CHAPTER THIRTY-THREE

Principles of Integrated Pest Management

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Most forest tree nurseries operating in the Northwest today consistently produce a profitable crop of high-quality trees. Successful nurseries integrate pest-management activities into the overall nursery operation. Four features of effective pest management are: 1) clear nursery goals, 2) a planned decision-making process, 3) realistic damage thresholds, and 4) a choice of responses.

Goals

Nursery goals should be clearly defined and comprehensive. Seedling quality, stock type, and quantity will be at the top of most lists of goals. Cost efficiency will also be a high priority. Issues of environmental and human safety must be addressed, as well as concerns about long-term productivity of the nursery soil. The specifics will vary between nurseries and sometimes between crops. Nevertheless, nursery goals provide the basis for good decision-making.

Nursery production is a carefully orchestrated process. Many pest-management measures are taken as part of the overall schedule of activities. Pest outbreaks are not always predictable, however, and advance planning can make the difference between a successful control operation that is consistent with overall nursery goals, and a hasty reaction that tries to solve an immediate problem only to create new ones later on.

The decision-making process

An important element in consistent pest control is the decision-making process: how the manager decides if a pest needs to be controlled, when to take action, and what methods to use. The process should be developed and made a part of the formal management policy so that it can survive personnel changes, and careful records should be kept so that methods of control can be evaluated or more-appropriate responses chosen in the future.

Pest-management decisions should be based on documented pest status, including historical occurrence, field monitoring data, and climatic or other predictive factors; the analysis of treatment options; and the potential of these elements to affect the nursery's goals. Such a process is illustrated in a flow chart (Figure 33-1) to help nursery managers arrive at sound decisions.

Damage thresholds

Pest management is enhanced when potential pests and options for managing them are identified before major losses occur. Nursery pests are always present, but as long as their numbers are low, damage is usually insignificant. Since all pest-management operations carry costs and risks, it is important to decide on realistic thresholds for pest populations and damage in order to guide effective treatment.

A choice of responses

Many pest problems can be prevented by careful planning or stopped when detected early. Preplanned options afford a reasoned selection of appropriate pest-management tools that are consistent with the nursery's goals. Most pest problems can be addressed by a range of cultural, chemical, and biological control tactics.

These four features of successful nursery pest management—clear goals, planned decision-making, realistic damage tolerances, and a choice of appropriate responses—together with systematic monitoring and evaluation, are the components of Integrated Pest Management (IPM). IPM is nothing more than a common-sense, systematic approach to problem-solving in the nursery. The following sections describe procedures to monitor various pests and discuss the range of available pest-management tools.

Monitoring of pests

Pest and damage monitoring provides both early warning of pest problems and a measure of the efficacy of control actions. Data accumulated systematically over several years can be the basis for predicting the impact of damage from pests and for setting thresholds of acceptable damage. Monitoring can consist of tracking the damage caused by the pest, the actual pest population, or a combination of both.

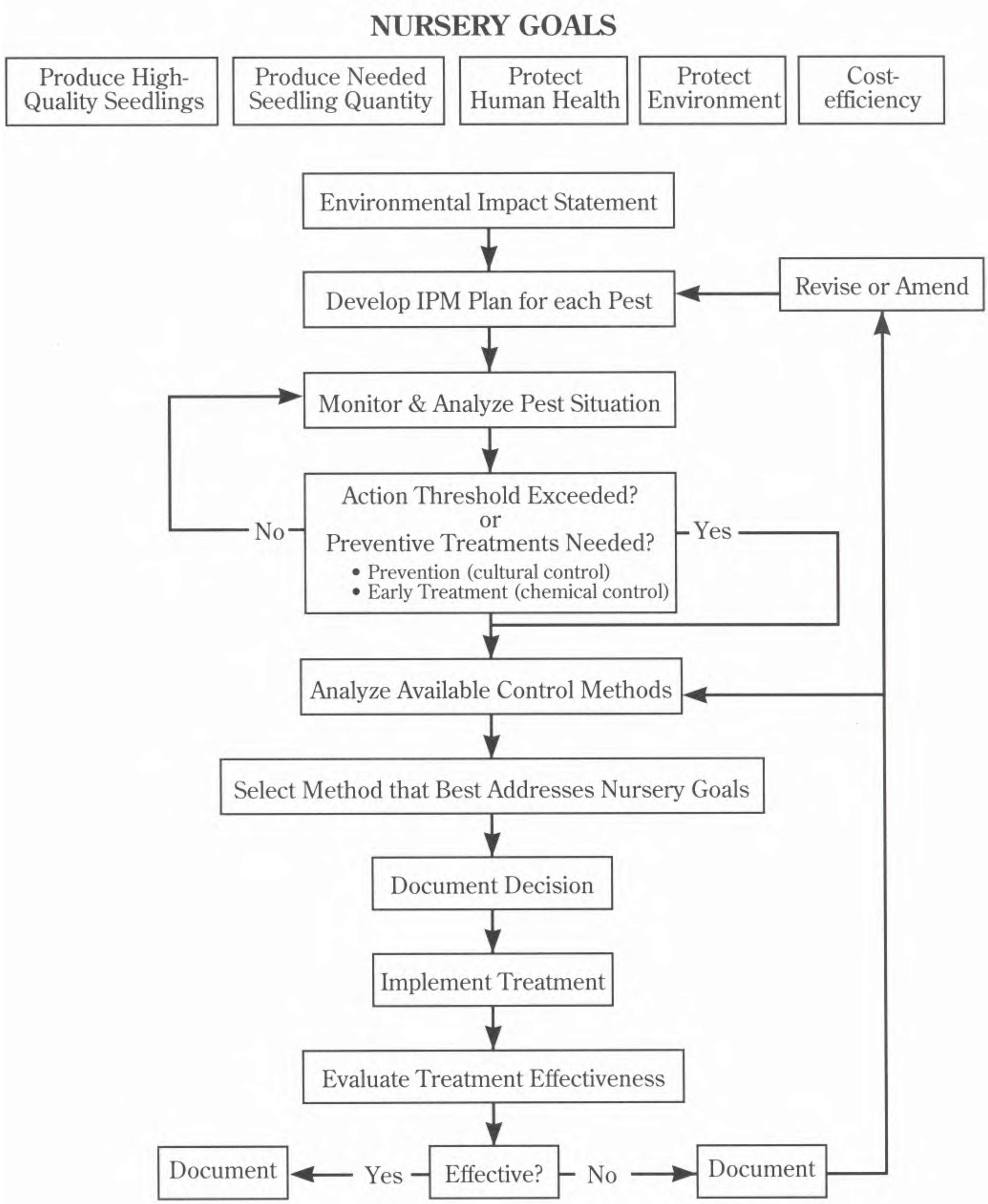

Figure 33-1. A flow chart to guide pest management decisions toward nursery goals. Taken from the Final Environmental Impact Statement, U.S. Department of Agriculture, Forest Service, Nursery Pest Management, Pacific Northwest Region, October 1989.

A good damage-monitoring program requires people trained to recognize early symptoms of trouble. It should also include systematic field-survey, record-keeping, and evaluation procedures. The program should cover all parts of the nursery regularly, with more-frequent attention given to areas with chronic problems and beds where particularly susceptible tree species are grown.

Knowing when and where to look and what to look for is critical to a successful program. Expert diagnostic help is available (see Introduction) but consistent success will depend on skilled nursery personnel. Private consultants can be hired to take over all or part of the process.

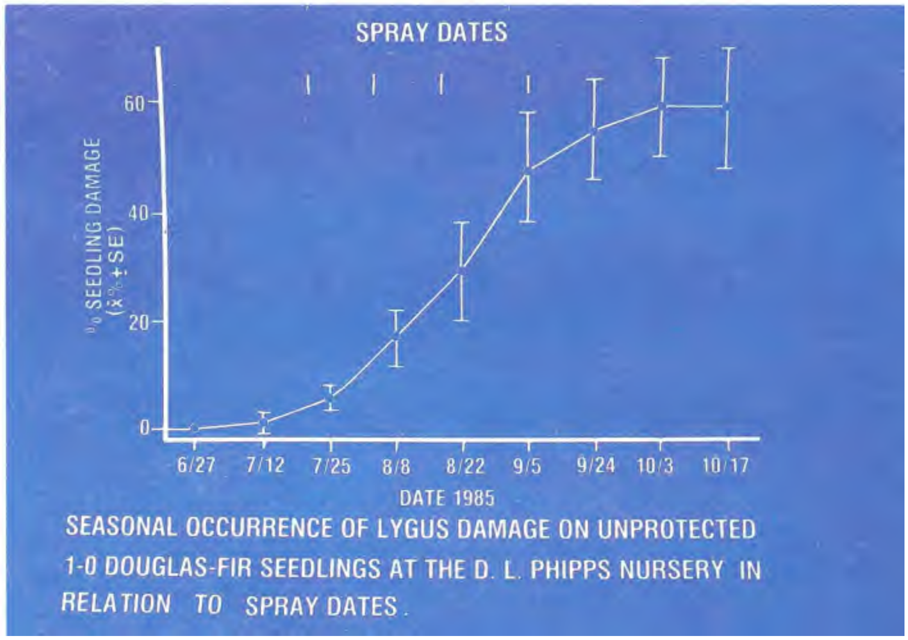

Figure 33-2. Cranberry girdler trap catch data for 2 years in a Pacific Northwest nursery. This information reflects moth abundance and defines the period for effective insecticide applications. Weyerhaeuser Co. photo.

INSECTS

In the Pacific Northwest, most detection surveys for insect problems should be conducted between May and September, when insects are most abundant and active. This handbook gives general guidelines on when to look for insect activity. However, the onset of problems from a given insect typically varies by several weeks over large geographic areas.

Foliage-feeding insects such as cutworms and lygus bugs are best detected by their damage. Sweep nets can also be used to gather insects from seedling foliage. The onset of lygus bug damage symptoms in 1+0 Douglas-fir can be used to time insecticide applications.

It is generally not feasible to monitor directly for root- and stem-feeding larvae such as white grubs, root weevils, or cranberry girdlers because numbers are low and populations are scattered. Often the first indication of root damage is the death of seedlings during the fall and winter months. Although cranberry girdler larvae are difficult to monitor, the pest can be trapped in the moth stage and moth populations assessed as an indicator of future damage by larvae (Figure 33-2).

NEMATODES AND FUNGI

Diseases caused by soilborne fungi and nematodes can be monitored by looking for typical damage on the seedling or by assaying the soil for the pest. Diseases such as gray mold, caused by fungi that are not soilborne, are usually monitored by observing the damage or signs of the pest on aboveground parts of the seedling.

Soil assay services may be employed to determine populations of nematodes and of the pathogenic soilborne fungi *Pythium*, *Fusarium*, and *Macrophomina.* Reliable assay results depend on an adequate sampling strategy and careful handling of samples.

A soil sampling tube is the quickest, easiest, and most reliable tool for collecting samples (Figure 33-3). The soil should be moist but not saturated. Soil cores should be taken to a depth of 12 inches. The sample that is submitted for analysis should be made up of a number of subsamples and should represent a single soil type and crop history collected from no more than one-eighth of an acre. Generally, the greater the number of subsamples, the more accurate the results. Subsamples should be thoroughly mixed in a clean container, then 1/2 liter (1 pint) of the mixture transferred into a plastic bag. Always pack soil bags in boxes before shipping them to the laboratory.

Improper handling of samples kills nematodes and fungi and will yield an inaccurate analysis. Do not leave samples in direct sunlight, in the trunk of a car, in the back of pickup, or in a freezer. While samples may be stored at 10-14 degrees C (50-58 degrees F) for a short time, or even longer at cooler temperatures, they should be sent in for analysis as quickly as possible.

Nematodes—An assay for nematodes will help both in diagnosis of current problems and prediction of future problems. Comparative samples must be collected from healthy and symptomatic areas. Both the soil and the roots of live symptomatic seedlings should be sampled. Dead seedlings should not be included in the sample because nematode populations will have declined due to the lack of food. If nematode numbers prove to be several times higher in the sympto-

Figure 33-3. Collecting soli for laboratory assay.

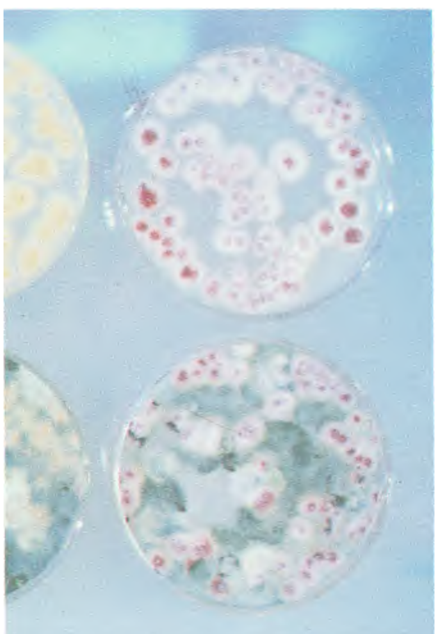

Figure 33-4. Counting *Fusarium* colonies, like these, determines the number of fungal propagules present in a soil sample.

matic area than in the healthy area, nematodes are the likely cause of the poor growth. If the populations are high in both areas, nematodes may still be involved as secondary agents and nematode control should be considered. Because nematode damage generally occurs in proportion to population, nematode assays are also useful for predicting future losses. However, since numbers are usually low in nurseries that fumigate regularly, predictive sampling may not be routinely needed.

Soil fungi—Samples collected for nematode assays may also be used to assay for soil fungi. Populations of *Pythium*, *Fusarium*, and *Macrophomina* can be determined by dilution-plate assays (Figure 33-4). As with nematode assays, information about soil fungi can provide a useful measure of current conditions and a gross indicator of future problems. Soil-fungi assays can determine the effectiveness of fumigation and may help diagnose damping-off problems in the early stages, thus allowing timely and specific response with fungicides. However, because fungal populations vary widely over short distances, because actual damage to seedlings requires both the presence of the fungus and specific environmental conditions which are poorly understood, and because pathogenicity of propagules is not known, it has not been possible to predict future disease losses reliably from soil-assay data. As more nurseries keep careful records, we will be better able to use soil assays to help manage certain pest problems.

Pest management

This section discusses the general methods for pest management: cultural, chemical, and biological control. Cultural control refers to the routine nursery operations that help reduce losses to pests. Chemical control involves the application of pesticides to the soil, seeds, or seedlings to reduce pest damage. Biological control involves the use of living organisms, generally predaceous insects or nonpathogenic fungi or bacteria, to manage pest populations. Few artificially introduced biocontrol agents are available for control of nursery pests in bare-root nurseries in the Northwest.

CULTURAL CONTROL

Cultural control of nursery pests provides the first and often the most effective defense. Both fungal and insect pests of nursery crops have critical environmental and nutritional requirements for feeding, reproduction, and infection of the host. Nursery cultural practices can modify these conditions to the disadvantage of the pest. Cultural control can limit pest populations or damage directly, by removing or suppressing the pest, or indirectly, by altering its environment or food supply. Five categories of cultural control will be considered: 1) soil management, 2) water management, 3) practices affecting seedling growth, 4) sanitation, and 5) growing resistant seedlings.

Soil management—Physical, chemical, and biological properties of nursery soil are critical to seedling health. Well-drained soils allow free root growth and limit opportunities for the water molds *(Pythium* and *Phytophthora)* to increase to damaging levels. Any place that collects standing water during heavy rains or irrigation is a potential trouble spot. It is often necessary to crown the fields and install underground drainage lines. Raised beds are usually beneficial as well. Soil compaction causes or aggravates many water problems. Minimizing equipment use, especially on wet soils, reduces compaction, and deep ripping can restore drainage in compacted soils. It may be necessary to stop using chronic wet spots for nursery production.

Organic matter in the soil is important for soil tilth and as a food source for microorganisms, both beneficial and damaging. Recent experiments show that most cover crops encourage soil pathogen populations, especially in unfumigated fields (Figure 33-5). In these experiments, no cover crop at all (bare fallow) gave the best subsequent conifer crop. Sudan grass harbored higher pathogen levels than bare fallow and resulted in increased seedling mortality. Legume cover crops (beans or peas) were most detrimental to the health of the subsequent seedling crop (Figure 33-6).

Other work, however, suggests that certain *Brassica* cover crops may reduce *Fusarium* and *Pythium* populations. Sawdust amendments have been effective in controlling seedling diseases in both eastside and westside nurseries. As yet there are no universal recommendations on the use of organic matter. However, it is clear that nursery managers should critically evaluate the addition of any cover crop or soil amendment.

Water management—Water is widely used as a cultural tool to limit problems caused by high summer temperatures and by freezing temperatures in late fall or early spring. Too much water, however, saturates soils, which denies oxygen to roots and allows soilborne fungi to reproduce and spread. Water on foliage for extend periods of time allows stem and needle pathogens such as gray mold to germinate and cause infection, and excessive irrigation washes off protective fungicides.

The art of water management starts with good soil drainage (Figure 33-7). Irrigation needs should be coordinated with summer cooling requirements and pesticide application schedules. Both the total amount of water applied, and the frequency and duration of the times the foliage is wet, should be kept to a minimum. Paying attention to details like leaking sprinkler heads will reduce *Phytophthora* problems.

Figure 33-5. Cover crops, such as sudan grass, are commonly grown in the fallow year between seedling crops in Pacific Northwest nurseries.

Figure 33-6. ***Fusarium*** **growing on cover crop residue. Recent work at Oregon State University found higher soil populations of** ***Fusarium*** **and** ***Pythium*** **under cover crops than in fallow soil.**

Seedling growth–Growers routinely modify seedling development to meet certain physiological and morphological standards. These manipulations can also affect seedling health. Growers regularly adjust the sowing rate to compensate for seedlots that germinate poorly. It is tempting to oversow (sow additional seed per square foot) to compensate for anticipated mortality from damping-off and Fusarium hypocotyl rot. But this is a questionable practice; disease is seldom uniformly distributed in

Figure 33-7. Water management is sometimes difficult in Pacific Northwest nurseries because of high rainfall and heavy soils. Tiling areas prior to sowing helps ensure good drainage.

Figure 33-8. Washing equipment helps to restrict movement of soilborne pathogens between blocks.

beds, and sowing too densely can result in increased losses to damping-off. The likely consequence of oversowing is poorly stocked patches of diseased seedlings interspersed among overstocked areas. High bed density creates a moist microclimate that favors stem and foliage fungi and makes it difficult to get good fungicide coverage. Oversowing also wastes valuable seed and increases the likelihood that seedlings will be culled because they are too small. Compensating for disease losses can be done by sowing additional bed feet at the same density, thus avoiding the problems of high seedbed densities.

Nitrogen fertilizers added early in the first growing season increase losses to damping-off and Fusarium hypocotyl rot. In soil of normal fertility, seedlings do not need supplemental nitrogen at this time.

Fertilization and irrigation are usually reduced to halt seedling growth before fall rains. Seedlings still growing into the fall are more vulnerable to upper stem canker and injury from early frosts. Root culture (pruning and wrenching) and top pruning are commonly practiced to curb and redirect seedling growth. These practices do not seem to affect pest development directly, although the clipped tops can support high gray mold populations.

Sanitation—Good nursery sanitation removes sources of possible infestation and checks the spread of many pests. Field equipment should be clean before it enters the nursery (Figure 33-8). It should be cleaned every time it is moved into a new field—particularly if into a fumigated field. Avoid moving transplant stock between or within nurseries since most soilborne fungi and insect pests can be spread this way.

Weed control is an important part of sanitation; weeds within the beds and in surrounding fields may harbor damaging insects. Similarly, hedgerow or windbreak trees may harbor pests that can damage nursery seedlings. Species for hedgerows and windbreaks should be selected to avoid those that are hosts for nursery seedling pests.

Seedings with minor root infections are difficult to distinguish from healthy seedlings during grading. Mark infected areas before lifting and lift and destroy after crop seedlings have been harvested. Seedlings that are culled because of pest damage should be disposed of outside the nursery to prevent reintroduction of the pest into the nursery environment (Figure 33-9). Take care to avoid the contamination of healthy stock at lifting.

Table 33-1. Commonly used fumigants for control of various soilborne diseases.

DISEASE	FUMIGANT
Charcoal root disease	methyl bromide + chloropicrin (67% + 33%)
Damping-off	dazomet, methyl bromide + chloropicrin (67% + 33%), vorlex
Fusarium hypocotyl rot	dazomet, methyl bromide + chloropicrin (67% + 33%)
Fusarium root rot	dazomet, methyl bromide + chloropicrin (67% + 33%)
Phytophthora root rot	dazomet, metam-sodium, methyl bromide + chloropicrin (67% + 33%)

Resistant seedlings—Cultural control of some pests can also be obtained by growing seedlings that are less susceptible or even immune to damage. True fir species should not be grown in areas where *Phytophthora* has caused damage. Instead, sow or transplant resistant species such as western redcedar, pine, spruce, or larch. Likewise, if larch needle cast is a problem because of infected mature larch trees surrounding the nursery, consider contracting with another nursery with lower hazard to grow this species.

It is difficult to summarize the strategies for cultural control of nursery pests. Perhaps the best general idea to remember is that every nursery practice has a potential positive or negative impact on pests. Knowledge and careful use of cultural practices can help take advantage of the beneficial aspects and decrease the negative ones.

Figure 33-9. **Cull seedlings should be disposed of well away from nursery beds.**

CHEMICAL CONTROL

Chemical control has been used for many years in forest nurseries. Pesticides can be classified into several categories depending on their target: soil fumigants, fungicides, nematicides, and insecticides. While specific products are mentioned in the following discussion, our purpose is not to make specific recommendations but rather to provide general information on why, how and when to use nursery pesticides.

Fumigants—Soil fumigation is probably the most widely practiced chemical pest management technique in bareroot nurseries. Fumigation reduces losses to many soilborne diseases in the Pacific Northwest (Table 33-1). Fumigants kill weeds and weed seed, nematodes, soil insects, and pathogenic fungi. Crops grown in fumigated soil are regularly more vigorous and more uniform than crops from unfumigated beds. On the negative side, fumigants are expensive and extremely toxic to all living organisms. They are completely nonspecific in their action and kill beneficial microorganisms in the soil as well as pathogens.

The most commonly used soil fumigants in the Pacific Northwest are dazomet and methyl bromide plus chloropicrin. Methyl bromide is a colorless and odorless gas. Chloropicrin is added and the mixture is injected in the soil and confined by a plastic tarp (Figure 33-10). Dazomet is a dry, micro-granular material that is incorporated into the soil by tilling or disking, and then sealed by rolling or watering the soil or placing a tarp over it (Figure 33-11).

Table 33-2. Commonly used fungicides for control of various nursery diseases.

DISEASE	FUNGICIDE
Damping-off	benomyl, captan, ethazole, metalaxyl
Douglas-fir needle rust	chlorothalonil, mancozeb, maneb
Fusarium hypocotyl rot	benomyl, Banrot
Fusarium root necrosis	none
Gray mold	benomyl, captan, chlorothalonil, dichloran, vinclozolin
Larch needle cast	benomyl, chlorothalonil, maneb
Lophodermium needle cast	chlorothalonil, mancozeb, maneb
Lower stem canker	none
Phoma blight	chlorothalonil
Phomopsis canker	benomyl, chlorothalonil
Phytophthora root rot	metalaxyl
Seed fungi	captan, thiram
Sirococcus tip blight	chlorothalonil, triadimefon
Tip blight of pine	chlorothalonil
Upper stem canker	benomyl, chlorothalonil
Western gall rust	none

The chemicals are most effective in warm and moist but not water-logged soils.' Soils should be thoroughly moistened 10 to 14 days before fumigation to allow fungal propagules, weed seeds, and insect resting stages to imbibe water and begin to germinate or grow. These active stages are much more sensitive to the fumigant than the dormant stages.

The fumigant must be allowed to dissipate completely before a crop is sown. For this reason fumigation is usually done early in the fall of the year before sowing. If dazomet is applied in the spring, a bioassay must be done before planting to ensure that residual fumigant is no longer present in the soil (Figure 33-12).

Fungicides—Several seedling diseases are readily controlled by fungicides. These chemicals are most often applied as foliar sprays but may also be used as seed treatments and soil drenches (Figure 33-13). Table 33-2 lists the most commonly used fungicides in the Pacific Northwest and the diseases they control.

Understanding fungicide action can help when planning treatments for specific diseases. Most fungicides must directly contact the target fungus or the target tissue to be effective. Foliar sprays should coat exposed seedling parts with the chemical. If applied before infection occurs, they will kill germinating spores. Fungi that attack roots or stems beneath built-up soil collars are beyond the reach of contact fungicides. Some chemicals can also be applied as soil drenches, but their effectiveness is often reduced because they are inefficient in treating large volumes of soil. Most chemicals are inactivated rapidly in the soil by microbial action or are immobilized by binding to organic matter or clay particles.

Applying fungicides directly to seed before sowing is seldom a good strategy for protecting against pre-emergence damping-off and seed rot.

Many fungicides are toxic to germinating seeds and reduce the germination and growth of seedlings.

A few fungicides are absorbed by seedlings through roots or leaves and are translocated throughout the seedling. These systemic chemicals can stop established infections, and they often remain active longer than contact fungicides. In most cases, however, systemic fungicides cannot eradicate an established fungus; when treatment stops, the fungus may become active again.

The use of fungicides could be dramatically reduced in most nurseries in most years without any measurable effect on seedling health. The price of unnecessary chemical use includes risk of fungal tolerance to the fungicide, disruption of natural microbial balances, increased speed of environmental degradation, and adverse effects on human health.

Ironically, frequent use of some of the most effective chemicals, such as the systemic fungicides benomyl and metalaxyl, results in the development of tolerant strains of fungi. This is due to these chemicals' mode of action. In some nurseries where benomyl was used frequently and exclusively, tolerant strains of gray mold arose and predominated. Treatment that involves alternating among two or three different fungicides or mixing several fungicides in one application will delay the buildup of tolerant strains.

Here are some guidelines to help growers use fungicides properly:

1. Accurately diagnose the problem and determine if pest populations or environmental conditions are such that unacceptable damage will result.

2. Determine the most effective control measure, considering the use of a combination of methods (for example, chemical and non-chemical).

3. Use fungicides prudently, and only when other methods are inadequate.

Figure 33-10. Methyl bromide-chloropicrin fumigation is commonly used to decrease populations of nursery pests in the soil. Chemical is injected into the soil and then a tarp is laid to trap the gas.

Figure 33-11. Fumigation using dazomet. The microgranular material is tilled in and then the soil surface is sealed with water.

Figure 33-12. Fumigated soil should be tested for pesticide residue before sowing. Radish seed will not grow in soil containing residual fumigant.

Figure 33-13. Spraying pesticides on 1+0 seedlings is a common practice of disease control.

4. Select the appropriate fungicide, considering not only pest-control effectiveness but the effect of the fungicide on human health and the environment.

5. Use only fungicides registered for specific diseases on specific hosts.

6. Apply fungicides at the lowest possible dosage that will achieve disease control. Never exceed label rates.

7. Apply fungicides at the proper time and to the proper part of the seedling to control specific pathogens.

If fungicide treatment does not work as well as expected, one of several things may be wrong: the disease may have been misdiagnosed (perhaps it is caused by abiotic factors); there may be too much pathogen inoculum present; the fungicide may not be reaching the site of pathogen activity; the fungicide may have been applied too late, after infection had already occurred; resident pathogen populations may have acquired resistance to the chemical used.

Insecticides—Table 33-3 lists the insecticides commonly used in Pacific Northwest nurseries. Like fungicides, they are probably applied more frequently than is necessary. The most important aspect of successful use is timing the application to coincide with a vulnerable life stage of the insect. Nurseries with good monitoring programs generally prevent insect damage most successfully, and do so with fewer applications of chemicals. On the other hand, if insecticides are not used until widespread crop damage is apparent, the opportunity to halt the epidemic with insecticides has usually passed. This is particularly true with larvae that feed beneath the soil; they must be controlled with sprays timed to catch the adults in their flight period, before they lay eggs. Sometimes sprays can be fine-tuned to the diurnal activity of the

Table 33-3. Commonly used insecticides for control of various nursery insect pests.

INSECTS	INSECTICIDES
Cooley spruce gall adelgid	carbaryl, endosulfan
Cranberry girdler	chlorpyrifos, diazinon
Cutworms	diazinon, esfenvalerate[1]
Grasshopper	carbaryl, diazinon
June beetle (white grubs)	dazomet, methyl bromide + chloropicrin (67% + 33%) (fumigants)
Leafrollers	acephate, diazinon
Lygus bugs	acephate, esfenvalerate[1]
Pine bark aphid	endosulfan
Root weevils	bendiocarb, orthene
Seedcorn maggot	chlorpyrifos, diazinon

[1]The insecticide fenvalerate has been replaced by esfenvalerate, a chemical with similar properties.

target pest.

Insecticide efficacy can be improved by continuing to monitor beds for insects and damage after treatment. The presence of target insects or seedling damage despite treatment may indicate the use of the wrong insecticide or improper timing or mixing of insecticides. Some nurseries have designated small check areas to evaluate insecticide applications. Periodic reviews of application records and data on pest damage are also useful.

Seedlings can be damaged if insecticides are improperly mixed or applied. Germinants and succulent 1+0 stock are particularly susceptible to phytotoxicity. Spraying in the cool of the morning and using wettable powders instead of emulsifiable concentrates can reduce the risk to sensitive stock. Tank mixing of insecticides with other chemicals should be done cautiously because of the potential for phytotoxic effects.

Nematicides—Nematodes seldom cause measurable losses in Pacific Northwest nurseries because the soil is regularly fumigated. Nematicides are therefore rarely used. Nematode populations, however, can increase and cause losses in transplant beds, particularly 1+1 or plug+1, if the beds have gone several years without fumigation. Soil nematode assays and regular monitoring of damage can identify potential trouble spots. The nematicides fenamphos, oxamyl, and dichloropropene are registered for use. The first two chemicals, which are applied after planting, have been tested and found effective for controlling nematodes on conifers in the Pacific Northwest. Dichloropropene is a soil fumigant used before sowing. It is intended primarily to control nematodes, but when chloropicrin is added it affords some control over soilborne fungi as well.

BIOLOGICAL CONTROL

Biological control consists of a relatively new and mostly untried set of strategies for controlling plant pests in forest nurseries. A biological control organism generally is a naturally occurring insect, fungus, or bacterium that either harms plant pests or benefits the host.

Predatory insects, as the name implies, lower the pest insect population directly by feeding on the pest. An example of this kind of biological control organism—one that nurseries have been using for some time—is ladybugs that feed on adelgids. Some fungi and bacteria produce toxins or antibiotics that inhibit growth of pathogenic organisms. Other beneficial microorganisms produce chemicals that increase seedling growth and thus reduce pest damage. Several such biological control agents are currently being investigated in the hope of using them to provide protection in the future.

Biological control has at least two potential advantages over chemical control. First, a biological control organism may grow and reproduce on the seedling; the population of a single application may protect the plant throughout the period of susceptibility. This contrasts with the need to spray certain pesticides several times to obtain good disease control. Secondly, most biological agents pose little or no threat to workers or the environment. Thus they can safely be applied several times if necessary.

Developing a biological control agent for bareroot nurseries is a difficult undertaking at best. The organism used has to be able to survive and grow in competition with all the many other organisms found on seedlings and in nursery soil. Thus, it is more difficult to develop a biological control that would be useful in outdoor, field situations than it is to develop one to control pests in indoor container nurseries.

Pest management checklist

The following checklist can help nurseries reduce losses from pests. If nursery managers monitor effectively, keep good records, and follow this checklist, they should be able to achieve a comprehensive, cost-effective pest control program without compromising the environment, the safety of the workplace, or the quality and quantity of seedlings.

BEFORE SOWING

Soil management

- Are drainage problems corrected?
- Is a cover crop necessary?
- Are organic amendments necessary?
- If sawdust is added, is it free of pests and other contaminants?
- Is supplemental nitrogen needed to grow cover crop and to break down organic matter?
- Are beds raised in preparation for sowing?

Fumigation

- Is fumigation necessary?
- Should it be done in fall or spring?
- Which chemical should be used?
- Has adequate moisture been maintained 10-14 days before fumigation?
- Are soil moisture and temperature favorable?

Pest monitoring

- Have pre- and post-fumigation *Fusarium* assays been done to test effectiveness of fumigation?
- Has an assay for seed fungi been done in selected seedlots?

Seed

- Have precautions been taken to assure clean seed?
- Have special protective measures been taken for seedlots with low vigor or high fungal populations?

Sanitation

- Is equipment cleaned before working fumigated beds?
- Is a clean water supply assured?
- Have sources of pathogenic fungi in surrounding windbreaks or cull piles been removed?

1+0 YEAR

Pest monitoring

- Have damage surveys been taken at appropriate times for damping-off, Fusarium hypocotyl rot and root rot, cutworms, and upper stem canker?
- Has timely pest monitoring been done for lygus bugs and other insects and diseases of 1+0 seedlings?

Direct control

- Based on history and current monitoring results, is pesticide application necessary for damp ing-off, insect pests, or upper stem canker?

Cultural practices

- Have irrigation requirements been coordinated for growth, cooling, and frost protection to avoid excessive water use?
- Are fertilization and irrigation coordinated to stop seedling growth before fall rains?
- Is mulching necessary to protect against lower stem canker and Phoma blight?
- Is ripping necessary to improve winter drainage?

Sanitation

- Is equipment regularly washed as it is moved between fields?
- Are weeds controlled to deny refuge to damaging insects?

2+0 YEAR

Pest monitoring

- Are timely damage surveys planned for Phytophthora root rot and gray mold?
- Are timely pest surveys planned for lygus bugs and cranberry girdler moths?

Direct control

- Based on history and current monitoring results, is pesticide use warranted for control of *Phytophthora*, lygus bugs, gray mold, or cranberry girdlers?

Cultural practices

- Have irrigation requirements been coordinated for growth, cooling, and frost protection to avoid excessive water use?
- Are fertilization and irrigation coordinated to stop seedling growth before fall rains?
- Is ripping necessary to improve winter drainage?
- Will top pruning cause gray mold problems?

Sanitation

- Is equipment regularly washed as it is moved between fields?
- Are weeds controlled to deny refuge to damaging insects?

TRANSPLANTS

Pest monitoring

- Has transplant stock been checked for pests?
- Is *Phytophthora* a likely problem?
- Is a nematode assay warranted?

Direct control

Based on nursery history, monitoring, and source of transplants, is pesticide application necessary to control *Phytophthora,* nematodes, or other pests?

Cultural practices

Is drainage corrected before transplanting?

Are beds raised?

Has care been taken to avoid overwatering or underwatering while transplants are getting established?

Sanitation

Is equipment regularly washed as it is moved between fields?

Are weeds controlled to deny refuge to damaging insects?

LIFTING AND STORAGE

Pest monitoring

Have seedlings with *Phytophthora* infection been identified?

Has gray mold been controlled prior to lifting?

Are storage containers monitored for mold development?

Direct control

Are fungicide treatments warranted before seedlings go into storage?

Cultural practices

Are plans made to keep seedlings clean, cool, and moist during lifting and sorting?

Do storage facilities have an adequate temperature monitoring, alarm, and recording system?

Are cooling facilities adequate to promptly establish and maintain target temperatures inside storage containers?

Sanitation

Are *Phytophthora-infected* seedlings lifted, sorted, and stored separately from healthy trees?

Are culls safely disposed of outside the nursery?

Is seedling foliage generally free of soil going into storage?

Are moldy seedlings removed from storage and disposed of, or outplanted as soon as possible if mold is superficial?

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