Integrated Pest Management

Second Edition

Best Management Practices

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INTEGRATED PEST MANAGEMENT
Second Edition 2016

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Purpose

The International Society of Arboriculture (ISA) has developed a series of Best Management Practices (BMPs) for the purpose of interpreting tree care standards and providing guidelines of practice for arborists, tree workers, and the people who employ their services.

These Best Management Practices include a succinct overview of the basic definitions, concepts, and practices that pertain to Integrated Pest Management (IPM). They are intended as recommendations for designing, planning, and implementing an IPM program as part of a comprehensive Plant Health Care (PHC) management system.

Because trees are unique living organisms, not all practices can be applied to all trees. A qualified arborist should write or review contracts and specifications using national standards and this BMP. Departures from the standards should be made with careful consideration of the objectives and with supporting rationale.

Introduction

Arboriculture is founded on the principles of Plant Health Care (PHC), which is defined as a comprehensive system for managing the appearance, structure, and vitality of ornamental landscapes within client expectations. PHC is a proactive, holistic management system that encompasses all aspects of landscape stewardship: site evaluation and preparation; plant selection, establishment, and cultivation; pest control; and plant utilization and removal.

PHC recognizes that trees and woody plants are part of a greater landscape ecosystem that includes turf grasses as well as annual and perennial herbaceous plants. These vegetative components interact with one another on multiple ecological levels through competition, allelopathy, nutrient cycling, microclimate alteration, and pest dynamics. To create sustainable landscapes, arborists and landscape managers must understand these interactions and adopt a landscape ecosystem approach in their PHC practices. Woody plants should not be managed in isolation from other vegetative and non-vegetation components; the impact of management actions on the entire landscape ecosystem should always be considered.

An essential component of PHC is pest management. Pests frequently threaten the health, structure, appearance, or value of landscape plants. For most of the 20th century, landscape pest management had a single dimension: chemical control. Beginning in the 1970s, a multidimensional approach to landscape pest management, called integrated pest management (IPM), evolved to address the ecological, social, and economic implications of overreliance on chemical pest control. Today, PHC embraces IPM as the preferred approach to managing landscape pests.

I. Definitions

Landscape Pest

A landscape pest is as a living organism—vertebrate, invertebrate, microbe, or undesirable plant—that interferes with or threatens the appearance, structure, or vitality of a desirable plant.

Landscape pests belong to several major groups of organisms (Figure 1):

- Vertebrates (e.g., rodents, rabbits, deer, birds, and reptiles)
- Insects and other arthropods (e.g., mites, ticks, and spiders)
- Mollusks (e.g., snails and slugs)
- Microorganisms (e.g., fungi, bacteria, viruses, phytoplasma-like organisms (PLOs), and nematodes)
- Weeds, vines, parasitic plants (e.g., mistletoes and dodder), and epiphytic plants (e.g., ball and Spanish moss)

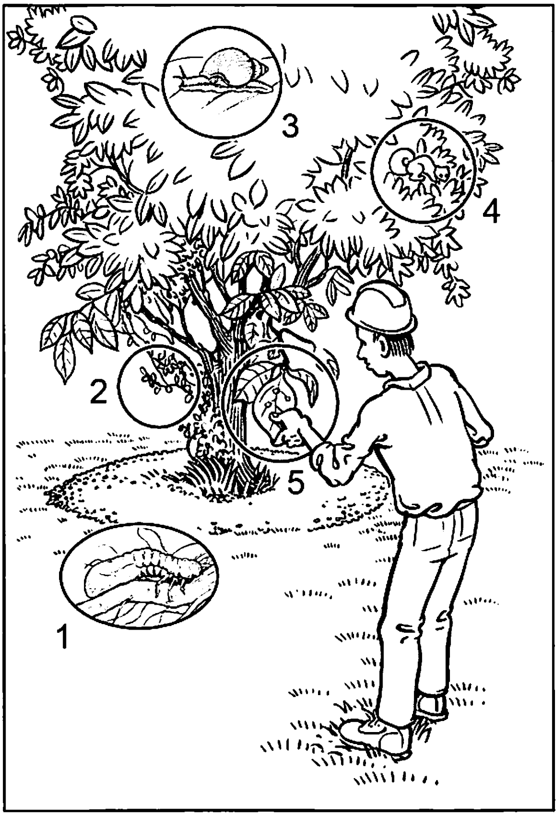

Figure 1. Landscape pests belong to several major groups of organisms including (1) insects and other arthropods, (2) undesirable plants, (3) mollusks, (4) vertebrates, and (5) microorganisms.

Most organisms found in the landscape are not pests. In fact, many organisms make positive contributions to the landscape by suppressing pest populations, facilitating organic matter cycling, increasing biodiversity, and enhancing amenity and recreation. Because clients may believe all insects and mites are harmful to landscape plants, many landscapes are managed with routine applications of broad-spectrum insecticides. This approach is detrimental because beneficial organisms are destroyed along with pests, which disrupts the landscape ecosystem and can result in secondary outbreaks of pests.

An organism may be a pest in some circumstances while not in others. In addition, the mere presence of a pest may not necessarily warrant control. The task of the landscape manager is to determine whether an organism is a pest and, if so, whether control is warranted, and what tactics should be used.

An organism may be considered a pest not because of the damage it does to the plant, but because it or a by-product of its activity becomes a nuisance. For example, many insects excrete a sugary substance (honeydew) while feeding on plant sap, which can then fall on patios, chairs, automobiles, and other surfaces, causing damage or limiting people's enjoyment of outdoor activities.

Integrated Pest Management (IPM)

Landscape IPM is a method for managing pests that combines appropriate preventive and therapeutic tactics into a single management strategy. Depending on the circumstances, a single tactic or combination of tactics may be appropriate for a specific pest problem. The goal of IPM is to manage pests and their damage at levels tolerable to the client. Pest eradication is not usually a feasible landscape IPM goal, except when dealing with a highly damaging pest. Typically, landscape IPM focuses on pest prevention and suppression rather than eradication.

When devising an IPM strategy, the ecological, social, and economic implications of pest management should be considered. An appropriate landscape IPM strategy will:

- Complement other PHC practices to promote plant appearance, structure, and vitality
- Avoid harmful effects on nontarget organisms (i.e., people, animals, and plants)
- Cause minimal disturbance to the built and natural environment
- Achieve the client's goals in a cost-effective manner

Action Thresholds

Pest presence does not necessarily constitute a pest problem. A pest becomes a problem when its population, or the injury it causes, exceeds a tolerable level, known as an action threshold. IPM practitioners use three types of action thresholds in managing pests: population, physiological, and aesthetic action thresholds.

Some organisms, such as biting insects, ticks, certain vertebrates, and weeds, are considered pests because they threaten human health by transmitting disease, cause discomfort with their bites and stings, destroy plants, and compete with valuable landscape plants and turf. Such pests are managed using a population action threshold, the population level above which personal comfort and safety, or landscape quality, is diminished. When the pest population exceeds this action threshold, control tactics are considered.

Most landscape pest problems result from organisms eating or inhabiting desirable plants, which can cause both physiological and aesthetic plant injury. A physiological action threshold is the injury level above which the health or structure of managed plants is compromised. An aesthetic action threshold is the injury level above which the appearance of managed plants is diminished. In both cases, control tactics are implemented when an action threshold is reached to prevent intolerable injury.

A population action threshold can also be used to manage physiological or aesthetic plant injury. For example, a dramatic increase in a spider mite population can often be detected prior to visible signs of plant injury. By establishing a population action threshold and routinely assessing the mite population, control measures can be quickly implemented, and thus prevent plant injury.

Many landscape pests can cause unacceptable aesthetic injury at very low densities, likely without adversely affecting plant health or structure. In addition, clients may have limited tolerance for aesthetic plant injury. As a result, aesthetic action thresholds are often lower than physiological action thresholds. IPM practitioners must determine the most appropriate action threshold for each plant-pest-client scenario.

Determining an appropriate action threshold for landscape pests requires knowledge, experience, and foresight. Some factors to consider when establishing an action threshold include:

- Client tolerances and expectations
- Plant value, condition, and susceptibility
- Type of pest
- Pest damage potential
- Time of year
- Site conditions
- Prevailing weather conditions
- Inspection frequency
- Potential for natural pest control

Based on these factors, action thresholds for landscape pests may vary from zero tolerance to considerable tolerance. While efforts have been made to develop standard action thresholds for specific pests, individual clients will differ in their pest tolerance and landscape management expectations. Therefore, communication with clients is important for educating them about IPM concepts, identifying their management goals, and establishing action thresholds appropriate for their property. In particular, clients should be informed that pest presence does not necessarily constitute a pest problem and that pest management decisions are based on action thresholds.

2. Monitoring

Monitoring is a critical component of landscape IPM. Monitoring is a program of regular landscape inspections to make observations and collect information required for pest management decision-making (Figure 2). Monitoring may be as frequent as every few weeks when there are high expectations for plant performance and during the warmer months of the year when generation times of pests are shorter and eruptive outbreaks are more likely to occur. The following information should be collected during routine IPM inspections:

- Client information
- Site information
- Plant information
- Pest information
- Beneficial organism information

Figure 2. Monitoring is a program of regular landscape inspections.

Clients are an important source of information because they are often observing plants on a daily basis. They may be able to tell you things such as how recently a pest appeared or how rapidly the onset of plant injury occurred. These conversations may further reveal the client's tolerance for a pest on a particular plant, which can be helpful when deciding if pest control is warranted. The client may also provide valuable site information for diagnosis and treatment of landscape pest problems. Valuable site information includes recent and past weather patterns, past and current landscape cultural practices (including management of other vegetative components), additions/removals of neighboring plant material, and hardscape construction/repair. These events can influence plant vitality and pest activity both positively and negatively. In many instances, the predisposing factor for pest-related plant stress is an adverse site condition such as drought or excessive irrigation. Identifying and correcting adverse site conditions are crucial to an effective IPM program.

Collecting plant information, including condition, developmental stage, and phenological stage, is another important aspect of an IPM inspection. A plant's condition and developmental stage can influence its pest susceptibility as well as its injury tolerance. Plants in poor health due to adverse site conditions or overmaturity can be particularly susceptible to certain pests and intolerant of the injury that they cause. In such cases, it may be appropriate to lower the action threshold for a pest to reduce the risk of injury and death. The plant's phenological stage can also influence injury tolerance and, therefore, impact pest management decisions. For instance, a late-season defoliating pest on a deciduous tree may not warrant management because the foliage will soon be shed and thus, the impact of pest feeding on overall plant health is minimal.

Several types of pest information should be collected during an IPM inspection, including:

- Pest identification
- Pest population level
- Life stage(s) present
- Potential for natural control of the pest

The presence of an organism on an injured plant does not imply that it is the causal agent. Incorrect identification of an organism can lead to misdiagnosis of the plant problem and improper recommendation for plant treatment. For example, the primary cause of a plant problem may be an abiotic factor, such as too much or too little soil moisture, that has predisposed the plant to a pest. Treating the pest certainly helps address the problem but does not fully correct it. Furthermore, most control tactics (particularly use of pesticides) are pest specific. Misidentification of the pest may lead to the wrong choice of pesticide, which can fail to treat or even exacerbate the pest problem. Once an organism is properly identified as a pest, its population level can be assessed for plant injury potential and then routinely monitored according to an action threshold.

When a pest is causing intolerable plant damage, the life stage of the pest must be properly identified so that an appropriate control tactic can be chosen. Many landscape pests can be effectively managed only during a vulnerable life stage. For example, many scale insects cannot be effectively controlled with pesticides once they reach adulthood and develop their protective waxy covering. In addition, many fungal diseases cannot be controlled with therapeutic fungicides once infection occurs, thus limiting disease control to nonchemical tactics. Employing control tactics inappropriate for the pest life stage is a waste of resources and may exacerbate the pest problem.

Pest control may not be necessary when there is high potential for natural suppression of the pest. IPM practitioners should acquaint themselves with the organisms that can naturally manage pest populations through predation, parasitism, or antagonism. These are collectively referred to as natural enemies of plant pests. Certain weather conditions can also naturally suppress pest activity by slowing their development or making them more vulnerable to natural enemies. While conducting IPM inspections, the practitioner should observe and note not only pest populations but also the presence of natural enemies and suppressive conditions. When natural suppression is high, the appropriate response may be to continue monitoring the pest and use chemical control tactics only as a last resort.

Monitoring Tools and Techniques

An important part of the monitoring process is looking for symptoms and signs of abiotic (non-living) and biotic (living) agents adversely affecting plant health. Recall that abiotic conditions often predispose plants to pests; therefore landscape monitoring encompasses scouting for pests as well as site conditions that are causing plant stress. Landscape observations should begin at a distance from the plant where symptomatic features like crown form, color, density, epicormic sprouts, and other irregularities are often more apparent. Closer inspection may reveal subtle yet distinctive symptoms—foliage distortion, discoloration, stippling, or abnormal growths. A closer look can also reveal distinctive signs of pest activity, such as fungal fruiting bodies, insect by-products (silk, honeydew, frass, wax, and sooty mold), and the exit holes of wood-boring insects. Pests that feed upon plant surfaces, such as caterpillars or scale insects, may be directly observed upon closer inspection of the plant. Others may be too small to see (spider mites) or may be concealed within plant tissues (leaf miners), necessitating more detective work to locate and identify the pest.

Numerous tools and techniques are available to facilitate landscape monitoring and plant inspection (Figure 3). A few of the most important ones are discussed here. A hand lens and various field guides are valuable for on-site identification of both plants and pests. There are also numerous mobile device apps now available from universities, state extension agencies, and commercial enterprises that can aid the field diagnostic process. If field identification is not possible, a specimen should be collected for identification by a colleague or diagnostic clinic.

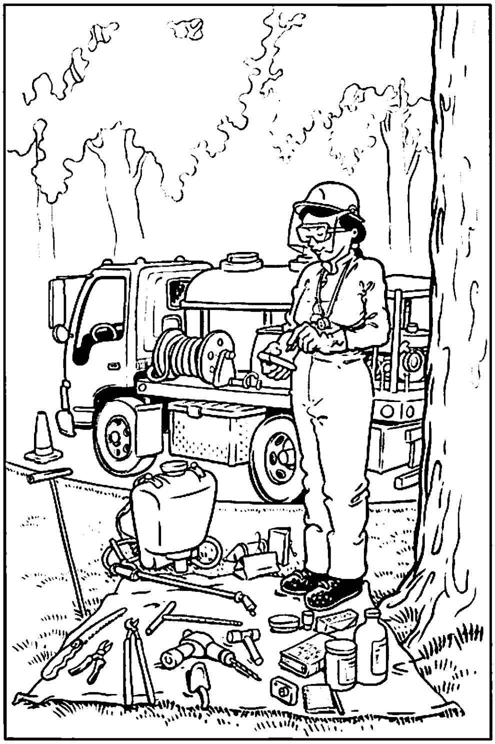

Figure 3. IPM practitioners use numerous types of tools and equipment for managing landscape pests.

Sometimes, it is difficult to evaluate a pest problem based solely on first-hand observations of the landscape. The pest may only be active at certain times (such as the black vine weevil at night) or current damage levels may provide insufficient information to guide management decisions. In addition, some pests can only be controlled during a specific life stage that is difficult to detect (as with clearwing moths). In these circumstances, trapping devices may be used to monitor pest abundance and life stage, to evaluate action thresholds, and to properly time control tactics (Figure 4). Trapping devices are commercially available for many insect pests.

Phenology calendars and degree-day models are knowledge-based tools that IPM practitioners can use for monitoring pest development and properly timing control tactics. Both of these tools help account for the annual and geographic variability in pest development, which can vary several weeks from year to year and location to location depending on emergent weather conditions. The life cycle and development rate of many landscape pests (particularly insects and mites) is highly dependent on the temperature of the surrounding environment. These organisms develop rapidly at warm temperatures and slowly at cool temperatures. As a result, the calendar timing of their development can vary substantially, making preventive pest control difficult.

A simple method for tracking the seasonal development of pests is a phenology calendar. Phenology is the study of relationships between periodic biological events and seasonal climate changes. Annual natural events, such as animal behavior and plant development, are often better correlated with seasonal climate changes than specific calendar dates. As a result, the development of insect and mite pests can be reasonably predicted by observing the budding, flowering, or fruiting of common native or landscape plants. For example, emergence of adult boxwood leafminer has been observed to coincide with the first flowering of common lilac, and spring cankerworms are active when saucer magnolias bloom.

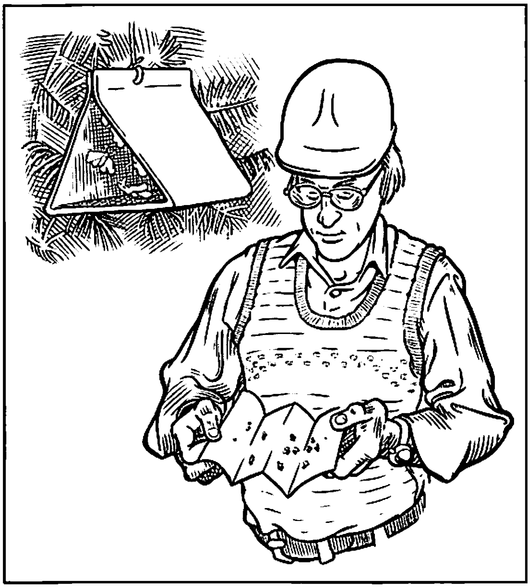

Figure 4. Pheromone-baited insect traps can be used to monitor pest abundance and life stage, evaluate action thresholds, and properly time control tactics.

With a few years of astute observation and recordkeeping, an IPM practitioner can develop a reliable phenology calendar. In addition, a number of state extension agencies across the United States have developed phenology calendars for common landscape pests. These calendars are handy for scheduling IPM inspections during peak pest activity and for optimally timing treatments for effective pest control.

A degree-day model is a more scientific approach to predicting the effect of seasonal warming on pest development. There is a lower threshold temperature below which insect and mite development slows dramatically or ceases. For insect and mite pests of woody plants, the commonly accepted lower threshold is 50°F (10°C). A simple degree-day model uses this lower threshold temperature and the daily average temperature (the average of the recorded high and low temperature in a specific region for a given day) to predict pest development stages.

To calculate degree days, the threshold value (50°F; 10°C) is subtracted from the daily average temperature. The numerical difference equals the degree-day units for that day (negative values are recorded as zero). A running total of the cumulative degree days is maintained throughout the growing season. In temperate portions of the United States, degree days usually begin accumulating in late February or early March. When the cumulative degree days reach a known target for a specific pest, intensive monitoring or preventive control tactics can be implemented.

Degree-day targets have been established for the life cycles of numerous pests and are commonly available through state extension agencies.

Phenology calendars and degree-day models may vary across regions, so use these tools carefully. They are intended only to supplement IPM decision-making. Additional landscape observations should be used to direct management actions.

Key Pests and Key Plants

IPM practitioners should become familiar with the key pests and key plants in their particular region and on their client's properties. These are the pests and plants that will warrant most of their attention during landscape monitoring and management.

Key pests are organisms that are frequently encountered in landscapes and predictably cause injury to landscape plants. Examples include aphids, mites, powdery mildew, and *Phytophthora* root rot. Key pests also include highly noxious pests, such as Dutch elm disease and emerald ash borer, for which the action threshold may be very low. IPM practitioners can improve their effectiveness by learning the life history of key pests, signs and symptoms of the injury they cause, and appropriate control tactics.

Key plants are defined in two ways. First, a key plant can be a species that has a high incidence of pest problems due to inherent susceptibility

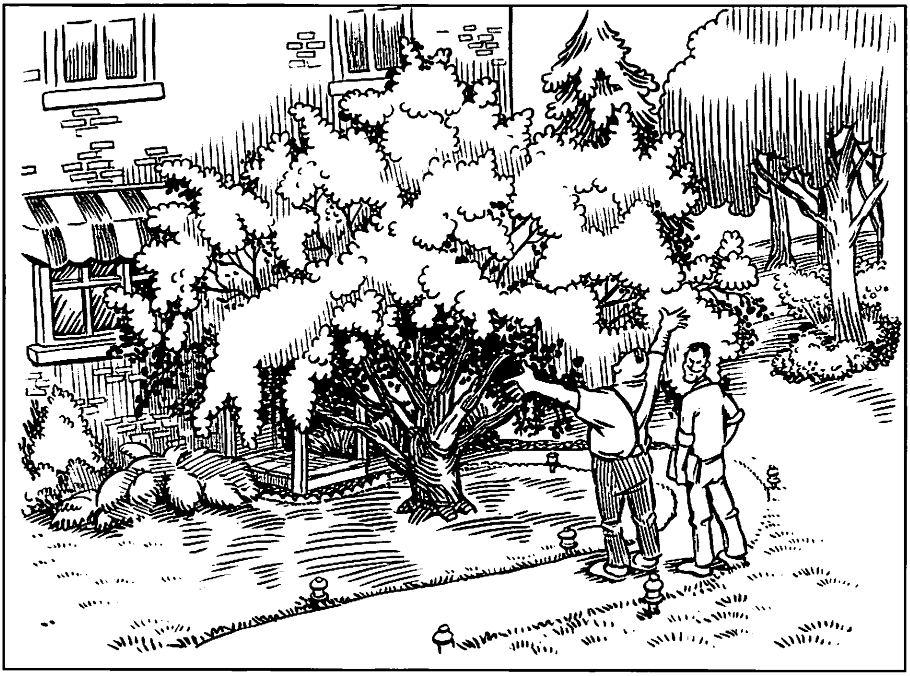

Figure 5. A key plant is a specimen that has high value in the landscape due to its location, function, size, appearance, or cultural significance.

or common mismanagement. For example, certain *Malus* species and cultivars are highly susceptible to a wide range of foliar diseases. Similarly, flowering dogwood (*Cornus florida*) is often plagued with pest problems when inappropriately planted in degraded soils on hot, sunny sites. Second, a key plant can be a specimen that has substantial value in a landscape due to its location, function, size, appearance, or cultural significance (Figure 5). Because value is often subjective, the IPM practitioner may not readily recognize key plants in the landscape and should consult with the client to identify his or her key plants.

By identifying key pests and key plants and understanding client expectations, the IPM practitioner can better determine the frequency and duration of IPM inspections that will be necessary to meet management objectives. This information is particularly important for pricing commercial IPM services, forecasting workloads, recruiting personnel, and procuring pest control supplies.

3. Pest Control Tactics

Preventive Tactics

Landscape pests are best managed by incorporating both preventive tactics and therapeutic control tactics into a single IPM strategy. Although IPM strategies are often pest specific, the following concepts and tactics are applicable to most landscape scenarios.

Preventive tactics are vital to a sound landscape IPM strategy. Plant selection and cultural practices are key preventive tactics used for managing landscape pests. They are used to achieve two basic pest prevention goals:

- Minimize plant stress by encouraging favorable plant development conditions
- Minimize pest activity by discouraging favorable pest development conditions

Plant stress is caused by a deficiency or toxicity of one or more plant survival factors (i.e., light, water, temperature, nutrients, and space). Both abiotic and biotic agents cause plant stress. Abiotic stress agents can be either natural (e.g., drought, infertile soil, and storm damage) or manmade (e.g., misguided landscape management, mechanical injury, and plant neglect).

Biotic stress agents include not only infestation by primary pests, but also competition and allelopathy from neighboring plants. Heavily stressed plants may have diminished defensive compounds in their tissues or reduced compartmentalization response, making them more vulnerable to pest infestation. Some stressed plants emit volatile compounds that attract insect pests. Another thing to consider is that stressed plants may have difficulty recuperating from a severe pest infestation that saps their energy reserves. As a result, the best course of action may be to cull unhealthy or heavily infested plants rather than expend resources on plants that are unlikely to recover fully.

On the pest side of the equation, it is also important to mitigate landscape conditions that promote pest development or activity. Many pests thrive under adverse site conditions including extremes of temperature, moisture, and light, as well as misguided management practices, such as improper irrigation, fertilization, and pruning. In many cases, the root cause of the pest problem is incompatible plant material or inhospitable landscape conditions. Fortunately, plant selection and cultural practices are reliable tactics for minimizing both plant stress and pest activity.

Plant Selection

IPM practitioners should always encourage clients to use pest-resistant plant species, high-quality nursery stock, and a diversity of plant species (Figure 6). Proper plant selection and placement is important to pest prevention and can considerably reduce the need for control tactics, particularly pesticide use. Certain plant taxa, such as the genus *Prunus*, have an inherently high incidence of pest problems. And some widespread landscape pests, such as deer, prefer to feed on a select group of plant species. Plant placement within the landscape also influences pest susceptibility. For example, boxwood (*Buxus* spp.) placed in poorly drained soils are more susceptible to *Phytophthora* root rot. Clients should be cautioned about the use of pest-prone plants on high-risk sites, particularly if they have high expectations for plant performance or limited resources to invest in pest control.

Figure 6. IPM practitioners should always encourage clients to use pest-resistant plant species, high-quality nursery stock, and a diversity of plant species.

High-quality nursery stock is much more tolerant of transplant and establishment stress, which can predispose plants to secondary pests, such as borers and canker fungi. The cultural needs of plants during establishment, particularly irrigation, should be carefully addressed to minimize predisposing stress. Choosing high-quality nursery stock also minimizes the risk of introducing pests from the nursery to the landscape.

Plant species diversification may help minimize the incidence and impact of pest problems in the landscape. Too much reliance on a few plant species can have catastrophic consequences for the landscape when an uncontrollable pest is introduced. A high density of a vulnerable plant species in the landscape may also favor insect dispersal and disease transmission. Not only can diversification decrease the likelihood of a landscape pest catastrophe, but it may also promote natural pest control by providing alternate food sources and refuge for the natural enemies of pests.

However, the choice of plant material used to diversify the landscape is critical. Studies have shown that adding additional species of *plants* provide opportunities for additional species of *pests* to become established in a landscape. This is especially true for non-native plants that are hosts for invasive non-native insects and diseases. Boxwoods and azaleas are prime examples. These plants, along with other key plants, may require more frequent IPM inspections and thus increase management costs. The plant diversity of the landscape is ultimately guided by the client's goals, and there may be limited opportunity for IPM practitioners to promote diversity within the landscape design. Nonetheless, clients should be educated on the dangers of low diversity, particularly on large properties, where the consequences of catastrophic pest outbreaks could be substantial.

Cultural Practices

Within the PHC management system, cultural practices are incorporated into the IPM strategy to mitigate plant stress and deter pest development (Figure 7). Cultural practices create favorable plant development conditions through treatments like mulching, irrigation, fertilization, and pruning. Prescribing appropriate cultural treatments requires knowledge of plant-specific needs and the ability to diagnose plant stress through observation and site assessment. IPM practitioners should also be able to recognize when chronic or severe plant stress has progressed to an irreversible point. In such instances, cultural treatments are not effective, and culling the afflicted plant is the most feasible remedy.

Landscape sanitation is an important cultural practice for preventing pest problems (Figure 8). Excessive buildup of plant litter provides breeding, refuge, and overwintering sites for certain pests. While it is important to maintain a litter layer over the root

Figure 7. Minimize plant stress by encouraging favorable plant development conditions, which may include soil decompaction or mulching.

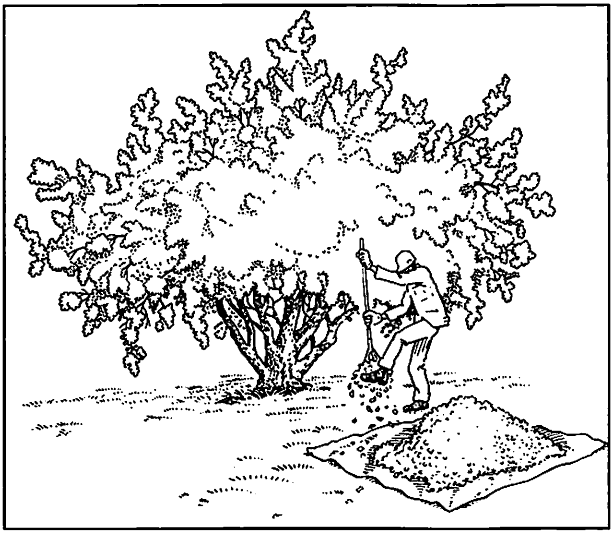

Figure 8. Landscape sanitation is an important cultural practice for preventing pest problems.

zone, excessive litter should be collected and disposed of seasonally. Dead branches and fruit that remain on plants can also harbor pests and should be removed periodically as well. Debris should be removed and properly disposed of by chipping, burning, composting, or landfilling.

Improper prescription of cultural treatments and pesticides can encourage pest activity or increase plant susceptibility to pests. For example, pruning during early summer can increase susceptibility to oak wilt (*Ceratocystis fagacearum*), while over-irrigation creates a favorable habitat for *Phytophthora* root rot. Use of broad-spectrum pesticides can decimate both insect pests and their natural enemies, which often leads to pest resurgence or a secondary pest outbreak. Fertilization, especially applications of high levels of nitrogen, uniformly reduce the resistance of woody plants to attack by insects and mites. Understanding the biology and behavior of key landscape pests helps prevent pest problems that arise from landscape management practices.

Although often beyond control of the IPM practitioner, certain landscape activities may cause plant stress or incite pest problems. It is important to educate clients and other professionals who work on or around the landscape about basic PHC concepts. In particular, these efforts should address common plant stress factors, such as improper irrigation, improper mulching, improper fertilization, soil compaction, mechanical injury, and misapplication of herbicides and de-icing salts.

Control Tactics

Although preventive tactics are foundational to a comprehensive pest management strategy, they are often insufficient for keeping all landscape pests at tolerable levels. When monitoring reveals that the action threshold for a particular pest has been exceeded, intervention may be necessary.

Scientific studies and technological advancements afford the modern IPM practitioner a wide range of potential control tactics for landscape pests. However, the challenge is selecting a tactic (or tactics) that meets the client's needs while also providing effective, safe, and affordable pest control. When selecting pest control tactics, several things should be considered:

- Establishing the management goal for the pest
- Identifying all possible pest control tactics and considering the advantages and disadvantages of each
- Choosing pest control tactics that have the least detrimental impact on the landscape ecosystem
- Integrating control tactics into a single pest management strategy for maximum efficiency and effectiveness

IPM practitioners must choose from three pest management goals: prevention, eradication, or suppression. For some pests, prevention may be the only feasible management goal. For example, many weeds, fungal diseases, and insect pests are most effectively controlled with preventive pesticide applications. Many of these pests cannot be therapeutically treated once they reach a certain developmental stage or infestation level.

Eradication entails the complete removal of a pest population through extermination or destruction of infested plants. It is rarely a stated goal in landscape IPM because it is usually unwarranted and difficult to achieve. Eradication is an extreme measure taken to manage pests that are particularly noxious; for which there are no alternative control tactics; or where government regulations call for the elimination of a pest from an area. In extreme examples, such as with Asian longhorned beetle (*Anoplophora glabripennis*), plants that are infested by the pest must be destroyed as part of an eradication program implemented by a government agency. Pest eradication on a large geographical scale is a difficult task and is typically effective only at the landscape level by destroying infested plants. Attempts at eradication are usually sponsored and conducted by government agencies rather than by commercial arborists. IPM practitioners should be aware of local or regional pest eradication programs and comply with them.

Suppression is the typical pest management goal in landscape IPM. The intent is to reduce the pest population and associated landscape damage to a tolerable level below the action threshold. Suppression is the preferred pest control approach because it usually can be achieved with limited applications of low-toxicity pesticides, while meeting the client's expectations for landscape appearance and plant health. This approach can be both cost- effective and environmentally responsible.

Typically, several control tactics are available for managing a landscape pest. There are always trade-offs among control tactics in terms of cost, feasibility, effectiveness, persistence, environmental impact, aesthetic impact, and social acceptability. The IPM practitioner should first discuss the potential pest control tactics and their trade-offs with the client, and use the client's input, along with personal knowledge and experience, to choose the most appropriate control tactic(s).

Cultural and Mechanical Control

Cultural control tactics entail either physical manipulation of the landscape or the use of mechanical devices to alter pest activity, reproduction, or survival. Many of the cultural preventive tactics previously described are also used as cultural control tactics. The main distinction is that cultural control tactics are implemented for existing rather than anticipated pest problems. Cultural control tactics are particularly desirable because they usually have limited impact on nontarget organisms and the environment.

Improper mulching and irrigation can create favorable conditions for landscape pests. Correcting improper mulch application (particularly mulch piled against trunks) removes favorable habitat for bark-feeding rodents and insects (Figure 9). Over-irrigation often causes problems with root pathogens such as *Phytophthora,* while insufficient irrigation can leave plants vulnerable to mites and wood-boring insects. Simply altering irrigation practices is often sufficient to manage these pest problems.

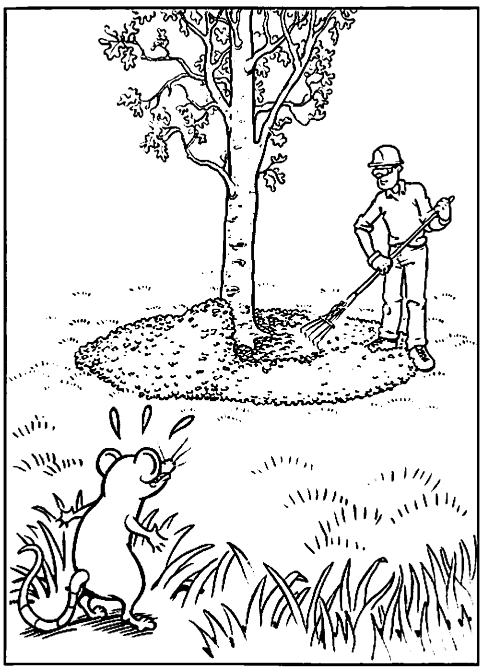

Figure 9. Correcting improper mulch application removes favorable habitat for bark-feeding rodents, insects, and pathogens.

Pruning is an effective cultural control tactic for some plant pests. Localized pest infestations on landscape plants can be controlled by removing and destroying infested portions of the plant (Figure 10). Removal of dead and dying branches removes breeding and feeding sites for certain pests. Crown thinning and raising improve air circulation and light penetration, which can decrease the severity of numerous fungal diseases. Pruning can also improve the efficacy of pesticide applications by permitting better spray penetration to the center of the canopy. Pruning must be properly timed to minimize plant exposure to pests, such as insect borers and fungal wilts, which can infest fresh pruning wounds.

Sanitation and eradication are also important cultural control tactics. Landscape sanitation entails the removal of dead or infested leaves, twigs, and fruits that accumulate in the plant or on the ground. Sanitation pruning is effective in suppressing destructive diseases like Dutch elm disease and defoliating pests including eastern tent caterpillars, fall webworms, and viburnum leaf beetles. Cultural control in combination with chemical control has been employed on a regional scale for invasive pests like Asian longhorned beetle where susceptible plant hosts are removed or treated with insecticides.

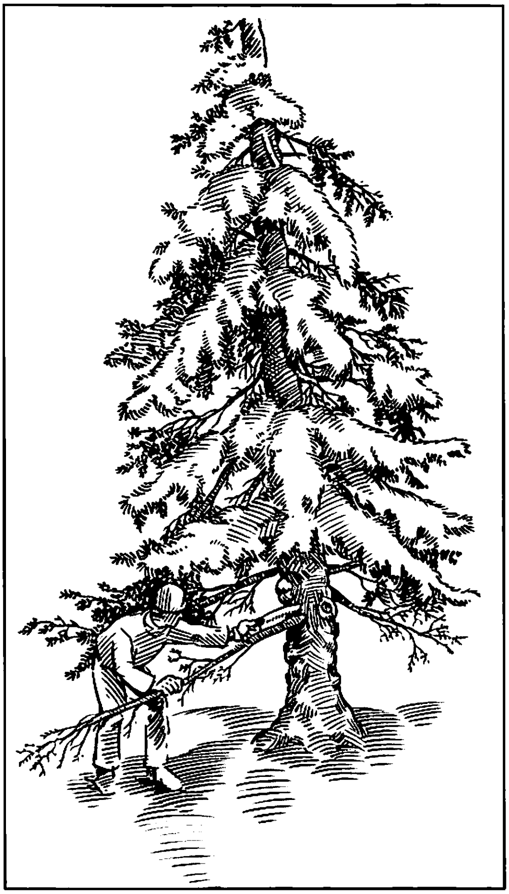

Figure 10. Localized pest infestations on plants can be controlled by removing and destroying infested portions of the plant.

A variety of mechanical devices can be used to alter pest activity, reproduction, or survival. Landscape damage by vertebrate pests such as deer, rabbits, rodents, and birds, can be discouraged by using barriers, repellents, and startling devices (e.g., noisemakers, flashers, and scarecrows). Where permissible by law, vertebrate pests can be controlled by lethal trapping or by live trapping and relocation. Licensure or permitting may be required for vertebrate pest trapping.

Arthropod pests can also be controlled using mechanical traps. Some wood-boring beetles, including granulate ambrosia beetles, can be managed by using trap logs baited with ethanol. Adult beetles are attracted to the logs, which are then destroyed before the immature life stages can complete development. A similar approach for emerald ash borer uses girdled trap trees (ash trees that have had a strip of bark removed to elicit release of stress volatiles) in combination with insecticide applications to suppress populations of beetles. Cankerworms and related caterpillars (family: Geometridae) can be suppressed by banding the trunk of susceptible trees with an adhesive that traps flightless female moths as they crawl up the trunk to mate and lay eggs in the crown. Another example of mechanical control is hand-picking bagworm larvae and the cocoons containing overwintering eggs from infested plants.

Biological Control

Biological control is the term used for a method for managing landscape pests using natural enemies—predators, parasites, and pathogens. IPM practitioners use both natural and applied biological control tactics. Most landscape pests have biological controls that naturally regulate their populations. In many instances, natural biological control maintains pest populations at tolerable levels and applied controls are not necessary. Natural biological control can be disrupted by disturbances in the landscape ecosystem. The most common disturbances to this natural suppression are the reduction in landscape diversity in favor of monocultures, the introduction of foreign pests, and the misuse of broad-spectrum pesticides. Organisms introduced from foreign regions often become landscape pests because their natural enemies are not present in their new environment. A classic example is hemlock woolly adelgid (*Adelges tsugae*). Broad-spectrum pesticides can decimate both insect pests and their natural enemies, which often leads to pest resurgence or a mite outbreak.

Natural biological control is sometimes insufficient to maintain pest populations at a tolerable level in managed landscapes. Applied biological control is an attractive pest control option, especially when working in environments where other control options are not possible. This can be particularly useful for clients who object to pesticide use on their property. There are three approaches to applied biological control: conservation, augmentation, and introduction.

Conservation of natural biological control is achieved by maintaining landscape ecosystems in ways that support natural enemies and their activities. One important way to conserve natural enemies is by selecting other control tactics, particularly pesticides, that are minimally disruptive. Using narrow-spectrum pesticides that kill only targeted pests will avoid collateral damage to natural enemies. Conservation may also involve providing habitat for beneficial organisms to increase their populations. For example, birds and bats—which often feed on pests—can be encouraged to inhabit the landscape by providing sources of water and shelter.

Utility rights-of-way can be valuable refuges for natural enemies if managed to provide shelter and food resources for predators and parasitoids. In addition, a diversity of flowering annual and perennial herbaceous and woody plants can be installed to provide season long pollen and nectar sources for the adults of many predatory and parasitic insects. Many reference books and websites list plants to aid in supporting these beneficial insects. In some cases, tolerating low levels of non-damaging herbivorous insects may help maintain predator and parasitoid populations because they provide a seasonal food source when pest populations are low. These alternative prey species allow natural enemies to establish sustainable populations that will suppress episodic outbreaks of more serious pests.

Augmentation of natural biological control involves the rearing and release of native and naturalized beneficial organisms to supplement existing populations of natural enemies in the landscape. Many types of beneficial organisms are commercially available for use in IPM programs, including lady beetles, lacewings, predatory mites, and parasitic wasps. Augmentation may also include the use of formulated microbial products including bacteria, fungi, and nematodes. These products may include bacteria such as *Bacillus thuringiensis* and *Chromobacterium subtsugae* for killing caterpillars and beetles; fungi such as Beauveria bassiana for killing aphids and whiteflies; or entomopathogenic nematodes for killing larvae of soil dwelling beetles and caterpillars that bore into woody plants.

Introduction of natural enemies, also known as classical biological control, is particularly valuable for non-native pests that threaten native ecosystems and have few feasible control options. The natural enemies of foreign pests are often introduced in an attempt to replicate the natural checks and balances found in the foreign pest's native habitat. Introduction of non-native enemies is a highly regulated process that is first carefully reviewed by governmental agencies to ensure that there will not be any adverse impacts on the native ecosystem by introduction of another foreign organism.

As with all pest control tactics, applied biological control has its limitations. It is important that the IPM practitioner and the client understand these limitations before choosing this option. Compared to chemical control, biological control (particularly augmentation) is generally slower and less consistent in controlling pests. Pesticides generally kill the targeted pest within minutes or hours of application, whereas biological control can take days or weeks to suppress a pest population. During this period, the pest can cause considerable injury to infested plants. There is also greater uncertainty about the efficacy of some biological control applications. Whereas most pesticides are highly effective, natural enemy augmentation may fail due to poor survival or dispersal of the organisms because of insufficient food sources or unfavorable site conditions. Other limitations of augmentation include poor persistence, high cost, and incompatibility with other IPM control tactics. In general, conservation of beneficial organisms may be the most sustainable biological control tactic over time.

Chemical Control

Chemical control tactics use pesticides for landscape pest control. Commonly used pesticides include insecticides, miticides, fungicides, bactericides, and herbicides. Chemical control is required when natural controls or other applied controls will not fulfill the pest management goal. Pesticides are also used as a preventive tactic against certain fungal diseases and are often applied prior to the emergence of certain insect pests. For example, tip moths and wood-boring beetles and moths are sometimes best controlled with applications of persistent insecticides that are applied before eggs are deposited on vulnerable plants. Preventive pesticide application should not be confused with cover spraying. Preventive application is performed only when landscape monitoring reveals that a pest is likely to infest desirable plants and cause intolerable injury. In contrast, cover spraying is performed with no regard to the identity of the pest or its potential to cause plant injury.

While pesticides are extremely valuable for controlling pests, their misuse can have negative consequences for the practitioner, the client, and the landscape ecosystem. IPM practitioners should not handle or apply pesticides without substantial training. In fact, many countries require licensure for commercial pesticide applicators. In addition, government employees and private applicators may require licensure to purchase and apply restricted-use pesticides. Pesticide applicators become licensed by passing standardized tests administered by state or provincial departments of agriculture and must maintain their licenses by participating in state-approved recertification programs. Licensing tests and recertification programs address numerous safety topics including pesticide labeling, environmental contamination, personal protective equipment, spill response, and pesticide handling and application.

Pesticide Selection and Application

For effective, responsible pest management, IPM practitioners should follow this procedure when choosing a chemical control tactic:

- Select an appropriate pesticide for the pest, the plant, and the landscape
- Read the label on the pesticide container and understand all information, including safety and environmental hazards, such as toxicity to pollinators and aquatic organisms
- Use the prescribed pesticide dosage
- Apply the pesticide at the recommended time and frequency
- Employ the correct pesticide application technique

Pesticide selection is based on pest identification, host plant identification, environment sensitivity, and client expectations. Correct pest identification is paramount in pesticide selection. Correct identification confirms that the organism is the cause of plant injury and permits selection of a narrow-spectrum pesticide. Mixing several broad-spectrum pesticides together to target an unknown pest is expensive, environmentally irresponsible, may be illegal, and may even worsen the pest problem.

It is also important to identify the host plant correctly. Correct identification can prevent misapplication of pesticides to food-crop plants and plants susceptible to phytotoxicity. Moreover, it is illegal to apply a pesticide to a plant for which it is not labeled. Pesticide labels typically identify permissible plant use, sensitive plant species, and phytotoxicity risk factors. When in doubt about a specific plant application, consult the pesticide manufacturer or a local regulatory agency.

In highly sensitive environments, pesticide selection is particularly important. Clients often have specific expectations about pesticide use on their property. It is important to understand and accommodate these expectations in the IPM strategy. Low-toxicity, limited-persistence pesticides may be required by law or by clients for use around bodies of water, structures, or places where people congregate. Be aware that certain pesticides are highly toxic to aquatic organisms or cause damage to structural surfaces. Pesticides with offensive odors or residues should be used with caution in sensitive areas.

Injecting pesticides into the vascular system of the plant or into the soil may limit exposure of nontarget organisms to pesticides and their residues. Injections are very useful where foliar spray applications are not possible due to concerns about pesticide drift or contamination of nearby buildings, vegetation, water sources, vehicles, people, or pets, or where injections are the most effective tactic available. Keep in mind that only certain pesticides are labeled for vascular or soil injection and efficacy of the treatment depends on the health of the plant's vascular system.

Misapplications of pesticides can result in significant mortality of bees foraging on landscape trees and shrubs. In response, pesticide manufacturers, at the behest of regulatory agencies, have added information to pesticide labels designed to alert applicators to the risk of harming pollinators and other beneficial insects. Some products have a "Bee Advisory Box" added to the label alerting applicators to restrictions on the label.

Biorational (biologically rational) control products are often appropriate for sensitive environments. Examples include horticultural oil, insecticidal soap, insect growth regulators, botanicals, fermentation products, and microbial extracts. These products tend to be less toxic because they have limited persistence, unique modes of action, or target-specific pests. In addition to biorational pesticides, arborists are well advised to select pesticides designated as "reduced risk." These pesticides are described with the following attributes: low impact on human health, low toxicity to nontarget organisms, low potential for groundwater contamination, low use rates, low pest resistance potential, and compatibility with other IPM tactics.

Some clients may desire an organic approach to managing landscape pests. The Organic Materials Review Institute (OMRI) is a nonprofit organization that conducts independent reviews of products intended for use in certified organic production. Many insecticides and miticides regularly used in arboriculture—including insecticidal soaps, horticultural oils, the microbial biological control agents *Bacillus thuringiensis* and *Chromobacterium subtsugae*, entomopathogenic nematodes, and products containing azadirachtin and spinosad—have formulations listed by OMRI.

Pesticides are generally differentiated as either contact or systemic pesticides. Contact pesticides kill pests through their direct physical contact with the material or its residue following spray application. In contrast, systemic pesticides are applied to the root zone, stem, or foliage of the plant and translocated through the vascular system to affected tissues. Systemic insecticides generally target sucking, leaf-mining, or cambium-feeding insects. Systemic fungicides are available for a number of foliar, vascular, and soil borne diseases. Both contact and systemic herbicides are used to manage grassy and broadleaf weeds. Some systemic pesticides also function in a contact manner.

The trade-offs for contact and systemic pesticides should be carefully considered before choosing a particular product. Contact pesticides generally kill pests rapidly, but their effectiveness depends on thorough spray coverage. This can be a challenge when treating large plants, dense plants, or plants in sensitive landscapes. In addition, some contact pesticides usually have limited residual effectiveness compared to systemic pesticides and may require repeated applications for sustained pest control.

In contrast, systemic pesticides may have delayed control due to translocation time in the plant but greater residual effectiveness because they are less susceptible to breakdown by rainfall or sunlight. When systemic pesticides are applied by soil or stem injections, there is less environmental exposure than with spraying (Figure 11). However, the potential exists for groundwater contamination from soil application, plant injury from repetitive stem injections, and exposure to pollinators though contaminated nectar and pollen, even for months or years following application.

Pesticides must be employed using correct dosage, timing, frequency, and application technique. People often mistakenly believe that mixing a pesticide at higher than recommend dosage improves long-term pest control. Overdosing pesticide is wasteful, environmentally irresponsible, and illegal. In addition, it can cause phytotoxic injury to treated plants.

Many pesticides require specific timing to be effective against the targeted pest. Fungicides are usually most effective when applied before the pathogen infects the host plant. Many insects can be chemically

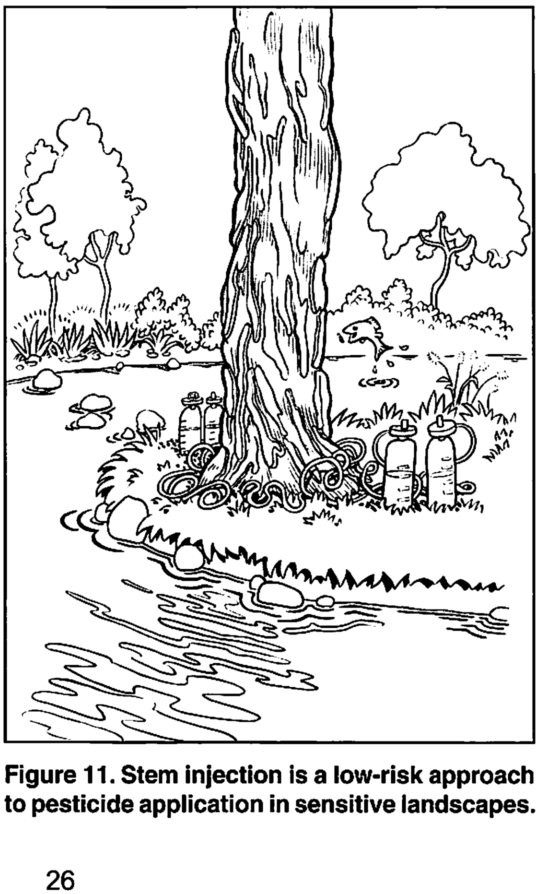

Figure 11. Stem injection is a low-risk approach to pesticide application in sensitive landscapes.

controlled only during a specific stage of their life cycle (for example the crawler stage of most scale insects are more susceptible than adults). Effective pest control may also require pesticide re-application. This is true for many foliar diseases and insects with multiple generations per growing season. Re-application frequency should be consistent with manufacturer's recommendations and published technical standards. Typical re-application times are 14 to 21 days. Some pesticides have label restrictions limiting the number of applications per season, or recommend to alternate applications with other pesticides to reduce the likelihood of developing pest resistance.

Most pesticides are intended for use with a specific application technique. It is important to select tools and techniques that minimize pesticide exposure to the applicator and sensitive areas during application. Pesticide labels usually have specific instructions on approved application techniques. Novel application techniques (e.g., mist blowers) should not be employed if they are not described on the product label. If in doubt about approved application techniques, consult with the manufacturer or a local regulatory agency.

Chemical Pest Control Failures

Chemical pest control failures often occur because of improper pesticide practices. Most pest control failures can be avoided by correctly identifying the pest, choosing the correct pesticide, and using the proper dosage, timing, frequency, and application technique. Pest resistance, pest resurgence, and secondary pest outbreaks are the most common chemical pest control failures that IPM practitioners face.

Pest resistance occurs when a pesticide selectively kills members of a pest population, leaving only resistant individuals to pass along their resistant traits to future generations. The most common cause of pesticide resistance is through repeated, frequent applications of a single pesticide. To reduce the risk of a pest population developing resistance, IPM practitioners often rotate use of several pesticides with different active ingredients or modes of action. Although resistance has been documented in agricultural settings, experts doubt that it is an important issue in urban landscapes. Local authorities like cooperative extension agents or horticultural entomologists should be consulted when there are concerns about the resistance potential of a specific pest.

Pest resurgence and secondary pest outbreaks result from harming natural enemy populations. Broad-spectrum pesticides can kill pests as well as their natural enemies. Pest resurgence occurs when the pest population rapidly rebounds in the absence of natural enemies, which are slower to repopulate. With secondary pest outbreaks, both the primary pest and natural enemies remain suppressed; a secondary pest takes advantage of the lack of predators and parasitoids to become a prominent pest. A classic example is secondary outbreak of mites following insecticide applications. Pest resurgence and secondary pest outbreaks can be minimized by choosing narrow-spectrum pesticides with limited persistence and making targeted pesticide applications based on landscape monitoring.

4. Documentation and Recordkeeping

IPM practitioners are often given long-term responsibility for clients' landscapes and woody plants. Over time, the practitioner can develop familiarity with the client and the landscape, which improves the practitioner's understanding and anticipation of plant and pest problems. A good IPM practitioner will not rely solely on memory to guide pest management decisions. He or she will keep detailed records of past landscape inspections, pest outbreaks, plant disorders, and treatment regimes. This documentation might include written descriptions, measurements, maps, and photographs. Important information to record for future reference might include dates of plant developmental stages, pest emergence, and pesticide treatments. When combined with local weather data, this information can be useful to forecast future pest outbreaks and precisely time preventive or therapeutic control treatments. Records can also be used to evaluate the efficacy of pest control strategies and refine IPM tactics for more effective pest management.

Documenting pesticide applications in particular may be important for legal reasons. Recording the type of pesticide applied, the concentration at which it was mixed, and the method of application may be helpful for refuting accusations of property damage or personal injury that happen to coincide with a pesticide application. Also, certain pesticides may have regulatory limits on frequency of application or how much of the material can be applied for certain uses. This type of documentation may be required by law in certain countries, states, or provinces. Check with local regulatory agencies to determine requirements for documentation of pesticide applications.

By following the practices outlined in this guide, arborists will be able to plan, design, and implement IPM as part of a comprehensive PHC program. Integrated pest management is one of the most effective approaches for addressing pest problems in ways that are ecologically sustainable, socially acceptable, and economically practical for the arboricultural industry and the clients we serve.

Glossary

abiotic–nonliving.

action threshold–pest population or plant damage level that requires action to prevent irreversible or unacceptable physiological and/or aesthetic harm.

allelopathy–chemical effect or inhibition of growth or development of plants that is induced by allelochemicals.

biological control–approach for managing pests using predators, parasites (parasitoids), or pathogens to suppress pest populations.

biorational pesticide–1) pesticide formulated from naturally occurring plant extracts, microbes, or microbial by-products that poses very low risk to nontarget organisms. 2) pesticide that has limited environmental persistence and poses very low risk to nontarget organisms.

biotic–pertaining to non-human, living organisms.

broad-spectrum pesticide–pesticide that kills a large number of unrelated species.

chemical control–approach for managing pests using pesticides.

contact pesticide–material that causes pest injury or death on contact or by contact with treated surfaces.

cover spraying–improper approach to pest management in which all landscape plants are treated with broad-spectrum pesticides with no regard to pest identity or plant injury potential.

cultural control–approach for managing pests using either physical manipulation of the landscape or mechanical devices that alter pest activity, reproduction, or survival.

diagnosis–process of identifying the causative agent(s) of a plant disorder by analyzing signs, symptoms, site conditions, patterns, climate, cultural history, and other factors.

frass–fecal material and/or wood shavings produced by insects.

honeydew–sugar rich excretion of sucking insects including aphids, soft scales, mealybugs, and whiteflies that supports the growth of a black fungus called sooty mold.

Integrated Pest Management (IPM)–a sustainable approach to managing pests by combining biological, cultural, physical, and chemical tactics, in a way that minimizes health, environmental, and economic risks. Choice of tactics is based on effectiveness, environmental impact, site characteristics, safety, economics, and client expectations and preferences.

key pest–organism that is frequently encountered in landscapes and predictably causes injury to plants.

key plant–1) a plant that frequently experiences unacceptable pest damage. 2) a plant of value to the client.

monitoring–a systematic inspection of the managed landscapes conducted at regular intervals to determine the types of pests, their numbers, the amount of damage caused by pests, the presence of beneficial organisms, and the effectiveness of treatments.

narrow-spectrum pesticide–pesticide that kills a single species or limited number of closely related species.

natural enemy–predator, parasitoid, or pathogen that targets an organism.

pest–living organism, including vertebrate, insect, mite, fungus, bacteria, virus, nematode, or undesirable plant, that interferes with or threatens plant health, aesthetics, or causes inconvenience.

pest eradication–an approach to pest management that entails total removal of a species from a particular area.

pest prevention–an approach to pest management that encourages favorable plant development conditions and discourages favorable pest development conditions.

pest resistance–1) in plants, the ability to resist pest infestation or infection. 2) in pests, the genetically acquired ability of an organism to survive a pesticide application at doses that once killed most individuals of the same species.

pest resurgence–increase in a primary pest population following a reduction in the population of its natural enemies due to broad-spectrum pesticide application.

pest suppression–an approach to pest management that reduces the pest population and associated plant injury to a tolerable level.

pesticide–any chemical used to manage or kill unwanted organisms such as weeds, insects, or fungi.

phenology calendar–a calendar that correlates pest activity or development with readily observable, seasonal events such as plant budding, flowering, or fruiting.

phytotoxicity–the ability of a chemical treatment to cause plant injury.

Plant Health Care (PHC)–comprehensive program to manage the health, structure, and appearance of plants in the landscape.

sanitation–cultural practice of removing dead, infested, or diseased plant parts to prevent or manage pest problems.

sign–physical evidence of a causal agent (e.g., insect eggs, borer hole, frass) (contrast with *symptom*).

secondary pest outbreak–increase in a secondary pest population following a reduction in the population of its natural enemies due to broad-spectrum pesticide application.

symptom–non-specific response of a plant, such as leaf discoloration or tissue distortion, caused by biotic or abiotic factors that alter normal growth and development (contrast with *sign*).

systemic pesticide–pesticide that is distributed throughout the plant by the vascular system following application to the foliage, stem, or soil.

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