or drought injury can happen in a matter of a few hours in small-volume containers* **(A)**, *especially when seedlings are exposed to direct sunlight* **(B)**.

Usually does not result in a crisis, but it should still be corrected promptly. This also illustrates the value of redundancy designed into the system. If there is only one fan and it fails, the whole cooling system is down. If there are three fans and one fails, two-thirds of the system is still operating.

1.5.5.3 Fire

Although container nurseries are generally low-hazard areas, fires can be devastating in propagation structures and other nursery buildings. Wood frame structures and those covered with fiberglass are particularly susceptible (Hanan and others 1978). If a wooden-framed double-poly greenhouse burns, heat builds up near the roof, the plastic melts, opens a hole, and releases the heat, so that the fires 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 rapidly.

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. Otherwise, the cooling fans will come on in response to the rise in temperature and quickly spread the fire throughout the house. Properly located and labeled disconnect switches for the fans would be a good precaution. Unfortunately, most fires in the propagation structure are above what would be wetted by the irrigation system but irrigating may still save part of the crop. Most containers are made of polystyrene or polyethylene plastic, both of which burn vigorously once ignited and so the potential fire hazard should be kept in mind where the empty containers are stored. Regular fire inspections and fire drills should be a part of every nursery's safety program (Hanan and others 1978).

1.5.5.4 Water crises

Flooding. Properly located facilities should not be subject to flooding from natural causes. However, if a flood can be anticipated, shut off all electrical equipment in the nursery and move equipment and anything else that could be damaged. If there is enough time, the perimeter of the nursery can be diked and then bailed; if not, about all that can be done is to wait for the water to subside, and then clean up.

Internal flooding is usually caused by a broken water line. Immediately shut off the water main and then repair the break. Flooding and its adverse consequences can be minimized and repair work simplified by dividing up the water system with strategically located valves that are labeled and easy to reach. Then, if an irrigation line breaks, it can be shutoff without affecting the water supply to the rest of the nursery, especially to critical uses such as the evaporative cooling system.

Lack of water*.* A complete loss of water pressure can be caused by pump problems, or some other catastrophe with the water supply system. When water lines break or pumps quit working, the problem and its solution immediately become apparent. Another possibility is a malfunction of the automatic irrigation controller. Depending on container size and ambient weather conditions, seedlings can do without irrigation for a few hours except when water is needed immediately during a temperature crisis. If there is water available in the greenhouse but no way to apply it automatically, then the seedlings can be watered by hand. Emergency phone numbers for plumbers, electricians, and pump specialists should be posted in the headhouse or other easily accessible location.

Irregular seedling growth patterns due to uneven distribution of water are common but can be difficult to diagnose. Although usually caused by a poorly designed irrigation system, even the best systems must be watched for plugged or malfunctioning sprinklers. (Monitoring the water in containers is discussed in section *4.2.6* and tests of irrigation efficiency systems are covered in section *4.2.3.5* of volume four of this series.)

1.5.5.5 Cultural problems

In contrast to equipment malfunction or severe weather, cultural problems develop more slowly, require closer observation to detect at an early stage, and rarely require immediate attention. However, cultural problems are just as important, and it is often harder to find their cause and correct them. In most cases, however, they can be prevented with a proper scheduling and cultural tech piques. The following discussion is intended to help nursery managers diagnose the cause of cultural problems. (A more detailed stepwise diagnosis procedure and damage keys can be found in volume five of this series.)

Delayed or erratic germination*.* Seed dormancy problems often occur in a random pattern, with seedlings of various sizes interspersed with empty cells (fig. *1.5.12).* Germination problems must be identified and corrected promptly or valuable production area will be lost for the rest of the crop cycle.

Germination tests can give the nursery manager an idea of what the germination rate and total germination should be for a particular seed lot. These tests can be performed by seed testing laboratories for a fee, or they can be conducted at the nursery. If time is available before operational sowing, a simple test can be run in which a series of containers can be sown with one to several seeds per cavity. The speed of emergence and the proper seed sowing density can be determined for each seed lot or species within a month.

Regardless of species, seedling emergence should be evident in operational sowings within *4* weeks if the seed has been tested and found viable, given the appropriate pregermination treatment, and if good sanitation procedures are followed. If emergence is slow or absent after several weeks, scrape some of the seed covering away gently and look for seeds. Missing seed indicates a seeder problem or animal predation. (See section *5.1.3* in volume five of this series.) Remove a few seeds, cut them in half, and examine with a hand lens. If the interior tissues are dark, then fungal decay is a possibility; if they are cream-colored and otherwise healthy, then a seed dormancy problem exists. Check recommended germination temperature against current temperature records. Examine the depth of the seed covering. If too deep, remove some of the seed covering; if too shallow, increase irrigation frequency.

In the case of partial germination, resowing or transplanting may be justified if the projected number of empty cells is greater than the oversowing factor. This must be done immediately, however, because resown seedlings or transplants may be overtopped and suppressed by their neighbors.

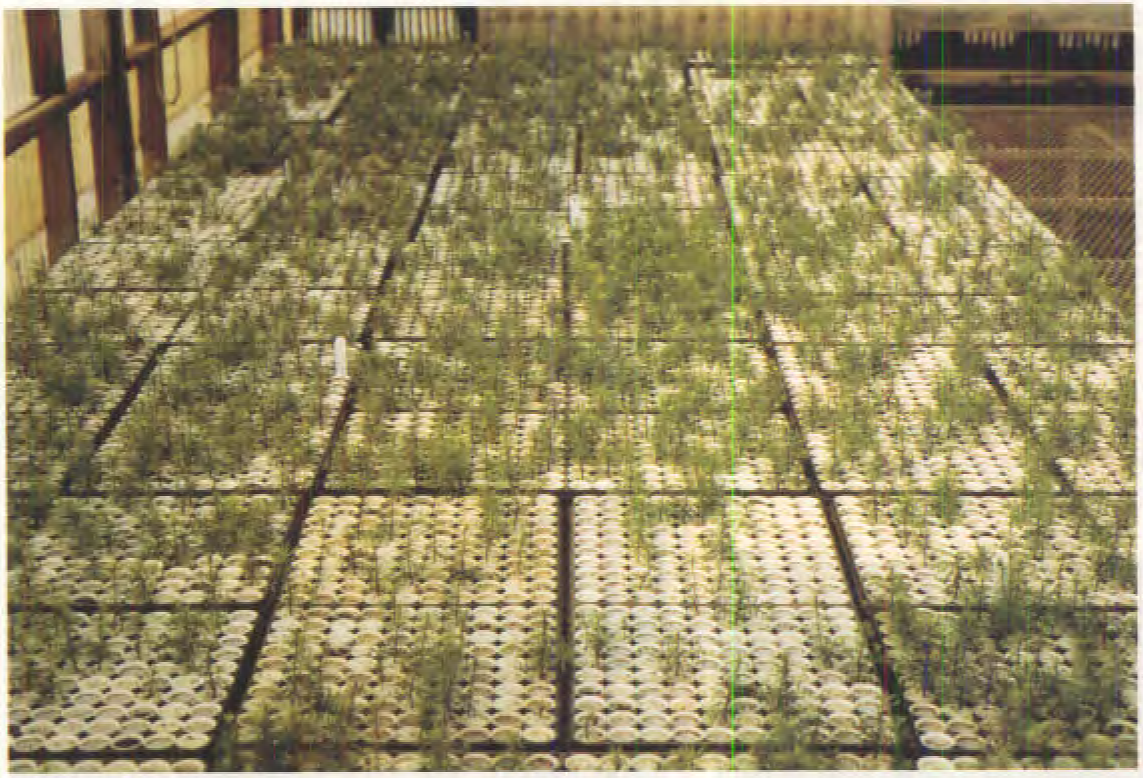


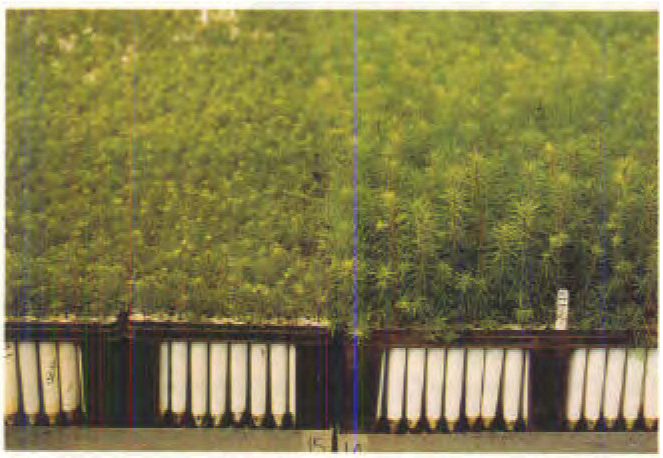
Figure 1.5.12—*Poor seed quality causes mosaic growth patterns due to irregular germination rates or seedborne disease, resulting in poor stand density and growing space utilization.*

Growth rate behind schedule. In spite of the best efforts to control growing conditions, weather differences from one year to the next will cause a corresponding variation in crop growth. Periodic measurements of rate of germination, seedling size, budset, and cold hardiness are important to compare one crop with the next. By developing a baseline of growth and development as a function of time, the growth of subsequent crops can be more accurately predicted. Previous growth records are invaluable in identifying and correcting growth problems (fig. 1.5.5A). The earlier a potential problem can be detected, the easier it is to correct it.

Be aware that seeds of the same species but from different sources can exhibit radically different growth patterns and may have to be cultured entirely differently. Species with wide geographic distributions, such as Douglas-fir *[(Pseudotsuga menziesii* (Mirb.) Franco] and ponderosa pine *(Pinus ponderosa* Dougl. ex Laws.), contain ecotypes that may react more like different species than seedlings of the same genus. For example, high-elevation Douglas-fir seedlings from Montana will grow much more slowly and set bud earlier than the same species from a coastal Washington seed source (fig. 1.5.13A). Coastal ecotypes can be grown without photoperiod lighting, whereas those from interior, high-elevation sources will set bud soon after germination without proper photoperiod control. A fertilization trial with six seed sources of Douglas-fir (fig. 1.5.1313) showed that coastal Washington sources could be grown to target height specifications with only 100 ppm nitrogen (N), whereas more interior sources from eastern Washington, Idaho, and Montana generally required at least 150 ppm N (Thompson 1994).

Premature dormancy. Seedlings that set terminal buds and stop shoot growth prematurely typically occur in an irregular pattern, and often bud set may be sudden (fig. 1.5.14A). Dormancy problems are usually a response to some environmental stress, so the first step is to check all of the environmental controls for proper setting and function. Examine hygrothermograph charts, computer weather records, and daily operating log for equipment malfunctions, abnormal weather events, or improper cultural procedures. If a specific cause can be found, correct the problem as quickly as possible, but often seedlings that have gone into premature dormancy are difficult to stimulate back to normal growth rates or the response may be variable (fig. 1.5.14B). If the cause is unknown, the following procedures can be tried in sequence:

1. Increase the photoperiod light intensity at night to 10 µmol/m²/sec (650 lux) and the duration of the light intervals to a ratio of 1 light period out of every 8 dark periods (see section 3.3.4 in volume three, chapter 3 of this series for more detailed information).
2. Increase the night temperature to 22 to 24 °C (72 to 75 °F).
3. Raise the nitrogen level in the nutrient solution. Most species can tolerate 300 ppm without adverse effects.
4. Spray with 50 ppm gibberellic acid.



A High-elevation PSME Low-elevation PSME

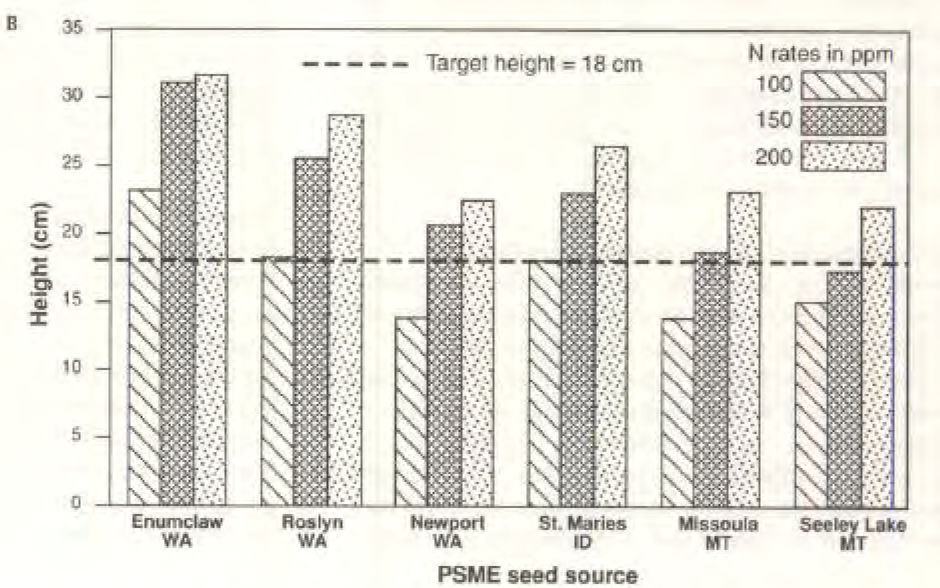


Figure 1.5.13—*Even ecotypes of the same species, such as these Douglas-fir seedlings (PSME) can exhibit radical variation in growth rate* **(A)** *and so seed sources may have to be cultured differently, such as supplying more nitrogen (N) fertilizer to slower growing seed sources* **(B)**. *(B, from Thompson 1994).*

Figure 1.5.14—*Premature bud set* **(A)** *or irregular bud break patterns* **(B)** *are typically caused by insufficient photoperiodic light intensity or other cultural problems related to daylength control.*

If none of these emergency measures works, then managers are left with either accepting a smaller seedling or allowing the crop to go through the dormancy cycle and shipping it with the next crop.

***Foliar symptoms*.** Abnormal foliage color can be caused by several different problems. Nursery managers should examine the seedling roots first, because many foliar symptoms are caused by root problems.

Wilting. Wilting is caused by the inability of the roots to replace moisture in the plant as fast as the foliage is losing it. The most common cause is lack of moisture in the root plug. If this is the case, the seedlings must be watered immediately. Sometimes wilting will occur on unseasonably hot, sunny days in otherwise healthy, well watered seedlings, especially after periods of cool cloudy weather. If this is the case, try increasing the humidity and decreasing peak day temperatures by brief bursts of irrigation. If the condition persists, then the irrigation procedures or schedule may have to be adjusted.

Wilting can also indicate problems with water uptake by the root system. A growing medium that is too fine or has been over compacted will have low aeration porosity and can easily become waterlogged. A waterlogged growing medium often promotes root rot. Under these conditions, wilting is often accompanied by chlorosis and stunted growth, which may be in a block pattern (see following sections). The only solution is to reduce the amount of irrigation at each watering, applying just enough water each time to force leachate out the bottom of the containers. The irrigation scheduling should also be adjusted, and the growing medium problem corrected during the next crop. (Growing media are discussed in volume two, and proper irrigation practices covered in volume four of this series.)

Chlorosis. Chlorosis is a reduction in the amount of chlorophyll present in the foliage and is a general symptom of many maladies. Careful observation of where the symptoms occur can yield important clues.

Chlorosis is a symptom of several mineral nutrient deficiencies including nitrogen, iron, magnesium, and sulfur, but the first two are the most common in container nurseries (fig. 1.5.15A). An examination of the symptom pattern, both on the seedling foliage and within the growing area, may be diagnostic (fig. 1.5.15B). If the damage is general or concentrated on the older foliage and is accompanied by stunting, suspect nitrogen deficiency. Iron deficiency symptoms are different in that only the new foliage is chlorotic. To confirm the diagnosis, check the pH and formulation of the nutrient solution and also check the pH of the growing medium. If an iron deficiency is suspected, pay particular attention to the pH levels and make sure that

A

B

Figure 1.5.15—*Chlorotic (yellow) foliage is a symptom that can be caused by many factors, but the pattern on the individual leaf* **(A)**, *and in the growing area can be diagnostic* **(B)**.

iron chelate fertilizers are being used. Chemical analyses of some symptomatic foliage are sometimes helpful, especially if they are compared to tests of healthy tissue. Compare the foliar nutrient levels to established standards. One quick check of the diagnosis is to apply a foliar fertilizer of the suspected deficient nutrient and observe whether the symptoms disappear within a week or two. (Mineral nutrient deficiency symptoms, foliage nutrient standards, and proper fertilization techniques are provided in volume four of this series.)

Spots. Chlorotic or necrotic spots on the seedling foliage or stem can be caused by several problems. Foliar spots can be caused by fungi, bacteria, and insects, and so these possibilities should be discounted first (see following section). Deficiencies of magnesium and calcium, and toxic levels of boron can be responsible, and managers should follow the advice in the previous section. If only the tips or margins of the foliage are chlorotic and particularly if necrotic tissue is present, then chemical damage should be suspected. Salt injury or pesticide damage can also cause these symptoms. Check the electrical conductivity level of the irrigation water first, then within the growing medium and from leachate. Air pollution is also a possibility but this should have been investigated during site selection. If the source of pollution is within the nursery itself, it can be eliminated. Sulfur dioxide is produced by burning high-sulfur fuels and the exhaust gases must be vented well away from the greenhouse. Check with the fuel supplier and if the carbon-to-sulfur ratio is less than 10,000:1, 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. Another source of internal air 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. (Proper fuel selection is discussed in section *3.1.4* in volume three, and air pollution symptoms discussed in *5.1.5.3* of volume five of this series.)

Determining the exact cause of cultural problems requires careful analysis and so inexperienced managers should consult with a nursery specialist.

Abnormal growth patterns. An important key to diagnosing cultural problems is to observe the spatial pattern in which the growth problem occurs.

Edge or breadloaf effect. Height growth is typically greater in the middle than it is at the edges of a bench or section of seedlings, and in extreme cases, the seedlings along the edge are also chlorotic (fig. *1.5.16).* If this pattern is pronounced, a profile view looks like 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. 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 root temperatures. The problem can be minimized by using white or light-colored containers. Styrofoam® containers are advantageous in this respect because of their insulating as well as light-reflecting qualities. Watering should be programmed to maintain adequate moisture in those edge containers subject to the most rapid drying. This means that the growing medium must be porous enough so the interior containers can tolerate the excess moisture they will receive. Maintenance of adequate humidity will also reduce the difference in water consumption between edge and interior cavities.

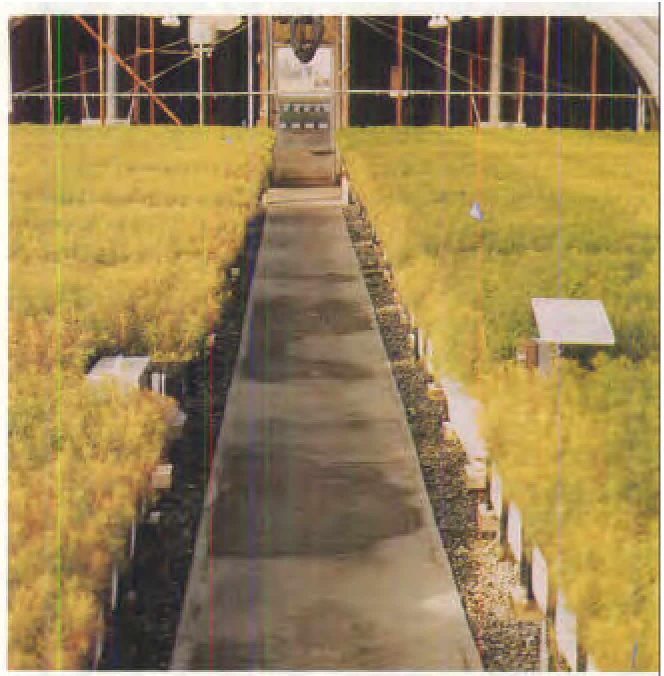


Figure 1.5.16—*Inadequate irrigation coverage and increased drying along the perimeter of the growing area causes a growth pattern called the "breadloaf effect."*

Rings or streaks. Chlorotic or stunted seedlings grouped in rings, circles, or streaks often indicate problems with irrigation uniformity. The watering pattern should be tested with a fixed grid of cups to determine whether the symptomatic seedlings are getting more or less water than the rest of the house. The situation can be compounded by high-salinity irrigation water or a growing medium composed of particles that are too fine in texture; in either case, the tolerance of the seedlings to water availability problems is reduced. The best solution is to redesign the irrigation system to provide more uniform water distribution. It may be possible to simply change to a nozzle that has better performance for the existing water pressure and spatial distribution. If this is impractical, a short-term solution is to hand-water the areas that are not getting enough. Or, if excess water runoff is not a problem, a coarse well-drained growing medium can be used and the duration of irrigation increased to make certain that all areas receive the proper amount of water. (Typical symptoms are illustrated in fig. 4.2.24, and proper irrigation system design is discussed in section 4.2.5 of volume four of this series.)

If the symptomatic seedlings vary in size and bud condition (fig. 1.5.14B), then the problem could be variable light intensity from the photoperiod light system. Seedlings that do not receive enough light intensity during the night can stop growing and set bud prematurely. This problem is particularly common with obliquely mounted light systems or overhead lamps of the wrong type or wattage. It may also only be obvious with certain species or seed lots, particularly those from high elevations or latitudes. The problem can be diagnosed by visiting the propagation area at night and measuring the light intensity in a grid pattern throughout the growing area. It may be possible to correct the problem by changing lamps; in extreme cases, however, the entire lighting system will have to be redesigned. (The symptoms are illustrated in figure 3.3.12, and the proper photoperiod lighting system design is discussed in section 3.3.4.5 of volume three in this series.)

Strips of symptomatic seedlings can also be caused by design problems in the growing area. For example, a bench that does not allow proper air pruning of the root system can cause irregular growth and even lead to root disease problems (fig. 1.5.15B).

Block pattern. If seedlings are completely absent from certain blocks of containers, suspect a sowing problem. Abnormal seedling growth patterns that vary between different blocks of containers can usually be traced to problems with the growing medium (fig. 1.5.17A). The problem can be either differences in porosity, uneven incorporation of chemical amendments, or poor container sterilization. The former can be caused by poor quality media or sloppy container-filling technique, especially if the containers are filled by hand. Some workers have a tendency to pack the growing media too tightly in the cells, causing porosity problems. Incorporation of slow-release fertilizer or other amendments can also cause differences in seedling growth between blocks of containers. For example, if too much dolomite has been incorporated into the growing medium of certain blocks, their seedlings will exhibit chlorosis or twisted needles (fig. 1.5.17B). These symptoms may be more common with certain species than others (Dumroese and others 1990). Another block pattern can be traced to older containers that have not been properly sterilized. Many root rot pathogens build up on residual growing media or roots that remain in the cells of the containers and infect the subsequent crop. This pattern can be particularly evident when crops are sown in a mixture of new and used containers. Better seedling growth in the new containers indicates a sterilization problem. (Growing media formulation is discussed in volume two, and container sterilization in section 5.1.7.2 of volume five of this series).

Mosaic pattern. A mosaic seedling growth pattern is one in which patches of normal seedlings are growing interspersed with patches of chlorotic, stunted, or otherwise abnormal seedlings. This syndrome is different from other abnormal growth patterns in that the patches of seedlings are relatively small in size and the pattern does not coincide with any obvious condition. One of the most common causes of mosaic growth patterns is uneven invasion of mycorrhizal fungi; this is commonly seen in bareroot nurseries, especially with crops that require vesicular-arbuscular mycorrhizae. Lack of mycorrhizae should not be a problem in container nurseries using the proper growing media and providing adequate fertilization, however.

A B

Figure 1.5.17—*Symptoms that occur in a block pattern* **(A)** *can be caused by root disease due to poor container sterilization, or by poor-quality growing media. For example, improper mixing of dolomitic limestone in the media can cause shoot tips with stunted, chlorotic, or curled ("clutching") needles* **(B).**

A B

Figure 1.5.18—*Chlorosis of new foliage* **(A)***, a symptom of a deficiency of iron or other micronutrients, is frequently caused by a build-up of salts in the growing medium due to improper leaching* **(B)**.

A more common cause of mosaic growth patterns in container seedlings can be caused by irrigation water that is high in pH or in soluble salts. Either of these conditions should have been detected during site selection but salts can also build up in the growing medium under poor irrigation practices. Often the seedlings are chlorotic; in the case of iron deficiency, the younger foliage is yellow while the older foliage remains green (fig. 1.5.18A). The situation can be easily remedied with special chelate fertilizers and by making certain that enough water is applied each irrigation so that the soluble salts leach down and out of the container (fig. 1.5.18B).

Random pattern. Sometimes, single seedlings that are distributed randomly throughout the propagation area exhibit disease symptoms or some type of abnormal growth (fig. 1.5.19A). Random distribution growth patterns are often caused by seed problems, and these can be either genetic or pathogenic in nature. For example, white albino germinants are occasionally found scattered randomly in some seed lots (fig. 1.5.19B). Seed-borne pathogens also affect random individuals and some seed lots are affected more than others. Because insects are highly mobile and often only attack one seedling at a time, insect damage is often found to be randomly distributed throughout the propagation area (fig. 1.5.19C).

Pest problems. The ideal propagation environment in container nurseries also leads to problems with pests, including fungal pathogens and insects.

Pest exclusion is one of the benefits of growing seedlings in sterile growing media and containers because all of the common fungal problems associated with native soil are eliminated. Fungi can be introduced on dirty containers and seed coats and through the irrigation water, however. Container nursery managers must remain particularly vigilant because the ideal propagation environment is also conducive to fungal growth. The mycelia or fruiting bodies of a fungus are sometimes visible on necrotic parts of the seedling, and these **signs** are necessary for the proper diagnosis and subsequent treatment of a disease. Growers must be able to distinguish between pathogenic and beneficial fungi, however. The fruiting bodies of mycorrhizal fungi can sometimes be seen on or in containers (fig. 1.5.20A), and some types of mycorrhizae can be seen on the seedling root system (fig. 1 .5.20B). Root rots can be diagnosed by stripping away the outer cortex and looking for white healthy tissue; brown roots indicate disease (fig. 1.5.20C). Samples should be collected and sent to nursery pest specialist for culture and identification. Disease outbreaks can be suppressed with fungicides by preventing the fungus from spreading to healthy tissue, but they should not be expected to cure seedlings that have already been injured.

The growing area should be inspected regularly for the presence of insects. Do not wait for damage symptoms to appear. Insect damage often occurs near the perimeter of the propagation area, or at other times in a random pattern (fig. 1.5.19A&C). Examine the foliage thoroughly; some insects are so small and so well camouflaged that they can easily be missed. Insect pests are also mobile and many hide during daylight hours, and so the propagation area should occasionally be inspected at night. Yellow or blue sticky cards and pheromone traps can help detect the presence and population levels of some insect pests. Proper identification is important; for example, harmless shore flies are almost identical to harmful fungus gnats. 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 of broadleaf seedlings during the rapid growth phase but are of less consequence during the hardening phase when the leaves are about to abscise anyway.

Diagnosing nursery pest problems requires experience as well as the proper knowledge and so new nursery managers should contact surrounding nurseries to see if they have had similar problems, or contact a professional nursery pest specialist. (See section 5.1.2 in volume five of this series for more help in pest diagnosis.)

Figure 1.5.19—*Random distribution of symptomatic seedlings* **(A)** *can be caused by seedborne fungi, genetic differences between individuals* **(B)**, *or insect pests that attack single seedlings* **(C)**.

Figure 1.5.20—*Growers must be able to distinguish beneficial organisms such as mycorrhizal fungal fruiting bodies* **(A)**, *and mycorrhizal roots* **(B)** *from brown, diseased roots* **(C)**.

1.5.6 Customer Relations

The importance of good customer relations cannot be overemphasized. The old adage "the customer is always right" should be part of the management philosophy of any nursery. Keep your customers involved in the development of the crop. If germination rates are low for a particular seed lot, notify the customer immediately because it may be possible to resow or otherwise correct the problem. Slow seedling growth, pest damage, or any cultural problem that will delay seedling delivery, affect the number of shippable seedlings, or that may require adjusting the grading standards should also be discussed with the customer when they are first noticed. There is nothing more irritating to a customer than unpleasant surprises at delivery time. By then, customers have already made a major investment in site preparation and plans for outplanting that may be lost if the proper number or quality of seedlings changes. Customers will be more understanding and sympathetic to major problems if they are kept informed of the condition of their seedlings throughout the growing cycle. Then, they will have time to adjust their planting programs. Inviting clients to view their seedlings is a good way to make them more knowledgeable about nursery culture, and also is a good time to discuss crop development and seedling grading standards. The key is to give everyone involved as much lead time as possible to make the necessary adjustments. There is plenty of competition in the container tree nursery business and frustrated customers may just decide to go elsewhere for their seedlings.

1.5.7 Summary

The final aspect of nursery development involves setting up the management system. There are several key aspects of every successful nursery: solid organization, professional personnel, a system of data collection and analysis, and an established system for solving problems. The management of a nursery must have a structured organization if it is to succeed, which ensures that responsibilities are assigned and that jobs get done. In small nurseries, the manager may also be the owner and may also perform all of these functions, but as the nursery increases in size and complexity, some of the tasks must be delegated to other personnel. Supervision requires special skills and new managers must be able to hire and keep good, productive employees. All nurseries should have a formal safety program and schedule regular safety meetings.

Each nursery should have a system for systematic collection and analysis of information of financial and production data as well as cultural records, including growing schedules, environmental conditions in the propagation area, and crop development records. Record keeping systems can be as simple as a daily log book or as detailed as a computer system that records and stores environmental data. Records of seedling growth rates are particularly useful for detecting growth problems early and for generating production trends for future crops. Communicating with customers is crucial, and the target seedling concept is a useful way to describe what type of seedling they expect, and for nursery managers to describe what they can realistically produce.

One of the most important aspects of nursery management is solving the day-to-day problems. Nursery managers can become better problem solvers by visiting other nurseries, attending workshops and training sessions, and keeping up with the latest published literature. Many crises are caused by equipment failure or severe weather, and although the timing of a crisis can never be predicted, the frequency of occurrence and the damage done can be minimized with proper management. In contrast to equipment malfunction or severe weather, cultural problems develop more slowly and rarely require immediate attention. However, they can usually be prevented with proper scheduling and quick diagnosis.

Finally, nursery managers must always keep in mind that their seedlings belong to the customer, who should be kept informed of any developments during the growing season. Nurseries must involve the customer in critical decisions so that there are no surprises at the time of seedling delivery.

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