The Container Tree Nursery Manual

Volume Five
The Biological Component: Nursery Pests and Mycorrhizae

Chapter 1
Disease and Pest Management

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5.1.1 Introduction

Diseases and pests are a continuing source of concern to managers of container tree seedling nurseries, and successful managers are aware of the various factors that can harm their crops. Before we discuss these damaging agents and how to identify and manage them, it is necessary to discuss some of the common terms used to describe disease.

5.1.1.1 Definitions

Stress, injury, disease, and damage. In container nursery management, we are concerned with growing healthy seedlings that will survive and grow after outplanting. The concept of "health" infers an optimum condition of seedling physiology and morphology, and a stress is any factor detracting from that optimum state. Plant pathologists make a distinction between injury and disease based on the duration of the stress. An injury is the result of a single damaging event, such as a severe frost, that causes a temporary departure from the normal seedling condition. According to the classic definition of disease, a stress factor must cause a sustained negative effect on seedling growth before it can cause a disease. The distinction between injury and disease, therefore, is a matter of duration. The situation is confusing, however, because some stresses, such as weather or animal damage, can cause either injury or disease (fig. 5.1.1). Insect feeding on seedling foliage constitutes injury (a single "acute" event) whereas other insects, such as aphids, can cause disease because they feed slowly over an extended period (a "chronic" problem).

In the broadest definition of disease, any harmful stress, whether by living or nonliving agents, that interferes with efforts to produce healthy, vigorous seedlings within the standard nursery rotation can be considered a disease. A working definition of disease, therefore, is any sustained departure from the normal physiological or morphological condition that characterizes a *healthy* seedling. Damage differs from injury in that damage infers economic loss to the seedling resulting from either abiotic or biotic diseases.

Abiotic versus biotic stresses (pests). Stresses that can produce disease can be either biological (living) or environmental (nonliving); environmental stresses include mineral deficiencies, damaging weather events such as frosts, mechanical injury, and chemical damage (table 5.1.1). Many different biological stress agents can cause disease, including fungi, bacteria, viruses, animals, and even weeds, which can cause growth loss through competition for water, light, or mineral nutrients.

Table 5.1.1—*Diseases in container tree nurseries can be caused by either biotic pests or abiotic stress factors*

Biotic pests	Abiotic stress factors
Fungi	Heat
Bacteria	Cold
Viruses	Nutrient deficiency
Nematodes	Nutrient toxicity
Rodents	Drought
Birds	Excess water
Deer/elk	Toxic chemicals
Snails	Air pollution
Weeds	Mechanical injury
Algae	Low light
Moss	Excessive light
Liverworts	

The definition of a pest is subjective, however, because a biological stress becomes a pest when it has a negative effect on humans or their material goods. Pest-caused diseases interfere with the objectives in agricultural systems; in natural ecosystems there are no such things as pests (Bohmont 1983). In container nurseries, a pest can be defined as any biotic stress factor that can cause disease. Many nursery pests do not cause problems in natural forests, but in the controlled environment of a container seedling nursery, these normally innocuous organisms can cause disease (see section 5.1.1.2). The terms pest and pathogen are sometimes used synonymously, but the term pathogen is generally restricted to microorganisms that cause disease, such as fungi, bacteria, and viruses.

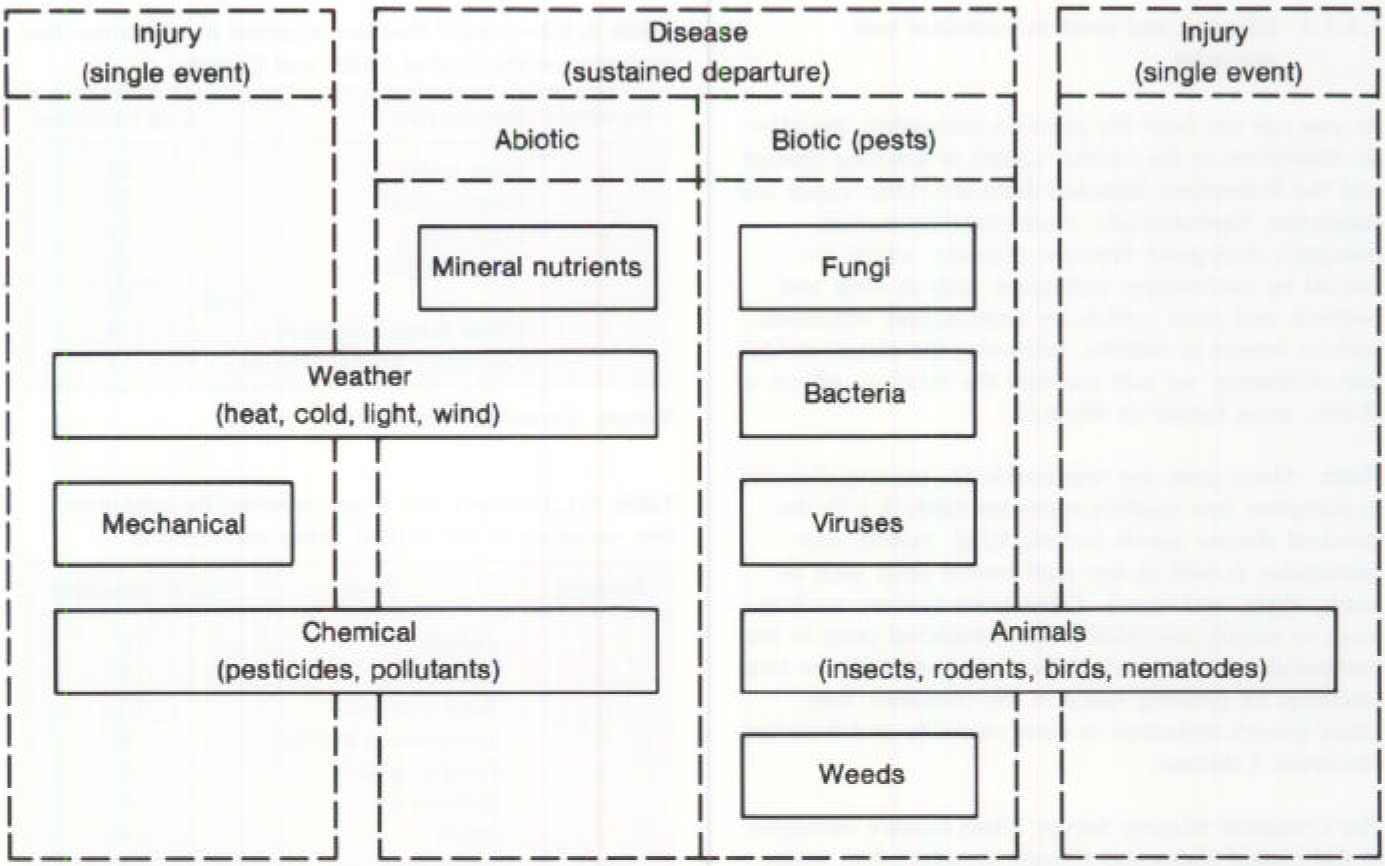


Figure 5.1.1—*Nursery diseases can be defined as a sustained departure from the normal seedling condition, whereas injuries are the result of a single damaging event. Some stress factors, such as weather or insects, can cause either injury or disease.*

Symptoms and signs. Although the term symptom is commonly used to describe both symptoms and signs, there is a particular, significant difference between the two terms in plant pathology. A symptom is a general term used to describe the physiological or morphological response of the host seedling to a stress factor. Disease symptoms can be obvious, such as foliar chlorosis, or more subtle, such as reduced growth. Symptoms are present in both biotic and abiotic disease. Signs are actual evidence of the causal organism and are therefore only found in biotic diseases. For example, the fungal mycelia that are sometimes evident on the diseased part of the seedling are signs of disease. Although both symptoms and signs are used in disease diagnosis, signs are more helpful because they implicate a specific organism or group of organisms, whereas symptoms may be caused by a variety of biotic or abiotic factors. (See section 5.1.1.3 for examples of symptoms and signs.)

Disease and pest problems. A disease or pest becomes a problem when it causes extensive economic loss. A pest that is causing insignificant losses is not generally considered to be a problem because the cost of treatment would exceed the economic benefit of control. The definition of a disease or pest problem, therefore, is subjective in that it involves an assessment of actual economic impact, or the potential for economic impact, by the nursery manager. The prudent manager will attempt to promptly identify all diseases and pests in the seedling crop before they reach damaging proportions.

5.1.1.2 Diseases and pests in container tree nurseries

As you can see from the previous discussion, the classic definitions of the various causes of seedling disease and the distinctions between them are rather vague and subjective. Operationally, most container nursery managers distinguish between diseases, which are caused by microscopic pathogens such as fungi and bacteria, and pests, which are macroscopic organisms such as insects or rodents. Following the classic definition of disease, we will consider the injurious effects of abiotic stress factors as diseases.

Pests. Many pests are responsible for causing diseases in container tree seedling nurseries (table 5.1.1): the standard disease agents include fungi, insects, and nematodes as-well as less well-known pests such as snails, algae, and weeds. Other plant species, such as moss or weeds, are usually not considered pests in the traditional sense but, when they compete with the crop seedlings for growing space in the container, they cause growth reduction or even mortality and therefore constitute a disease.

The Container Nursery Survey asked nursery managers in the United States and Canada to report their major disease and pest problems and rank them in order of importance. Interestingly, 14% of the respondents reported that they had experienced no major disease or pest problems; the remaining nurseries, however, listed 515 different problems. Fungal diseases ranked first, with 38% of the responses and, surprisingly, insect pests ranked a close second with 36%. Animal damage constituted the third major pest category, with 16%, and plant pests (including weeds, algae, mosses, and liverworts) the fourth, with 10% of the responses.

A breakdown of the fungal disease category from the Container Nursery Survey revealed four principal fungal diseases (table 5.1.2). This category was dominated by two diseases: grey mold (39%) and damping-off (25%), which together accounted for almost two-thirds of the disease problems. That relatively few fungal diseases were reported in the Survey probably reflects the sanitary environment maintained in most container nurseries. In fact, 7% of the nurseries reported that they had no major fungal diseases.

Table 5.1.2—*Fungal diseases reported by container tree nurseries in the United States and Canada*

Ranking	Fungal pest	% of nurseries
1	Grey mold	39
2	Damping-off	25
3	Root rots	15
4	Shoot blight	10
	Total	89
	Other fungal diseases	4
	No major fungal disease	7

Source: *Container Nursery Survey.*

Table 5.1.3—*Insect and mites reported by container tree nurseries in the United States and Canada*

Ranking	Pest	% of nurseries
1	Aphids	16
2	Cutworms	15
3	Root weevils	10
4	European crane fly	9
5	Fungus gnats	8
6	Budworms	6
7	Mites	4
8	Whiteflies	4
9	Lygus bugs	3
	Total	75
	Other insect pests	10
	No major insect pests	15

Source: *Container Nursery Survey.*

There were 19 different types of insects and related pests (such as mites) reported in the Container Nursery Survey (table 5.1.3). Aphids and cutworms were the most common insects pests, with 16% and 15% of th e reported occurrences. Root weevils, European crane fly, and fungus gnats formed a second group with ratings of 8 to 10%. Ten minor insect pests with less than 1 % occurrence ratings were also reported, indicating that many incidental insects can cause disease in container nurseries. Again, a significant number of respondents (15%) reported no major insect problems.

Table 5.1.4—*Abiotic disease problems reported by container tree nurseries in the United States and Canada*

Ranking	Environmental stress factor	Stress factor class	% of nurseries
1	Cool, damp weather during growing season	Temperature	15
2	Heat	Temperature	15
3	Low light during winter growing season	Light	11
4	Nutrient deficiency or toxicity	Nutrient	11
5	Cold	Temperature	8
6	pH problems	Nutrient	8
7	Water distribution	Water	6
8	Salt injury	Nutrient	6
9	Winter drying	Water	6
10	Air pollution	Chemical	3
11	Wind	Water/mechanical	3
12	Variable weather	—	2
13	Intense sunlight	Light	2
14	Interruption of photoperiod from outside lights	Light	2
15	Cold irrigation water	Water	2
		Total	100

Source: *Container Nursery Survey.*

Biotic pests often cause infectious diseases that can readily spread from seedling to seedling; this multiplication effect can occur rapidly in the favorable container nursery environment and often becomes serious. Many fungal pathogens begin as saprophytes, which feed on dead plant tissue, but then spread to living tissue and cause disease. Insect pests may build up populations on weed species and subsequently spread to crop seedlings.

Abiotic disease. Any environmental stress factor can cause disease when it adversely affects seedling growth, and table 5.1.1 lists some of the more common abiotic stress factors. Several of these factors--heat, water, and mineral nutrients--are required for normal seedling growth but can induce physiological stress when they reach extreme levels. Other abiotic factors-air pollution, for example-often originate outside the normal container nursery environment. Mechanical injury can occur whenever seedlings are handled; it is important to realize that seemingly minor incidents can cause damage to succulent container seedlings.

Fifteen abiotic diseases were reported in the Container Nursery Survey (table 5.1.4). Temperature-related problems accounted for 60% of the stress factors and nutrient problems, including pH and salt injury, were also commonly reported. Low sunlight intensity during the winter crop, primarily in northern latitude nurseries, was the major light-related problem.

Abiotic diseases are noninfectious because they do not spread from one seedling to another. Perhaps the major influence of abiotic stresses is that they can weaken the host seedling and predispose it to attack by biotic pathogens. Improperly applied cultural practices such as irrigation or fertilization can lead to abiotic disease.

Many people tend to discount abiotic disease and focus instead on the more traditional biological disease agents such as fungi or insects. Sutherland and others (1982), however, reported that, for three of four conifer seedling species, abiotic diseases were more common than biotic diseases in disease samples submitted to a pathology laboratory (fig. 5.1.2). Consulting pest specialists usually find that abiotic diseases are very important in nursery pathology because a majority of seedling diseases are either directly caused by abiotic factors or are indirectly related to predisposing environmental factors.

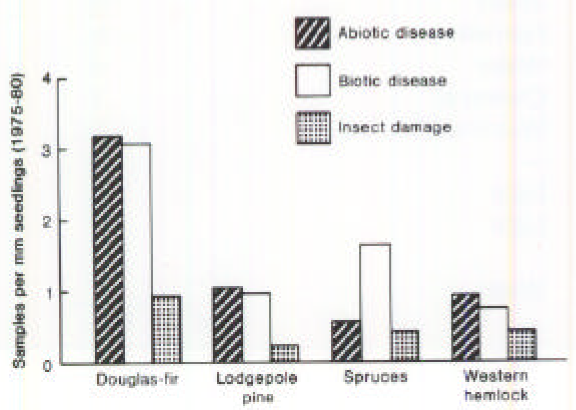


Figure 5.1.2—*Abiotic diseases were more common than biotic diseases or insect damage for three of four conifer seedling species, based on samples received at a diagnostic pest laboratory (modified from Sutherland and others 1982).*

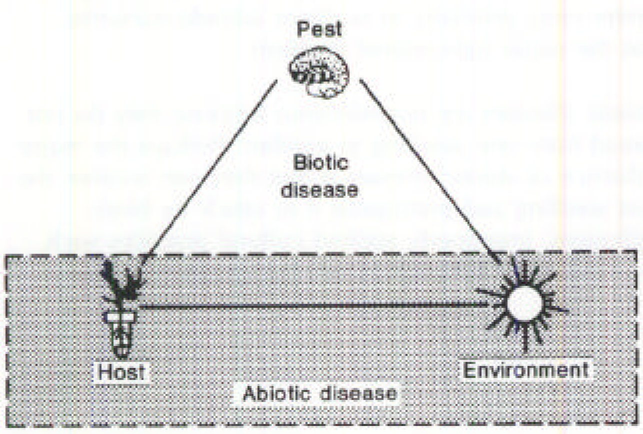


Figure 5.1.3—*Biotic diseases are the result of the interaction of a pest, the host seedling, and the environment (the classic "disease triangle"). Abiotic diseases result from the adverse effects of environmental stresses and the host seedling.*

5.1.1.3 Disease development in a container nursery

Container nurseries offer a unique opportunity to study the development of disease. Greenhouses are artificial environments that are initially pest-free and do not have the "background" pest levels that typify traditional bareroot nurseries; therefore, all biological pests are introduced. The biotic diseases caused by these pests develop in an environment that has none of the normal population controls found in the natural environment. Abiotic diseases also seem to develop more rapidly in container nurseries, probably because of the succulent nature of container seedlings.

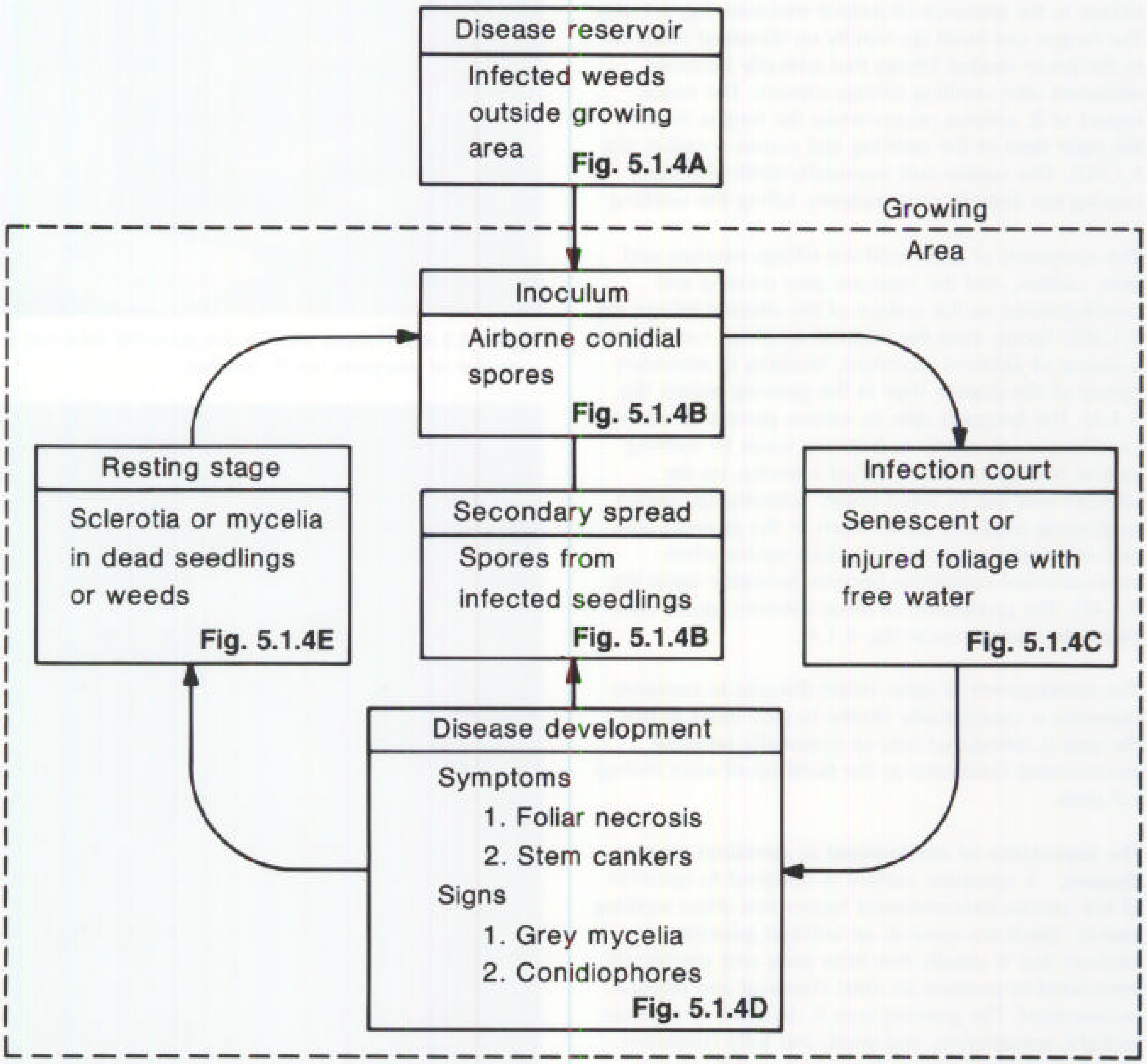
Factors involved in disease development. Biotic disease has traditionally been described using the "disease triangle," which illustrates the interrelationships between the pest, the host, and the environment (fig. 5.1.3). Although many diseases may appear to involve only the host seedling and the biological pest, environmental factors are always involved to some degree. Environmental stress may weaken the seedling and predispose it to attack by the pest, or a particular environment may favor pest populations, enabling them to build-up to harmful levels.

With the elimination of the biological pest, abiotic disease can be visualized as a two-way relationship between the host seedling and adverse environmental stress (fig. 5.1.3). Abiotic disease may develop suddenly as the result of a single injurious climatic incident, such as a freeze, or more gradually as a difficult-to-detect growth loss resulting from below-optimum environmental factors, such as a mineral nutrient deficiency.

Development of biotic diseases. Because container nurseries are artificial systems that do not initially contain any endemic diseases, potential disease agents must be introduced into the nursery. Pests can enter in many ways: growing media, irrigation water, reusable containers, propagation materials (seeds, transplants, or cuttings), airborne inoculum, contaminated soil or growing medium on tools, etc., and mobile pests that enter the growing area directly (see section 5.1.7.2 for more information).

The development of a biotic disease in a container nursery can best be illustrated with an example such as grey mold disease, which is caused by the fungus *Botrytis cinerea* (fig. 5.1.4). Good discussions of this disease are founding Coley-Smith and others (1980), Sutherland and Ban Eerden (1980), and James (1984).

Figure 5.1.4—*An example of disease development in a container tree nursery: grey mold, caused by the fungus* Botrytis cinerea. *(See figures 5.1.4A–E on pages 10-11.)*



B. cinerea is an aggressive saprophyte that colonizes dead or senescent plant material and thus can infect weeds or other plants adjacent to the growing area (fig. 5.1.4A). *B. cinerea* produces abundant spores, which can be aerially transported into the growing structure through the ventilation system (fig. 5.1.413). This airborne inoculum lands on seedling foliage, and these spores can germinate and infect senescent or injured foliage in the presence of surface moisture (fig. 5.1.4C). The fungus can build up rapidly on damaged tissue or in the lower shaded foliage that typically becomes senescent after seedling canopy closure. The major impact of *B. cinerea* occurs when the fungus invades the main stem of the seedling and causes a canker (fig. 5.1.4D). This canker will eventually girdle the stem, causing top dieback or completely killing the seedling.

The symptoms of grey mold are foliage necrosis and stem cankers, and the signs are grey mycelia and conidiophores on the surface of the affected foliage (fig. 5.1.4D). Spores from the infected seedlings can become a source of airborne inoculum, resulting in secondary spread of the disease later in the growing season (fig. 5.1.4). The fungus is able to survive periods of adverse conditions over winter or between crops by forming special resting structures, called sclerotia, on the infected seedling or weed tissue. Sclerotia can persist in growing media or plant debris in the growing area and eventually are able to produce spores when environmental conditions become favorable again (fig. 5.1.4E). The production of these airborne spores completes the disease cycle (fig. 5.1.4).

The development of other biotic diseases in container nurseries is conceptually similar to grey mold in that the pest is introduced into an essentially pest-free environment conducive to the build up of most biological pests.

The importance of environment in container nursery diseases. A container nursery is designed to optimize all the various environmental factors that affect seedling growth. Seeds are sown in an artificial growing medium that is usually free from pests and specifically formulated to produce an ideal chemical and physical environment. The growing area is designed to regulate sunlight, temperature, and wind, and fully controlled greenhouses have automatic environmental controls that maintain ideal levels of humidity, temperature, carbon dioxide, and day-length. Moisture and nutrient

Figure 5.1.4A—*Weeds outside the growing area can be a source of inoculum for* B. cinerea.

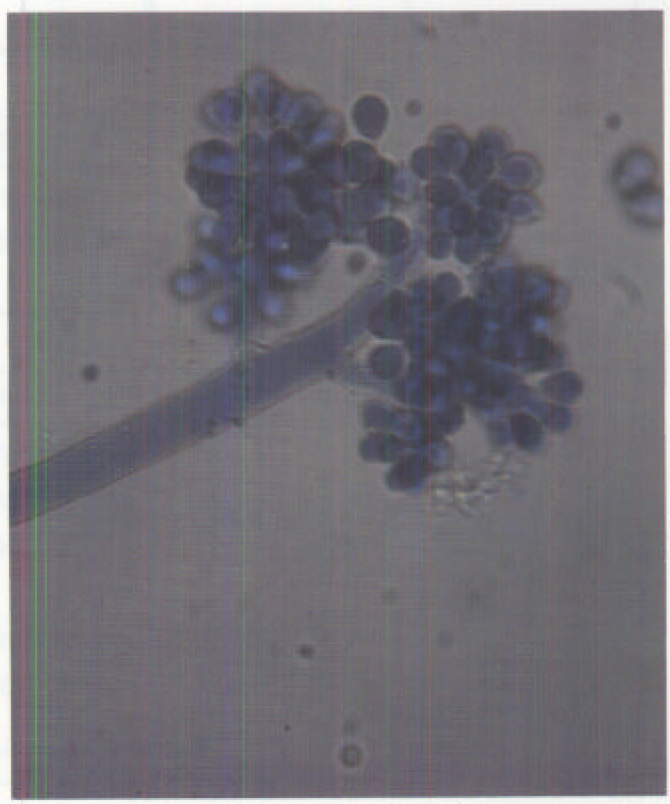


Figure 5.1.4B—*Airborne spores (conidia) are the principal means of* B. cinerea *spread (photo courtesy of L.S. Gillman, USDA Forest Service).*

Figure 5.1.4C—*Botrytis infections usually begin on damaged seedling tissue in the presence of free moisture.*

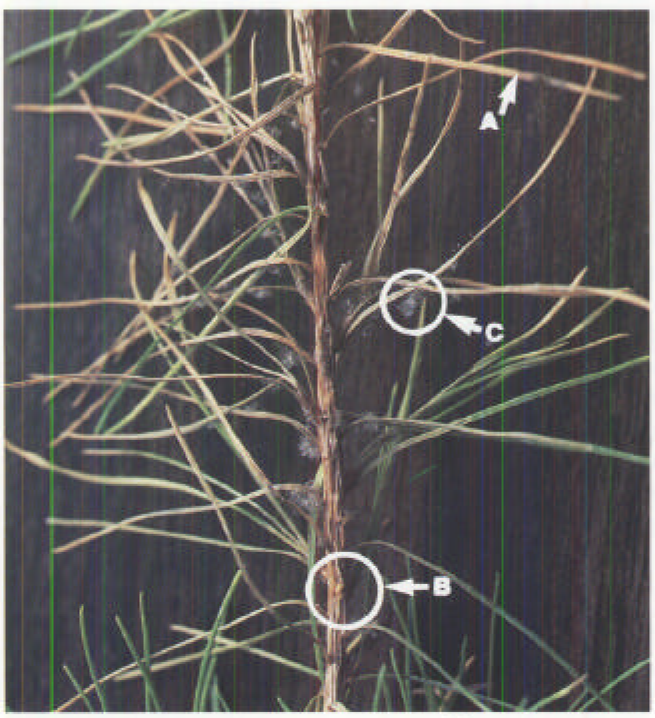


Figure 5.1.4D—*Diagnosis of grey mold: symptoms include necrotic foliage* **(A)** *and stem canker* **(B)** *and signs include the grey fungal mycelium with conidiophores* **(C)**.

Figure 5.1.4E—*Between crops,* B. cinerea *forms resting structures, called sclerotia* (arrow), *which can produce conidial spores when environmental conditions become favorable for growth.*

levels are carefully monitored and maintained at optimal levels. Seedling growing density is controlled by the size and spatial arrangement of the growth containers. The accelerated seedling growth that can be achieved in container nurseries yields crop rotations of less than 1 year compared to the 1 to 3 years in the typical bareroot operation.

Unfortunately, an environment designed to produce such rapid seedling growth also favors the development of many biotic and abiotic diseases. Landis (1984) discusses many of the factors responsible for the high disease potential in container nurseries:

Favorable climate. The moderate temperatures, high humidity, and low wind velocities in a container nursery are ideal for many pests.

Very dense stocking levels. Compared to the ideal stocking levels for bareroot seedlings of 161 to 269 seedlings/m^2 (15 to 25/ft^2), the growing density of container seedlings can be 1,076/m^2 (100/ft^2) or higher.

Monoculture. In most container nurseries, the crop consists of one species or several closely related seedling species, and individual seed lots are composed of seedlings from the same genetic base. To aggravate this condition, all the seeds are sown at the same time and therefore the seedlings are always at the same stage of growth.

Accelerated growth promotes succulence. The rapid seedling growth that is achieved in container nurseries often consists of relatively large, thin-walled cells that are very succulent; container seedlings are therefore quite susceptible to abiotic stresses and attack by pests.

Sterile environment. The controlled environment in container nurseries is designed for excluding pests: the growing medium is considered essentially sterile and the growing surfaces and containers are usually sterilized between crops. These conditions can lead to rapid disease development and spread because there is no complement of natural predators and competitors or environmental controls on pest populations-the "biological vacuum" discussed by Baker (1957). Insects such as whiteflies that have a rapid reproduction potential can build up to damaging levels in a short time in container nurseries.

The container nursery manager should be aware of this high disease potential, be especially vigilant for the appearance of new diseases or pests, and design growing schedules that promote vigorous, well-balanced growth. Environmental conditions should be closely monitored and alarm systems used to guard against potentially damaging weather.

5.1.1.4 Discussion of pesticides and chemical control techniques

A variety of different pesticides are mentioned in this publication, but the reader should understand that their mention cannot be interpreted as an endorsement or recommendation by the Forest Service or the U.S. Department of Agriculture. The information on chemical control is presented as a review of published literature: no new research findings are included, and no specific pesticide recommendations can be made. Trade names and active ingredient (or common) names of specific chemicals are mentioned only to illustrate which pesticides have been used, either successfully or unsuccessfully, in the past. We hope that this type of information will help nursery managers make informed decisions about potential pesticide use.

Because this manual will be used in many different states, provinces, and countries, no attempt is made to list which chemicals are legally registered for use. Pesticide registration is dynamic, and it would be impossible to keep registration information up to date. The most recent complete list of pesticides used on seeds and seedlings in tree nurseries can be found in Hamel (1983). Before using any pesticide, nursery managers should contact their local pesticide specialist for information on local registration and use. Modern nursery management requires the judicious use of pesticides, and so growers should learn all that they can about the action and impact of each specific pesticide chemical before implementing its use. Aspects of pesticide use are discussed in detail in section 5.1.8.

5.1.2 Diagnosis of Diseases and Pest Problems

Diagnosis consists of a systematic search for the causes of a disease or pest problem using symptoms, signs, and pattern of occurrence (Peterson and Smith 1975*).* Disease diagnosis in a container nursery consists of three phases: 1) *identifying* a disease, 2) diagnosing its true cause, and 3) *determining the impact* of the disease on nursery production.

5.1.:!.1 Identifying diseases and pests in container nurseries

Identification of diseases and pests requires a certain degree of experience and training. Nursery workers need a rudimentary knowledge of seedling physiology and morphology before they can detect those minor deviations from the normal seedling condition that constitute a disease. This knowledge can come from either direct experience or formal training but ideally a grower will have a combination of both. *A* formal education in horticulture and seedling physiology provides a sound conceptual background, but there is no substitute for actual nursery experience. Direct "hands-on" experience with container seedlings at all stages of nursery culture is necessary to quickly recognize when seedlings appear abnormal.

Early detection is extremely important for controlling nursery diseases and pests, especially for integrated pest management (IPM) programs. Container seedling growers must adopt an attitude of vigilance and make periodic inspections of the crop so that problems can be identified early. Many pests are difficult to eradicate once they become established. Davidson and others (1988) recommend three different techniques for monitoring insect pests: visual inspection, beating, and trapping devices. Parrella (1987) recommends monitoring populations of nursery insect pests with yellow sticky cards placed throughout the greenhouse to determine if insect pests are present and if possibly harmful populations are building up. Baker (1986) presents a useful identification guide to greenhouse insects found on yellow sticky cards.

Most diseases and pests affecting container seedlings cause readily identifiable symptoms such as discolored foliage, but many problems do not become evident until irreversible injury has already occurred. This is particularly true for diseases or insect injury of roots because foliar symptoms only develop after the roots are severely damaged. Minor stunting or undetectable growth loss is especially difficult to diagnose unless the grower has some type of growth standards for comparison. Seedling measurements, such as shoot height, stem caliper, and total dry weight, should be taken regularly and growth curves constructed for each seedling species so that "normal" growth patterns can be established. Growth of subsequent crops can then be compared to these growth standards and potential problems identified.

5.1.2.2 Steps in disease and pest diagnosis

A systematic approach to diagnosis of disease or pest problems is most effective, and Bohmont (1983) and Peterson and Smith (1975) provide step-by-step procedures. Blanchard and Tattar (1981) discuss the technical aspects of disease diagnosis, including handling disease specimens, and Streets (1972) presents an entire manual on the diagnosis of plant diseases. The following procedure is recommended by the author and requires only a 5 or 10 power hand lens, a sharp knife, and an inquiring, open attitude. Streets (1972) states that the most important attribute in disease diagnosis is "the ability to observe accurately." If possible, make the diagnosis with other members of the nursery staff, especially those in charge of day-to-day cultural operations, because they may be able to relate the disease symptoms to some recent cultural or climatic incident.

1. Check all parts of the seedling for symptoms and determine what parts are actually affected. Frequently, foliar symptoms are an indication of root disease (fig. 5.1.5), so remove the seedling from the container and carefully check the root system. Note the symptom pattern on the seedling itself-is one part of the shoot or root system affected more than another (fig. 5.1.6)?

2. Determine whether all species or seedlots within a species are equally affected. Abiotic diseases usually affect several different species of seedlings, whereas biotic diseases are often restricted to one species (table 5.1.5). Environmental stresses are non-discriminatory, but biotic pests are often host-specific. Exceptions to this general rule do exist, however. Frosts can injure one species or ecotype, and there apparently is a genetic predisposition to other types of abiotic injury, such as pesticide phytotoxicity (fig. 5.1.7). When only a single, occasional seedling is affected, the problem is usually genetic (fig. 5.1.8).

Figure 5.1.5—*Foliar symptoms, such as the "clutching" and "tip-burn" in this Douglas-fir seedling, are often indicators of root injury.*

Figure 5.1.6—*Abiotic injury is sometimes expressed in a definite pattern, such as the heat injury on the right side of this seedling.*

Table 5.1.5—*Characteristics of diseases used to help determine whether they were caused by abiotic or biotic factors*

Disease characteristics	Type of disease: Abiotic	Type of disease: Biotic
Hosts	Often affects several species or ages of seedlings	Usually restricted to one species and age class
Symptoms		
Pattern within growing area	Regular: spatially related to some environmental factor	Random locations initially
Rate of development	Rapid and uniform	Relatively slow and uneven
Signs	No evidence of a pest	Evidence of a pest may be present
Spread	Related to one incident with no secondary spread	May spread over time if conditions warrant

Source: modified from Sutherland and Van Eerden (1980).

Figure 5.1.7—*The scattered damage pattern in this progeny test of different western white pine selections demonstrates that some types of abiotic injury correlate to genetic differences in stress tolerance.*

Figure 5.1.8—*Genetic problems are expressed as individual, scattered, symptomatic seedlings.*

3. Note the pattern of the disease symptoms within the growing area. Determine if the disease pattern is random or regular (table 5.1.5). What sections of the growing area are affected and are these areas related to any cultural operation such as the irrigation application pattern or to structural features in the growing area? Abiotic problems are usually expressed in a regular pattern that can be correlated to some cultural factor such as the growing tray (fig. 5.1.9) or position on the bench (fig. 5.1.10). Biotic diseases often initially show a random distribution because they develop from inocula randomly introduced from the air or on seeds (fig. 5.1.1 1). Disease "pockets" (fig. 5.1.12) are diagnostic because they typically result from the secondary spread of a biotic pest.

4. Check several symptomatic seedlings thoroughly with a hand lens for signs of a biotic pest. Fungal mycelia or fruiting bodies are sometimes visible on the affected tissue (fig. 5.1.13). However, insects in the growing area are often concealed, particularly in the growing medium. Collect specimens of any potential pests for subsequent identification.

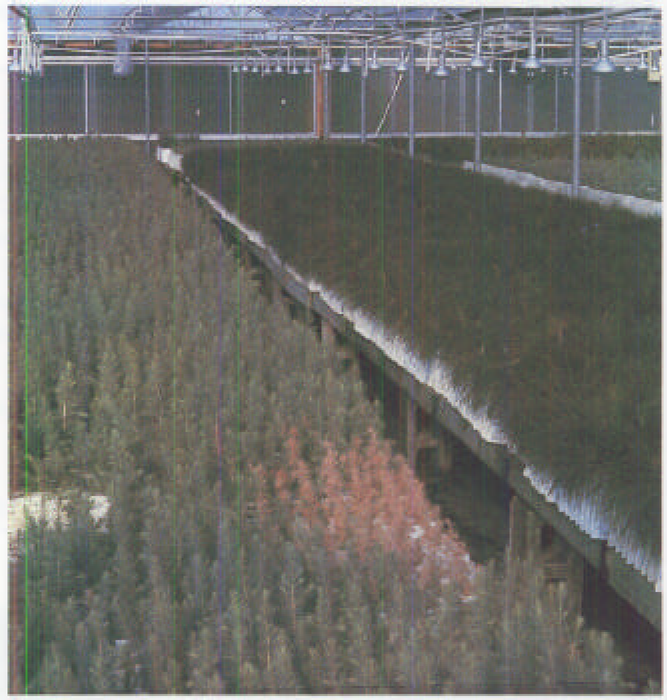


Figure 5.1.10—*Symptoms that are restricted to one particular area of the nursery or bench are often caused by abiotic problems. In this case, a heat duct under the bench ruptured and desiccated one patch of seedlings.*

Figure 5.1.9—*Abiotic problems sometimes cause regular disease patterns. In this case, only certain blocks of seedlings are stunted.*

Figure 5.1.11—*Biotic diseases often are expressed in a random pattern. In this example scattered symptomatic seedlings were infected with seedborne pathogenic fungi.*

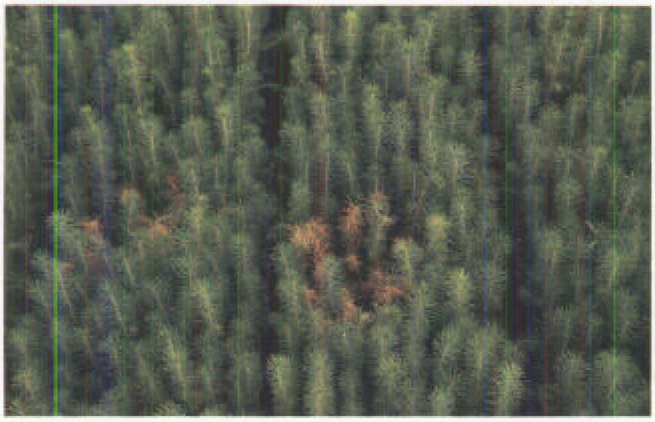


Figure 5.1.12—*Disease "pockets," or groups of symptomatic seedlings, are another random disease pattern that is typical of biotic pests.*

5. Always consider the possibility of abiotic disease. Check cultural and weather records and ask nursery workers about any unusual incidents. Examine the growing medium for evidence of adverse conditions such as waterlogging (sour smell or excessive growth of algae) or salinity build-up (salt crust on the container, especially around the bottom drainage hole).

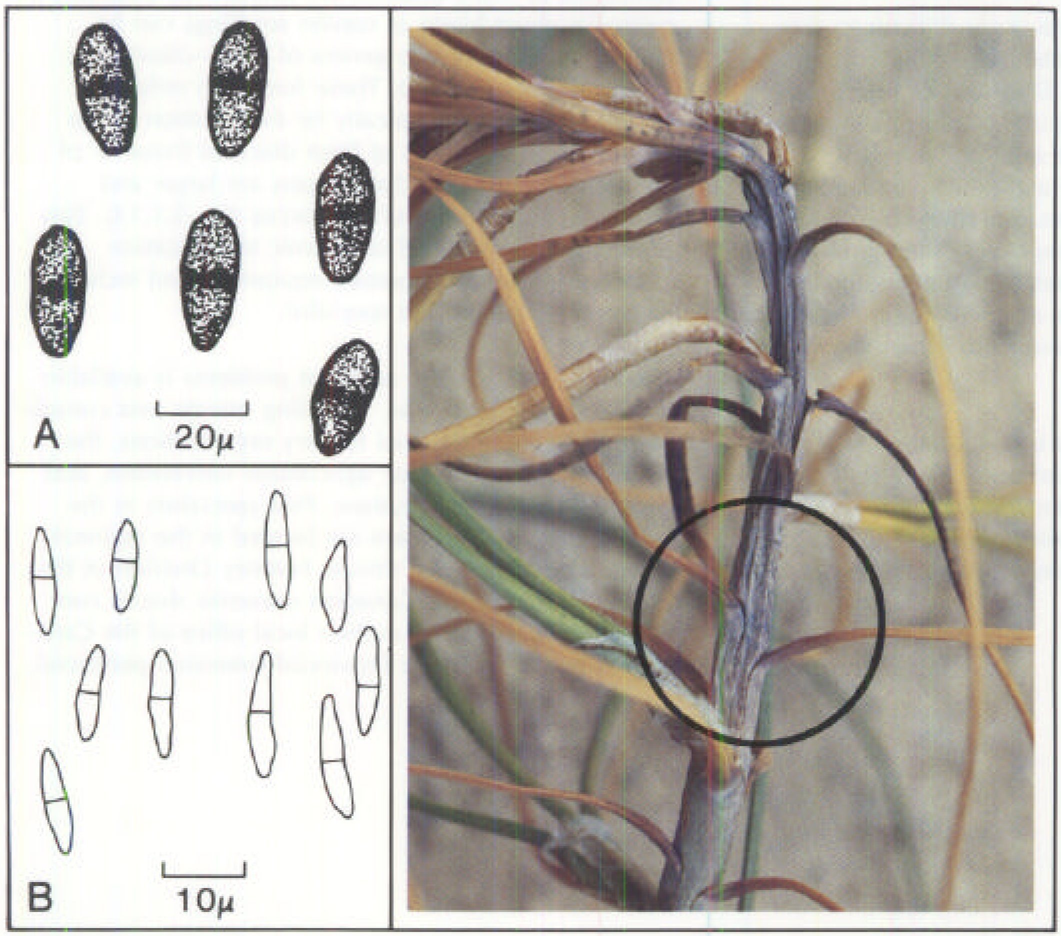


Figure 5.1.13—*Diseases cannot always be definitively diagnosed by symptoms alone; this shoot blight (***symptom***) could have been caused by either of two different fungal pathogens. Positive diagnosis requires culturing the fungus from the black pycnidia (***sign***, circle) and identifying it, based on spore characteristics, as either* Sphaeropsis sapinea **(A)** *or* Sirococcus strobilinus **(B).**

6. Establish the disease history. When did the symptoms first appear? Is this problem new or has it been observed before? Try to correlate these facts with cultural or weather records. Abiotic diseases are usually related to a particular damaging incident and their symptoms usually develop rapidly, whereas biotic diseases develop more slowly and may spread over time if environmental conditions are favorable (table 5.1.5).

7. Document your analysis of the disease problem with written notes and color photographs if possible. Many times disease symptoms or signs will change over time, or other saprophytic organisms may colonize the affected tissue and obscure the true cause of the problem. Collect diseased seedlings to send to a pest specialist for confirmation.

Insect pest problems are particularly difficult to diagnose because the insect is often gone by the time the symptoms become obvious. Diagnosis of insect-caused root injury is especially difficult because many root-feeding insects, such as root weevils, have larvae that live in the growing medium and adults that are active only at night. Insect problems can often be diagnosed by monitoring their populations within the growing area. Because they are so mobile and often nocturnal, the presence and abundance of many insect pests can be monitored with pheromone traps, which attract the adults.

After completing the disease investigation, it is a good idea to contact other local container nurseries to see if they have had similar problems. It may be that the disease or pest problem has already been identified, and effective control measures already tested and established

Assistance with disease and pest problems. Experienced nursery managers can diagnose common disease and pest problems in their nurseries and initiate proven treatments. It is a good idea, however, to have this tentative diagnosis confirmed by a pest specialist because many nursery diseases are relatively complicated and may involve more than one pest or a predisposing environmental stress factor. Accurate disease diagnosis is essential before proper control measures can be designed and an improper diagnosis could lead to additional seedling losses if the wrong control treatment was applied.

Many fungal diseases cannot be accurately diagnosed until the causal organism is isolated from the diseased tissue and grown on an artificial medium because the symptoms of many diseases are similar. For example, a particular shoot blight of conifer seedlings can be caused by either of two genera of fungi--*Sirococcus* spp. or *Sphaeropsis* spp. These fungi can only be differentiated microscopically by examination of the fruiting bodies in slides of fresh diseased tissue or of cultures: the spores of Sphaeropsis are larger and darker than the spores of Sirococcus (fig. 5.1.13). This isolation procedure and taxonomic identification require the special laboratory equipment and techniques of a trained pest specialist.

Assistance with disease and pest problems is available from a variety of sources, including private pest consultants, State and Provincial forestry organizations, the extension service of State agricultural universities, and Federal forestry organizations. Pest specialists in the United States Government are located in the regional offices of the State and Private Forestry Division of the USDA Forest Service. Canadian nurseries should contact the pest specialists at their local office of the Canadian Forestry Service or Provincial extension personnel.

Collection, storage, and shipping of diseased samples. Most disease and pest diagnoses require careful examination of the affected seedlings by a trained pest specialist, and so disease samples must be collected and shipped to a diagnostic laboratory. Sample collection and handling are discussed by Streets (1972) and usually consist of the following steps:

1. Collect samples as soon as the symptoms become evident and especially when signs develop. If sample collection is delayed, secondary organisms may become established and mask the symptoms of the original disease or insect problem. Sample the entire seedling so that the pest specialist can examine all facets of the disease. Collect a series of seedlings showing a gradation of disease, if possible, from healthy to severely damaged seedlings; this allows the pest specialist to make relative comparisons and estimate the disease impact. Leave the seedlings in the containers if possible so that pests in the medium or evidence on the containers can be examined.

2. Protect samples from deterioration due to heat or drying by placing the seedlings in plastic bags and storing them under refrigeration. Insects should be placed in a bottle with air holes and some plant material for food in the bottom. Make sure that all samples are properly identified with species, seedlot, age, date, description of the symptoms and signs, and any other useful information such as location in the growing area and previous cultural practices and weather conditions. Use pencil on all labels because ink often smears in humid sample bags.

3. Submit a written description of the disease problem with your tentative diagnosis and color photographs of the symptoms if possible.

4. Ship samples to the diagnostic laboratory as quickly as possible. The best procedure is to contact the pest specialist for specific handling and shipping recommendations.

5.1.2.3 Assessing disease and pest impact

The fact that a disease or pest exists in a container nursery does not necessarily mean it will affect nursery production, so an assessment of its impact is required. A disease or pest problem may not be economically serious if it remains at an endemic level or can be controlled early enough that the number of seedlings lost remains within the normal oversow factors.

The impact of a disease or pestreflects economic loss and can be measured in terms of expected growth loss or direct seedling mortality. It is simple enough to inventory dead seedlings, but growth losses are more difficult to quantify. If the growth loss is severe enough, the seedlings will not reach the desired size within the normal crop rotation and may have to be culled. If some of the diseased seedlings are merely stunted but have the potential for recovery, they can be held-over for additional growth and the major impact of the disease will be the cost of the additional growing time. When the disease is infectious, the seedlings will often have to be culled even if the actual infection is relatively minor. Some fungal pests such as 8. cinerea can develop into aggressive storage molds.

The normal procedure for determining the impact of a disease or pest is to conduct an inventory of the affected seedlots and directly count or statistically estimate the percent seedling loss. A pest specialist should be consulted to train the grading crew to recognize diseased seedlings and establish grading standards for categories such as "cull," "hold-over," and "shippable." A complicating factor with many fungal diseases is that seedlings may be infected but do not yet exhibit symptoms; these latent infections are extremely difficult to diagnose, even by a trained pathologist. Sometimes a second disease survey must be run later to identify these latent infections.

Disease and pest impact information can be used to make management decisions concerning therapeutic control measures for the current crop as well as help to plan preventative control measures for future crops.

5.1.3 Diseases and Pests of Seeds and Germinants

Seeds and seedlings are most susceptible to diseases and pests during the time interval between seed preparation (for example, stratification) and when the newly emerged seedling forms woody stem tissues. As is the case for many organisms, seedlings are least resistant to all forms of stress during their earliest stages of development.

Disease and pest identification and diagnosis can be difficult during the germination and emergence stage because the germinating seed is not visible. Diseases and pest problems can develop and spread quickly during this period, and succulent germinants can be killed within a few days. During this period, growers must be especially alert for problems in order to prevent severe seedling losses. Germinating seeds should be checked daily for biotic pests, and environmental conditions should be carefully monitored to prevent unnecessary abiotic stresses.

Because diseases and pest problems can occur so quickly during the germination period, the grower needs a rapid method for identification. A damage key of the disease and pest problems of seeds prior to emergence is presented in figure 5.1.14. Growers can use this key and the pictures and descriptions that follow for tentative identification of pre-emergence problems. (Letters in the key refer to subheadings in the appropriate section of the text.)

5.1.3.1 Seed disease and pest problems

The germination period is an anxious time for container nursery managers while they are waiting for the germinants to appear. Conifer seed germination usually takes from 2 to 4 weeks and the grower should frequently excavate seed to check for germination and disease or pest problems.

If the seed cannot be located under the seed covering, then there are two possible explanations (fig. 5.1.14).

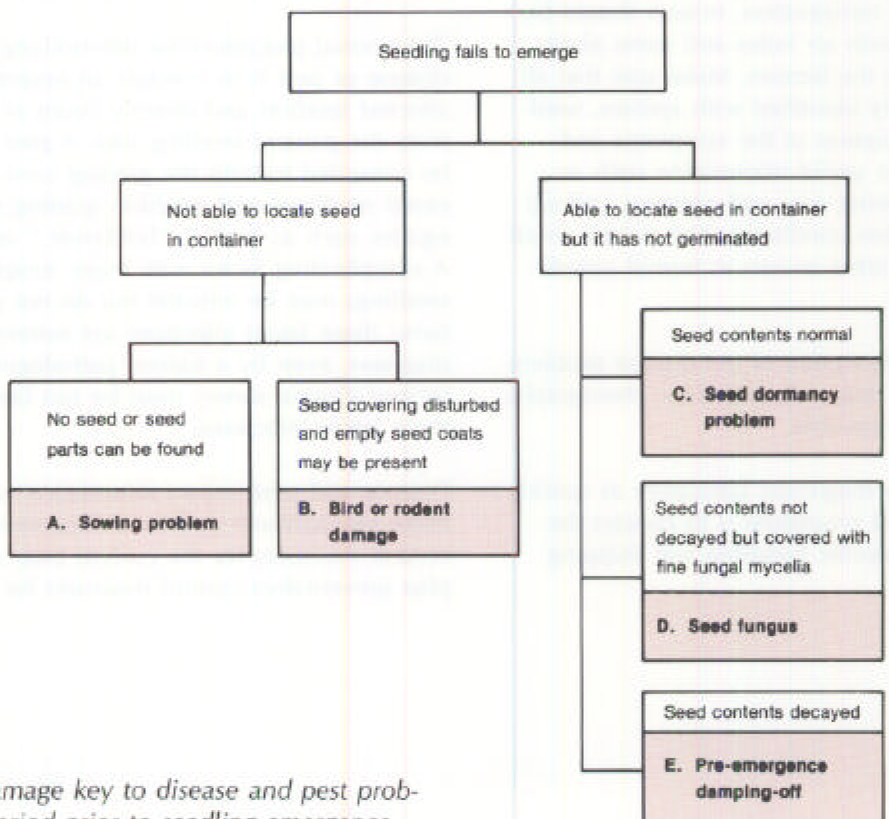


Figure 5.1.14—*Damage key to disease and pest problems during the period prior to seedling emergence.*

A. Sowing problems. Complete absence of the seed in the container indicates that there must have been a problem with the seed sowing operation. The calibration of the seed sowing equipment should be checked for accuracy and precision. If the problem is widespread, then resowing may be justified.

B. Bird or rodent predation. It is difficult to quantify the overall impact of animal damage because the incidents are generally episodic. Bird predation is often due to migrating flocks, which can do severe damage in a short time. One nursery that participated in the Container Nursery Survey reported that from 25 to 50% of their sown seed was eaten by goldfinches.

Hosts. Birds and rodents will eat all species of conifer seed but prefer the seeds of the large-seeded pines such as white pine, sugar pine, and pinyon.

Symptoms/Damage. If the seed cannot be located in the container, but the seed covering has been scattered around, then bird or rodent predation is a possibility. Rodents may either eat the seed and leave the discarded seed coats on top of the container (fig. 5.1.15) or remove the seeds and hide them in a cache. Birds generally eat the seed immediately, leaving spent seedcoats. Rodents feed mostly at night, whereas birds usually feed during the day. Rodent predation can occur in open and closed growing areas, but bird predation is more common in open compounds. Birds also cause clipping injury to emerging seedlings by feeding on the seed coat that clings to the cotyledons.

Disease development. Seed predation is usually terminal. Seedlings can sometimes recover from clipping injury, although severely damaged germinants are weakened and prone to other pests such as damping-off fungi.

Figure 5.1.15—*Disturbed seed coverings and empty seedcoats are evidence of rodents feeding on the seeds.*

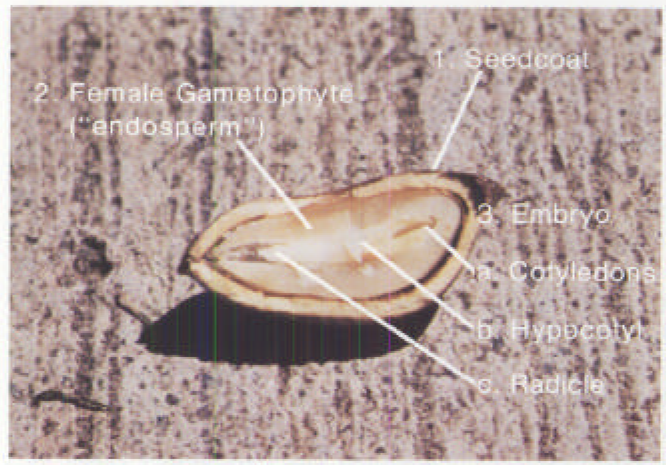


Figure 5.1.16—*This longitudinal section of a limber pine seed illustrates the three components of a healthy seed: 1. seedcoat, 2. female gametophyte, which is commonly called the endosperm, and 3. embryo, consisting of seed leaves (cotyledons), stem (hypocotyl), and root (radicle).*

Disease management. Bird and rodent predation is best controlled through prevention: exclusion through proper growing area design and use of screens, and elimination of suitable habitat around the growing area. If pest exclusion is impossible, trapping and baiting will reduce populations. Carlson (1983) recommends snap or live traps, or poisoned baits appropriate to the situation. Excess seed can be scattered around to attract rodents and keep them from reaching the crop seed; finding cracked seeds is a good indication that there is a rodent predation problem. Traps or bait should be placed on the floor, near potential entry holes. Chemical seed treatments for repelling birds and rodents have been used, but many of these chemicals are phytotoxic and may reduce germination.

C. Seed dormancy problems. If the sown seed can be located in the container but still has not germinated (fig. 5.1.14), then a sample of seeds should be excavated and each seed cut longitudinally to examine the seed contents.

A longitudinal section of a typical conifer seed is shown in figure 5.1.16; the embryo should be clearly visible and the endosperm should be firm and completely fill the seedcoat. If the seed does not appear normal, then the problem could be poor seed quality, and the remainder of the seed lot should be sampled and tested for germinability.

If the seed contents appear normal, then the problem may be seed dormancy. Many species of seed require cold-moist or other stratification treatments to break dormancy; otherwise the seed will not germinate. Seed dormancy and treatments to break dormancy, including stratification, are provided in volume six in this series, and in Seeds of Woody Plants of the United States (Krugman and others 1974).

D. Seed fungus. If the bisected seed is not decayed but the seeds are covered with a fine fungal mycelium (fig. 5.1.17), the problem may be a disease caused by the seed fungus *Caloscypha fulgens*. This pathogen has only been reported in container seedling nurseries in British Columbia (Sutherland and Van Eerden 1980). It has caused serious disease in bareroot nurseries in Ontario, where losses have ranged as high as 95% of the viable seed sown (Epners 1964). Sutherland (1984) reported a disease incidence of 1 to 5% in infected seedlots in British Columbia. The reason for the greater loss in bareroot nurseries is probably postsowing spread of the fungus, which should be less in container nurseries because intercavity spread is difficult (Sutherland and Van Eerden 1980). The true extent and impact of this disease is extremely difficult to quantify because the infected seed is not decayed and could easily be diagnosed as poor quality seed. Sutherland and others (1987) present an excellent discussion of the seed fungus as well as color photographs.

Figure 5.1.17—*The seed fungus* Caloscypha fulgens *can be identified by the fine mycelium on the seed coat, in combination with an undecayed seed interior (courtesy of J.R. Sutherland, Canadian Forestry Service).*

Hosts. Apparently, most species of conifer seed are susceptible. The seed fungus has been isolated from seeds of eastern white pine, scotch pine, red pine, and white spruce and has been shown to infect jack pine, black spruce, and Norway spruce (Epners 1964). Sutherland (1979) recovered the pathogen from Douglas-fir, Engelmann spruce, white spruce, and grand fir and reported that seeds of other conifers, including lodgepole pine and western hemlock, are susceptible. Sutherland (1979) stated that one-third of all spruce seedlots in British Columbia are infested, but seed from species with serotinous cones, such as some ecotypes of lodgepole pine, are disease-free (Sutherland 1986).

Symptoms/Damage. This disease is difficult to identify because the seed does not germinate and the problem may be confused with seed dormancy or pre-emergence damping-off. Unlike damping-off fungi, however, the seed fungus does not decay the seed; instead, their contents are firm and mummified and the seed may be covered with a fungal mycelium (fig. 5.1.17) (Sutherland and Van Eerden 1980). Seedlots exhibiting poor germination after stratification should be suspect (Sutherland 1986), but positive identification of this disease is best made by a pathologist.

Disease development. *Caloscypha fulgens* is seedborne and usually invades cones while they are in contact with forest duff. The fungus is especially prevalent in seed lots collected from squirrel caches (Sutherland 1979). It can survive for years on dry, stored seed (Epners 1964) and can spread among seeds during stratification, in cold storage prior to sowing, or after sowing (Sutherland and Van Eerden 1980). This fungal pest kills the seeds before they start to germinate but does not affect germinated seeds or seedlings (Epners 1964). Although the fungus apparently spreads in the seedbed in bareroot nurseries, intercavity spread should be difficult in container nurseries (Sutherland and Van Eerden 1980). A good illustration of the life cycle of *Caloscypha fulgens* is provided in Sutherland and others (1987).

Disease management. Because this disease is usually the result of poor cone collection or storage practices, several practices can reduce its incidence: 1) collect only cones that have not been on the ground for a long time, 2) do not collect cones from squirrel caches, and 3) insure proper air drying of cones through proper handling and storage practices. Hand picking cones from standing trees followed by proper handling should reduce seed fungus incidence, and seed orchard collections should be disease-free (Sutherland 1986).

Identification of infected seedlots should help prevent the disease, and seed-screening techniques are being developed (Sutherland and others 1981). For infested seedlots, the following cultural practices should reduce losses in the nursery: 1) do not stratify the seeds or keep stratification periods as short as possible, 2) sow seeds promptly after stratification to reduce the presowing storage period, 3) keep greenhouse temperatures warm to promote rapid germination, and 4) sow as few seeds per cavity as possible (Sutherland 1986). Epners (1964) suggested pelleting seed with the fungicide captan, and Salt (1974) found that treating spruce seed with thiram effectively reduced seed losses. Because the fungus does not affect germinated seed, temperatures and other environmental conditions should be maintained at optimum levels during the germination period to increase speed of germination (Sutherland and Van Eerden 1980).

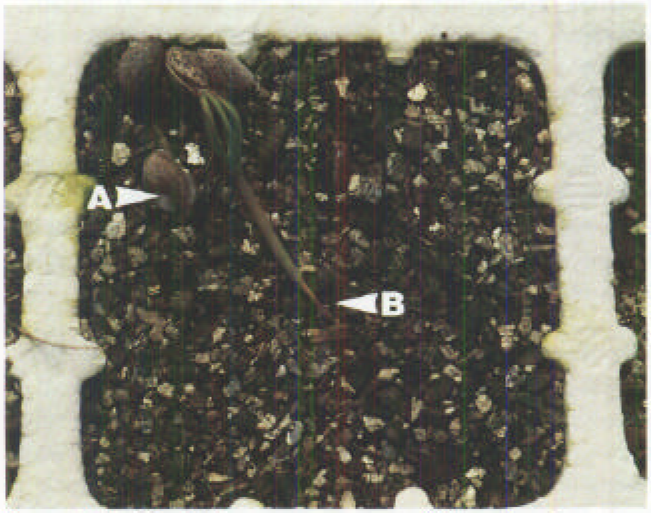


Figure 5.1.18—*Both pre-emergence (**A**) and post-emergence (**B**) damping-off can occur in container tree nurseries and can be caused by the same group of fungi, in this case* Fusarium *spp.*

Figure 5.1.19—*Pre-emergence damping-off is often caused by seedborne fungi, such as* Fusarium *spp., which can be seen growing on this ponderosa pine seed (courtesy of L.S. Gillman, USDA Forest Service).*

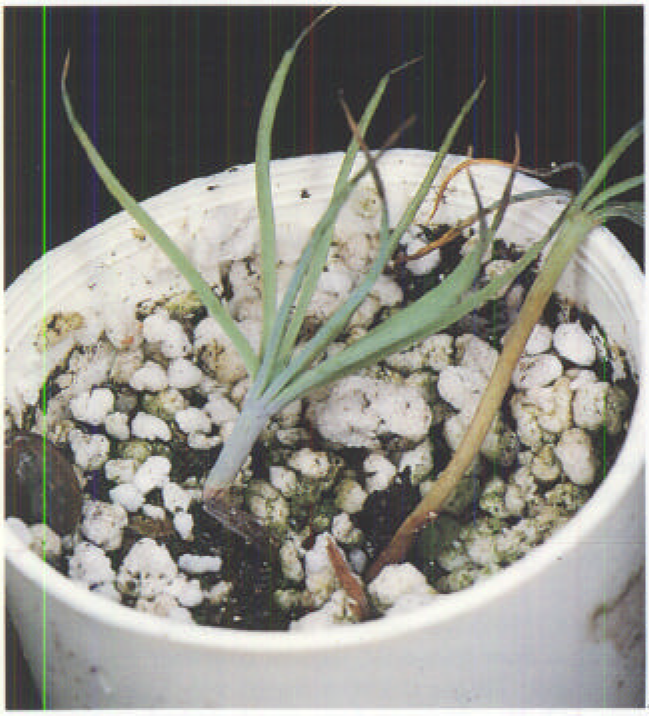
E. Damping-off. Damping-off is a common disease that affects seeds, germinants, and young seedlings of many plant species, and woody plants are no exception. Traditionally, two different types of damping-off are recognized: pre-emergence damping-off, which affects seeds and germinants before they emerge, and postemergence damping-off, which affects young seedlings until their stems become woody. Both forms of the disease occur in container nurseries and are caused by the same group of fungi (fig. 5.1.18). Damping-off was ranked second among the diseases affecting container seedlings, with a relative occurrence of 25% based on responses during the Container Nursery Survey (table 5.1.2).

Hosts. All species of seed and seedlings are affected.

Symptoms/Damage. Pre-emergence damping-off is a difficult disease to diagnose because the affected seeds are not visible; consequently, the losses are often attributed to "poor seed" (Baker 1957). If the germinants have not emerged after a reasonable period, the seed should be excavated and examined; if the seed contents are decayed, then damping-off fungi may be involved (fig. 5.1.14). Sometimes, the germinated seed is killed after the radicle of the seed has emerged (fig. 5.1.19).

The classic symptoms of postemergence damping-off (fig. 5.1.20) include decay of the seedling hypocotyl at the ground line, causing the seedling to topple over. Other stresses can produce symptoms similar to fungal damping-off (see section 5.1.5.3), but the distinguishing characteristic is the presence of decayed root tissue.

Another germinant disease that is usually classed with postemergence damping-off is cotyledon blight. This decay of the cotyledons develops when seedborne fungi spread from the seedcoat during the "birdcage" stage of germination (fig. 5.1.21).



A

B

Figure 5.1.20—*Postemergence damping-off causes a constriction and decay of the seedling stem, which makes the seedling fall over (courtesy of L.S. Gillman, USDA Forest Service).*

Figure 5.1.21—*Cotyledon blight is one form of post-emergence damping-off that is obviously seedborne.*

Disease development. Pre-emergence damping-off is a fungal decay of seeds and young germinants and several different fungi can be involved. Traditionally, *Rhizoctonia* has been considered to be the major cause of damping-off in ornamental container nurseries (Baker 1957); Peterson (1974) states that four fungal genera (*Pythium, Fusarium, Phytophthora, and Rhizoctonia)* "are being encountered" in container tree nurseries. A search of the literature, however, reveals that only Fusarium spp. have actually been implicated as a cause of damping-off of conifer seedlings in containers: *Fusarium oxysporum* (Schlect.) for Douglas-fir (Graham and Linderman 1983); Douglas-fir, western larch, grand fir, subalpine fir, and ponderosa pine (James 1985a); and Douglas-fir and pinyon container seedlings (Landis 1976). Although *F. oxysporum* is most commonly mentioned, other members of the genus may also cause damping-off disease of container seedlings. James (1985a) recovered *F. avenaceum* from diseased conifer seedlings and Pawuk (1978) demonstrated that four seedborne species of *Fusarium* could produce damping-off of longleaf pine, that is, *F. moniliforme, F. solani, F. roseum,* and *F. tricinctum. Pythium* spp. have also been isolated from diseased container seedlings and these fungal pests may be more common than generally realized; Peterson (1974) concluded that *Pythium*-infected tissues are often overgrown by other fungi such as *Fusarium* spp.

The reason that the more traditional damping-off fungi are not being reported from container tree nurseries is probably due to the use of soilless growing media, which are generally considered to be pathogen-free. *Rhizoctonia, Pythium*, and *Phytophthora* spp. are primarily spread through contaminated irrigation water or growing media, especially from mixes containing soil (Baker 1957). McCain (1978) reports that peat is often infested with Pythium and Rhizoctonia spp., but Stephens and others (1983) could recover neither fungus from non-soil components of artificial growing media including peat, perlite, and vermiculite. Coyier (1978) assayed perlite and peat moss samples for bacteria and fungi and found that, while perlite was sterile, the peat moss samples contained many species of pathogenic and nonpathogenic fungi and bacteria. James (1987) has regularly isolated F. oxysporum from the roots of weeds growing in greenhouses.

McElroy (1985) has isolated both *Pythium* and *Fusarium* spp. from unopened bags of container medium; James and Gilligan (1984) reported very high populations of both pathogens from one brand of growing medium and demonstrated that the recovered Fusarium isolates could cause damping-off. Kim and others (1975) made fungal isolations from 52 randomly selected samples of peat and found that all samples contained *Fusarium* spp., 29% contained *Pythium* spp., but no *Rhizoctonia* spp. were isolated from any of the peat-based media.

Apparently, seedborne fungi are a primary source of inoculum for damping-off fungi in container nurseries. Pawuk (1981) found that seedlots of four species of southern pines were infected with *Fusarium* spp. at intensities of 54 to 90% and the same author (Pawuk 1978) found that some *Fusarium* spp. isolates from longleaf pine seed caused both pre-emergence and postemergence damping-off. Graham and Linderman (1983) reported that *Fusarium oxysporum* isolated from Douglas-fir seed caused significant pre-emergence damping-off losses. Three species of pathogenic Fusarium were isolated from spruce seed and seed debris games 1985b). In an earlier study, James (1983) recovered *Pythium* and two *Fusarium* species from Douglas fir seed; the *Fusarium* spp. were isolated from within the seedcoat. *Fusarium* spp. have also been recovered from several species of pine seed in container nurseries in the western United States, including pinyon and ponderosa pine.

Because container seedlings are spatially isolated in individual cells, secondary spread of damping-off is not as severe a problem as it is in bareroot nurseries. When more than one seed is sown per cell, fungal inoculum introduced on seedcoats can spread to adjacent seedlings and cause damping-off or other diseases, such as root rot, later in the growing season. Graham and Linderman (1983) report that *Fusarium* spp. grew and sporulated on Douglas-fir seedcoats and considered this to be a potential source of secondary disease spread. Fungal spores from infected seeds could be splashed from container to container during irrigation.

Other damping-off fungi have been isolated from growing medium on used containers (Baker 1957) and from dust and soil particles from the floors of container nurseries (Stephens and others 1983). James (1987) has isolated Fusarium spp. from several different types of reusable containers, which had already been "sterilized" by conventional techniques (fig. 5.1.22).

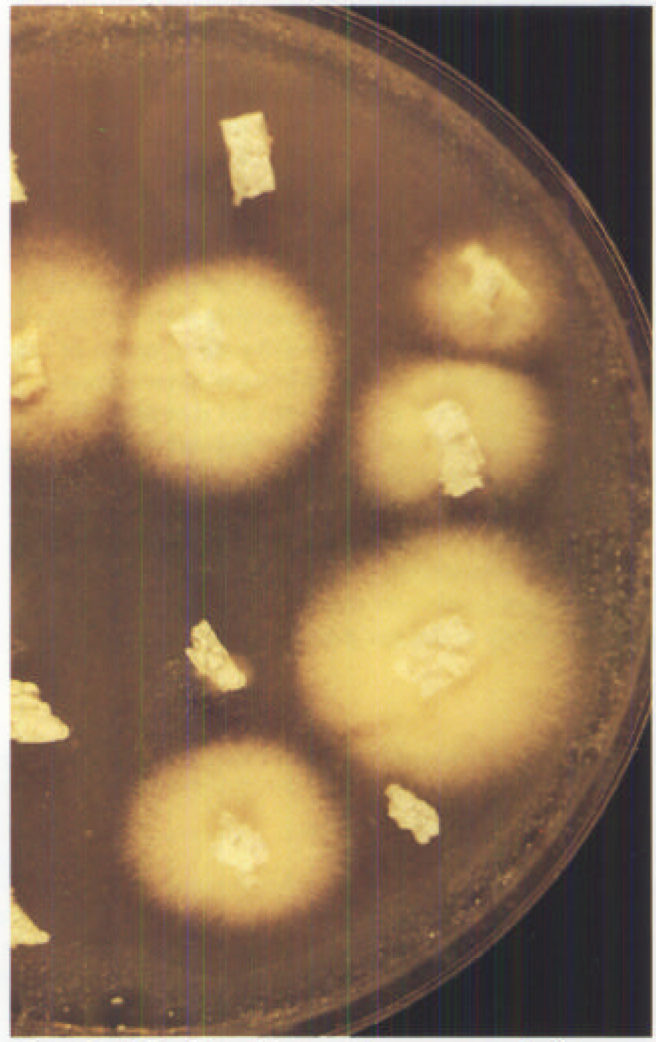


Figure 5.1.22—*Reusable containers may contain propagules of nursery pests that carry-over from previous crops, including fungal pathogens such as this species of* Fusarium, *which was isolated from a used Styrofoam block (courtesy of R.L. James, USDA Forest Service).*

Disease management. *Cultural*. Damping-off is actually not as common in container nurseries as it is in bareroot nurseries, and when it does occur, some environmental or cultural factor is usually involved (table 5.1.6). The most important of these factors is seed quality: fungal contamination is more common in dirty seed lots, and poor quality seed produce weak germinants that are particularly susceptible to damping-off. Reusable containers should be carefully cleaned to prevent fungal inoculum from carrying over to the next crop. Contaminated growing media are a source of fungal inoculum, and fine-textured mixes often compact and provide an ideal environment for damping-off fungi. High pH, either in the growing medium or irrigation water, can favor damping-off, but the low pH of most sphagnum peat should inhibit this fungal disease (Carlson 1983). Oversowing leads to weak germinants that are more susceptible to disease. Fertilization with high nitrogen levels and over-irrigation can also predispose seedlings to damping-off as can a growing environment of high humidity, low light, and extremely high or low temperatures.

Chemical. Because many of the fungi responsible for damping-off are seedborne, seeds can be sanitized prior to sowing. Seed treatments include standing water soaks, running water rinses, and chemical treatments with bleach, hydrogen peroxide, or fungicides. If a contaminated growing medium is suspected, chemical fumigation or pasteurization can be attempted (see section 5.1.7.2 for more discussion on seed and growing media treatments). Fungicidal drenches can be applied after the disease symptoms become evident. This practice is rarely curative: most of the damage has already been done by the time the chemical is applied. However, drenches can stop secondary spread of the disease. Sutherland and Van Eerden (1980) conclude that drenches are seldom effective against damping-off, besides being expensive and potentially hazardous to the environment. (See section 5.1.7.4 for more information on fungicides used to control damping-off.)

Table 5.1.6—*Environmental conditions and cultural practices affecting damping-off in container tree nurseries*

Environmental condition or cultural practice	Effect on disease development	
	Encouraging	Discouraging
Seed quality	Dirty or contaminated; slow, weak germinants	Clean and sterile; vigorous germination
Growing medium	Contaminated	Pest-free
	Fine-textured	Mixture of particle sizes
	Over-compacted	Good porosity
pH	High (>6.5)	Acid (4.5–6.0)
Growing density	Oversowing	One seedling per cavity
Nutrition	High nitrogen	Well-balanced fertilization especially phosphorus, potassium, and calcium
Irrigation	Frequent, heavy applications	Frequent, light applications
Growing environment	High humidity	Moderate humidity
	Low light	Adequate light
	Extreme temperatures	Ideal temperatures

5.1.3.2 Diseases and pests of germinants and young seedlings.

Once the germinants have emerged, the symptoms and signs of disease or pest damage become more apparent. Figure 5.1.23 provides a damage key to the common disease and pest problems of germinants and young seedlings. (Letters in the key refer to subheadings in the appropriate section of the text.)

A. Postemergence damping-off. See section 5.1.3.1 for discussion of damping-off.

***B. Heat injury**.* Symptoms very similar to postemergence damping-off can be caused by high temperatures at the growing medium surface. Levitt (1980) reviewed the literature on seedling diseases caused by heat stress and reported that stem injury of conifer seedlings can result from an exposure to growing media temperatures as low as 45 °C (113 °F). Seidel (1986) exposed 2- to 4-week-old seedlings of ponderosa pine, Douglas-fir, grand fir, and Engelmann spruce to a series of time--temperature treatments and found that seedlings from all species died from temperatures in the range of 48 to 68 °C (118 to 154 °F), depending on exposure time.

Heat injury, which sometimes only occurs on the sunny side of the seedling, is promoted by dark-colored seed coverings that absorb more heat than lighter colors. Boyce (1961) described a disease, called "white spot," characterized by white, shrunken, watery-appearing lesions on the south side of the seedling stem just above the soil surface. James (1987) states that western larch germinants are especially susceptible to heat injury, which can be identified by stem swellings at the root collar. Apparently, this symptom develops when the lateral meristem is killed and basipetally translocated photosynthate causes increased stem growth above the damaged area. The distinguishing difference between fungal damping-off and heat injury is that the seedling radicle shows no sign of decay after heat injury (fig. 5.1.24).

***C. Chemical injury**.* Pesticides can also cause symptoms similar to damping-off. Several chemicals, including surfactants, can cause these symptoms and it is therefore impossible to identify which chemical is responsible for a specific injury. As with heat injury, chemical injury can be distinguished from fungal damping-off by the lack of decay of the seedling radicle.

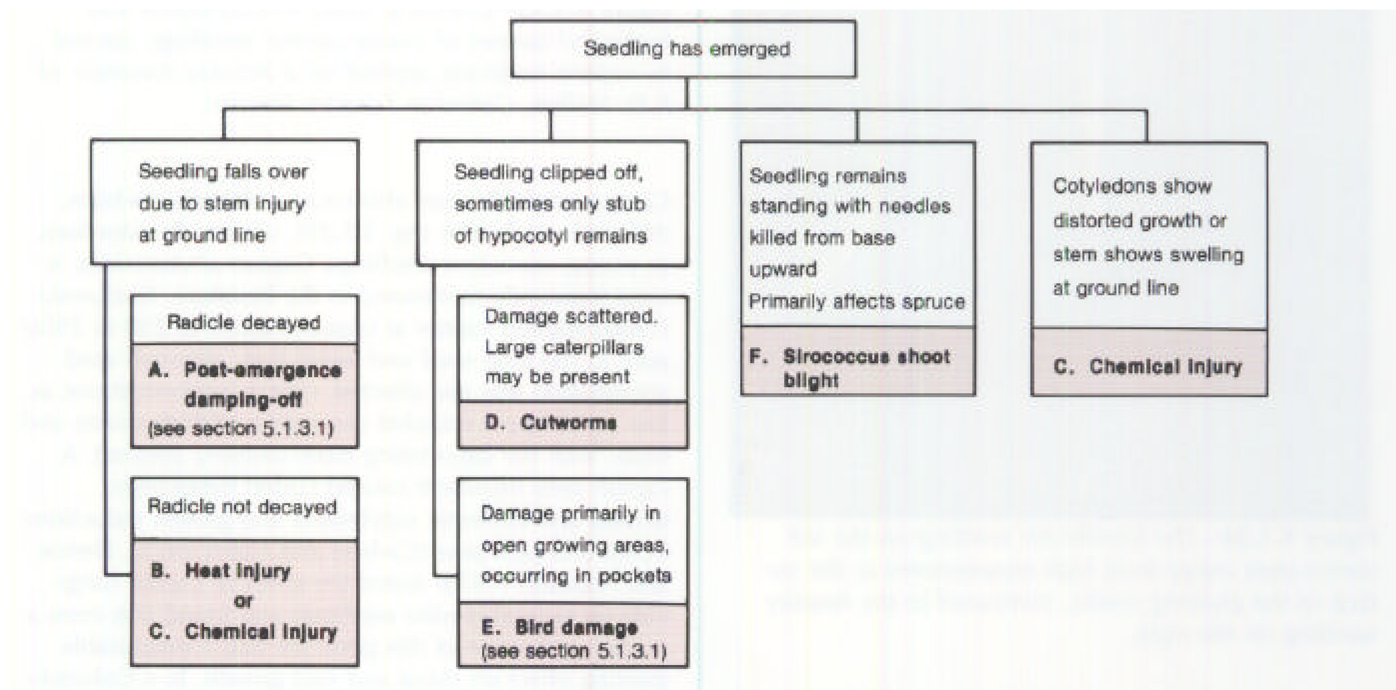


Figure 5.1.23—*Damage key to disease and pest problems of germinants and young seedlings.*

Figure 5.1.24—*The bitterbrush seedling on the left shows stem injury from high temperatures at the surface of the growing media, compared to the healthy seedling on the right.*

Figure 5.1.25—*Chemical injury to cotyledons and hypocotyl* (arrow) *of young conifer seedlings, caused by captan fungicide applied on a hot day (courtesy of R.D. Hallett, Canadian Forestry Service).*

Certain pesticides can also cause chlorosis, tip-burn, distorted cotyledons (fig. 5.1.25), or growth reductions in young, succulent seedlings. Captan phytotoxicity is most frequently mentioned in the literature. Kozlowski (1986) applied captan at concentrations of 250 to 2500 ppm to red pine seed and found that, although seed germination was not affected, captan concentrations as low as 500 ppm retarded elongation of both shoots and roots, with the latter being more severely affected. A captan seed treatment caused curled hypocotyls, twisted and chlorotic cotyledons and growth reductions in red and jack pine (Carlson and Nairn 1975). Denne and Atkinson (1973) tested the effect of captan fungicide on several conifer seedlings and found that even a single application of this pesticide had a measurable stunting effect on shoot and root growth. In a Colorado container nursery, however, captan did not injure blue spruce germinants, whereas dicloran caused a stem swelling that mechanically weakened the seedling stem (fig. 5.1.26).

Figure 5.1.26—*One symptom of chemical injury is stem swelling, which occurs just above the surface of the growing medium. In this case, an early season application of dicloran caused damage to the stem cambial tissue, but the actual swelling did not develop until later in the growing season.*

Even chemicals that are not directly applied to seedlings can cause injury. Fumes from preservatives used to protect wood from decay, such as pentachlorophenol, caused twisting and chlorosis of cotyledons and eventual death of red and jack pine seedlings (Carlson and Nairn 1975). Arsenic toxicity was diagnosed as the cause of needle burn, stunting, and occasional mortality of red pine and other conifer seedlings in a Minnesota container nursery. The source of the arsenic was cromated copper arsenate used as a wood preservative in the bench frames and apparently the chemical leached into the paperpot containers around the perimeter (Croghan 1984). Herbicide vapors in the air or pesticide-contaminated irrigation water can also cause leaf burn or distortions. Hanan and others (1978) list specific symptoms for several types of herbicide injury to horticultural crops.

D. *Cutworms*. Cutworms are moth larvae that feed on the succulent shoots of young seedlings. Sutherland and Van Eerden (1980) list three species of cutworms that can cause damage to container seedlings, and Matthews (1983) considers the variegated cutworm, *Peridroma saucia*, to be the most common species in container nurseries in British Columbia. There are no published accounts of the amount of actual damage, but cutworms were ranked as the second most important insect pest reported in the Container Nursery Survey (table 5.1.3).

Hosts. Cutworms are not host-specific and will feed on most species of forest tree seedlings (Sutherland and /an Eerden 1980).

Symptoms/Damage. Cutworms injure young seedlings by feeding on succulent foliage and stems of young seedlings ("clipping") (fig. 5.1.27), often consuming the entire shoot, leaving just a "stump." Cutworms can cause chewing injury on the stem, resulting in sunken or depressed areas that can resemble fungal lesions. Seedlings cut off at the ground line might be mistaken for seedlings suffering from damping-off (Palmer and Nicholls 1981).

Most cutworms are large, variably colored, thick-bodied caterpillars, up to about 4 cm (1.6 inches) long (fig. 5.1.27). They feed mostly at night and hide during the day; the caterpillars can sometimes be found under the surface of the growing medium or under containers. Shrimpton (1987) states that containers with cutworms can be easily spotted: the cutworms in the soil cause the container plug to be elevated above the plugs of surrounding seedlings. The adult moths, often called "millers," are woolly, mottled grey to brown, and about 2 cm (0.8 inch) long. They can sometimes be seen flying around the growing area but do no damage themselves (Sutherland and Van Eerden 1980).

Figure 5.1.27—*Cutworms are thick-bodied caterpillars that clip seedling foliage and may eventually consume the entire shoot (courtesy of J.R. Sutherland, Canadian Forestry Service).*

Life cycle. The life cycle of cutworms consists of egg, larval, pupal, and adult stages and ranges from one to several generations per year, varying with the climate. The adult moths lay eggs in growing medium or on plant debris; soon after the eggs hatch, larvae begin feeding on plant tissue and continue to grow until pupation. A few cutworms can cause significant losses because they can move from seedling to seedling and the large larvae consume considerable amounts of plant material. Cutworms probably overwinter in the pupal stage (Sutherland and Van Eerden 1980).

Pest management. Growing areas should be screened to exclude the adult moths. Larvae can be hand-picked out of the containers and destroyed, but this is impractical in large operations. Because the adult moths are attracted to certain weed species for egg laying, keeping the growing area weed-free should help reduce the incidence of cutworms (Shrimpton 1987). Chemical controls, such as poison baits containing attractants and insectide sprays or drenches (see section 5.1.7.4), are usually directed at the larvae. Contact insecticides and baits are more effective than protective insecticides because the larvae consume very little of the shoot, and it is difficult to apply protective insectides to the lower stem region (Shrimpton 1987). Sprays to control adult moths were most effective when applied late in the day (Sutherland and Van Eerden 1980).

E. Bird damage. See section 5.1.3.1.

F. Sirococcus blight. A blight is a descriptive term for a disease that causes rapid dieback or death of plant tissue (Peterson and Smith 1975). Sirococcus blight, caused by the fungus *Sirococcus strobilinus* primarily affects spruce seedlings in the northwestern United States and coastal British Columbia. This seedborne pest is spread through poor cone collection practices, and older cones are most likely to be diseased (Sutherland 1986). Within infested seedlots, 1 to 3% of the seed may be infested, and secondary spread between emerged seedlings in the nursery has resulted in losses as high as 40% (Sutherland and Van Eerden 1980). James and Gilligan (1985) reported that this fungus caused disease in 18 of 19 seedlots and was the most damaging disease of spruce seedlings in a northern Idaho container nursery. Sirococcus blight was the fourth most important disease reported by nursery managers during the Container Nursery Survey (table 5.1.2). Sutherland and others (1987) present an excellent review of sirococcus blight.

Hosts. Although sirococcus blight can affect both spruce and pine in container nurseries, it has been most damaging on Sitka and white spruce in the northwestern United States and coastal British Columbia (Sutherland and Van Eerden 1980). The pest was shown to be seedborne on Sitka, white, and Engelmann spruce in British Columbia (Sutherland and others 1981) and is suspected to be seedborne on Engelmann spruce in Idaho (James and Gilligan 1985).

Symptoms/Damage. The fungus attacks germinants and very young seedlings and kills primary needles from the base upwards; the affected needles become desiccated and turn light brown to reddish brown (fig. 5.1.28). The seedlings usually die and remain upright (Sutherland and Van Eerden 1980). This disease could be mistaken for fusarium root rot (see section 5.1.4.2) but can be differentiated by looking for the characteristic butterscotch- or dark-colored pycnidia on the hypocotyl or the base of the cotyledons. On older (4 months) seedlings, S. strobilinus can cause a shoot blight or tip dieback that sometimes leads to seedling mortality (James and Gilligan 1985).

Disease development. The fungus is mainly introduced into the nursery on seed, although spores may be blown in from outside the growing area. Once introduced into a container nursery, the fungus can apparently spread to adjacent seedlings through spores disseminated by irrigation or rain splash. The disease pockets that develop often mask the random distribution that is characteristic of seedborne pathogens. The disease is favored by the cool, moist conditions and low light intensities that often occur in Northwest container nurseries (Sutherland and Van Eerden 1980). A good illustration of the disease cycle of sirococcus blight is presented in Sutherland and others (1987).

Disease management. Chemical. Seed assays can be performed to detect Sirococcus-infested seedlots (Sutherland and others 1981), and a recently developed monoclonal antibody assay may prove to be a simple, rapid, and accurate diagnostic procedure (Mitchell 1986). If infested seedlots can be identified, they can be chemically treated prior to sowing, or germinants of infested seedlots can be closely monitored for the appearance of the disease. Prompt identification will allow fungicides to be applied (see section 5.1.7.4) as soon as the disease becomes evident to prevent secondary spread of the disease (Sutherland and Van Eerden 1980). Benomyl or daconil fungicide drenches applied to Sirococcus-infested seedlots have produced conflicting results (Matthews 1987). Fungicides should be applied regularly to protect new foliage because irrigation or rain may wash the chemicals off older seedling foliage.

Figure 5.1.28—*Sirococcus blight is a seedborne fungal disease that affects young spruce seedlings. Diagnosis can be made using symptoms (brownish, withered foliage) and signs (dark pycnidia at the base of the shoot, arrow) (photo courtesy of R.L. James, USDA Forest Service).*

Cultural. Seeds originating from seed orchards should be selected to be free from Sirococcus (Sutherland and others 1982). In the nursery, diseased seedlings should be rogued as soon as they become evident to prevent secondary spread. Manipulating environmental conditions such as reducing relative humidity and increasing temperature and light may be helpful in minimizing disease intensity (Sutherland and others 1980).

5.1.4 Diseases and Pests of Seedling Root Systems

Root diseases and pests are at least as common as those of seedling shoots and are frequently more damaging. The relative importance of root diseases and pests may be underestimated because roots are hidden from view, and root problems are often expressed through foliar symptoms. Experienced pest specialists realize that many foliar symptoms are often indicators of advanced root injury.

As in previous sections, a damage key is provided for the commonly reported root diseases of established container seedlings (fig. 5.1.29). The descriptions in this key should help the grower tentatively identify the disease; more information on the disease is provided in the sections referred to by the key. (Letters in the key refer to subheadings in the appropriate section of the text.)

5.1.4.1 Insect pests

Although some insects cause incidental injury when they are accidentally introduced into container tree nurseries, some species are specific pests of tree seedlings.

A. Root weevils. Although several weevils damage container nursery stock, the black vine weevil (*Otiorhynchus sulcatus*) is one of the most damaging (Sutherland and Van Eerden 1980). Both the black vine weevil and the strawberry root weevil (*O. ovatus*) were reported from container nurseries in the United States and Canada in the Container Nursery Survey. Sutherland and others (1982) consider weevils to be the most prevalent, destructive, and difficult-to-control insects in British Columbia container nurseries. Root weevils

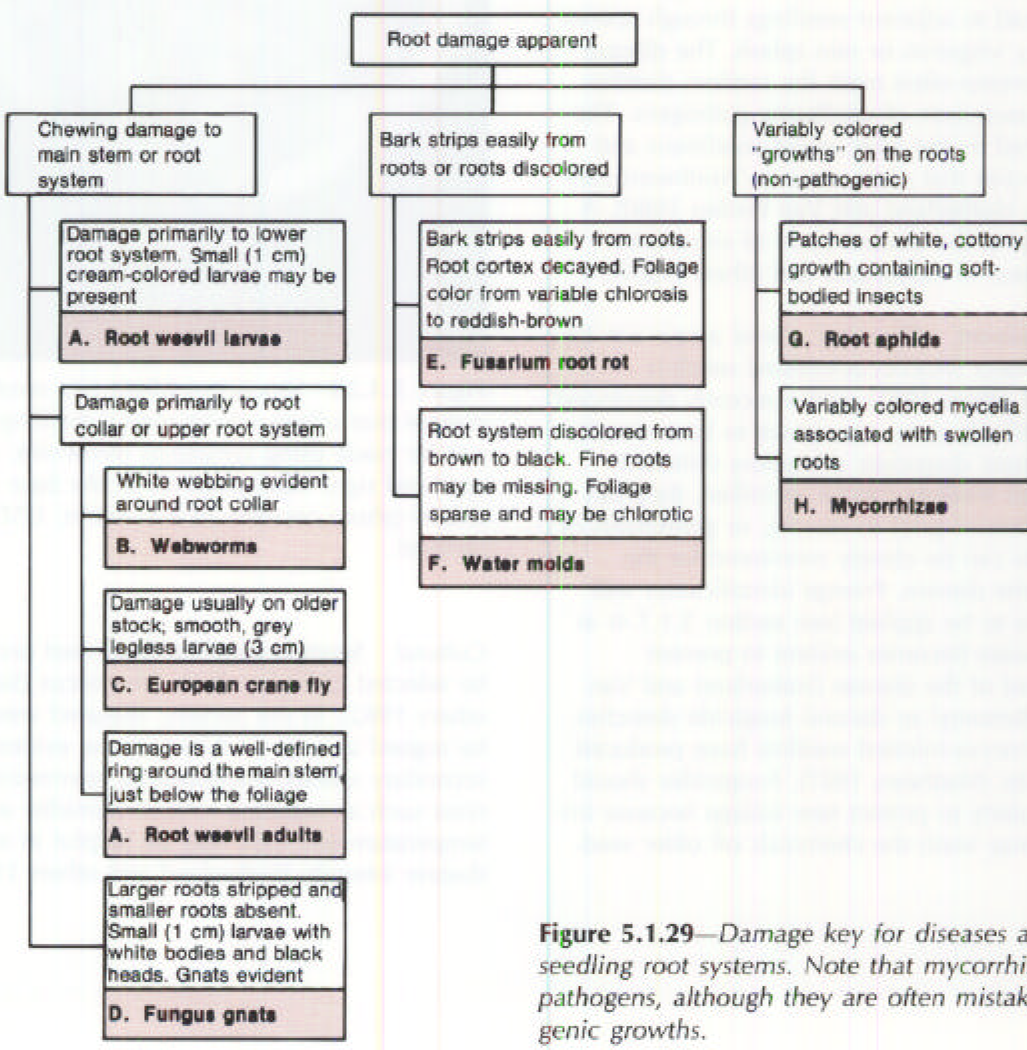


Figure 5.1.29—*Damage key for diseases and pests of seedling root systems. Note that mycorrhizae are not pathogens, although they are often mistaken for pathogenic growths.*

Figure 5.1.30—*Adult weevils (**A**) can girdle the stems of container tree seedlings; their larvae (**B**) cause chewing damage to the roots. The black vine weevil (**left**) is larger and considered to be more damaging than the strawberry root weevil (**right**). (Courtesy of J.R. Sutherland, Canadian Forestry Service.)*

were the third most important insect pest based on responses to the Container Nursery Survey, with a relative occurrence of 10% (table 5.1.3).

Hosts. Weevils can attack all species of seedlings, but western hemlock (Matthews 1983) and spruce seedlings (Shrimpton 1986) are particularly susceptible.

Symptoms/Damage. Identification of adult weevils can be confusing, and Carmean (1986) provides a key to the common species. Adults of both the black vine and strawberry root weevils are small-from 0.3 to 1.2 cm long (0.1 to 0.5 inch)-but the black vine weevil is larger. The color of the adults ranges from tan to dark and they have the typical weevil shape (fig. 5.1.30A).

Adult weevils girdle seedling stems, resulting in a neat ring about 6 mm (0.25 inch) wide just below the point at which the foliage begins. Usually only one seedling is attacked at a time. This damage usually occurs in early summer, because the adults feed before the stem tissues become too woody. Seedlings at the outside of a block of containers or at the perimeter of the growing area are attacked most frequently (Shrimpton 1986). Adult strawberry root weevils can cause more significant damage than adult black vine weevils, which cause only minor injury. Adults may go unnoticed because they feed at night and hide during the day, but they can sometimes be found under containers or other material in the growing area.

Figure 5.1.31—*The larvae of the black vine weevil can sometimes be found in the seedling plug, where they strip the roots* **(A)** *and often completely consume the lower portion of the root system* **(B)** *(***A***, courtesy of G. Shrimpton, British Columbia Ministry of Forests;* **B,** *courtesy of J.R. Sutherland, Canadian Forestry Service).*

Weevil larvae are more destructive than the adults. Larvae of both species are cream-colored, with brown heads and no legs; larvae of the strawberry root weevil are smaller than larvae of the black vine weevil (fig. 5.1.30B) (Sutherland and Van Eerden 1980). Weevil larvae can sometimes be found within the growing medium, where they chew the bark from larger roots and completely consume smaller roots (fig. 5.1.31A). Because larvae consume increasingly more root tissue as they grow, the supply of water and mineral nutrients to the seedling shoot is gradually reduced. Foliar symptoms are not usually visible until later in the growing season, when the entire seedling can be easily lifted out of the container; inspection of these seedlings reveals that the entire lower section of the root system has been consumed (fig. 5.1.31 B) (Sutherland and Van Eerden 1980). Because the container plug must be dissected to find the larvae, their populations are not routinely monitored.

Life history. The life cycles of all weevils affecting container seedlings are similar, but the speed of development and number of generations per year may be increased by the favorable conditions in heated greenhouses. Adults lay their eggs within or on the growing medium during the summer. When the larvae hatch, they begin feeding on the root system; they may overwinter as larvae or pupate into adults, which also can overwinter. Interestingly enough, all adult weevils in this genus are females (Shrimpton 1987).

Pest Management. *Chemical*. Insecticides can be applied to control either the grubs or the adults, although foliar pesticides that kill the adults are most effective. Because the timing of these applications is critical, monitoring to determine periods of adult weevil activity is essential. Foliar pesticides (table 5.1.7) should be applied to the seedling foliage soon after finding adults so that the adults are killed before females begin laying eggs (Sutherland and Van Eerden 1980). Under conditions of overlapping generations, such as may occur in greenhouses, foliar sprays may need to be applied at 3- to 4-week intervals because the toxicity of the insecticides lasts only a few days. The spray should be carefully applied to completely cover the seedling foliage because weevils often feed out of direct sunlight (Capizzi and Green 1984).

Because not all adult weevils are killed by protective foliar treatments, a chemical drench (table 5.1.7) may be required to control larvae in the growing medium. Capizzi and Green (1984) recommend that several drenches can be applied in either the spring or fall. Drenches are operationally hard to administer because the chemical must uniformly penetrate the growing medium for complete control.

Cultural. There are no published cultural controls for this insect.

Table 5.1.7—*Insecticides for the control of adult and immature root weevils in ornamental container stock*

Active ingredient	Trade name	Formulation (oz/100 gal)
Foliar sprays for adult weevils		
acephate	Orthene 75S®	16
azinphos-methyl	Guthion 50WP®	16
permethrin	Pounce 3.2 EC®	8
fenvalerate	Pydrin 2.4 EC®	5.3–10.6
fluvalinate	Mavrik Aquaflow 2E®	9.6
bendiocarb	Turcam® or Dycarb 76WP®	21
Drenches for immature weevils		
carbofuran	Furadan 4F®	1–2
acephate	Orthene Tree and Ornamental Spray®	16

This listing does not constitute a recommendation: these specific products are those listed in the source and may not be currently registered. Other products may be available as well. Consult with a pesticide specialist and check label for information on registered uses and application rates.

Source: Capizzi and Green (1984).

B. Webworms (including cranberry girdler). Webworms, the larvae of a group of moth-like insects that includes the cranberry girdler (*Chrysoteuchia topiaria*), have been a problem in bareroot forest nurseries for several years but have only recently been implicated as the cause of container seedling injury. Webworm adults (fig 5.1.32A) do no damage, but the larvae (fig. 5.1.32B) feed on the stem and upper root system of container tree seedlings. The amount of damage caused by webworms is not well known, although one severe infestation by a related webworm resulted in the loss of several thousand 2 + 0 container spruce in an interior British Columbia nursery (Shrimpton 1986). At present, only nurseries in Idaho, Montana, and British Columbia have been affected by this insect pest.

Hosts. Spruces and Douglas-fir are the only reported hosts, although the cranberry girdler attacks other conifers in bareroot nurseries.

Symptoms/Damage. The chewing injury of the webworm larvae is similar to that caused by other girdlers such as root weevils. However, webworms strip the outer bark from the root collar and upper roots while weevils consume the lower part of root system (fig. 5.1.33A). Damage occurs most often during the month of August in British Columbia (Shrimpton 1986). The most distinguishing characteristic of webworm damage is the presence of white, silky webbing containing bits of growing medium at the root collar (fig. 5.1.33B).

Life cycle. Webworm moths become active in late spring and lay their eggs in dense stands of plants, so container seedlings provide an ideal habitat. The moths, which are pale brown with a distinctive snout-like projection from the head, measure from 1.3 to 2.5 cm (0.5 to 1.0 inch) in length (fig. 5.1.32A). They have a characteristic jerky zigzag flight pattern. The larvae hatch in a few days and feed until pupation in the fall; the webworm larvae are short [0.6 to 1.9 cm (0.25 to 0.75 inch)], thick-bodied, and coarsely haired. The larvae overwinter in silken cocoons just under the surface of the growing medium and pupate the following spring (Metcalf and Flint 1962). Some webworms have more than one generation per year, which could be a significant factor in the favorable greenhouse environment.

A

B

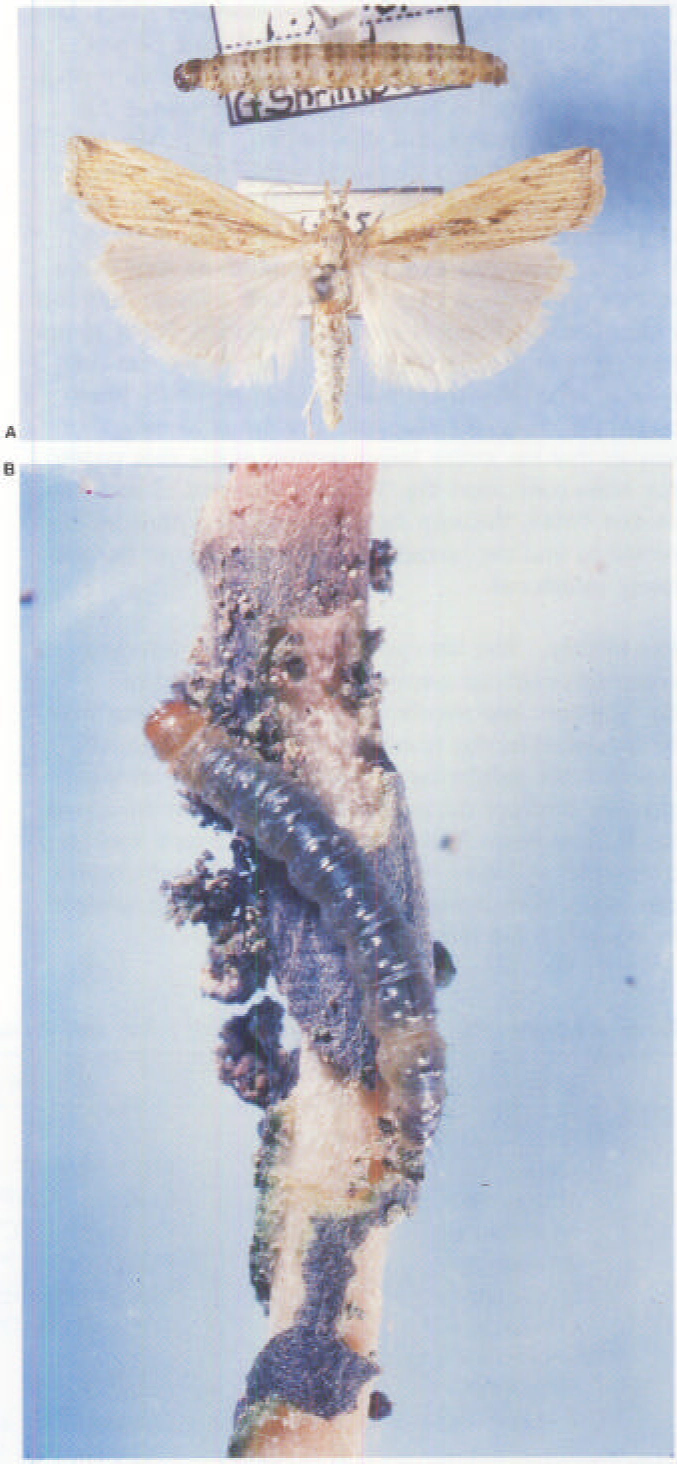


Figure 5.1.32—*Webworms are newly recognized pests of container tree seedlings. The adult moth* **(A)** *has a distinctive snout but is not injurious; the larvae* **(B)** *girdle the upper root system (courtesy of G. Shrimpton, British Columbia Ministry of Forests).*

A

B

Figure 5.1.33—*Webworm damage to a container spruce seedling. The bark has been stripped off the seedling stem and the upper part of the root system (**A**). Note the remnants of "silk-like" webbing at the soil surface (**circle**), which are signs of this insect pest (**B**).*

Pest management. Specific control measures for these insect pests have not been established for container nurseries. However the following controls, which have been used for cranberry girdler in bareroot nurseries, have some applicability. Grass acts as a reservoir for webworms, and so populations can be reduced by eliminating the amount of grass around nurseries by mowing or with herbicides. Susceptible seedlings should be grown as far away from open fields as possible (Shrimpton 1983). Screening all greenhouse openings would exclude the adult moths from the growing area. Insecticides can be used for either the adult or the larvae. Diazinon has been applied within the seedling crown to control the moths and insecticidal drenches, such as chlorpyrifos, have been used against the larvae. Pheromone traps can be used to determine webworm occurrence and establish moth activity periods (Tunnock 1985).

***C. European crane fly*.** The European crane fly, or European marsh crane fly (*Tipula paludosa*) is an introduced pest that has only been reported in the Pacific Northwest. The range of this insect pest is apparently limited by climate; the southern range of the European crane fly is currently around 45° latitude (Oregon to Nova Scotia) (Anonymous 1983). Larvae of the European crane fly, called "leatherjackets" (fig. 5.1.34), feed on the seedling stem and upper part of the root system. This feeding eventually girdles the stem and cuts off the water and mineral nutrients from the root system, causing foliar wilt and stunting. This insect was ranked fourth in the Container Nursery Survey, with a relative occurrence of 9.8% based on responses from container nursery managers (table 5.1.3). Because of the crane fly's life cycle, the damage should be restricted to older container seedlings, especially 2 + 0 or holdover stock (Sutherland and Van Eerden 1980). Nurseries in wet climates are more likely to be affected because the eggs and young larvae are susceptible to desiccation (Anonymous 1983). This pest could be introduced to new areas because the larvae often remain with the seedling plug after it leaves the nursery (Shrimpton 1985).

Hosts. There are no published reports of host specificity, but the only serious outbreak of damage was on bareroot Sitka spruce in British Columbia (Sutherland and Van Eerden 1980).

Symptoms/Damage. This insect is difficult to detect during the growing season because the larvae feed under the surface of the growing medium, and the damage is usually not noticeable until seedlings are lifted for shipping. Leatherjackets create a well-defined feeding ring about 2.5 cm (1 inch) wide at the root collar, only consuming the bark. They usually completely girdle the seedling stem and may eventually consume some of the upper root system. The damage is usually spotty in distribution, because the larvae usually attack small groups of 1 to 7 seedlings in a given area (Shrimpton 1986).

The larvae have tough, leather-like skin and no distinctive head, which helps distinguish them from cutworms. Although the larvae are initially small [3 mm (0.1 inch)], they grow rapidly, eventually reaching 4 cm (1.6 inches) in length (fig. 5.1.34A). They can sometimes be found in the upper layers of the growing medium. Pupae are brown and spiny and about 3.3 cm (1.3 inches) long, and the empty pupal cases are left protruding from the medium by emerging adults. Adult crane flies (fig. 5.1.34B) resemble large greyish brown mosquitoes with bodies about 2.5 cm (1.0 inch) in length, two wings and very long legs (Sutherland and Van Eerden 1980). Adults are most abundant in late summer (Shrimpton 1985).

Life history. Under normal conditions in the Pacific Northwest, the European crane fly passes through all four life stages (egg, larva, pupa, and adult) in 1 year. Adults do not damage seedlings but lay eggs on the surface of the growing medium in the late summer or early fall. The larvae feed through the fall and winter and pupate the following summer. Adults emerge, mate immediately, and lay eggs, completing the life cycle (Sutherland and Van Eerden 1980).

Pest management. The decision on whether control is warranted should be based on the amount of injury sustained and the presence of the adults in the nursery. Adult crane flies can be excluded from greenhouses with screening. Although biological controls have proven effective in laboratory trials, none have been implemented in operational situations (Anonymous 1983). Protectant sprays against adult crane flies are ineffective because they do not feed on seedlings. Insecticide drenches and baits for larvae control may be worthwhile (Sutherland and Van Eerden 1980) (see section 5.1.7.4). In British Columbia container nurseries, diazinon is applied in the evening during the fall when the leatherjackets feed near the surface of the growing medium. An estimate of control can be made following these applications because the larvae often crawl to the surface before they die. This insect is primarily a pest of grasses, and lawns surrounding the nursery should also be treated appropriately to eliminate any reservoir populations (Shrimpton 1985).

A

B

Figure 5.1.34—*The larvae of the European crane fly* **(A)**, *which are called "leatherjackets," girdle the seedling stem, whereas the adult* **(B)** *is a large harmless mosquito-like insect (courtesy of J.R. Sutherland, Canadian Forestry Service).*

***D. Dark-winged fungus gnats**.* These small flies (*Bradysia* spp.) are common nuisances around greenhouses but their importance as damaging pests of container tree seedlings has not been realized until recently. Actually, adult fungus gnats are harmless; the larvae, however, can feed on the roots of young succulent tree seedlings, cuttings, or fleshy seeds when conditions are favorable. Fungus gnats placed fifth in the ranking of insect pests from the Container Nursery Survey (table 5.1.3). Shrimpton (1986) considers fungus gnats to be secondary pests, usually only attacking seedlings weakened by other pathogens, such as fusarium root rot. The role of these insects in disease transmission has always been suspected and now has recently been confirmed for verticillium wilt in greenhouses (Kalb and Millar 1986).

Hosts. The larvae normally feed on soil fungi and organic matter, but larger larvae can attack healthy root tissue of many plants including pine seedlings (Mead 1978). Seeds and cuttings of hardwood species and seedlings of many woody species have been damaged in western container nurseries.

Symptoms/Damage. The first evidence of infestation by fungus gnats is the presence of the adults, which hover around the host plants and fly when disturbed. Fungus gnat adults are small, dark, mosquito-like flies (fig. 5.1.35A) similar to many other small flies common in greenhouses. Shrimpton (1986) trapped small flies in British Columbia container nurseries and identified 11 different species. It can be difficult for the amateur to differentiate between dark-winged fungus gnats and shore flies, which are also common, but harmless (table 5.1.8).

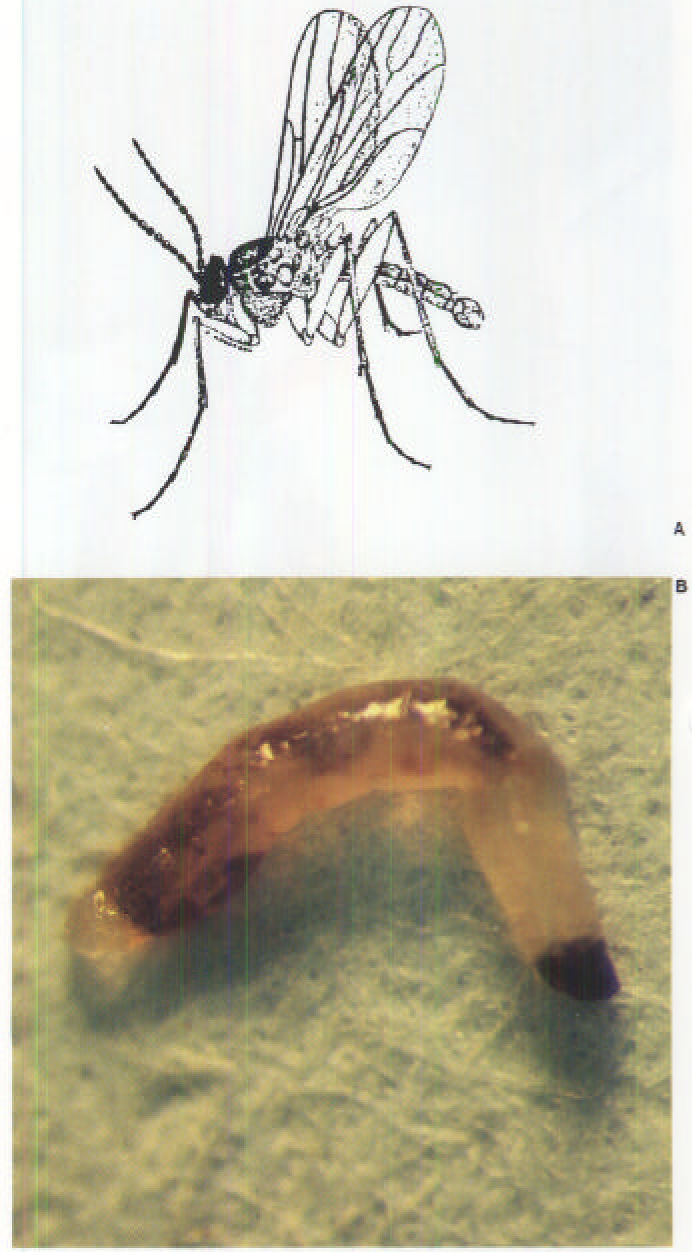


Figure 5.1.35—*Adult fungus gnats* **(A)** *are a common nuisance in container tree nurseries but are not damaging to seedlings; the larvae* **(B)** *can cause serious chewing injury to the root system of container tree seedlings (***A***, courtesy of J.R. Baker, North Carolina Extension Service.).*

Table 5.1.8—*Distinguishing characteristics of two common greenhouse flies: shore flies and dark-winged fungus gnats*

Characteristic	Shore flies	Dark-winged fungus gnats
Family	Ephydridae	Sciaridae
Body	Resemble fruit flies	Resemble tiny mosquitoes
Size	2–4 mm (0.08–0.16 in.)	2–4 mm (0.08–0.16 in.)
Wings	Contain pale spots	Gray with "Y"-shaped vein
Antennae	Short with a bristle	Long and bead-like
Larvae	No distinct head	Slender with dark shiny heads

Source: modified from Kennedy and Helgesen (1973) and Shrimpton (1986).

Symptoms of injured seedlings include wilting and sudden loss of vigor. Examination of affected plants with a hand lens may reveal the presence of larvae in the upper layer of the growing media (Peck 1982). The larvae are legless, semitransparent worms with black heads and range up to 0.5 cm (0.2 inch) in length (Nelson 1978) (fig. 5.1.35B). The larvae may consume small roots completely or just the exterior of the larger roots, leaving just the stripped vascular tissue. By the time symptoms become evident, damage is usually so severe that control of the larvae is not practical. Instead, the adults should be controlled as soon as they are noticed.

Life history. Female gnats lay eggs on moist surfaces, preferring growing media that are rich in organic matter. Infestations appear to be most severe in containers that contain algae or moss, which develop in response to overwatering. Eggs hatch in about 6 days, and the larvae feed for a couple of weeks and pupate in the growing medium. After 5 to 6 days, the adult flies emerge, completing the life cycle (Nelson 1978). Because of their short life cycle, populations of dark-winged fungus gnats can build-up rapidly in greenhouse environments where organic matter food sources are present and warm, moist conditions exist (Peck 1982).

Pest management. Chemical. Insecticides can be used to control either larvae or adults. Many common insecticides are effective against the adults (see section 5.1.7.4), but it is sometimes difficult to reach areas where the adults may be hiding. Insecticides can be applied as drenches to control the larvae, but all surfaces where the gnats are breeding must be treated (Peck 1982). Hamlen and Mead (1979) tested 12 common insecticides on fungus gnats and found that all were effective; insecticides were more effective than growth regulators and surface-applied pesticides were as effective as drenches.

Cultural. Cultural control methods involve general greenhouse sanitation: removing infested containers, avoiding overwatering, controlling algae and mosses, and sterilizing containers and surfaces in the growing area (Peck 1982). Lindquist and others (1985) report that the type of growing medium affects fungus gnat populations and also the efficacy of insecticides: more adult fungus gnats emerged and insecticides were less effective in a medium containing composted bark. Shrimpton (1986) describes a method of monitoring fungus gnats, and potentially controlling them, that involves yellow sticky ribbons hung in the greenhouse. The adult fungus gnats are attracted to the ribbons and become stuck. Parrella (1987) discusses the use of yellow sticky cards in ornamental greenhouses, and recommends hanging one card per 929 m^2 (10,000 ft^2), for monitoring insect pest populations. Shrimpton (1986) states that horticultural greenhouses have successfully reduced greenhouse fly populations by hanging these yellow sticky ribbons at a density of one per 0.93 m^2 (10 square feet). Baker (1986) presents an excellent guide for identifying the greenhouse insects trapped on yellow sticky cards.

5.1.4.2 Fungal diseases of roots

Fungi cause many root diseases of container nursery seedlings. Although the advent of soilless growing media has reduced the amount of damage, fungal root rots still cause problems for container nursery managers. Several species of fungi can cause root rot and, although rhizoctonia root rot is one of the main root diseases of ornamental plants (Baker 1957), *Rhizoctonia* spp. have not been widely reported in container tree nurseries. Instead, Fusarium spp. are the most commonly reported root pathogens (Pawuk 1981, James 1985a). Phytophthora root rot, caused by several species of *Phytophthora*, has been identified in container tree nurseries only rarely. Its occurrence can usually be attributed to poor aeration of the growing medium.

Seedlings affected by root rots may show a variety of aboveground symptoms. One of the first indications of root disease is a general loss of vigor, followed by needle-tip dieback, needle curling ("clutching"), chlorosis, and wilting. Even relatively low root pathogen levels can severely reduce seedling growth by injuring fine root tips and therefore interfering with water and mineral nutrient uptake. If root rots are suspected, growers should remove several seedlings from the containers and examine the roots. Healthy plants should have numerous white root tips, whereas diseased roots show various degrees of water-soaking and appear brown or black (Cline 1985).

E. Fusarium root rot. Fusarium root rot is one of the most common diseases of conifer seedlings in the world and is widespread in North American nurseries (Bloomberg 1981, Smith 1975). Fusarium wilt affects many different horticultural plants and is the most important pathological problem of plants grown in artificial growing media (Couteaudier and Alabouvette 1981). Because this fungus prefers warmer temperatures, heated container nurseries are ideal for build-up of this disease.

Hosts. Most conifer seedlings, including spruces, true firs, pines and larch are susceptible to fusarium root rot, but the disease is apparently most serious on Douglas-fir.

Symptoms/Damage. The foliar symptoms of fusarium root rot are variable: newly infected seedlings typically have scattered chlorotic or curled needles (fig. 5.1.36) followed by tip dieback, wilt symptoms, and stunting as the disease progresses. The seedling foliage often turns a reddish brown just before the seedling dies. Diseased root systems show lack of fine root development and extensive cortical decay so that the epidermis is easily stripped away from the core tissues (fig. 5.1.37). One of the most diagnostic signs of this disease is the production of fruiting structures (sporodochia) on the seedling stem (fig. 5.1.38A), where yellow-orange spore masses are exuded games 1985a, Landis 1976). These spores are typically multicellular and sickle-shaped and can be used to positively identify the fungus (fig. 5.1.38B).

Disease development. Apparently, several different species of Fusarium can cause root rot of container tree seedlings, including F. oxysporum (Graham and Linderman 1983), F. solani games 1983, Landis 1976), and F. avenaceum games 1985a). One of the main sources of Fusarium inocula in container nurseries is the seed, although the fungus has also been isolated from growing media, used containers, weeds, and irrigation water. Pawuk (1981) isolated only low levels of Fusarium spp. from air and water samples around greenhouses but recovered the fungus from four species of southern pine seed with infection intensities of 54 to 91 %. Graham and Linderman (1983) isolated F. oxysporum from Douglas-fir seed and James (1983) recovered F. oxysporum and F. solani from the exterior and interior of conifer seed. Seed from squirrel-cache-collected cones often are infested with Fusarium spp. and other potentially pathogenic fungi games 1986). This widespread fungal pathogen has also recently been isolated from reusable containers that had already been sterilized (fig. 5.1.22).

Figure 5.1.36—*Initial symptoms of fusarium root rot include twisted, chlorotic needles near the tip of the seedling shoot.*

Figure 5.1.37—*Advanced disease symptoms of fusarium root rot, showing the twisted, chlorotic foliage and lack of fine root development.*

A

B

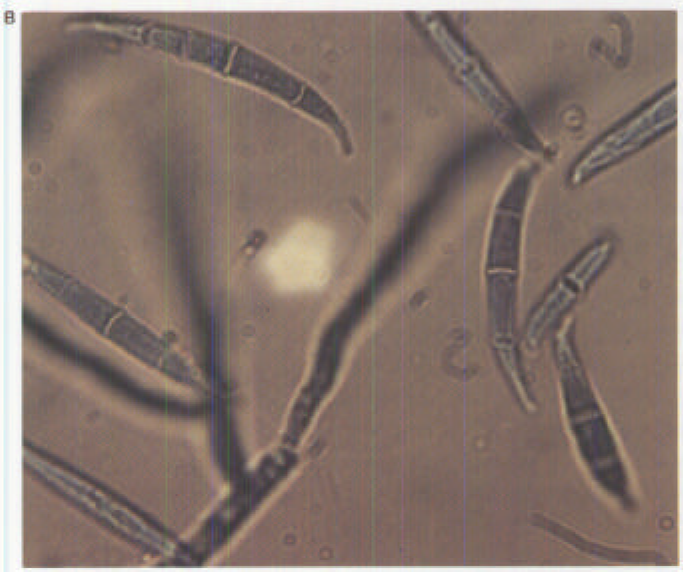


Figure 5.1.38—Fusarium *spp. often produce fruiting bodies (sporodochia,* arrow) *on the stem of infected seedlings* **(A).** *Stained fresh mounts of this tissue reveal the characteristic "banana-shaped" multicellular spores (macroconidia) of this fungus* **(B)**.

Although initial infections are usually random, secondary spread is probably due to spores splashed from diseased seed or seedlings during irrigation (Graham and Linderman 1983), and disease pockets apparently develop as a result of this secondary spread. Bloomberg (1981) discusses fusarium diseases in detail and reports that high temperatures [25 to 35 °C (77 to 93 °F)] stimulate fungal growth and that high nitrogen fertilization appears to increase disease losses. Normal-appearing seedlings are often infected with the fungus but do not develop foliar symptoms. *Fusarium* is a common rhizosphere inhabitant, and the disease only develops when the seedling becomes stressed, by drought or heat for example. The cultural practice of moisture-stressing seedlings to harden them may thus actually enhance disease development (James 1986).

Disease management. *Chemical*. Chemical control methods can be divided into sanitation of containers and surfaces in the growing area, seed treatments, growing medium treatments, and fungicidal drenches. Because Fusarium spp. can be introduced into container nurseries on seed, growers might consider seed treatments prior to sowing. Growing media should be assayed to make sure that they are pathogen-free, and containers should be carefully cleaned and treated with heat or chemical sterilants. Fungicidal drenches (see section 5.1.7.4) are commonly used to control fusarium root rot, but these treatments function primarily to limit the spread, rather than cure the disease.

Cultural. Growers can reduce the impact of fusarium root rot by using a growing medium that stimulates healthy root growth and discourages pathogens (Couteaudier and Alabouvette 1981) and by promptly roguing diseased seedings to prevent secondary spread.

F. Water molds. The water mold fungi, species of *Pythium* and *Phytophthora, are* commonly occurring pathogens that cause serious root diseases in many plants. Although both of these fungal genera have been consistently linked to root rot of ornamental container stock, only *Pythium* is a serious pest of forest tree container seedlings. Peterson (1974) predicted that phytophthora root rot will not be a serious pest of container tree seedlings because most nurseries use well-drained growing media.

Hosts. All seedlings are susceptible to root rots caused by water molds.

Symptoms/Signs. Water mold fungi cause wilt symptoms, followed by chlorosis and stunting. *Pythium*-infected roots are black and water-soaked and are often hollow and collapsed (Nelson 1978). Because symptoms develop from the root tips, container seedlings affected with pythium root rot often have a root system with few lateral roots (fig. 5.1.39). Phytophthora root rot is characterized by a distinctive reddish brown discoloration of the cambial region of the infected root; in some hardwood species, the stain is blue-black or inky colored (Kuhlman and Smith 1975).

Disease development. Water molds are so named because they have motile spores that swim in water and therefore thrive in damp soils. Unlike many other fungi, they have no airborne spore stage. Both *Pythium* and *Phytophthora are* favored by wet, poorly drained media and cool temperatures. They are able to withstand periods of drying by forming thick-walled resting spores (Baker 1957).

Disease Management. These root rots are more easily prevented than controlled. Although water molds can be seedborne, they are most often introduced in contaminated irrigation water or growing media. Growers, therefore, should check their water sources and media. Irrigation water can be tested for *Pythium* and *Phytophthora* by a "baiting" procedure in which baits of unripe fruit (apples or pears) are suspended near the water surface (fig. 5.1.40). These baits attract motile zoospores, which penetrate the fruit and can be subsequently isolated and identified on a selective medium (McIntosh 1966). Water molds thrive in wet conditions, and so growing media should be formulated to provide good aeration and drainage. Fungicidal drenches (see section 5.1.7.4) can be used to control water molds, but many of these chemicals (e.g., metalaxyl) are only fungistatic, merely stopping the spread of the disease, not eradicating it.

Figure 5.1.39—*One of the characteristic symptoms of pythium root rot is the absence of fine, lateral roots.*

Figure 5.1.40—*The presence of water mold fungi* (Pythium *spp. or* Phytophthora *spp.) can be tested by suspending apple or pear "baits" in the irrigation water. The motile fungal spores attack the baits, causing visible bruises that can then be cultured for the fungus (courtesy of S.J. Campbell, USDA Forest Service).*

Cylindrocarpon root rot. Several species of *Cylindrocarpon have* been isolated from tree seedling roots, but only recently have these fungi been associated with a serious root disease of container tree seedlings. *Cylindrocarpon* spp. have been isolated from conifer seed and roots of both diseased and apparently healthy sc lings games 1988); this fungus has also been found peat-based growing media (Carter 1988). Cylindrocapon root rot can affect many different Northwestern conifer seedlings: disease symptoms include root browning, loss of fine root tips, and decay of the root exterior (figure 5.1.41). Shoot symptoms are slow to develop, however, and therefore seedlings in the early stages of the disease may not be culled during seedling grading. Dennis (1988) consistently isolated a *Cylindrocapon* species from the roots of diseased Douglas-fir seedlings late in the growing season, during seedling storage, and even after outplanting. Apparently, this opportunistic fungus functions like *Fusarium* spp. in that it is a normal rhizosphere inhabitant and becomes pathogenic when the host seedling is stressed game 1988). Because so little is known about this disease control strategies have not been developed at the present time, although several operational trials are underway in British Columbia (Dennis 1988). Cultural controls effective for other root rot fungi, including using a well-drained growing medium and minimizing unnecessary stresses, should also be effective against Cylindrocarpon.

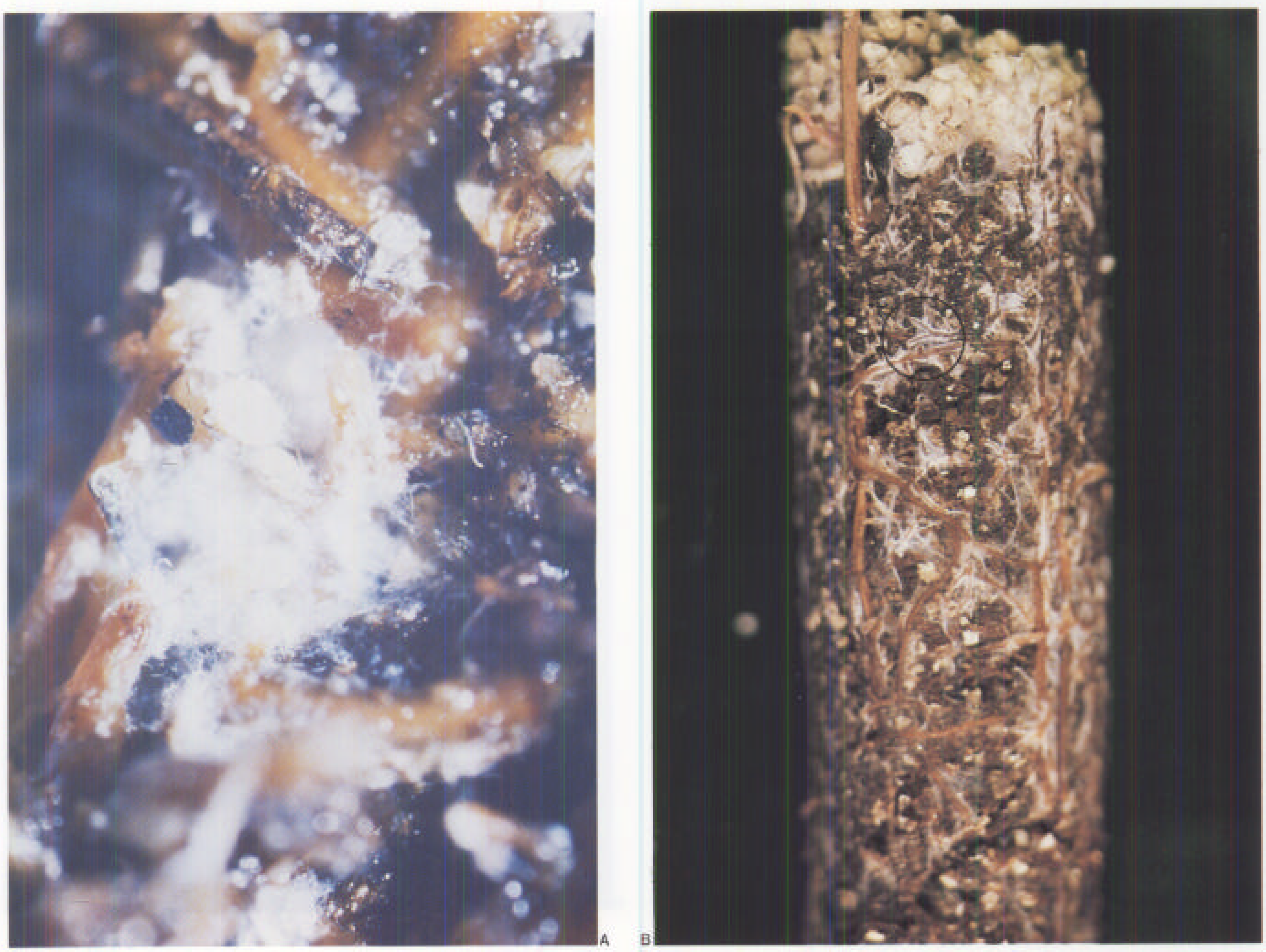
5.1.4.3 Nondamaging growths on root systems

There are several growths that are often visible on the exterior of container plugs that do not indicate disease.

G. Root aphids. One species of aphid--*Rhizomaria piceae*--feeds on the mycorrhizae of spruce container seedlings. The small colonies of these insects are covered with a white cottony substance and can be seen on the exterior of seedling plugs (fig. 5.1.42A). They apparently do not damage the seedling (Sutherland and Van Eerden 1980) and therefore require no treatment.

Figure 5.1.41—*Cylindrocarpon root rot is a newly recognized disease of container tree seedlings, such as this western white pine (courtesy of R.L. James, USDA Forest Service).*

H. Mycorrhizae. Mycorrhizae--the word literally means "fungus-roots"--are complex structures that develop as a symbiotic relationship of a fungus and plant roots. These structures can be seen macroscopically on the exterior of the container plug and have the appearance of a swollen root with fuzzy, variously colored external mycelia extending into the surrounding medium (fig. 5.1.42B). It is easy to distinguish between damaging root-rotting fungi and beneficial mycorrhizae because the latter are never associated with decay. For a detailed discussion of mycorrhizae and their management in container nurseries, refer to chapter 2 of this volume.



A B

Figure 5.1.42—*Not all visible growths are caused by pathogenic organisms. Root aphids form cottony, white colonies* **(A)** *on the exterior of the root plug but are apparently not harmful to the seedling. Beneficial ectomycorrhizae, which can vary in color, are often seen on the exterior of the root plug* **(B)** *and are sometimes mistaken for pathogenic fungi. (***A***, courtesy of J.R. Sutherland, Canadian Forestry Service).*

5.1.4.4 Abiotic root diseases

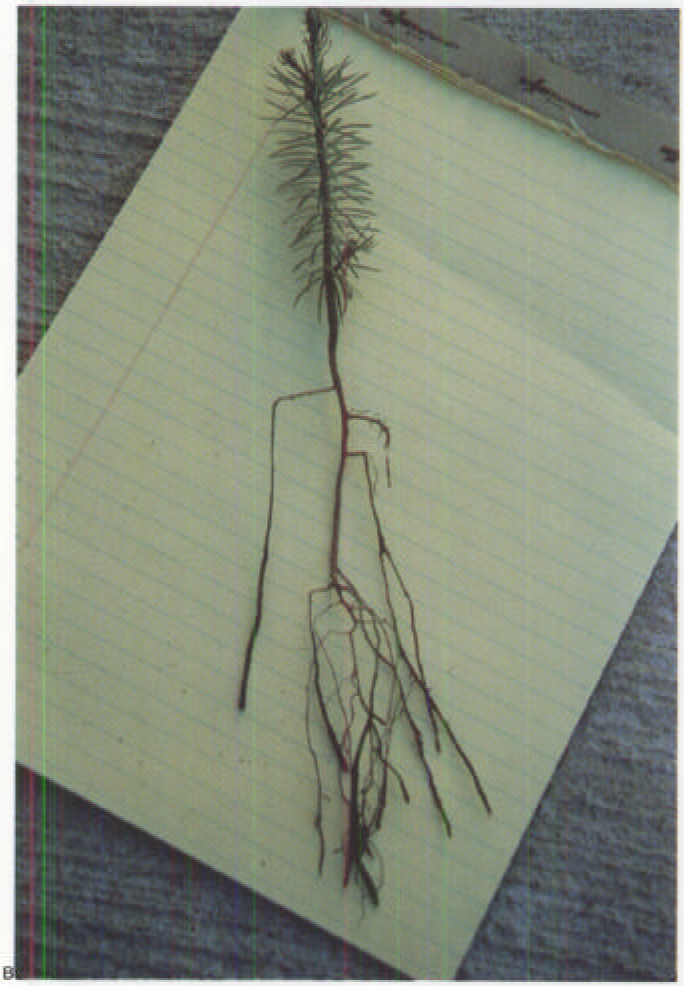
Roots of container tree seedlings are subject to several environmental stress factors that can cause disease.

Temperature stress. Container seedling root systems are more exposed to extreme temperatures than bareroot seedlings. Direct sunlight can raise root temperatures to damaging levels in exposed containers. Heat injury is difficult to diagnose. Using white containers to reflect sunlight and cooling with irrigation will reduce this hazard.

Cold injury is a serious problem in container nurseries because substantial damage can occur during overwinter storage (see section 5.1.6 for more discussion).

A

Figure 5.1.43—*Seedlings grown in compacted or waterlogged growing media sometimes develop abnormal growths: "cauliflower-like" swellings* **(A)** *or dark, swollen corky roots* **(B.)**. *The seedling in B was also infected with* Fusarium *spp., an opportunistic fungus that often attacks already-weakened seedlings.*



B

Waterlogged media. One of the drawbacks of using containers is that the natural drainage patterns found in field soils are not present. Containers develop a perched water table that creates a layer of saturated medium at the bottom of the container (see volume four of this series). The peat-vermiculite media used in most container tree nurseries are particularly liable to compaction, which can further aggravate the problem. Waterlogged media reduce the necessary gas exchange between the roots and the atmosphere and can lead to oxygen deficiency.

A growing medium that has been overwatered will often develop excessive growth of mosses and algae and may smell sour when removed from the container. Cauliflower-shaped growths may be present on the roots (fig. 5.1.43A); these hypertrophic structures are swollen lenticels that develop in response to low levels of soil oxygen (Boyce 1961). Lieffers and Rothwell (1986) report that black spruce seedlings grown in waterlogged media produced a large number of swollen lenticels, which they consider an adaptive response to saturated conditions. Tamarack seedlings grown under the same conditions did not develop the swollen lenticels, which may indicate that some species have a higher tolerance to waterlogged conditions than others (Tripepi and Mitchell 1984). Another common symptom of waterlogging injury is dark, swollen roots that feel soft and spongy (fig. 5.1.43B); these roots are often infected with pathogenic fungi.

5.1.5 Diseases and Pests of Seedling Shoots and Foliage

Shoot diseases and pests are relatively more important in container nurseries than in bareroot nurseries, primarily because of the warm, moist environment that is conducive to disease development. As an example, grey mold, which requires free moisture for spore germination and infection, is much more devastating to container seedlings than to bareroot stock. Sutherland and others (1982) attribute the importance of shoot diseases in container nurseries to changes in cultural practices, especially the use of artificial growing media, which reduces the incidence of the soil-borne root diseases so damaging in bareroot nurseries. Responses from growers in the Container Nursery Survey show that grey mold and other shoot blights make up 49% of the reported diseases for container nurseries in the United States and Canada (table 5.1.2).

Shoot diseases and pest problems can be caused by fungi, insects, or abiotic stresses. Symptoms of many of these diseases are similar and so a damage key can be helpful (fig. 5.1.44). Often shoot symptoms are caused by root problems and so the root system of symptomatic seedlings should also be examined. (Letters in the key refer to subheadings in the appropriate section of the text.)

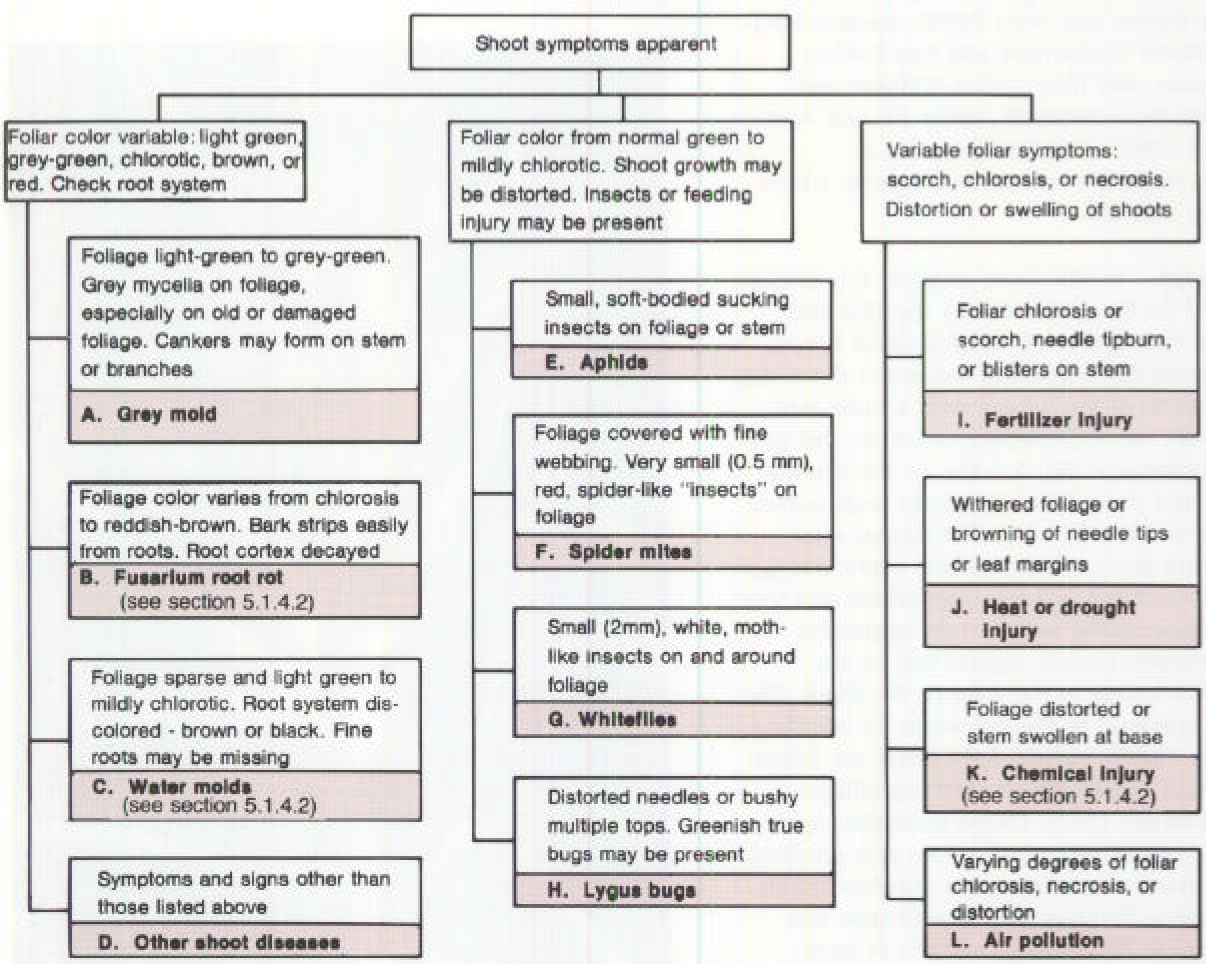


Figure 5.1.44—*Damage key to disease and pest problems of seedling shoots and foliage.*

5.1.5.1 Fungal diseases of shoots

A. Grey mold. The fungus that causes grey mold--*Botrytis cinerea*--is the most damaging pest of ornamental container plants (Nelson 1978) as well as the most damaging pest of conifer seedlings in container tree nurseries (James 1984). The importance *B. cinerea* was confirmed by the Container Nursery Survey, in which growers from the United States and Canada ranked it as the most serious pest, with 39% of the total responses (table 5.1.2). Mittal and others (1987) have reviewed grey mold disease.

Hosts. Grey mold attacks most species of container seedlings but certain species are particularly susceptible: redwood and giant sequoia (Peterson 1974); western larch, lodgepole pine, Engelmann spruce, and ponderosa pine (James and Woo 1984); western hemlock and Douglas-fir (Sutherland and Van Eerden 1980); Scotch pine, and blue spruce (Gilman and James 1980); mountain hemlock, noble fir, and Alaska-cedar (Matthews 1983). Grey mold is also a serious problem in eastern container nurseries where most species are affected.

Symptoms/Damage. As the name implies, this disease can be identified by the grey, cottony mycelia and spore masses on the surface of affected shoot tissue, especially on senescent needles of the lower shoot (fig. 5.1.45). Examination of the fungus with a hand lens will reveal stalked, spore-producing structures that produce a fuzzy appearance (fig. 5.1.46). As the disease progresses, infected shoot tissue becomes watersoaked and brown lesions often develop. The fungus may spread to the main stem, where cankers eventually girdle and kill the shoot (fig. 5.1.47) (Sutherland and Van Eerden 1980). Because the fungus is an aggressive saprophyte, symptoms usually appear first on the shaded, senescent foliage at the base of the shoot. The disease is most common in the fall when the seedling canopy becomes closed, natural light levels are lower, and moisture often condenses on seedling foliage (Sutherland and others 1982). Under favorable conditions, 8. cinerea can spread rapidly from one seedling to another and disease "pockets" can develop within the seedling crowns. Peterson (1974) estimates that losses to this disease have exceeded 20% in some greenhouses. Mittal and others (1978) reported that 40% of a container pine crop (52,000 seedlings) was killed by grey mold.

Figure 5.1.45—*Grey mold, which is caused by the fungus* Botrytis cinerea, *can be identified by the grey, cottony mycelia that usually develop on senescent needles at the base of the shoot.* B. cinerea *can rapidly spread in this ideal environment and form disease pockets.*

Figure 5.1.46—*"Hair-like" conidiophores are a sign of* Botrytis spp. *that can be seen with a hand lens.*

Figure 5.1.47—*Infection with* B. cinerea *often spreads from the initial foliar infection to the main stem, where cankers form that can eventually kill the top.*

Figure 5.1.48—*Sclerotia are stress-resistant resting structures of* B. cinerea *(arrow) that allow the fungus to survive the period between nursery crops.*

Disease development. The disease cycle for grey mold is presented in the introductory section 5.1.1.3 (fig. 5.1.4A-F). B. cinerea spores can be introduced into a container nursery in the air, on seeds, or in irrigation water (Sutherland and Van Eerden 1980). Peterson and others (1988) state that the likelihood of spores carrying over between crops is low; instead, *Botrytis* spores originate outside the greenhouse and are drawn in by cooling fans. They also speculate that *Botrytis* infections may develop in July or August, several months earlier than widely believed. The fungus usually invades weak or damaged foliage first and then spreads to adjacent healthy tissue. James (1984) reviewed the literature on *B. cinerea* and lists free surface moisture, high humidity, and cool temperatures as conducive to infection. When environmental conditions become unfavorable, resting structures called sclerotia form (fig. 5.1.48) and can persist in soil or plant debris; these sclerotia produce spores when favorable conditions return.

Disease management. Reducing grey mold damage requires a combination of both cultural and chemical control methods. Container nursery managers should strive to make the environment less favorable for *Botrytis* growth and apply protective fungicides to limit initial infections (Sutherland and others 1983). The type of greenhouse may actually influence development of grey mold: fiberglass houses produced an environment that was over 14 times more favorable for grey mold than the environment in plastic-covered greenhouses (Peterson and others 1988). Apparently, the fiberglass houses produce taller, more succulent seedlings that are prime hosts for *Botrytis* infection.

Cultural. Several cultural practices can be used to reduce the incidence and extent of grey mold infections (Sutherland and others 1983, Cooley 1981):

1. Keep seedlings healthy and vigorous and avoid injuring the foliage. Fertilizer-burned or frost-damaged foliage is particularly susceptible to Botrytis infection.

2. Avoid overly dense seedling growing levels by selecting a container that allows adequate spacing for seedling development. Containers can also be placed at a wider spacing to allow better air circulation during periods when seedlings are especially vulnerable.

3. Reduce the time that seedling foliage is wet by encouraging air circulation, irrigating early in the day, using surfactants in the irrigation water, providing underbench heating, or force-drying foliage with fans.

4. Follow a strict sanitation policy that includes removal and destruction of all plant debris, prompt roguing of infected seedlings, and sterilization of containers and growing area surfaces between crops.

Chemical. All fungicides registered for the control of grey mold are protectants that must be applied before infection takes place. There are a number of chemicals registered for controlling *B. cinerea* on ornamental plants, but not all of these are registered for tree seedlings. New chemicals are also continually being developed, so growers should monitor trade publications and check with a certified pesticide specialist for up-to-date information. McCain (1987) lists the latest chemicals used for controlling *Botrytis* cinerea. A partial list of fungicides used for *B. cinerea* control in container tree nurseries (table 5.1.9) reveals three things: first, there is a considerable difference in effectiveness among the six chemicals; second, some seedling species are much more susceptible to *B. cinerea* infection than others; and third, certain fungicides (e.g., dicloran, in this table) provide better protection on some species than others.

The timing of protective fungicide applications is important. These chemicals must cover susceptible plant tissue before *Botrytis* spores germinate and penetrate the foliage. Because *Botrytis* infections are most common in the fall, fungicide applications should begin in late summer. Peterson and others (1988) found that environmental conditions favoring spore germination were most prevalent in July and August in British Columbia tree nurseries, earlier than previously thought. Because of the ingrowth of new foliage and the rinsing effect of irrigation, protectant fungicides should be applied at regular intervals (1 to 2 weeks) during the susceptible period.

Botrytis spp. may develop tolerance to fungicides that are used repeatedly (Cooley 1981; James and Woo 1984; Gillman and James 1980), and so fungicides should be used in rotation during the growing season. Tolerance of B. cinerea to the fungicide benomyl has been demonstrated in vitro by culturing different isolates of the fungus on agar plates containing varying concentrations of the fungicide. Figure 5.1.49 provides a good illustration of fungicide tolerance: mycelial growth of *B. cinerea* isolate 78--38 shows tolerance to several benomyl concentrations, whereas fungal isolate 78--18 is well controlled by the fungicide.

Regardless of the effectiveness of pesticides, chemical control of grey mold is virtually impossible without a corresponding and coordinated program of cultural control practices.

B. Fusarium root rot. See section 5.1.4.2 for discussion of this disease.

C. Water mold. See section 5.1.4.2 for discussion of this disease.

D. Other fungal diseases of shoots and foliage.
Although grey mold is by far the major foliar disease of container seedlings, there are other foliar diseases caused by fungi.

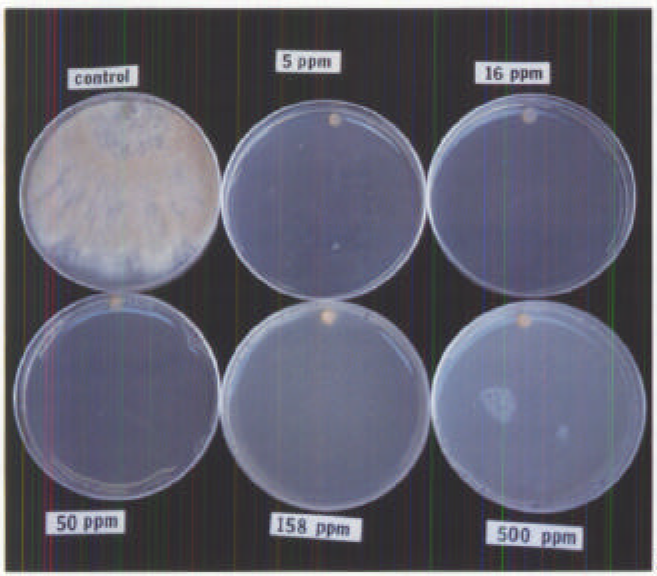
Table 5.1.9—*Effectiveness of some fungicides used to prevent grey mold* (Botrytis cinerea) *infections on western larch and lodgepole pine container seedlings*

Fungicide		Application rate (per 100 gal H_2O)	Percent infection	
Active ingredient	Trade name		Western larch	Lodgepole pine
None (control)	—	—	96.2 a	27.6 a
dicloran	Botran®	1.33 lb	58.5 b	0.5 c
benomyl	Tersan 1991®	1.00 lb	54.8 c	12.8 b
captan	Captan®	2.00 lb	29.7 d	0.1 c
chlorothalonil	Daconil 2787®	1.50 lb	8.4 e	1.7 c
chlorothalonil	Bravo 500®	2.75 pt	5.9 e	0.2 c
iprodione	Chipco 26019®	1.00 lb	6.8 e	0.2 c

This listing does not constitute a recommendation: these specific products are those listed in the source and may not be currently registered. Other products may be available as well. Consult with a pesticide specialist and check label for information on registered uses and applications rates.

Within each column, values followed by the same letter do not differ significantly at the P - 0.05 level.

Source: James and Woo (1984).



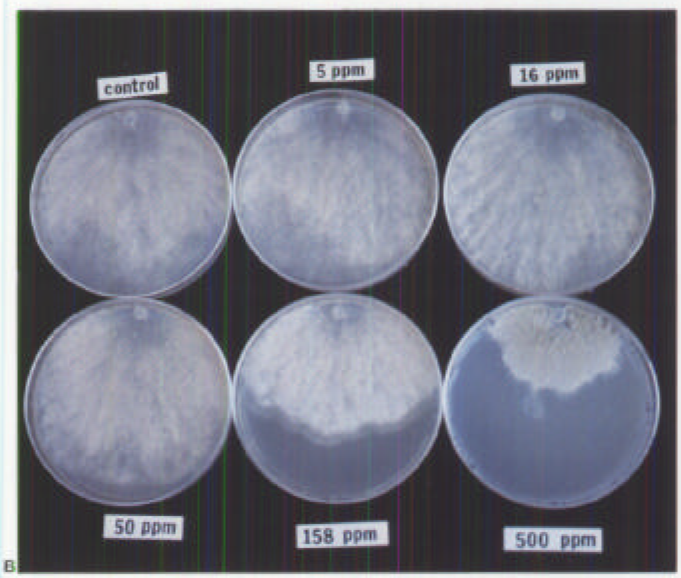


Figure 5.1.49—*Tolerance of the grey mold fungus* (Botrytis cinerea) *to the fungicide benomyl in vitro. Mycelial growth of* B. cinerea *isolate #78–18* **(A)** *is completely inhibited by the fungicide in the culture media, whereas isolate #78–38* **(B)** *grows at all concentrations of the fungicide. (Courtesy of L.S. Gillman, USDA Forest Service.)*

Fusiform rust. Fusiform rust (caused by *Cronartium fusiforme*) is the most severe disease problem in bareroot nurseries in the southern United States and poses a serious threat to southern pines grown in containers in open compounds. This disease can be controlled with carefully scheduled applications of the systemic fungicide triadimefon, which can be applied as a seed treatment, soil drench, or foliar spray (Rowan 1983). It also can be controlled culturally: delaying sowing until after mid-June avoids the spore dispersal period (Barnett 1987).

Sirococcus shoot blight. Sirococcus shoot blight is primarily a disease of germinants (see section 5.1.3.2) but can cause a stem canker and tip dieback of older seedlings later in the growing season. *Sirococcus* spp. spores are apparently seedborne but can also originate from trees adjacent to the nursery or in nearby shelterbelts (Sutherland and Van Eerden 1980).

Rhizoctonia. *Rhizoctonia is* a common pathogen of ornamentals but is apparently rare in forest nurseries. It has been observed on longleaf pine, where it causes a foliage blight; the mycelium is plainly visible and spreads from seedling to seedling when the foliage remains wet for extended periods (Pawuk 1981).

Melampsora rust. *Melampsora* spp., which require both a conifer and a poplar host to complete their life cycles, have caused minor damage to Douglas-fir and lodgepole pine seedlings in British Columbia nurseries (Sutherland and Van Eerden 1980).

Colletotrichum acutatum. *Colletotrichum acutatum* is a newly reported pathogen that causes dieback of terminal and lateral shoots of western hemlock container seedlings. This disease was previously unknown in North America and its damage potential has not been established (Hopkins and others 1985).

5.1.5.2 Insects affecting seedling shoots and foliage

Many insects feed on the foliage and shoots of container tree seedlings, causing different types of injury (fig. 5.1.44). Diagnosis of insect injury can be difficult because these pests are very mobile and therefore not readily associated with the damage.

E. Aphids. Several aphid species have been identified in forest nurseries, incuding giant conifer aphids (Cinara spp.). Aphids were listed as the most common insect pest of container nurseries in the United States and Canada, based on the Container Nursery Survey (table 5.1.3). Although Sutherland and Van Eerden (1980) consider aphid damage to be minimal in British Columbia nurseries, Johnson (1965) reported growth losses as high as 70% in bareroot Douglas-fir seedlings infested by giant conifer aphids. These aphids also caused significant distortion of the terminal shoots of outplanted Scotch pine seedlings (Holopainen and Soikkeli 1984). Giant conifer aphids are often attracted to seedling grafts on tree improvement stock (Shrimpton 1987). Besides these growth effects, the mere presence of aphids on container seedlings implies poor nursery management practices to the seedling user.

Hosts. Many seedling species can be affected.

Symptoms/Damage. Giant conifer aphids (fig. 5.1.50) are relatively large, with long legs and dark bodies, and are usually visible on seedling twigs (Sutherland and Van Eerden 1980). Eggs are black, approximately 1 mm (0.04 inch) long, and there is usually only one per needle (Shrimpton 1987). Foliar chlorosis is the most obvious symptom of infestation; another symptom is the honeydew that aphids produce, which attracts other insects, such as ants and wasps.

Life cycle. The life cycle of most aphids is complex, and reproduction can be either sexual and asexual. Because aphids produce many generations per year, their populations can build up rapidly. When conditions become unfavorable, aphids become winged or lay eggs that survive overwinter (Nelson 1978).

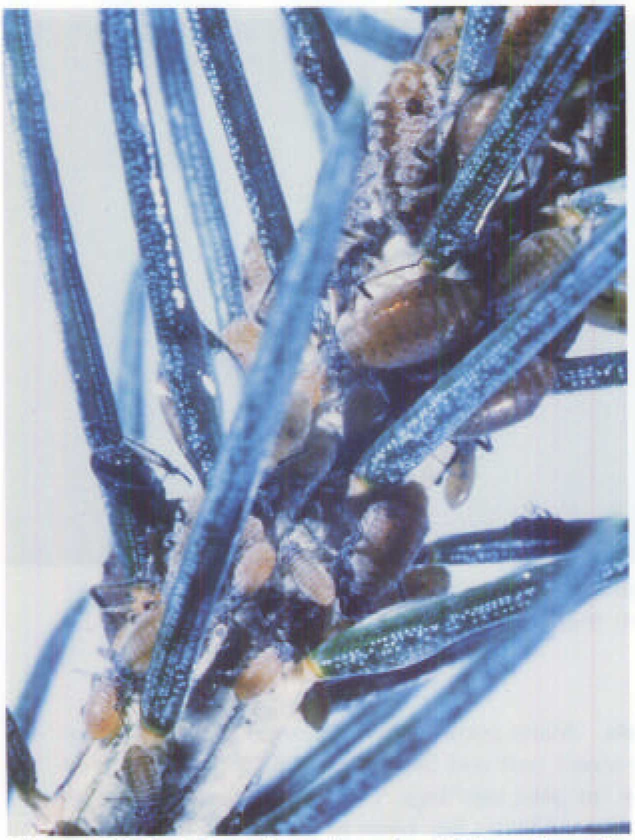


Figure 5.1.50—*Several species of aphids, such as the giant conifer aphid (*Cinara *spp.), occur on container tree seedlings (courtesy of J.R. Sutherland, Canadian Forestry Service).*

Figure 5.1.51—*Although spider mites are barely visible to the naked eye, they can easily be diagnosed by the fine webbing that they construct on infested foliage.*

Pest management. It is impossible to exclude aphids from container nurseries, but they can be managed by prompt identification and treatment with insecticides (see section 5.1.7.4). If aphids are not controlled at the nursery, they can lay eggs that overwinter on the foliage. Aphids are very difficult to control in the egg stage, and so infested seedlings could be sent to the planting site (Shrimpton 1987).

F. Spider mites. Mites are arthropods, but not insects, because they have 8 legs in their adult forms. There are many species of mites that can damage container crops, but the two-spotted or red spider mite is one of the most damaging of all greenhouse pests (Nelson 1978). Spider mites are not common on conifers but are a serious pest of many hardwood species, especially under warm, dry conditions (Matthews 1983, Sutherland and Van Eerden 1980).

Hosts. Mites are not host specific and have been recorded on both hardwood and conifer seedlings.

Symptoms/Damage. Red spider mites are difficult to detect because they are so small. The first evidence of an infestation is chlorotic stippling of seedling foliage, but the best sign of their presence is the fine webbing that they produce. This webbing may eventually cover the foliage (fig. 5.1.51). When mite infestations become heavy, leaves appear scorched. The small red mites are often visible, under a hand lens, on the underside of the leaves.

Life cycle. The complete life cycle of spider mites can take only 10 to 20 days and is accelerated by low humidity and warm temperatures. Mites form several resting stages that, together with the egg stage, are resistant to environmental stresses (Nelson 1978).

Pest management. Mites are too small to be excluded from growing areas and are usually noticed first near vents, where they have been blown in. Miticides, such as those containing dicofol, can be applied as aerosols or sprays, but these are only partially effective because the egg and resting stages are resistant to pesticides. Miticide applications must be made as often as 2 days apart because many different stages of mites may be present at any one time. A good discussion of miticides is provided by Nelson (1978).

G. *Whiteflies*. The greenhouse whitefly--*Trialeurodes vaporariorum*--is a small [2 mm (0.08 inch)] insect with four wings that resembles a miniature moth (fig. 5.1.52). Although whiteflies are a major pest of ornamental greenhouse crops, they ranked eighth compared to other insect pests reported in the Container Nursery Survey (table 5.1.3). Parella (1988) presents a detailed discussion of the biology and taxonomy of the greenhouse whitefly.

Hosts. Many seedlings are affected but infestations of broad-leaved species are most common.

Symptoms/Damage. The first sign of a whitefly problem is the adults, which fly up when the host plant is disturbed. Immature whiteflies resemble scale insects that are oval-shaped and flattened against the underside of the leaf. Both adults and immature white flies suck plant juices, causing a yellow stippling of leaves; they also excrete honeydew, which often promotes growth of black sooty molds (Nelson 1978).

Life cycle. Depending on temperature, the whitefly life cycle takes from 4 to 5 weeks. The eggs hatch into flat scale-like crawlers that are transparent to yellow-green. After several growth stages, the nymphs pupate into winged adults (Nelson 1978).

Pest management. Because whiteflies thrive in the warm, humid environment of greenhouses, there are no effective cultural controls except to remove infested plants. Chemical sprays, particularly resmethrin and kinoprene, were effective against whiteflies but had to be applied two or three times in sequence to control overlapping generations (Nelson 1978).

***H. Lygus* bugs.** Lygus bugs have only recently been identified as serious pests of conifer seedlings (Overhulser and others 1986). Although several different lygus bugs are pests of agricultural crops, only *Lygus hespurus* and the tarnished plant bug, *L. lineolaris*, have been identified in forest nurseries. Lygus bugs are sucking insects that feed on young, succulent plant tissue, such as terminal shoots and buds, and cause stunting and multiple leaders.

Figure 5.1.52—*Whiteflies are common greenhouse pests that resemble tiny white moths.*

Hosts. Many conifer species are potential hosts for this insect pest and Shrimpton (1985) notes a preference for pine seedlings. The most serious damage in the United States has been to bareroot Douglas-fir in Oregon (Overhulser and others 1986), and the recent incidence of "bushy-topped" loblolly pine seedlings in bareroot nurseries in the southern United States has also been attributed to lygus bugs (South 1986).

Symptoms/Damage. Adult lygus bugs are true bugs, mottled yellow-green to reddish brown, 7 cm (0.25 inch) long, with flat oval bodies (fig. 5.1.53A); the wingless nymphs (fig. 5.1.53B) are smaller, varying from 1 to 6 mm (0.04 to 0.24 inch), and resemble aphids (Shrimpton 1985). Adults and nymphs feed by sucking plant juices and introduce a toxic saliva into the plants, which causes distorted needles, stem lesions, and deformed tops (fig. 5.1.53C). This feeding injury often results in bud abortion, multiple tops, and bushy-topped seedlings (fig. 5.1.53D) (Overhulser and others 1986). Up to 20% of conifer and bareroot seedlings have been attacked in British Columbia nurseries (Shrimpton 1985).

A

B

C

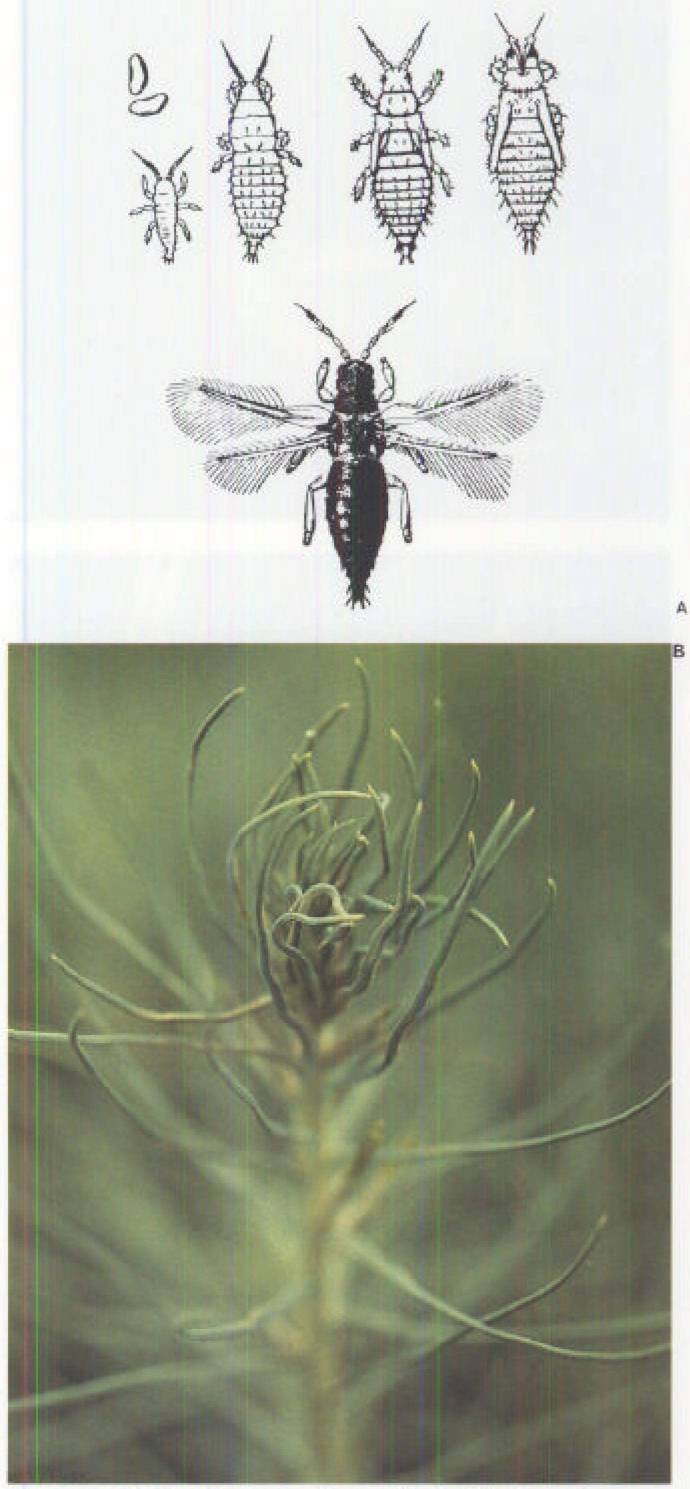
D

Figure 5.1.53—*Both the adults* **(A)** *and nymphs* **(B)** *of the lygus bug can cause distorted shoot growth* **(C)** *or terminal bud abortion, which can lead to multiple-topped seedlings* **(D)** *(courtesy of Oregon State University, Corvallis).*

Life History. Lygus bugs overwinter as adults and feed and lay eggs on plants as soon as the weather warms. Eggs hatch after 10 to 14 days, and flightless nymphs begin to feed on plant tissue. The adult insects are active fliers and readily move from one crop to another. Three to four generations are possible per year in warm climates (Overhulser and others 1986).

Pest Management. The presence of lygus bugs is often difficult to confirm; trapping has been used in agriculture but a test of several traps in British Columbia netted few insects (Shrimpton 1985). Chemical control is more effective on the flightless nymphs, because adult lygus bugs are highly mobile and therefore difficult to control with insecticides. In British Columbia, foliar applications of diazinon and cypermethrin during the summer months were effective (Shrimpton 1985). Overhulser and others (1986) found that multiple applications of fenvalerate, acephate, and endosulfan between July and September reduced damage by 80 to 90% in bareroot nurseries.

Thrips. These very small insects [1 mm (0.04 inch)] feed on a variety of greenhouse crops including tree seedlings. Thrips can go through the various stages of their life cycle (figure 5.1.54A) in as little as 2 weeks, and their populations can thus build-up very rapidly in a greenhouse environment. Adults are passively carried into the growing area through the ventilation system and lay eggs on the seedling foliage (Nelson 1978). Nymphs have piercing-sucking mouthparts, and their feeding causes small necrotic spots on the foliage, followed by twisting and curling of the shoot tips (figure 5.1.54B). It is difficult to see these insect pests, and symptomatic foliage should be carefully examined with a hand lens, or they can also be detected by tapping the damaged foliage over white paper (Nelson 1978). The extent of thrips damage in container tree nurseries is unknown but was severe enough on Douglas-fir seedlings in one Idaho nursery to warrant control measures. Common insecticides are effective in controlling this pest (see section 5.1.7.4).



Figures 5.1.54—*The greenhouse thrips* (**A**) *is an insect pest of ornamental crops that occasionally causes injury to container tree seedlings* (**B**). (**A**, *courtesy of J.R. Baker, North Carolina Extension Service*).

Figure 5.1.55—"Fertilizer burn" is often characterized by needle tip dieback in conifers **(A)** or scorched leaf margins in hardwoods **(B)**.

5.1.5.3 Abiotic problems affecting seedling shoots

As discussed in section 5.1.1.2, abiotic diseases are often more common than those caused by biological pests. Because seedling shoots are directly exposed to cultural practices and the ambient environment, they are often injured by abiotic stress factors.

I. Fertilizer injury. Chemically, fertilizers are salts and can therefore cause salt injury to seedling foliage or roots. Although fertilizer burn of roots is common, the symptoms are usually expressed through foliar symptoms. Direct injury to seedling foliage can sometimes occur, especially when granular fertilizer is applied to containers as a top dressing (Sutherland and Van Eerden 1980), or when concentrated liquid fertilizers are applied without a clear water rinse. Sutherland and others (1982) consider fertilizer burn to be the most common abiotic disease of container seedlings in British Columbian container nurseries, primarily because it often disposes seedlings to attack by *Botrytis* spp.

Hosts. All species of seedlings are susceptible, and young, succulent germinants are particularly prone to injury.

Symptoms/Damage. Hallett (1982) describes the following symptoms of fertilizer injury:

1. Needle mortality in conifers, either needle-tips scattered randomly throughout the crown or entire needles in the mid-shoot position (fig. 5.1.55A). Hardwood seedlings exhibit a marginal leaf scorch (fig. 5.1.55B).

2. Chlorosis, needle-tip burn, or seedling mortality that corresponds to irrigation patterns.

3. Blisters on succulent shoot tissues.

Environmental conditions are very important in the development of fertilizer burn: damage is most likely to occur under hot, dry conditions, which accelerate evapotranspiration and concentrate salts in the growing medium or on the foliage.

Disease management. Fertilizer burn can be reduced by the following cultural practices:

1. Use proper fertilization techniques:

   Apply fertilizers as liquids rather than as dry fertilizer incorporations or top-dressings.

   Use frequent applications of diluted liquid fertilizer rather than a few concentrated fertilizer applications.

   Follow liquid fertilizer applications with a clear water rinse.

2. Avoid unnecessary drought stress, particularly after fertilization.

3. Use a growing medium that is buffered by a high cation exchange capacity, and has good porosity to promote leaching.

J. Heat or drought injury. These two stresses are considered together because they often occur under similar environmental conditions, that is, high temperatures that cause excessive transpiration (heat injury to germinants is discussed in section 5.1.3.2).

Hosts. All container tree seedlings are affected, although shade-tolerant species are most susceptible.

Figure 5.1.56—*Foliar symptoms of heat or drought injury are caused by extreme levels of seedling moisture stress. Moisture stress is a result of high temperatures or low soil moisture, or a combination of both.*

Symptoms/Damage. Common symptoms of drought injury include withered foliage and a browning or drying of the needle tips or leaf margins (fig. 5.1.56). Drought injury is often difficult to distinguish from fertilizer burn, although the latter usually affects individual needles whereas drought stress can affect the entire shoot. Hardwood foliage senesces more rapidly when drought stressed, and individual leaves abscise from the base toward the tip of the shoot (Tinus 1987). Direct heat can also cause injury to seedling tissue. High heat levels can develop at the surface of the growing medium from direct and reflected sunlight. This intense heat often causes a girdling injury to suc-

Figure 5.1.57—*High levels of direct or reflected heat can cause injury to seedling stem tissue, resulting in a stem lesion* **(A)** *or a constriction at the surface of the growing medium* **(B).**

culent stem tissue. Although this injury normally occurs in younger seedlings before stem lignification, the constriction symptoms may not be manifested until later in the growing season, when normal cambial growth does not occur. The abrupt change between healthy and injured stem tissue produces a constriction just above the surface of the growing medium (fig. 5.1.57).

Disease management. Heat or drought injury can be minimized by proper nursery design and cultural practices:

1. Avoid excessively high temperatures or high sunlight levels, especially with succulent plants. Shade-tolerant species, such as western hemlock, can suffer foliage damage if moved from shade to direct sunlight without an acclimatization period (Matthews 1987).

2. Use a growing medium that contains a mixture of particle sizes to supply adequate moisture, yet has good aeration and leaching properties.

K. Chemical injury. See section 5.1.3.2.

L. Air pollution. This damage category includes all types of aerially induced chemical injury. Forest container nurseries are not normally established in areas that are subject to traditional sources of industrial air pollution, although more and more urban areas are becoming seriously polluted. Pollution damage often occurs in valleys where pollutants are trapped by air inversions and accumulate to damaging levels. Hanan and others (1978) discuss sources and types of air pollution damage to horticultural plants and also list indicator species that can be used to document exposure to major pollutants.

The most recent and comprehensive treatment of air pollution injury in container tree nurseries is provided by Scarratt (1985), who states that the most common pollution sources originate within the nursery itself. Heating furnaces, gasoline and diesel generators, and nursery vehicles produce several gaseous pollutants including carbon monoxide, carbon dioxide, sulfur dioxide, nitrous oxides, and ethylene. Sulfur dioxide and ethylene are considered to be the most serious threats to container seedlings and can be damaging in concentrations of 1 ppm or less (Mastalerz 1977).

Hosts. Susceptibility varies between seedling species. In Ontario greenhouses, jack pine was most severely damaged; tamarack, European larch, eastern white pine, and red pine suffered intermediate damage; and northern white-cedar, Japanese larch, and black spruce were least affected (Scarratt 1985).

Symptoms/Damage. Air pollution injury always occurs on the foliage because gases enter plants through the stomates. Symptoms vary with the type of pollutant and the seedling species. In Ontario nurseries, conifer seedlings exhibited varying degrees of cotyledon and needle tip necrosis and curling, whereas birch seedlings showed marginal and interveinal chlorosis and necrosis. The most insidious symptom, however, is growth loss. Scarratt (1985) reported growth loss exceeding 40% in height and 85% in dry matter production in jack pine seedlings.

Disease development. Air pollution damage can be either chronic or acute. Individual incidents of exposure to high levels of pollutants can cause acute injury in which symptoms develop immediately after exposure to the pollutant. Chronic injury in which undetected growth losses are caused by continued exposure to sublethal levels of air pollution, is probably more common. Scarratt (1985) demonstrated that seedlings exposed to chronic pollution did not exhibit visible symptoms but suffered growth losses.

Disease management. There are no treatments that can alleviate the effects of air pollution injury once it has occurred, but several cultural practices can help prevent pollution losses (Scarratt 1985):

1. Do not locate oil furnaces inside, or in structures immediately adjacent to, growing areas.

2. Install heating units and carbon dioxide generators so that they have adequate air supplies for efficient combustion and sealed vents for exhaust gases. Heating systems that use fossil fuels should be located downwind from the growing areas and away from depressions in which exhaust fumes could accumulate.

3. Make periodic inspections of heating systems for leaking gases and adjust burners for peak combustion efficiency.

4. Never operate gasoline or diesel-powered vehicles in growing areas or where their exhaust gases could be sucked into building vents.

5.1.5.4 Problems caused by other plants

Plants are not generally considered to be disease-causing agents but, in keeping with the strict definition of a disease, plants such as weeds or liverworts compete with the crop seedlings for light, water, and mineral nutrients and can cause reduced growth or even death.

Weeds. Biologically, there is no such thing as a weed On a management basis, however, any plant that grows where it is not wanted is a weed (Bohmont 1983). In a container tree nursery, any noncrop plant that grows in the containers or even on the floor of the growing area is considered a weed.

Weeds are considered pests because

1. They reduce seedling growth or even kill seedlings by competing for light, water, and mineral nutrients. Because weeds germinate and grow much more rapidly than most woody plant species, they can easily outcompete the crop seedlings for the limited growing space in the container.

2. They serve as reservoirs for insect and disease pests. Whitcomb (1988) reports that aphids often build up populations on weeds such as bittercress (*Cardamine pennsylvanica*) and spider mites can be found on sorrel (*Oxalis* spp.).

3. Their presence in forest nurseries gives the impression of overall poor management.

Weed control is more critical in container facilities than in bareroot nurseries because weeds can easily dominate the volume of growing medium in small containers. Weeds are a serious problem in container nurseries in which seedlings are germinated in enclosed areas and then taken to open compounds for the remainder of the growing season.

Hosts. All species of seedlings are susceptible.

Symptoms/Damage. Weeds generally germinate much more rapidly than woody plant species and are easily recognized once they develop true leaves, although there could be some confusion during the cotyledon stage. Growers must become familiar with the common weed species in their area so that they can be promptly removed.

There are few published reports that quantify the detrimental effects of weeds on container tree seedlings, but Whitcomb (1988) reviews literature that reports growth losses of 24 to 44% due to weed competition in ornamental container stock.

Weed development. Because of the predominant use of artificial growing media in container nurseries, weeds are usually not a serious problem in enclosed growing areas. Growing media are sometimes contaminated, however, when weed seeds are wind-blown into opened bags of medium or cached in closed bags by mice. Weed seeds can also be introduced into growing areas by wind, or in soil on equipment or workers' feet. Because some weeds have very small seeds, they can be distributed by the irrigation system in container nurseries with surface water sources.

Weeds that are present in the growing medium germinate within a few days after the containers are placed in the growing area and develop rapidly. Weed seeds that are blown or carried into the greenhouse can show up anytime during the growing season but are generally not a problem in the containers after seedling crown closure. Weeds grow extremely well in the favorable nursery environment and can become a serious problem in unpaved growing compounds.

Weed management. Cultural. Cultural control of weeds includes screening vents and irrigation water intakes to exclude weed seeds, cleaning soil or growing medium from shoes and equipment before they are brought into the growing area, and hand weeding. Hand removal of weeds from the containers is most practical and economical when the weeds are still small, e.g., during the thinning operation. Once weeds become established in the container, their roots dominate the growing medium and hand weeding can uproot the crop seedling. The weed population produces a reservoir of weed seeds around the nursery that can be reduced by burning or mowing the weeds before they go to seed. All weeds should be physically removed from the growing areas between crops; growing compounds with paved floors or fabric ground coverings will have fewer weed problems. Whitcomb (1988) concludes that herbicides should only be considered as part of an overall weed control program that emphasizes sanitation.

Chemical. Chemical control of weeds in container nurseries can be divided into two categories: selective herbicides that are applied directly to the containers, and nonselective chemicals that are used to eliminate weeds around the growing area.

Herbicides are not as commonly used in container nurseries as in bareroot nurseries because the high organic content of most growing media inactivates many chemicals and the succulent seedlings are more susceptible to phytotoxic injury. Heat pasteurization or chemical fumigation of the growing medium (see section 5.1.7.2) will eliminate weed seed contamination, although most commercial media should be weed-free. Pre-emergence herbicides are not used in container tree nurseries although some postemergence or contact herbicides are being tested on seedlings in outside growing areas. Hallett and Burns (1983) tested a variety of postemergence chemicals and found that only glyphosate, when applied late in the growing season, provided acceptable weed control without seedling injury (table 5.1.10). Ahrens (1985) reported

Table 5.1.10—*Low-risk herbicides that have been found effective for container tree seedlings*

Herbicide action	Active ingredient	Trade name	Source
In noncrop areas (under benches and around perimeter)			
Soil sterilant	diuron	Karmex®	Whitcomb (1988)
	bromacil	Hyvar X®	Whitcomb (1988)
Pre-emergence	oryzalin	Surflan®	Peck (1984)
	diquat	Diquat®	Peck (1984)
Contact	glyphosate	Roundup®	Peck (1984)
In containers with seedlings*			
Contact	glyphosate	Roundup®	Hallett and Burns (1983)

This listing does not constitute a recommendation: these specific products are those listed in the source and may not be currently registered. Other products may be available as well. Consult with a pesticide specialist for information on registered uses and applications rates.

*Weed control with any "over the seedling" herbicide will vary with seedling species: some species, such as western hemlock and western larch, are very sensitive.

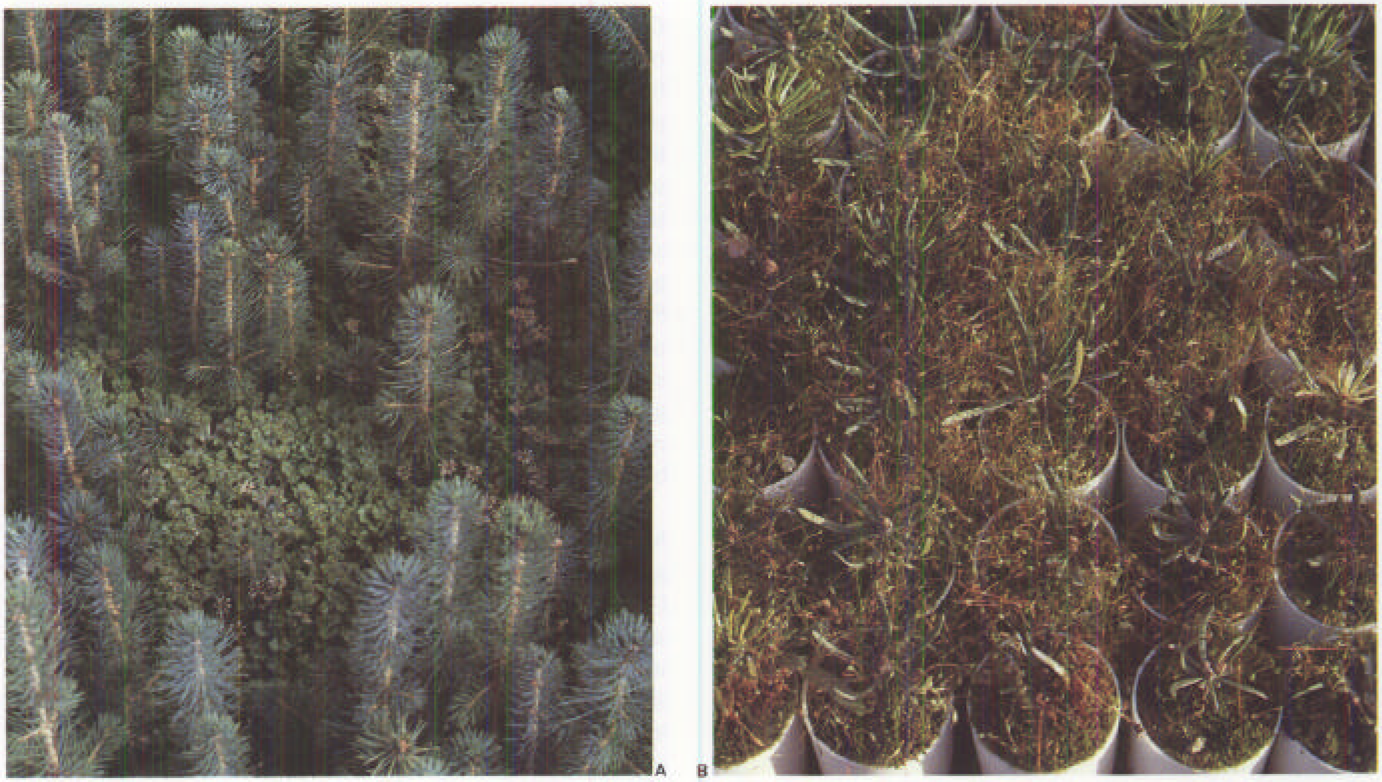
glyphosate phytotoxicity in peat-based growing media, so growers should be cautious using this chemical. One of the real problems with postemergence herbicides is that crop seedlings vary in their susceptibility to phytotoxic injury. Gilreath and Gilreath (1986) tested four postemergence herbicides on 17 different species of woody plants and found that each herbicide was phytotoxic to at least one crop species.

Chemical control of weeds around the growing area is usually done between seedling crops because it is difficult to apply herbicides uniformly under benches and some herbicides can volatilize and injure seedlings. Three different types of herbicides can be used on noncrop areas: pre-emergence, postemergence (contact), and soil sterilants (table 5.1.10). Because preemergence herbicides are only effective on germinating weeds and do not kill established plants, all existing weeds must be removed before application. Contact herbicides are generally nonselective, that is, they kill all plants on contact. Soil sterilants are pre-emergence herbicides that are effective for extended periods of time, but some weed species are tolerant of these chemicals (table 5.1.10).

Using any chemical in the enclosed environment of a container nursery is potentially hazardous, and nursery managers are cautioned to read the herbicide label carefully and implement small-scale tests before attempting a full-scale chemical weed control program.

Cryptogams (moss, algae, and liverworts). *Cryptogams* is a collective term for plants that reproduce from spores instead of seeds. These lower plants thrive in the container nursery environment and cause serious problems in containers when they completely cover the surface of the growing medium and interfere with water and nutrient infiltration. Liverworts (fig. 5.1.58A) and larger mosses (fig. 5.1.58B) can also physically overshadow small seedlings and compete with them for light. The exact amount of damage caused by these plant pests is difficult to determine and varies from nursery to nursery, but Ross and Puritch (1981) state that damage is increasing, especially in older growing facilities. Liverworts have proven to be especially troublesome in older growing stock types, such as 2 + 0 seedlings; the liverworts become established during the first year and then outcompete the seedlings during the second year. The problem is most serious in coastal container nurseries where the cool, moist climate favors the establishment and growth of liverworts (Shrimpton 1987).

Hosts. All species of seedlings can be affected but slower-growing conifers such as spruces and true firs seem particularly vulnerable.



A B

Figure 5.1.58—*Cryptogams, such as liverworts* **(A)** *and mosses* **(B)**, *can become nursery pests when they cover the opening of the container cavity and restrict infiltration of water or fertilizer solutions.*

Symptoms/Damage. All these plants can be seen with the naked eye. Ross and Puritch (1981) identified five bryophytes (true mosses and liverworts) and nine algal species from container nurseries in British Columbia and list some keys for culturing and identifying species. Haglund and others (1981) report that mosses can eventually choke out small seedlings and cause stunting and chlorosis. Unless these plant pests become established early in the season, they are progressively shaded-out as soon as the seedling grows large enough to completely shade the surface of the growing medium. Mosses and liverworts are more of a problem in open growing areas and shadehouses, probably because of the difficulty of complete sanitation between crops.

Cryptogam development. Moss and algae develop from residual material on reused containers and from water or airborne spores. Ross and Puritch (1981) found algae, but no spores of mosses or liverworts, in irrigation water and did not isolate any cryptogams from peat or growing media samples. They report that the major sources of contamination were used containers and airborne inocula, which are easily spread by the greenhouse ventilation system; some species are able to spread vegetatively as well as from spores. Cryptogams can develop rapidly on the surface of the growing medium under the moist growing environment of a container nursery. Algae and moss develop rapidly whereas liverworts and lichens are much slower growing.

Cryptogam management. Cultural. Cryptogams can be controlled by encouraging vigorous early seedling growth and limiting the source of the inocula with proper sanitation practices. Several cultural practices inhibit development of cryptogamic plants. Using a light-colored seed covering that completely covers the surface of the growing medium inhibits the growth of these plant pests. Many container nurseries in British Columbia use a special "forestry sand" for a seed covering which has drastically reduced the liverwort and moss problem (Sutherland 1987). Hallett and Burns (1983) specifically mention a lime-based grit covering, and perlite has also been effective. Promoting rapid seed germination and early-season seedling growth will ensure that cryptograms will not become established in containers. Reducing irrigation frequency will allow the seed covering to dry out and lower the humidity at the growing medium surface, which should discourage growth of cryptogams (Hallett 1982). Gravel floors of growing areas are especially subject to the development of cryptogams, which should be physically removed or killed with chemicals before the crop is sown.

Chemical. Several chemicals have been used to control cryptogams, including fungicides and surfactants, but few materials are registered specifically for that purpose. There are several chemicals that have controlled algae on greenhouse surfaces including copper sulfate and calcium hydroxide; a bromine compound (Agribrom®) was found to be effective in controlling algae in greenhouses and is apparently not phytotoxic to ornamental crops (Anonymous 1987). Ross and Puritch (1981) recommend filtering the air used for cooling and eliminating cryptogams from greenhouse surfaces and containers. The benches and floors of the growing area should be thoroughly cleaned between rotations, and reusable containers should be disinfected between rotations (see section 5.1.7.2).

Most herbicides that would effectively control cryptogams are also phytotoxic to tree seedlings. Pawuk (1983) tested 11 different chemicals for control of algae and concluded that the fungicides maneb and dichlone were the most effective and yet were not phytotoxic to shortleaf pine seedlings. Haglund and others (1981) initiated a moss control test with chemical treatments involving fungicides and surfactants, alone or in combination. X77® was the least phytotoxic of the eight surfactants tested, and a tank mix of X77 surfactant and captan fungicide gave "virtually complete" moss control. This solution was applied at a rate that thoroughly wetted the moss, and the authors suggested that applications be made in the late afternoon on a cloudy day because phytotoxic injury is more severe in bright sunlight. Dodine (Cyprex®) is a fungicide used for control of liverworts in British Columbia nurseries; it is applied to cover the liverworts and penetrate the surface layer of the growing medium (Shrimpton 1987). Obviously, any potential chemical control method should be carefully reviewed and tested before being attempted operationally.

Many of the common disinfectants such as chlorine bleach can be used to control cryptogams in noncrop areas (see section 5.1.7.2). Matthews (1983) reports that container nurseries in British Columbia use specially formulated soaps to reduce moss and algae growth on floors, pallets, and used containers. Peck (1984) reports that a cryptocidal soap (Safer's De Moss®) controlled mosses on greenhouse surfaces and retarded subsequent infestations.

5.1.6 Diseases and Pest Problems During Seedling Storage

The type of storage conditions will determine the types of disease problems that will be encountered. Originally, all container seedlings were either shipped directly from the growing area or were held in shadehouses or other sheltered storage structures until shipment. Many of the same diseases that occurred in the growing area could carry over into the shadehouse. With the advent of refrigerated storage, however, fungal diseases such as storage molds became a more serious problem.

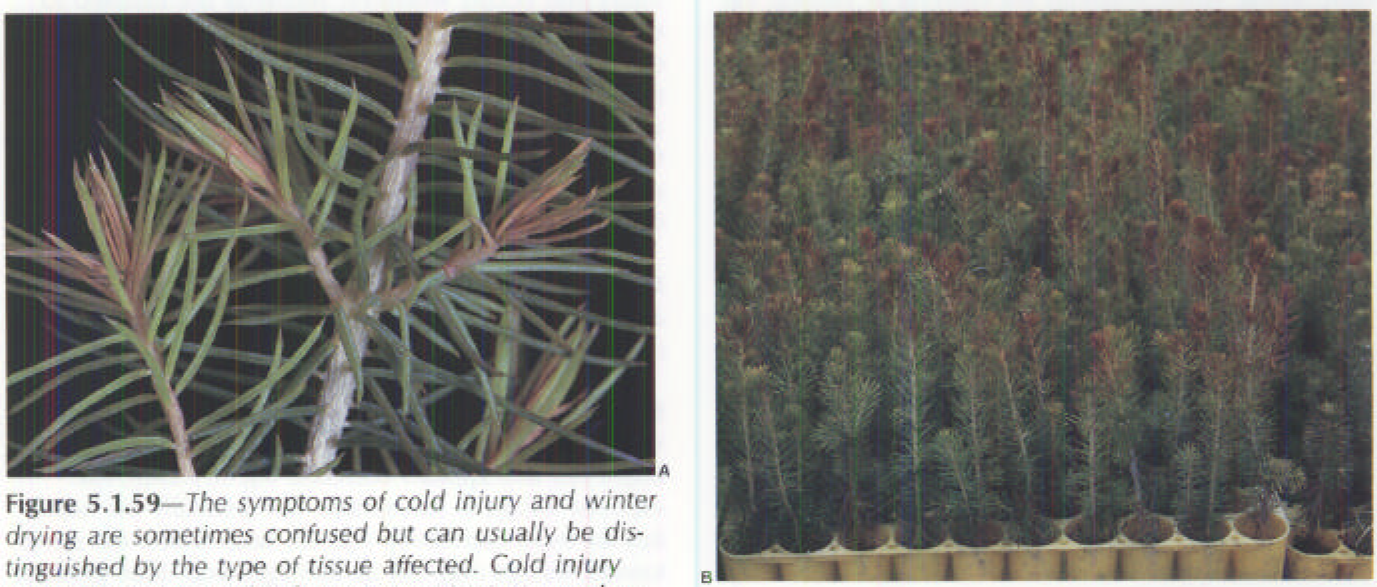
5.1.6.1 Problems during sheltered storage

Many of the diseases discussed in the previous sections can also be encountered in shadehouses, although disease severity is usually diminished because of the less-favorable environment. Container tree seedlings must be hardy and dormant if they are to be stored over winter, thus making cultural practices to induce hardiness and dormancy crucial (see chapter on hardiness in volume six of this series). Seedlings in sheltered storage are susceptible to two major types of overwinter damage: cold injury and winter drying.

Cold injury. Whenever tree seedlings are held overwinter, they are susceptible to cold injury, and container seedlings are particularly vulnerable because of their extended period of succulence. One of the major problems with the rapid growth rates achieved in container nurseries is the difficulty in slowing growth and inducing dormancy and cold hardiness. *Cold injury is directly related to seedling dormancy and cold hardiness.* The root systems of container seedlings are particularly vulnerable to cold injury because the roots are less hardy than other seedling tissues and are exposed in containers.

Hosts. All species of container seedlings are susceptible, but species or ecotypes from low elevations, coastal areas, and southern latitudes are most likely to be injured.

Symptoms/Damage. Foliar cold injury is initially expressed as pale, water-soaked tissue that eventually turns from straw-colored to brown or bright red (fig. 5.1.59A), depending on the seedling species and degree of injury. Symptoms develop relatively soon



A

B

Figure 5.1.59—*The symptoms of cold injury and winter drying are sometimes confused but can usually be distinguished by the type of tissue affected. Cold injury generally affects nonhardy meristematic tissue, such as shoot tips* **(A),** *whereas winter drying affects all the mature needles of exposed shoots* **(B),** *even if they are cold-hardy. (***A,** *courtesy of R.D. Hallett, Canadian Forestry Service.)*

after exposure to freezing temperatures, usually within a couple of weeks, and meristematic tissues such as shoot tips show damage first. This characteristic helps distinguish cold injury from winter desiccation, which usually affects all exposed foliage and develops over a longer time period. Buds can sometimes be killed by frosts that do not injure hardier foliage (fig. 5.1.60A). The most insidious form of cold injury is cambial damage, which can easily be overlooked because the bark must be removed to expose the symptoms. Cold-damaged cambial tissue turns varying shades of brown, and this damage may occur in intermittent patches along the stem (fig. 5.1.60B). Roots are particularly susceptible to cold injury because they do not harden as much as the shoots, and cold damage to container seedling root systems can be common during overwinter storage. Overwintering losses can be severe. Hallett (1984) reports that 11.8 million container seedlings (38% of the total crop) were lost in the Maritime Provinces in the winter of 1982-83.

Disease development. Cold injury can develop from a single frost or during an extended period of cold weather. Damage is most common in the late fall or early spring, when seedlings are entering or coming out of dormancy. Young Scotch pine seedlings showed wide individual variation in cold tolerance when exposed to a simulated frost. Some showed injury after 2 hours at -4.5 °C (24 °F), whereas others remained tolerant at -7.5 °C (20 °F) (Holopainen 1988). Symptom expression may be delayed during an extended period of cold weather but can be accelerated by bringing seedlings into a warm environment. Cambial or root injury may cause delayed bud break or foliar wilting after the seedlings are returned to a growth promoting environment.

Disease management. Losses to cold injury can be significantly reduced by carefully planned and executed cultural practices:

1. Develop growing schedules that include an adequate hardening period.

2. Avoid moving seedlings out of enclosed growing structures until they are adequately cold hardy or all danger of frost has passed.

3. Protect nonhardy seedlings with irrigation, supplemental heat or protective coverings.

4. Try to grow seedlings that are adapted to the local environment; exotic species or seed sources will require special handling and protection.

5. Monitor seedling hardiness with cold hardiness tests to determine when seedlings are ready for storage. Glerum (1985) summarizes the latest technology in cold hardiness testing.

***Winter drying*.** Winter drying is actually desiccation injury and occurs whenever seedlings are exposed to drying conditions, generally wind or direct sunlight; damage is most severe when the growing medium and roots remain frozen for extended periods. Seedlings can even become desiccated when they are stored under frost-free refrigeration without proper packaging. Winter drying is not directly related to seedling dormancy or cold *hardiness.*

Hosts. Conifer seedlings are most susceptible, although hardwoods could be damaged in extreme circumstances (Boyce 1961).

Symptoms/Signs. Winter drying is often referred to as winter burn because the affected foliage often turns bright red and appears scorched (fig. 5.1.59B). All exposed foliage is susceptible, but generally the needle tips are most commonly injured; buds within the symptomatic foliage may not be damaged and often produce normal shoots after outplanting. Tip dieback or even seedling mortality can occur in extreme cases. Winter drying can be distinguished from cold injury by foliage color and timing of symptom expression.

Figure 5.1.60—*Symptoms of cold injury (brown, discolored tissue) to the buds* **(A)** *or the stem cambium* **(B)** *are less visible than foliar injury. Cold injury to the bud affects only the potential new shoot growth, whereas stem injury is usually fatal.* (**B**, *courtesy of R. Timmis, Weyerhauser Company, Centralia, WA.)*

Disease development. Compared to bareroot stock, container seedlings are more susceptible to winter drying because of the limited amount of moisture reserves in small containers. Desiccation can become severe when seedlings in frozen growing media are exposed to sunlight or drying winds. Winter drying is slower to develop than cold injury, usually requiring weeks rather than days. Seedlings that are exposed around the perimeter of the storage area are most severely damaged, especially when the root systems are not properly insulated. In areas with snow cover, shoots that protrude above the snow often show winter burn.

Disease management. Proper storage structure design and some preventative cultural practices can reduce winter drying losses:

1. Protect seedlings from direct exposure to sun and wind with sheltering structures.

2. Group seedlings together on the ground with some sort of insulating material around the perimeter.

3. Cover seedling foliage with mulches or sheeting material; complete snow cover provides an ideal type of protection.

Animal damage. Seedlings stored in outdoor holding areas are subject to animal predation from rodents and larger animals, such as rabbits and deer. Ironically, structures for overwintering container seedlings are an ideal environment that protects small animals from their natural enemies.

Hosts. All species of seedlings are susceptible.

Symptoms/Damage. Rodents leave small teeth marks (fig. 5.1.61 A) on the lower stem, whereas rabbits usually clip the entire stem off at a smooth 45° angle. Deer usually browse seedlings, clipping the seedling shoot; because deer have no upper incisors, deerbrowsed tissue has ragged edges (Byford 1987). Tracks and fecal droppings often help in identifying the specific pest.

Animal management. Protecting container seedlings in sheltered storage is very difficult. Byford (1987) presents a series of questions for determining if animal control in nurseries is justified:

1. Is a control program worth the effort? Is the economic loss or nuisance greater than the cost of control?

2. Is there some way to keep the animals from getting to the seedlings, e.g., screens or fencing?

3. Can the offending animals be repelled from the site? Can chemicals, visuals, or sound be used to keep animals from the growing area?

If none of the above actions are effective, then the final step is to remove the problem animals with trapping or chemical poisons. There are specific controls for some common animal pests.

Deer. Watchdogs may discourage deer in a small storage area, but fencing is a more common approach. Although tall exclusion fences are sometimes used, deer are able to jump many such structures. The best system is a permanent, low-impedance electrical fence, but proper design is important. Byford (1987) describes a 5-strand deer fence with a low-impedance electrical charger that is both effective and cost-efficient. Temporary fences are sometimes used; these consist of a single-strand electrical fence that repels deer by shocking them after they have been attracted to an electrically charged bait.

Chemical repellents are another option for deer control, and there are two basic types: contact repellents and area repellents. Contact repellents are applied directly to the seedlings, and the deer are repelled by the taste of the chemical. Frequent reapplications of contact repellents are often necessary because the chemicals wash off the foliage and any new shoot growth is unprotected. Area repellents are applied on or near the seedlings and repel deer by smell alone. In a comprehensive test in Connecticut, a wide variety of deer repellents were tested including human hair, hot sauce, and some conventional chemicals (thiram, Magic Circle Deer Repellent®, Big Game Repellent®, and Hinder®). Results were variable between the study areas, but the researchers found that, under heavy browsing pressure, none of the repellents were very successful (Byford 1987).

Rabbits. Controls for these common animal pests include live-trapping, fencing, or chemical repellents. Three-foot-high chicken-wire fences are very effective in excluding rabbits but must be secured to the ground to prevent rabbits from going under the fence. Most rabbit repellents (e.g., thiram) are taste repellents, but they suffer the same limitations as the deer repellents (Byford 1987).

Figure 5.1.61—*Feeding injury by small rodents can be diagnosed by the small teeth marks on the seedling stem (**A,** circle) and often occurs during outdoor overwinter storage. Small rodents can be controlled with various types of traps or poison baits (**B**).*

Rodents. Cats are often used in greenhouses to control small rodents but they are less effective in large outside seedling storage areas. Fencing is obviously ineffective for rodents; it is difficult and expensive to build a completely rodent-proof structure. Snap trapping is some times used to control rodent populations although chemical baits are usually the cheapest and most effective means of dealing with large numbers of these pests (Carlson 1983). Byford (1987) discusses two types of rodent poisons: single-dose rodenticides (zinc phosphide), which kill the animals after one feeding, and anticoagulants (warfarin, coumafuryl), which are only effective after continued ingestion of the poison. Anticoagulants are safer around nontarget animals and often more effective because "bait shyness" will not develop. Anticoagulant poisons must be provided in plentiful supply for several weeks to be effective. Byers and Carbaugh (1987) tested the efficacy of several rodenticides in laboratory and field tests and found that zinc phosphide pellets ZP Rodent Bait AG® gave better control of pine voles (Microtus pinetorum) and meadow voles (M. pennsylvanicus) than other similar products. If possible, place baits both under the containers and on the container surface, especially around the perimeter of a group of seedlings (fig. 5.1.61 B). Any pesticide should be carefully placed to minimize the possibility of accidentally poisoning other animals, especially pets.

5.1.6.2 Problems during refrigerated storage

As with bareroot seedlings, storage mold of container seedlings is a principal concern in refrigerated storage. Whenever seedlings are stored under refrigeration, storage mold is inevitable; the question is not whether mold will develop, but when it will occur because the likelihood of storage mold increases with storage time. Many different fungi can cause molding of bareroot stock, most of which are introduced on soil particles; because container seedlings are grown in artificial growing media, this major source of fungal inoculum has been eliminated. The major storage mold fungus of container stock is *Botrytis cinerea*, the same pathogen that is responsible for grey mold in growing stock.

***Botrytis storage mold*.** Botrytis storage mold can be a serious problem in stored container stock because the fungus can spread unobserved in the cool, moist environment of the storage container. Often the problem is not identified until the seedlings are shipped to the planting site and by that time the entire storage container is usually affected and the seedlings ho,, t be destroyed. Storage molds are particularly cost',, because stored seedlings are at their maximum ,i.~. and the nursery manager has usually committed stock to a customer.

Hosts. The same seedling species that are susceptible to grey mold in the nursery are vulnerable to botrytis storage mold: redwood, giant sequoia, western larch, lodgepole pine, ponderosa pine, Engelmann spruce, western hemlock, Douglas-fir, Scotch pine, blue spruce, mountain hemlock, noble fir, and Alaska-cedar. Because *B.* cinerea is not very host-specific, probably all conifer and hardwood seedlings are susceptible.

Figure 5.1.62—*When container tree seedlings are stored under refrigeration,* Botrytis cinerea *can develop into a damaging storage mold because of its affinity for cold, moist, dark conditions.*

Symptoms/Damage. Storage molds usually develop in the interior of the storage bundle, so that several storage containers need to be opened and checked throughout. The grey, cottony mycelium and fruiting bodies (fig. 5.1.62) can be seen on the foliage or stem; in advanced cases, the infected foliage becomes soft, water-soaked, and spongy.

Disease development. Botrytis storage mold is almost always the result of a pre-existing infection that originated during the nursery period, especially on species like Douglas-fir and western hemlock. Seedlings that are damaged by fertilizer burn, cold, or mechanical injury are particularly vulnerable (Sutherland and others 1982). Surface moisture accelerates the spread of *B. cinerea*, and mold severity is directly related to the temperature and the length of storage. Because *B. cinerea* thrives under cold temperatures, it grows well under refrigerated storage conditions.

Disease management. *Cultural*. Sutherland and others (1982) list the following cultural controls for botrytis storage mold:

1. Prevent grey mold infections from developing in the nursery.

2. Carefully inspect seedlings during prestorage grading and rogue-out diseased individuals.

3. Store seedlings, especially those with any dead or damaged foliage, for the shortest time possible.

4. Make certain that seedling foliage is dry before storage.

5. Store seedlings at as cold a temperature as possible. Where feasible, frozen storage [-1 to -2 °C (about 30 °F)] is recommended because all free moisture on the seedling foliage is turned into ice crystals, which apparently suppresses the spread of *B. cinerea*.

6. Inspect stored stock frequently, especially seedlots with dead or damaged foliage, so that diseased seedlings can be rogued before the disease spreads through the entire storage container.

7. Insure that seedlings are properly hardened-off prior to storage (see the chapter on hardening in volume six).

Chemical. Protective fungicides that are applied to seedlings prior to storage may be of some value, although Sutherland and Van Eerden (1980) reported that results have been erratic. Fungicides that are registered for grey mold (table 5.1.9) can either be applied as a spray late in the growing season or as a spray or dip immediately before storage. Because many fungicides persist on the seedling foliage during handling, shipping, and outplanting, nursery and field personnel may be exposed to prolonged contact with storage fungicides. Therefore, these chemicals should be used cautiously and only as a last resort.

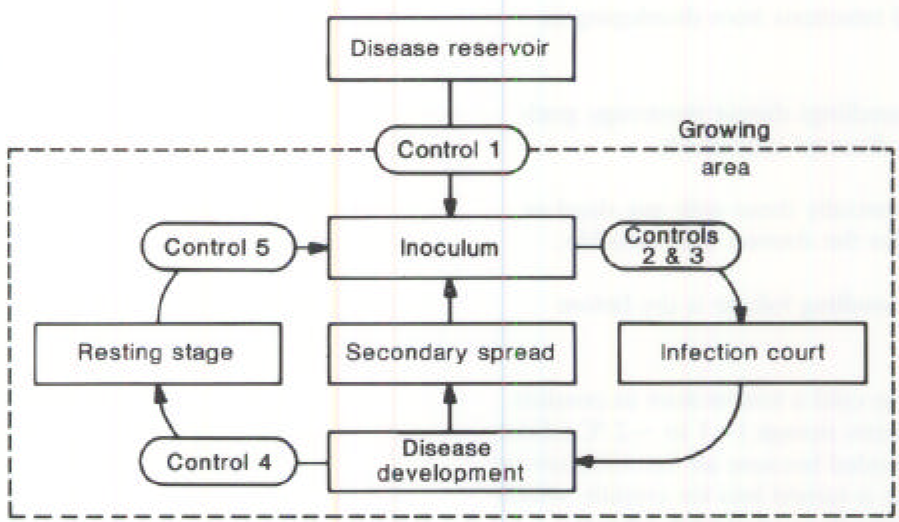
5.1.7 Disease and Pest Management Strategies

The management of nursery diseases and pests is covered in two places in this publication: what follows here is a general discussion of nursery disease and pest management, whereas specific control measures are included in the discussion of the individual pest problems.

5.1.7.1 Philosophy of management instead of control–integrated pest management

Nursery managers have traditionally talked about "controlling" a disease. This usually involved waiting for the disease to occur and then spraying some toxic chemical on the already dead or dying seedling. Today, we take a more scientific approach to nursery disease control that involves a variety of cultural and chemical measures that are designed to manage the disease (fig. 5.1.63). Nursery disease management should be a series of interrelating processes that are incorporated into the entire spectrum of container nursery culture, rather than as a knee-jerk reaction to a specific pest. Often, a single control measure will not be effective because most nursery diseases are very complex and require an integrated management approach using several different control measures. Chemical pesticides (fig. 5.1.64) should be just one part of a comprehensive pest management program that integrates both chemical and cultural control measures.

Integrated pest management (IPM) is a concept that has been proposed for some time but has only recently been implemented in some ornamental container nurseries (Davidson and others 1988). IPM can be defined as the selection, integration, and implementation of a pest control program that is based on predicted economic, ecological, and sociological consequences (Botrell 1979). Nursery managers will recognize that most of the individual components of an IPM program are not new: IPM includes standard cultural, mechanical, and chemical controls as well as biological controls and host genetic resistance. The main difference is the organization of the different pest control strategies into a single, comprehensive program--IPM is a systems approach rather than an incident approach.



Disease Control Techniques

1. Keep surroundings clean of weeds
2. Apply protectant fungicides
3. Use cultural techniques to keep foliage dry
4. Rogue out diseased seedlings
5. Clean and disinfect growing area between crops

Figure 5.1.63—*An integrated pest control program for grey mold* (Botrytis cinerea) *consists of both cultural (1, 3, 4, 5) and chemical (2, 5) control measures.*

Perhaps the most important selling point of an IPM program is the sociological-political aspect. All forms of agriculture, including container tree nurseries, are coming under increasing scrutiny concerning pest control activities, especially the use of pesticides. Progressive nursery managers should begin to integrate their current pest management treatments into an IPM program framework, as well as consider the newest pest management options, such as the use of suppressive growing media (see section 5.1.7.3).

The concept of disease management has been presented in several different ways; the following treatment is based on the four phases of disease management presented by Smith (1970) and Bohmont (1983): exclusion, protection, eradication, and resistance. This approach is preferable to the traditional division of disease management into chemical and cultural control, which separates these two control options rather than integrating them. The four-phase approach allows both chemical and cultural controls to be discussed together and is also applicable to both biotic and abiotic diseases. Exclusion and eradication can only be applied to biotic disease agents whereas protection and resistance can be used for both biotic and abiotic problems.

5.1.7.2 Exclusion: preventing pest entry

The container nursery environment is initially pest-free and so the most logical approach to disease management is to attempt to prevent diseases by excluding disease agents from the growing area. Diseases are much easier to prevent than to cure. Moody (1984) states the case well when he says that all disease controls are based on one criterion-prevention. Excellent discussions on disease prevention through sound sanitation practices are provided in Nelson (1978) and Hanan and others (1978).

Figure 5.1.64—*Pesticides should be part of a comprehensive pest management program that integrates both chemical and cultural control measures.*

Selecting the site. Disease prevention begins with nursery site selection. Sutherland and others (1982) state that nursery location is one of the two most critical factors in determining disease incidence. McCain (1978) recommends that container nurseries not be established in locations where host-specific pathogens such as fusiform or gall rusts are a problem. Another solution is to remove the primary or alternate rust hosts from a reasonable distance around the nursery during nursery development. Matthews (1983) reports that, to control the spread of European pine shoot moth in British Columbia, regulations require that infested pines be eliminated for 100 m (328 feet) around nurseries. He also mentions that shrubs and grass surrounding nurseries can harbor insect pests including thrips, aphids, weevils, and the European crane fly. Any unnecessary structures or vegetation around a nursery site should be removed because they provide cover for seed-eating rodents and birds.

With existing container nurseries, however, we need to identify how potential pests generally get into the growing area:

1. *Wind*--Airborne spores, seeds, or insects can be introduced through the ventilation system.

2. *Water*--Fungus and cryptogam spores and weed seeds can be introduced through the irrigation water.

3. *Growing media*--Most commercial mixes are considered "essentially sterile," but potentially harmful fungi have been isolated from some types of growing media or their components.

4. *Containers*--Reusable containers may contain residual growing medium that harbors pest propagules or moss or algae from the previous crop.

5. *Surfaces in the growing structure*--Floors, benches, and other surfaces in the growing area may harbor pests from the previous seedling crop.

6. *Propagation materials*--Seed, transplants, or cuttings are sometimes infected before they reach the nursery.

7. *Transported soil and growing medium*--Infested materials can be carried into the growing area on tools, equipment, or on shoes of workers or visitors.

8. *Mobile pests*--Insects, birds, and rodents can enter the growing area directly.

Using certified seed, transplants, and cuttings. One of the most effective ways of excluding pests from nurseries is to use only seed, transplants, and cutting materials that are certified to be pest free. Hanan and others (1978) discuss some of the horticultural practices that are used to prevent pest spread through propagation materials; these practices are not as applicable for forest tree seed and transplants but there are some examples. In British Columbia, certain nurseries are in the balsam woolly adelgid ("aphid") infestation zone and thus Abies spp. seedlings grown in these nurseries must be treated with insecticides and be certified pest free before they can be shipped to other nurseries outside this zone (Matthews 1983). To overcome this problem, Abies spp. are normally grown in nurseries outside the infestation zone.

Although there is not an operational pest-free seed certification program for forest tree seed at the present time, certain precautions during seed collection and handling can lower the incidence of disease. Any cone or seed handling practice that keeps seed clean will reduce the possibility of introducing seedborne pathogens into the nursery. Cones collected from the ground, and from squirrel caches in particular, are considerably more dirty than cones collected directly from the tree. Sutherland (1979) showed that the incidence of the seed fungus Caloscypha fulgens is significantly higher in cones collected from squirrel caches. Pathogenic species of Fusarium were observed to be more prevalent on seed lots from ground-collected cones in north Idaho and western Montana (James 1986).

Treating seed. Many different pathogenic organisms, including fungi, bacteria, viruses, and nematodes, can be carried on seed. Andersen and Leach (1961) provide a good discussion on testing seeds for pathogens. Tree seed has been shown to be infected with several fungal pathogens, and even nonpathogenic fungi can cause seed handling problems during stratification. Kliejunas (1985) reported that, even though none of the fungi were known pathogens, stratification bags of Jeffrey pine seed had extensive mold development, with groups of seed bound together with mycelia. Several different types of seed treatments are available.

Table 5.1.11—*Effects of four seed treatments on ponderosa pine seed from fungus-contaminated seed lots collected from squirrel caches*

Seed treatments	Treatment period	% Germination	% Clean seedcoats	% Diseased germinants
Standing water soak	24 hr	21.5 a	22.3 a	95.3 a
Running water rinse	48 hr	28.2 b	38.3 b	77.0 a
5.25% Household bleach	5 min	22.5 a	53.9 c	60.0 b
3% Hydrogen peroxide	5 hr	36.3 c	54.5 c	76.6 a
Average	—	27.1	41.7	77.0

Values followed by the same letter do not differ significantly at the P – 0.05 level.
Source: James and Genz (1981).

Cold water soaks. Standing water soaks are common presowing or prestratification seed treatments but this practice greatly reduced germination and did not remove all seedcoat contaminants in a trial with Douglas-fir seed (James 1983).

Water rinses. A 48-hour running water rinse has been advocated as a way to remove seedcoat-contaminating fungi. Seeds can be loosely enclosed in open-mesh bags and placed in a water tank with vigorously moving water, which should wash away most surface contaminants. James and Genz (1981) compared this seed treatment to the standard standing water soak and reported a significant increase in germination and reduced fungal and bacterial contamination of ponderosa pine seed (table 5.1.11).

Hot water soaks. Hot water soaks have been recommended as a seed treatment for ornamental species. The seeds are placed in cotton or plastic-mesh bags and immersed in hot water at 49 to 53 °C (120 to 127 °F for 30 minutes, and then cooled in running tap water (Handreck and Black 1984).

Chemical sterilization. Chemical sterilization of seeds with sodium hypochlorite or hydrogen peroxide has shown variable results. The concentration of the chemical solution and the treatment time are the most important factors affecting chemical seed treatments. The major problem with treating seeds with strong disinfectants is that solutions strong enough to kill surface contaminants are often phytotoxic to the seeds. The effectiveness of chemical seed treatments also varies between different types of seeds: species with thin seedcoats may be more easily damaged than those with thick seedcoats, and rough-surfaced seeds such as those of firs (*Abies* spp.) are particularly difficult to treat.

Hydrogen peroxide. A 40-minute soak in laboratory grade (30%) hydrogen peroxide was effective in surface-sterilizing Douglas-fir seeds for research purposes, although Fusarium spp. propagules sometimes survive the treatment because they are carried internally in the seed (Graham and Linderman 1983). Barnett (1976) recommends using 30% hydrogen peroxide for seeds of southern pines, with soaking times ranging from 15 minutes for shortleaf pine to 1 hour for longleaf pine. Several studies report variable results for other species: longleaf pine (Campbell 1982), and lodgepole pine, ponderosa pine, and Engelmann spruce (Fuller and Hildebrand 1985). James (1983) found that a 3% hydrogen peroxide treatment for 64 hours reduced most seedcoat contamination with only a negligible effect on germination of Douglas-fir seed. James and Genz (1981) found that ponderosa pine seed treated with 3% hydrogen peroxide for 5 minutes and then rinsed showed significantly increased germination and decreased seedcoat contamination (table 5.1.11). Carlson (1983) recommends a 15-minute agitated soak in 3% hydrogen peroxide, followed by a cool, clear water rinse.

Sodium hypochlorite (household bleach). Saeur and Burroughs (1986) provide an excellent discussion of the various aspects of treating corn seed with sodium hypochlorite. They report that the strength of commercial brands of household bleach can vary from 5.25 to 6.00%, and that effective surface disinfection depends on the pH, formulation, and strength of the solution. They also found that the effectiveness of sodium hypochlorite seed treatments is affected by pathogen concentration and seedcoat properties-spores trapped in seedcoat cracks or air bubbles may not be reached by the disinfectant.

For conifer seed, James (1983) reported that a 2-hour soak in a 5.25% bleach solution effectively removed pathogenic fungi from the seedcoat but greatly reduced germination of Douglas-fir. James and Genz (1981) found that a 5-minute soak in 5.25% bleach followed by a thorough rinse significantly reduced seedcoat contamination of ponderosa pine without affecting germination (table 5.1.11). Wenny and Dumroese (1987) recommend a 10-minute soak in an agitated bleach solution-2 parts stock laundry bleach (5.25% sodium hypochlorite) to 3 parts water-followed by a thorough rinse in running tap water. This seed treatment reduced losses to damping-off fungi such as *Fusarium* spp. on many thick-coated conifer seeds, such as Douglas-fir and pines, but is not used on species with thinner seed coats, such as true firs, larch, or spruces. Kliejunas (1985) treated seed of several western conifers with a dilute bleach solution (0.525%) and reported reduced germination and poor control of seed mold fungi.

Merthiolate. Jobidon and Thibault (1980) reported that bleach and hydrogen peroxide did not work well with papery, porous seeds such as those of American green alder, and found that a 15-minute treatment in 1 % aqueous merthiolate gave very satisfactory results.

Obviously, more work is needed on different solution concentrations and varying treatment intervals. Growers should test any potential seed treatment on a small scale before attempting it operationally.

Fungicide seed treatments. The literature is contradictory on the benefits of using fungicides to control seedborne fungi. Bloomberg (1981) reviewed the literature on seed treatments for controlling Fusarium spp. and lists captan, thiram, and benomyl as seed fungicides but cautions that phytotoxicity may outweigh disease control benefits. Pawuk (1979) tested the effectiveness of 15 different fungicide seed treatments on three species of southern pines, and found that captan and thiram were the least phytotoxic of the chemicals and that phytotoxicity varied between species, with slash pine being the most sensitive species. Belcher and Waldrip (1972) reported that thiram reduced fungal contamination without reducing slash pine germination, even with treatments as long as 30 minutes in a 6% thiram solution. James (1983) found that captan effectively eliminated fungal contaminants on Douglas-fir seed but was severely phytotoxic. Kliejunas (1985) treated seeds of several western conifers with captan or thiram and reported that neither chEmical significantly reduced germination, with the exception of thiram on white fir and incense-cedar. Carlson (1983) concluded that, even though thiram and captan may reduce losses to damping-off, they may inhibit germination or cause growth distortions. (See section 5.1.3.2 for more information on chemical injury caused by phytotoxicity.)

Fungicide seed treatments may be ineffective because the activity spectrum of many fungicides is narrow, resistant strains of the pathogen may develop, and the pesticides may be washed off the seed by frequent irrigation. The harmful effects of seed treatments may be more serious in container nurseries because the biological and chemical buffering capacities of artificial growing media are very low (Sutherland and Van Eerden 1980).

Treating growing media. A very effective way to exclude disease organisms from the container nursery is to eliminate them in the growing medium. Heat pasteurization or chemical fumigation were common greenhouse operations when soil was used as part of the growing medium, but these practices are less common now that soilless growing media are the standard. According to the Container Nursery Survey, only 5% of the container nurseries in the Unites States and Canada routinely treat their growing media.

Although most growers assume that artificial growing media such as peat-vermiculite mixes are sterile, recent evidence indicates that this may not always be true. The inorganic components of most mixes such as vermiculite or perlite are initially sterile because of their exposure to high temperatures during processing. However, the organic components of growing media may sometimes contain pathogenic fungi, for example, *Fusarium* or *Pythium* spp. in peat (see section 5.1.3.1).

Many manufacturers of commercial growing media treat their product before packaging, but it would be wise to specify that the media be pest-free when purchasing commercial media. Container nursery managers should have their growing media assayed for pathogenic fungi after mixing or before purchasing commercial products. Most nursery pest laboratories or seed processing firms can provide pathogen assays at a reasonable cost. Compared to the potential losses from infested media, the costs of assays or treatment are quite reasonable; Mastalerz (1977) estimates that the cost of pasteurization is only 1 to 2% of the total crop production costs.

Treating growing media to eliminate pathogenic organisms is called sterilization, although pasteurization is a better term because no operational media treatment completely eliminates all living organisms. Basically, there are two methods for treating growing media: heat and chemical fumigants. Excellent descriptions of these processes are provided in Baker and Roistacher (1957), Bunt (1976), Mastalerz (1977), Ball (1985), and Lawson and Horst (1987).

Heat treatments. Several heat sources can be used for pasteurizing growing media: moist heat from steam, aerated steam, hot water, or microwave ovens; or dry heat from flame or electric pasteurizers. Regardless of the heating method, it is important to maintain the entire mass of growing medium at a uniform temperature that exceeds the thermal death points of the various nursery pests. Pests vary in their ability to tolerate high temperatures (fig 5.1.65), but most can be eliminated by being subjected to a temperature of 60 to 82 °C for at least 30 minutes (table 5.1.12). Excessive temperatures can cause problems by eliminating beneficial soil organisms and producing toxic chemical compounds. Heat treatment requires expensive application equipment but is cost effective if steam-generating equipment is readily available (fig. 5.1.66).

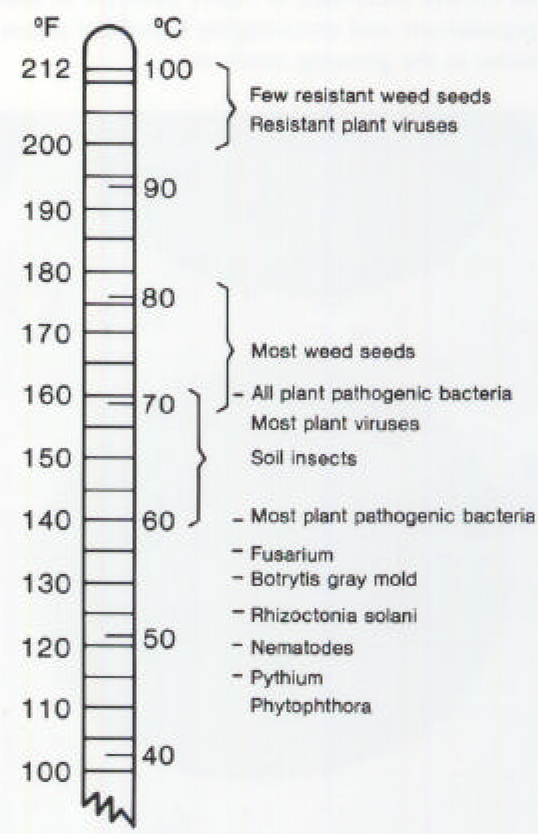


Figure 5.1.65—*Various sources of heat can be used to pasteurize growing media or used containers, but the types of pests controlled depends on the temperature. Most sources recommend maintaining a temperature of 60 to 82 °C (140 to 177 °F) for at least 30 minutes (modified from Baker and Roistacher 1957).*

Figure 5.1.66—*Steam pasteurization is not commonly practiced in container tree nurseries but this traditional disease control technique is highly effective in reducing pest populations and encouraging beneficial micro-organisms in the growing medium.*

Figure 5.1.67—*Seedling roots can penetrate the sides of rough-textured container walls, such as in this Styrofoam® block. These roots often remain after the seedling plugs have been extracted and may serve as a source of disease inoculum for the next crop.*

Chemical fumigants. A variety of chemical fumigants are available for treating growing media, but they vary in their effectiveness against different disease organisms (table 5.1.12). All of these fumigants are biocides, that is, extremely toxic to all organisms; most are also restricted-use pesticides and should be handled with extreme caution. McCain (1978) concludes that methyl bromide is the most useful fumigant for treating container growing media and recommends using a relatively thick (4 mil) plastic tarp to completely contain the gas. The main advantage of chemical fumigants is their low capital cost and the fact they can be applied without expensive application equipment; however, they must be applied under a tarp and the treated medium must be ventilated for an extended period before planting (table 5.1.12). A good discussion of commonly used fumigants in ornamental container nurseries is provided in the Ball Redbook (Ball 1985), and McCain (1987) presents an excellent discussion on chemical fumigants used in ornamental greenhouses in California.

***Sterilizing containers and growing area surfaces*.** Reusable containers usually contain some residual growing medium or pieces of roots that could contain pathogenic fungi. Seedling roots grow into the pores of containers with rough-textured walls, such as Styroblocks®, and remain after the seedling plug has been extracted (fig 5.1.67). Cryptogams (liverworts, moss, and algae) also grow on containers and are very difficult to remove from reusable containers.

Benches, floors, and other surfaces in the growing area often serve as reservoirs for biotic pests, particularly cryptogams and weeds. Containers should be treated with steam, washed with surface disinfectants, or chemically fumigated between crop rotations (fig. 5.1.68). Nelson (1978) lists several disinfectants that can be used on containers, benches, and other surfaces in the growing area (table 5.1.13). Matthews (1983) mentions use of a pestcidal soap for cleaning containers or greenhouse surfaces. Northwestern container tree nurseries have recently been testing another disinfectant, called sodium metabisulfite, which releases sulfur dioxide when mixed with water (Sturrock 1988). McCain (1977) also stresses the importance of sanitation in container nurseries and lists common disinfectants.

Weeds should be hand-pulled or killed with herbicides between crops (see table 5.1.9 for a list of low-risk herbicides).

Table 5.1.12—*Heat treatments and chemical fumigants for growing media and containers*

		Target organisms				
		Fungi	Insects	Nematodes	Weeds	Application information[1]
Heat treatment						Control of specific organisms related to temperature (see fig. 5.1.65)
Steam	—	Yes	Yes	Yes	Yes	
Aerated steam	—	Yes	Yes	Yes	Yes	
Dry heat	—	Yes	Yes	Yes	Yes	
Fumigants						
Active ingredient	Trade name					
Methyl bromide/ chloropicrin (98%/2%)	Dowfume MC-2®	Most	Yes	Yes	Most	Restricted use; heed label directions
Methyl bromide/ chloropicrin (67%/33%)	Dowfume MC-33®	Yes	Yes	Yes	Most	Restricted use; heed label directions
Chloropicrin	Larvacide® Picfume®	Yes	Yes	Some	Yes	Restricted use; heed label directions
Metam-sodium	Vapam®	Most	Yes	Yes	Some	Follow label directions
Dazomet	Basamid® Mylone®	Most	Yes	Yes	Most	Follow label directions
Dichloropropene	Telone II® D-D®	No	Some	Yes	No	Follow label directions; *not for greenhouse use*
Methyl isothiocyanate/ dichloropropene	Vorlex®	Yes	Yes	Yes	Yes	Follow label directions

[1]All treatments require growing media that are porous and moist. Temperatures during application should be >10 °C (50 °F), except for chloropicrin, which should be >16 °C (59 °F).

This listing does not constitute a recommendation: these specific products are those listed in the sources and may not be currently registered. Other products may be available as well. Consult with a pesticide specialist and check label for information on registered uses and application rates.

Source: adapted from Bunt (1976), Nelson (1978), Hanan and others (1978), Lambe and others (1982).

A B

Figure 5.1.68—*Reusable containers should be cleaned and sterilized between crops with chemical disinfectants, fumigants, or steam. Containers can be dipped in a sodium hypochlorite (household bleach) solution and then rinsed with water* **(A)**, *or cleaned with hot water or steam in special equipment* **(B)**.

Table 5.1.13—*Common disinfectants for treating surfaces and tools in container tree nurseries*

Disinfectant[1]	Application rate	Application
LF - 10®	1 part to 100 parts water	Growing area surfaces Cooling pads Containers and tools (dip or soak and rinse before using)
Physan 20® (benzylkonium chloride)		Growing area surfaces Cooling pads Containers and tools (dip or soak and rinse before using)
Household bleach (5.25% sodium hypochlorite)	1 part bleach to 9 parts water	Growing area surfaces Cooling pads[2] Containers and tools (dip or soak and rinse before using)
Alcohol—grain, wood, or rubbing (70 to 100%)	Full strength	Growing area surfaces Containers and tools (dip or soak but do not rinse)
Formalin (40% formaldehyde)	1 part formalin to 50 parts water	Wooden benches or pallets (soak for 30 minutes; rinse and aerate before using) Containers
Copper naphthenate	2% solution in Stoddard solvent (Varsol®)	Wooden benches or pallets (paint or dip and allow to dry before using)

[1]All these chemicals are phytotoxic to seedlings and should never be used on or near seedlings.
[2]May destroy structure of some preformed cooler pads
Source: modified from Nelson (1978), Moody and Smith (1982).

Treating irrigation water. Surface sources of irrigation water can contain pathogenic fungi such as *Pythium* or *Phytophthora* spp., weed seeds, and cryptogam spores. Irrigation water should be tested prior to use and treated if a problem exists (see volume four of this series for more information).

Maintaining physical barriers. Mobile pests such as insects, birds, and rodents must be physically excluded from the growing area with screening or fencing. Air intake vents can be screened to prevent weed seeds and insect pests from entering the growing area. Gravel, asphalt, or cement floors prevent weeds from becoming established and make cleanup between crops much easier.

Following hygienic practices. Greenhouse workers should clean soil from their shoes before entering the growing area. Equipment and tools can be sterilized with steam or surface disinfectants between uses, and transfers of plant material between different sections of the nursery should be carefully monitored.

5.1.7.3 Protection: protecting seedlings from existing pests and abiotic stress factors

This second phase of a disease management program is needed when excluding the biotic pest from the growing area is not practical, and for minimizing the adverse effects of abiotic stress factors.

Modifying the environment. Unfortunately, the environment in a container nursery is ideal for many biotic pests, especially fungi, which benefit from the warm temperatures and high humidities. Container nurseries should be designed to provide the proper range of environmental conditions that favor seedling growth, without allowing damaging climatic stresses to develop. Alarm systems should also be installed in the growing area to alert the grower of adverse environmental conditions.

Seedling storage is one of the most crucial periods for development of both biotic and abiotic problems. Botrytis storage mold thrives in the cold, moist environment of refrigerated storage but can be successfully controlled by storing seedlings at slightly below freezing temperatures. Container seedlings under sheltered storage are subject to winter drying and must be properly protected (see section 5.1.6 for more details).

***Cultural practices*.** Many cultural practices can minimize the impact of seedling diseases even after they have become established in the nursery. The organic components used in artificial growing media can affect disease incidence and development. Selection of a growing medium that is porous and well-drained will reduce root rots, and using a medium that contains composted hardwood bark may reduce the impact of certain pathogenic fungi (Hoitink 1980). Hoitink and Kuter (1985) reported that some sources of "light" peat moss harbor organisms that are suppressive to pathogenic fungi, whereas "dark" peat sources do not. Lindquist and others (1985) found that populations of fungus gnats varied significantly between 20 different types of artificial growing media.

Containers that create high seedling growing densities can favor diseases such as grey mold because of the high humidites that occur in the dense seedling canopies. Cultural practices that create one germinant per cavity (use of high germination seed, accurate sowing calculations, and precision sowing) should produce more vigorous seedlings and may reduce damping-off losses. Most foliage diseases, particularly grey mold, can be reduced by any cultural practice that minimizes the time that the seedling foliage is wet: encouraging air movement, spacing containers, irrigating early in the day (McCain 1978); and controlling temperatures and relative humidity so that condensation does not occur (Nelson 1978).

Managing microorganism populations by using suppressive growing media. The concept of managing microorganism populations to enhance plant growth is relatively new because it has only recently become operationally possible with the advent of artificial growing media. In the near future, nursery managers may be able to create "suppressive" growing media that are specially formulated to resist disease organisms. Suppressive soils can be created by introducing beneficial organisms into the growing medium or by using growing medium components that suppress disease organisms. Linderman (1986) gives an excellent overview of the possibilities of this technology.

One of the practical possibilities of microbial management is the suppression of pathogenic organisms through the introduction of beneficial organisms. Lawson and Horst (1987) state that most artificial growing media contain very low populations of beneficial microorganisms. Before any organism can be artificially introduced into a growing medium, the existing microbial population must be reduced by some cultural treatment, such as chemical fumigation or heat pasteurization. Heat pasteurization has some advantages because some beneficial organisms are not killed, and may actually be favored, by heat treating at lower temperatures (Baker 1970).

Once the growing medium has been fumigated or pasteurized, the next step is to introduce the desired microbes into the growing medium, by treating either the seed or the medium (Lawson and Horst 1987). Among the microorganisms that may have potential usefulness are mycorrhizal fungi, fungi that are antagonistic to pathogens, rhizobacteria, and free-living microbes such as nitrogen-fixing bacteria. The benefits of inoculating seedlings with mycorrhizae have been well established, and inoculation techniques for container seedlings have been recently developed (see chapter 2 in this volume). Some soil-inhabiting fungi (for example, *Trichoderma* spp.) are actively antagonistic to pathogenic fungi because they compete with the pathogens for substrate, and some are mycoparasites on pathogens, such as *Fusarium* spp. Another possibility is to introduce a nonvirulent isolate of a normally pathogenic organism, such as *Fusarium oxysporum*. Growth promoting rhizobacteria, such as *Pseudomonas* spp.

and *Bacillus* spp., enhance plant growth through antagonism of pathogenic organisms or through production of growth-regulating substances. Free-living microbes can also affect plant growth indirectly through effects on other microorganisms in the root zone. The most practical solution may be a combination of these treatments (Linderman 1986).

When the desired organisms have been introduced, they must be culturally encouraged by management of the growing medium environment. Managing beneficial microorganisms involves an understanding of both their ecological requirements and interactions with other microbes.

Another way to create a suppressive growing medium is to incorporate special components, such as composted tree bark, into the medium. Lawson and Horst (1987) state that hardwood bark suppressed a wider range of pathogenic fungi than pine bark and that beneficial organisms were most abundant in composts older than 1 year. Hoitink (1980) reports that species of *Phytophthora, Pythium, Rhizoctonia, Botrytis*, and other pathogenic fungi were killed by the heat generated during the composting process. Some ornamental growers are now using a 4:1 (v/v) mixture of composted bark and peat moss for the organic medium component to create a pathogen-suppressive growing medium. Three mechanisms have been proposed for this suppressive effect: 1) bark-based media are coarser than peat-based media, resulting in improved aeration, 2) bark composts support high levels of microorganisms that are antagonistic to pathogens, and 3) water extracts from hardwood bark seem to have fungicidal properties (Hoitink 1980).

The practical application of microorganism management in the growing medium is still some years away, but the concept has tremendous potential for container tree nurseries and more research in this area is justified.

Chemical protection. Many of the currently used fungicides are protectants that form a chemical barrier between the seedling and the pathogen (table 5.1.14). Protectants prevent fungal spores from germinating or kill the germinating hyphae before they penetrate the host tissue (Smith 1982). Systemic fungicides are absorbed into the foliage or roots and are then transported throughout the seedling, but only a few protectants fall into this category (table 5.1.14). Some fungicides are able to kill pathogenic fungi after they have initiated an infection; these chemicals, called *eradicants*, are discussed in section 5.1.7.4. Chemical protection against pathogenic fungi must be accomplished by residual pesticides that persist on the plant and prevent attack by the fungus. An effective protectant fungicide should, according to Bohmont (1983):

1. Remain active for a relatively long time.
2. Have good adhesive properties and resist washing-off.
3. Have good spreading properties (usually aided by addition of wetting agents).
4. Resist breakdown in sunlight.
5. Have a broad-spectrum effectiveness against the target fungus to avoid build-up of resistant strains. Smith (1982) reports that several pathogenic fungi have developed resistance: Botrytis cinerea is now resistant to benomyl (fig. 5.1.49) and iprodione.
6. Not be overly phytotoxic to the crop seedling.

On an operational basis, protectant pesticides must be applied so that they completely cover the seedling foliage, which can be difficult in the dense canopies usually found in container tree nurseries. This problem can be partially alleviated by mounting a bar in front of the spray head to separate the foliage and allow the fungicide to penetrate the canopy. Extended protection requires that the pesticide be applied at regular intervals to cover new foliage and make up for the chemical that has washed off.

Table 5.1.14—*Commonly used pesticides for control of fungal diseases of container tree seedlings*

Active ingredient	Trade name	Mode of action
Grey mold *(Botrytis cinerea)*		
benomyl	Benlate®	S P,E
captan	Captan®	NS P,E
DCNA (dicloran)	Botran®	NS P
chlorothalonil	Bravo®/Danconil®	NS P
Damping-off (*Fusarium* spp. and *Pythium* spp.)		
captan	Captan	NS P,E
etridiazole + thiophanate methyl	Banrot®	S(?) P
metalaxyl	Subdue®/Ridomil®	S P
benomyl	Benlate	S P,E
Root rots (*Fusarium* spp. and *Pythium* spp.)		
benomyl	Benlate	S P,E
etridiazole + thiophanate methyl	Banrot	S(?) P,E
captan	Captan	NS P,E
etridiazole	Truban®	NS P
Sirococcus blight *(Sirococcus strobilinus)*		
chlorothalonil	Bravo/Daconil	NS P
maneb	Manzate®	NS P,E(?)

Some formulations (e.g., Banrot) are a combination of two or more chemicals. This listing does not constitute a recommendation: these specific products are those listed in the source and may not be currently registered. Other products may be available as well. Consult with a pesticide specialist and check label for information on registered uses and application rates.

S = systemic, NS = nonsystemic; P = protectant, E = eradicant. (?) means that the exact action of some pesticides is not completely understood, or that the action depends on dosage.

Source: Container Nursery Survey.

5.1.7.4 Eradication: eliminating pests after disease development

This phase of disease management is by far the most difficult to achieve because once a biotic pest is established in the growing area, it can be almost impossible to eradicate. Because most pests exist in close association with their hosts, it is almost impossible to kill them without damaging the host seedling. In addition, once the disease has progressed past a certain point, the host seedling has usually suffered enough physical injury or growth loss so that it is not saleable.

Roguing diseased individuals. Roguing involves prompt removal and destruction of the diseased seedling and associated materials, such as the growing medium or containers, that may also harbor inoculum. This practice will not save the original host seedling but will halt secondary spread (fig. 5.1.63). Most fungal diseases, including grey mold, sirococcus blight, and fusarium rot, are able to spread from seedling to seedling, particularly in the container nursery environment. Some insects, such as aphids, can build up high population levels on the original host and spread to adjacent seedlings. Effective roguing requires prompt disease identification, so growers need to make frequent surveys of the growing area and train workers to identify and report diseased seedlings.

Removing weeds*.* Besides being unsightly and spreading seeds within the growing area, weeds should be immediately controlled because they can serve as reservoirs for nursery pests such as aphids, spider mites, Fusarium spp., and Botrytis cinerea.

Chemotherapy: curing diseased seedlings with chemicals. Chemotherapy involves applying a pesticide to a diseased seedling to kill the pest without damaging the host. In general, this is much more difficult for pests such as fungi, weeds, and cryptogams (liverworts, moss, and algae) than for insects because the former are plants living in close association with the host plant; it is difficult to kill one plant without injuring the other. Also, most fungal pathogens exist partially or completely within the host plant tissue and are therefore difficult to reach with fungicides (Bohmont 1983).

Eradicants are fungicides that destroy pathogenic fungi after an infection has occurred. Protectant fungicides (see previous section) are ineffective once the pathogen has penetrated the host seedling (Smith 1982). Some eradicant fungicides are *systemics* because they are absorbed into the leaf tissue or roots and are physiologically transported throughout the plant, where they can attack the pest. Few commercial fungicides are true systemics, although benomyl and triadimefon are reported to have some systemic activity. Fungicides commonly used in container tree nurseries are listed in table 5.1.14.

Commercial fungicides differ in their effectiveness against fungal pathogens. Most chemicals (e.g., metalaxyl) are effective against one particular group of pathogens such as the water mold fungi (*Pythium* and *Phytophthora*) but provide no control of other fungal pests. Some fungicide formulations contain a mixture of two chemicals (e.g., Banrot®) and are used on a wide variety of fungal pathogens (table 5.1.15). A good discussion of common fungicides, their application rates, target pathogens, cost and other useful information can be found in the Ball Red Book (Ball 1985); McCain (1987), Smith (1982), and Hallett (1984) also present good discussions on fungicide use in container nurseries. Nursery managers should carefully check pesticide labels and consult with pesticide specialists to determine which pesticides should be applied against specific fungi.

Although most fungus control chemicals are advertised as fungicides (which kill fungi), many are actually *fungistats* (which inhibit the growth of the fungus). Baker (1985) states that fungicidal drenches such as PCNB or fenaminosulf will inhibit but not eliminate *Rhizoctonia, Pythium*, and *Phytophthora* and that frequent applications may be necessary to be effective. He also points out that fungistats suppress disease symptoms and merely postpone the problem until the seedling is transplanted or sold, at which time the fungus may become active again.

Chemotherapy is easier with insecticides and animal poisons that can be applied around the crop seedlings and eliminate the pest without phytotoxic effects on the host. Commonly used insecticides in container tree nurseries are listed in table 5.1.16. Hallett (1984) lists pesticides that are in operational use in container tree nurseries in the Maritime Provinces.

Disinfecting the growing area*.* Pest organisms should be eradicated from the growing area as soon as possible if the control treatments will not harm the crop seedlings. The best time to completely disinfect the growing area is between crops. (See section 5.1.7.2 for more discussion on this topic.)

Table 5.1.15—*Spectrum of effectiveness of some common fungicides used to control damping-off in container tree nurseries*

Active ingredient	Trade name	Pathogens affected			
		Pythium	*Phytophthora*	*Rhizoctonia*	*Fusarium*
etridiazole	Truban®	+	+	–	–
etridiazole + methyl thiophanate	Banrot®	+	+	+	+
metalaxyl	Subdue®/Ridomil®	+	+	–	–
benomyl	Benlate®	–	–	–	+

+ = effective control; – = no control

This listing does not constitute a recommendation: these specific products may not be currently registered. Other products may be available as well. Consult with a pesticide specialist and check label for information on registered uses and application rates.

Table 5.1.16—*Commonly used pesticides for control of insect pests of container tree seedlings*

Active ingredient	Trade name
Aphids (*Cinara* spp.) & adelgids (*Adelges* spp.)	
malathion	Malathion®
diazinon	Diazinon®
acephate	Orthene®
Cutworms (*Peridroma* spp. & *Euxoa* spp.)	
carbaryl	Sevin®
diazinon	Diazinon
chlorpyrifos	Lorsban®
Root weevils (*Otiorhynchus* spp.)	
endosulfan	Thiodan®
carbaryl	Sevin
carbofuran	Furadan®
European crane fly (*Tipula paludosa*)	
diazinon	Diazinon
endosulfan	Thiodan
acephate	Orthene
Dark-winged fungus gnats (*Bradysia* spp.)	
diazinon	Diazinon
malathion	Malathion
dimethoate	Cygon®

This listing does not constitute a recommendation: these specific products were reported in the Container Nursery Survey and may not be currently registered. Other products may be available as well. Consult with a pesticide specialist and check labels for information on registered uses and application rates.

Source: *Container Nursery* Survey.

5.1.7.5 Resistance: managing pests through genetics

The final phase of the disease management process involves the genetic selection of seedlings for immunity, resistance, or tolerance to disease. A plant is considered immune when it remains free of disease symptoms in the presence of a disease agent and predisposing environmental conditions. Resistance involves the inherent ability of a plant to restrict disease development after a pathogen has initiated an infection. Tolerance concerns the ability of a plant to remain relatively healthy in spite of an established disease (Smith 1970).

Breeding for resistance to specific pathogens is an established practice in horticulture and has been attempted successfully for some forest diseases such as white pine blister rust. Tree seedling nurseries in northern Idaho are growing western white pine seedlings from seed collected from parent trees that have been shown to be resistant to blister rust. It is probably not practical to genetically select seedlings to resist nursery diseases because many of these diseases are unique to the nursery environment. Many nursery diseases could be avoided, however, by selecting for rapid germination and early seedling growth.

5.1.8 Pesticide Use

Pesticides are an accepted part of nursery culture, but the nursery manager should be aware of proper application, storage, and disposal of these chemicals, which when used inappropriately can be hazardous to workers, the public, and the environment.

5.1.8.1 Legal implications

Pesticides are regulated by several federal and state laws. In the United States, the major federal legislation is the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) as amended, which is administered by the United States Environmental Protection Agency. Because pesticide laws are constantly changing, nursery managers should check the label for current application information and consult with pesticide specialists to make sure that they are operating within the current laws, policies, and regulations.

5.1.8.2 Application techniques

Pesticides can be applied in many different ways: dusts, aerosols ("smokes"), mists, granules, drenches, dips, baits, or liquid sprays. The choice of application method will depend on the type of pesticide, the characteristics of the target pest, the susceptibility of the crop seedlings to phytotoxicity, the environmental conditions, the equipment available, and the legal restrictions (Hanan and others 1978, Nelson 1978). In container tree nurseries, pesticides are applied as seed treatments before the growing season; as growing medium drenches, liquid sprays, or baits during the season; and as baits or aerosols during the seedling storage period.

New pesticide application technology is being studied in container nurseries (Lindquist 1986). Foam applicators add a foaming agent to the pesticide-water mixture to provide better coverage and less spray drift; they may also use less pesticide. Low-volume applications include thermal pulse-jet applicators, rotary atomizers, and electrostatic applicators. The latter devices place an electric charge on spray droplets as they are emitted, which potentially gives better coverage of lower leaf surfaces and less drift. Container nursery managers should stay abreast of the latest pesticide application technology.

Seed treatments. Pesticides such as captan and thiram are applied to seeds to control fungal diseases such as damping-off. The chemicals are usually applied to larger conifer seeds as a dust, or are pelleted on smaller seeds using a methyl cellulose or latex sticker. The amount of fungicide varies from 113 to 226 g (4 to 8 ounces) of 50% chemical per 0.45 kg (1 pound) of seed; approximately 57 g (2 ounces) of sticker is required to apply 113 g (4 ounces) of fungicide to 0.45 kg (1 pound) of conifer seed (Hanson and others 1961). The literature contains conflicting evidence on the benefits of chemical seed treatments, and because many of these pesticides have proven phytotoxic, growers should test any potential seed treatment (see section 5.1.5.3).

Growing medium drenches. The objective of a pesticide drench is to completely saturate the growing medium with a fungicide or insecticide, usually applying the chemical through the irrigation system. Drenches applied through the irrigation system require a substantial amount of pesticide because the solution is usually applied until some degree of leaching occurs. Because of the large amount of pesticide used, drenches are expensive and may be environmentally hazardous because of the surplus runoff. Fungicides such as fenaminosulf, benomyl, or PCNB are often applied as drenches for control of root-rotting fungi. Insecticide drenches are often used for control of root insects, including weevils and the European crane fly. Because of the heavy amounts of irrigation that are normally applied in container nurseries, drenches must be repeated at 6- to 8-week intervals to maintain the proper pesticide concentration in the growing medium solution (Nelson 1978).

Liquid sprays. Spraying is the most common pesticide application method used in container nurseries and numerous pesticides are formulated for mixing with water and spraying onto the plant. Emulsifiable concentrates (EC) are oily preparations with an emulsifying agent that keeps the liquid chemical suspended in the water solution. Wettable powders (WP) contain very small particles that must be suspended in the aqueous solution with constant agitation. WP formulations generally tend to be less phytotoxic than EC formulations of the same pesticide (Nelson 1978).

Because some seedling foliage is covered with a waxy cuticle that repels water, surfactants (also called wetting agents or spreaders) are often added to the pesticide solution to lower the surface tension of the liquid, thus increasing foliar coverage by the pesticide. Check the label because some pesticides already contain a surfactant; for example, there are EC formulations in which the emulsifying agent is itself a surfactant (Nelson 1978). Surfactants are commercially available, but because some are phytotoxic, they should all be tested for possible phytotoxicity before operational use. An excellent discussion of the properties of surfactants and a comparison of commercial brands is provided by Bohmont (1983).

Liquid sprays can be applied through the irrigation system or with hand or mobile tank sprayers. WP formulations should be premixed in a bucket to ensure that no solids plug the injector pump or spray nozzles (Nelson 1978). Pesticide sprays should be applied at high pressure to produce small droplets and force the chemical down into the seedling canopy. Some nurseries attach a bar in front of the spray boom to separate the seedlings and allow the pesticide to reach the lower shoot. Pesticides are usually applied late in the day, after a thorough irrigation, to allow the chemical maximum contact with the foliage. Many pesticide sprays are applied as protectants and so should be reapplied at regular intervals to ensure that new growth is covered and to replace chemicals that are washed off by irrigation. A good discussion of pesticide application equipment and methods is presented by Bohmont (1983).

Baits and aerosols. Pesticide baits are sometimes used to control rodents during the seed germination period and during sheltered storage. All poison baits should be placed in locations where they will be encountered by the pests but not by pets and other nontarget animals.

Aerosols are sometimes used to control botrytis storage mold in sheltered storage. Chlorothalonil is available in a formulation called Exotherm Termil® , which is used in enclosed storage buildings (Nelson 1978). Insecticidal aerosols can only be used in closed greenhouses.

5.1.8.3 Safe use of pesticides

All pesticides are poisons and should therefore be handled with caution; nursery managers must realize that any pesticide has both a benefit and an inherent danger (Powell 1984). Fungicides and herbicides are generally less hazardous to workers than insecticides. The relative toxicity rating of a pesticide is called the LD_{50}, which is the milligrams of the chemical required per kilogram of body weight to kill 50% of a test population. Pesticides are given three different ratings to cover the three major routes of accidental contact: oral, dermal, and inhalation. Hanan and others (1978) and Nelson (1978) list the LD_{50} ratings for the pesticides commonly used in container nurseries and give the following general rules for handling pesticides:

1. Purchase and use proper clothing and protective gear. Despite the discomfort in hot, humid greenhouses, insist that all employees wear protective clothing when handling, mixing, and applying pesticides. Employees should never work alone when applying pesticides.

2. Read the label and be sure you understand the information before using the chemical. The label contains information on toxicity, brand name, common and chemical names, ingredients, uses, and application instructions and rates. Safety precautions and antidotes will also be listed.

3. Choose a pesticide formulation that lowers worker exposure. The pesticide formulation affects ease of handling and worker exposure. Powell (1984) states that wettable powder formulations are particularly hazardous because of the fine dust that is produced during handling, and liquid formulations can splash. Flowable granules, water-dispersible granules, and dry applied granules or pellets present a lower exposure hazard.

4. Be particularly careful when mixing pesticides. Powell (1984) reports that over 90% of pesticide exposure cases are associated with the preparation and initial mixing operations. Protective clothing, including respirators, needs to be used during mixing operation as well as during application.

5. Use the proper equipment when applying pesticides. Spray nozzles should be selected for the specific purpose. For example, to apply a protective fungicide to seedling foliage, select a nozzle that produces a fine spray that covers the foliage, not one that mists or produces large droplets that splash.

6. Never smoke, drink, or eat in an area where pesticides are stored, mixed, or applied. Wash thoroughly after handling any chemical.

7. Be aware of the major symptoms of pesticide poisoning and the acceptable antidotes. Pesticide applicators should be trained in first aid, and emergency numbers including poison control centers should be posted close to the telephone. Report any incidents and adverse health effects immediately to the local safety officer.

The pesticide program should be assigned to one or two specially trained and certified applicators who are responsible employees (Nelson 1978); this is important, not just for safety, but for accurate recordkeeping. Although only specially trained personnel should be allowed to handle pesticides, all employees should be trained in pesticide safety and what to do in an emergency. Excellent reviews of the subject are provided by Singer (1980) and Bohmont (1983).

5.1.8.4 Pesticide storage

Pesticides should be stored in well-ventilated, locked closets or rooms that can be maintained between 4 to 32 °C (39 to 90 °F). The door should be clearly marked with a sign indicating that the room contains hazardous pesticides and it is a good idea to keep an up-to-date list of the contents posted as well (Nelson 1978). A fire extinguisher and a telephone with a list of emergency phone numbers should be readily available. Many government organizations have specific regulations for pesticide storage. Local fire departments should be notified of pesticide storage locations and potential hazards.

Pesticides should be stored in their original, labeled containers, never (even temporarily) in unmarked containers. Pesticide containers should be checked periodically for leakage. An up-to-date inventory should be kept on all stored chemicals that lists date of acquisition, time and amount of use, and current balance (Singer 1980).

All chemicals, including pesticides, have a recommended shelf life. Information provided by the manufacturers is helpful but is usually based on optimal storage conditions. The principal factors that can reduce shelf life are temperature, moisture, and light. Some pesticides can be ruined by freezing and others degrade when temperatures exceed 100 °C (212 °F). All pesticides should be kept in waterproof containers and should be stored on pallets to keep them from getting wet. Peck (1984) presents an excellent discussion on aspects of pesticide shelf life and storage, and lists the advertised shelf lives for many common pesticides that are used in forest tree nurseries.

5.1.8.5 Disposal of hazardous chemicals

Disposal of empty pesticide containers and surplus pesticides is regulated by law, and all waste pesticides should be considered hazardous to the public and the environment. Contact local authorities including extension agents or regional Environmental Protection Agency officials to determine the proper disposal method. Detailed instructions are provided by Bohmont (1983) and Singer (1980).

5.1.9 Conclusions and Recommendations

Diseases and pests are a source of continuing concern in container tree nursery management. Nursery managers must be able to identify major diseases and pests quickly and accurately, before they can inflict significant damage to the seedling crop. Although biological pests are always present, abiotic stress agents often cause more loss in container tree nurseries. Disease and pest problems are often more catastrophic in container nurseries because the ideal seedling growing environment also favors many pest organisms, and actively growing, succulent seedlings are more susceptible to abiotic stresses.

Disease diagnosis requires a certain degree of experience and training, and nursery workers should be trained to spot new diseases or pests quickly, as well as incidents of abiotic injury. Early detection should be encouraged through regular inspections of the crop, because most nursery diseases and pests become more difficult to eradicate once they have become established. All nursery workers should receive annual training in disease and pest identification and control; laborers who are in the growing area daily have the best chance to spot potential problems before they can intensify or spread. The damage keys and color photographs in this publication can be used to help identify common nursery diseases and pests. Although nursery managers should make tentative diagnoses of disease and pest problems, they should confirm their conclusions with a trained nursery pest specialist.

Nursery managers should adopt a philosophy of disease and pest *management* instead of *control*. By correctly identifying the disease or pest and understanding their life cycles, growers can use a variety of cultural and chemical measures to manage the problem and limit their losses. Chemical pesticides should be just one option in a comprehensive pest management program that integrates both chemical and cultural controls. This program should include the four necessary aspects of a complete pest management program: *exclusion*--preventing pest entry; *protection*--protecting seedlings from existing pests or abiotic stress factors; eradication-eliminating pests after disease establishment; and resistance-managing diseases and pests through genetics. Because container nurseries are initially free from disease and pest organisms, managers should put most of their efforts into preventing the damaging agents from gaining entry into the nursery. Environmental control systems should be regularly monitored to insure against malfunction, and cultural practices periodically reviewed and adjusted to minimize the development of harmful abiotic stresses.

5.1.10 References

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