8

Principles and Methods of Disease and Pest Control

Purpose and Expected Outcomes

This chapter is designed to classify the methods of disease and pest control and discuss the rationale behind their use, their effectiveness, and the environmental consequences of their use.

After studying this chapter, the student should be able to

1. Discuss the general principles of pest control.
2. Discuss the rationale behind each of the four control strategies.
3. Classify pesticides.
4. Classify insecticides.
5. Classify herbicides.
6. Discuss the strategies for the safe and effective use of herbicides.
7. Describe the equipment used in the application of pesticides.
8. Describe the pros and cons of each pest-control strategy.

Overview

In Chapter 6, we learned that the expressed phenotype depends on the genotype (the kinds of genes) and the environment in which the genes are expressed ($P = G + E$). The environment *(E)* should not be limited to the growth factors (light, moisture, temperature, and nutrients), even though these are the essential components. *Biological competitors* in the general environment may compete with useful plants for these growth substances to the detriment of the latter or destroy tissues and interrupt physical and developmental functions of cultivated plants. In terms of the environment, some of these competitors are native, or endemic, to particular areas. Others are imported by a variety of modes.

Diseases and pests must be controlled because they cause economic loss to a horticultural operation. The loss may come as a result of

1. Increased cost of production (additional inputs)
2. Decreased yield
3. Decreased quality

For the home growers or those who cultivate plants as a hobby and not for sale, losses to horticultural plants may come in more subtle ways. There may be emotional drain from the disappointment of a ruined crop or blemishes on plants in the landscape that reduce their aesthetic value.

Diseases and pests must be controlled safely and economically. A cost-effective control calls for a good understanding of the nature of the disease (pathogen), the environment, and the plant species (host).

From the formula $P = G + E$, the effective control of pests can be handled by either changing the crop growing environment or improving on the nature of the plant (genetic constitution) to include disease resistance genes.

Module 1

Principles of Pest Control

The purpose of pest control is to minimize or completely eliminate the economic loss to a horticultural operation through reduced productivity, reduced product quality, or reduced aesthetics.

8.1 Control Strategies

8.1.1 PRINCIPLES OF CONTROL

Four basic principles are involved in pest control—exclusion, eradication, protection, and resistance.

Exclusion

Exclusion involves activities that prevent the pathogen from being introduced into a given area in the first place. If introduced, the conditions should prevent a pathogen from becoming established. Excluding the pathogen on a large scale often involves enacting government policies that make it illegal to import or export certain plant materials. This legislative control (or quarantine) is discussed in detail in Module 2 of this chapter.

Eradication

If a pathogen succeeds in entering and becoming established in an area to some extent, measures may be undertaken to curtail its spread while reducing the current population until the pathogen is eventually eliminated completely from the area.

Protection

Protection entails the isolation of the host from the pathogen. Such isolation is usually accomplished by applying a chemical to the host. Physical methods of protection are also used.

Resistance

A form of protection of genetic origin is resistance, whereby a plant or host is equipped with disease-resisting genes. Resistance breeding is undertaken by breeders to incorporate these genes into new cultivars through planned crosses and the use of other plant improvement strategies. The result of resistance breeding is a plant armed with natural means of defense, thus eliminating the need to use chemicals.

8.1.2 PREVENTING PEST ATTACK

Pest control is an additional production cost that can be eliminated or reduced by adopting certain preventive strategies. Some of these strategies are described as follows and include the observance of good cultural practices.

1. *Certain environmental conditions predispose plants to diseases.* Chapter 7 stated that one of the three factors that must be present for disease to develop is the proper environment. This environment includes proper temperature, light, and humidity. Warm and humid conditions often invite diseases; aeration is needed to reduce the creation of this kind of microclimate around plants. Plants should be properly spaced and humidity controlled (e.g., by watering at the right time of day to allow excess moisture to evaporate).
2. *Select and use adapted cultivars.* Plants have climatic conditions under which they grow and perform best. When grown in the wrong regions, plants are unable to develop properly and are more likely to succumb to diseases.
3. *Use pest-resistant cultivars.* If certain pests are prevalent in the production area, it is best to use resistant cultivars, if available, in any production enterprise. For soilborne diseases, tree seedlings grafted onto an appropriate stock may be desired.
4. *Plant at the best time.* Seasonal planting may prevent exposure to unfavorable climatic conditions. This approach applies mostly to annuals, which complete their life cycles in one growing season. Sometimes short-duration cultivars may be selected to successfully grow a crop in a short window of opportunity where conditions reduce pest incidence.
5. *Provide adequate nutrition.* Strong and healthy plants resist diseases better than malnourished ones. Soil testing reveals the nutritional status of the soil so that fertilizer amounts can be amended for adequate plant nutrition.
6. *Observe good sanitation.* Because plant remains left on the soil surface can harbor pathogens, debris should be removed or buried in the soil. Diseased plant parts can spread the problem to healthy plant parts. Similarly, wounds provide easy entry to disease organisms. As such, the horticultural operation of pruning should be undertaken as needed to remove diseased plant parts, following up with proper wound dressing. Tools should be cleaned and disinfected periodically.
7. *Remove weeds.* Weeds compete for nutrients and also harbor diseases and other pests. Since weeds are volunteer plants in a cultivated plot, they are usually found in areas in which they are capable of performing under the prevailing conditions. They are thus more competitive than the cultivated crops, which require the grower's care.
8. *Use quality seeds or seedlings (or appropriate planting material).* Poor-quality seeds may have a high proportion of weed seeds and may also carry seedborne diseases. Obtain all planting materials from reputable nurseries or growers.
9. *Prepare the soil or growing medium properly for planting.* Depending on the tillage operation desired, weeds must be controlled by either killing them with chemicals or plowing them under the soil. In greenhouse culture, the growing medium should be sterilized to eliminate pests. Garden soils can also be sterilized by the method of solarization. A well-prepared soil or growing medium should drain freely to avoid waterlogged conditions, which prevent good plant development.

These general strategies of disease prevention are applicable to all production types. In addition, some production enterprises may use unique strategies that help to reduce pest incidence.

8.1.3 DESIGNING CONTROL STRATEGIES

Effective control of diseases and pests should take into account the pathogen (e.g., bacterium), the host (species), and the environment. A good strategy should be effective, inexpensive, and safe (in terms of both application and residual consequences for consumers and the environment). From the perspective of the pathogen, the strategy should exploit the vulnerability of the pathogen by administering the control at the stage in the life cycle at which it is most vulnerable. The strategy should also consider the stage in the life cycle at which the organism is destructive to horticultural plants. Control measures should be effected *before* the destructive stage. Certain organisms are destructive at more than one phase in their life cycles. For example, an insect may lay unsightly eggs on the flowers or leaves of ornamental plants or fruits. When the eggs hatch, the larvae may be destructive and the adult harmless. What may be a problem or undesirable in one case may have no economic consequence in another. Eggs on flowers may be unsightly and undesirable, but for a plant whose economic part is the seed, blemishes on the pods may not affect the quality of the seeds they carry. A control strategy should also consider the feeding habits of the organism, since insects may either suck or chew plant parts.

From the perspective of the host plant, control strategies should consider inherent genetic capacity. Some diseases affect young plants and others older plants. Certain cultivars have disease resistance genes and are able to resist infection. To be effective, a control strategy should consider the environment in several ways. Weather factors such as temperature, precipitation, and winds limit the effectiveness of the control measure. Rainfall after pesticide application may wash away the chemicals. In this age of environmental awareness, there is a call for reduction in pesticide use, since residues end up in groundwater as pollutants.

Cultural practices should be considered in adopting a strategy for disease control. For example, by changing crop spacing, pruning, adopting crop rotation, weeding, and taking other cultural measures, disease incidence can be effectively controlled. Finally, the cost of the control measure should be considered.

8.1.4 PRINCIPLES AND METHODS OF CONTROL

Controlling Insect Pests

Based on the nature of the agents employed, there are six general methods of control.

1. *Biological control.* The principles involved in the biological control of pests are geared toward favoring organisms (natural enemies) that are antagonistic to the pest or pathogen, and improving the resistance of the host.
2. *Cultural control.* Cultural control employs the principles of protection and eradication by helping plants avoid contact with the pest or pathogen and reducing the population of or eradicating the causal organism in the area. Cultural methods depend on certain actions of the grower.
3. *Regulatory or legislative control.* Regulatory control involves the intervention of government with laws aimed at excluding the pathogen or pest from a given geographic area.
4. *Chemical control.* The chemical control of pests involves protecting plants from the pathogen or pest, curing an infection when it occurs, and destroying the pest if the attack is in progress.
5. *Mechanical control.* Insects can be controlled by mechanical methods that employ devices to prevent them from making contact with the plants or lure and entrap the insects.
6. *Integrated pest management (IPM).* The method of integrated pest management, as its name suggests, entails the use of a combination of the other general methods of pest control in a comprehensive approach to disease and pest control. However, efforts are made to minimize the use of chemicals.

The preceding methods are discussed in detail in the various modules in this chapter.

Controlling Diseases

The principles of disease control are exclusion, eradication, protection, and resistance.

1. *Exclusion.* The principle of exclusion entails the use of a method such as regulation to prevent the introduction of the pathogen into an area where it does not currently exist.
2. *Eradication.* When disease incidence occurs to a limited extent or is restricted in distribution, it is feasible to completely eliminate the pathogen from the area.
3. *Protection.* Plants can usually be protected from pathogens by applying a chemical that prevents the pathogen from infecting the host.
4. *Resistance.* Plant breeding programs aim at providing a level of resistance (not total immunity) to a disease in plants. Whereas certain plants may be susceptible to a disease, others may be able to resist it, depending on a variety of factors such as the age of the plant, the environment, and the aggressiveness of the pathogen.

These four basic principles apply to controlling insects. Similarly, some methods of insect control (e.g., cultural, regulatory, and chemical) are applicable to diseases. In controlling diseases and insect pests, four general strategies may be adopted, depending on whether the attack is yet to occur or is already in progress. A single strategy may involve the use of one or more principles and methods of pest control. These strategies are summarized in Table 8–1.

TABLE 8–1 Strategies and Methods of Pest Control

Strategy 1: Exclude Pathogen from Host		
Methods:	Quarantine Crop inspection Crop isolation Use of pathogen-free planting materials	
Strategy 2: Reduce or Eliminate Pathogen's Inoculum		
Methods:	Cultural	Crop rotation Host eradication Improved sanitation Improved crop growth environment Soil drainage Aeration of soil Proper soil pH Proper soil nutrition Remove weeds
Methods:	Physical	Heat treatment Solarization Sterilization Traps—polyethylene sticky sheets Mulches
	Chemical	Seed treatment Soil fumigation
	Biological	Trap crops Antagonistic plants (repellants)
Strategy 3: Improve Host Resistance		
Methods:	Cultural	Improved crop growth environment Nutrition, moisture, drainage
	Biological	Genetic resistance (plant breeding) Resistant cultivars

TABLE 8–1 Strategies and Methods of Pest Control *(continued)*

Strategy 4: Protect Host Directly		
	Biological	Use natural antagonists
	Chemical	Use pesticides
		Seed treatment
		Spray plants
	Physical	Use protective aids (e.g., tree guard)

8.2 Classification of Pesticides

Pesticides are chemicals designed to kill pests. They are frequently very toxic to humans and thus should be used judiciously and with care. Pesticides differ not only in chemical composition but also in killing action, toxicity, residual effect, specificity, species destroyed, cost, and effectiveness, among others.

Based on the type of organisms on which they are used, there are two broad categories of pesticides in horticulture:

1. *Pesticides used to control unwanted plants.* **Pesticides** used to control unwanted plants are called *herbicides.* Plants that are pests are generally called *weeds.* Weeds may be defined as plants out of place. The different types of herbicides are based on killing action, specificity, active ingredient, and other characteristics as described in detail in Module 4 of this chapter.
2. *Pesticides used to control nonplant pests of plants.* Horticultural plants are attacked by a wide variety of pests that may be grouped on the basis of animal class. The major pesticide groups are described in the following sections. They are readily identified because the prefix denotes the class of animals (the suffix -*cide* is common to all).

Pesticide
A substance or mixture of substances used to control undesirable plants and animals.

8.2.1 INSECTICIDES

Insecticides are pesticides designed to control insects. They are the most widely used pesticide for killing animal pests. Module 3 of this chapter is devoted to a detailed discussion of insecticides.

Insecticide
Pesticide used to control unwanted insects.

8.2.2 FUNGICIDES

Fungicides are pesticides designed to control fungal pathogens. There are two basic kinds:

1. *Protective fungicides.* Unlike the protection offered by other kinds of pesticides, protective fungicides offer protection only to the part of the plant surface that is covered by the chemical. It is critical therefore to apply fungicides in a uniform and even manner over the entire surface to be protected. One of the oldest and still widely used nonsystemic fungicides is Captan, which is applied as a protective spray or dust in vegetables, fruits, seed treatments, and ornamentals.
2. *Systemic fungicides.* Systemic fungicides penetrate the plant tissue and circulate through all parts of the plant to combat infection. This relatively new group of fungicides is more efficient in controlling pests. An example is the benzimidazole (e.g., benomyl), which is effective against *Botrytis, Sclerotinia,* and others.

In terms of chemistry, fungicides may be classified as *organic* or *inorganic.*

Phytotoxicity
The immediate (acute) or continuous low (chronic) impact of a chemical on a plant or its part.

1. *Organic fungicides.* Organic fungicides are more selective and pose less environmental danger. The newer types are especially readily biodegradable and less **phytotoxic** (damaging to plant tissue). The most widely known class of organic fungicides is the dithiocarbamates, which include old and still useful fungicides such as thiram, maneb, zineb, and mancozeb. Thiram is used in apple and peach orchards, turf, and vegetable gardens. Other classes of organic fungicides are the substituted aromatics, thiazoles, triazines, and dicarboximides.
2. *Inorganic fungicides.* The core elements in inorganic fungicides are sulfur, copper, and mercury. Sulfur is available in one of several formulations: powder, colloidal sulfur, or wettable powder. When applied, it may kill by direct contact at high environmental temperatures (21°C [above 70°F]) by fumigant action. Sulfur is used in controlling powdery mildew. One of the most popular copper formulations is *Bordeaux mixture,* the oldest fungicide (consisting of $CuSO_4$ and hydrated lime), which is effective against downy mildew. It also repels insects such as flea beetles and leaf hoppers. Inorganic copper fungicides are not water soluble.

8.2.3 NEMATICIDES

Nematicides are chemicals designed to penetrate the relatively impermeable cuticle of nematodes. They are generally applied by professionals by injecting fumigants of halogenated hydrocarbons under pressure into the soil.

8.2.4 RODENTICIDES

Rodenticides are pesticides designed to kill rodents. Rodents are most effectively controlled by poisoning. The most widely used class of rodenticides are the coumarins. They must be ingested repeatedly to kill the pest. Thus, they are safe in case of accidental ingestion. An example is Warfam, which was developed by the University of Wisconsin. Coumarins are anticoagulants.

8.2.5 MOLLUSCIDES

Chemicals that are designed to kill mollusks are called *molluscides.* These chemicals are usually formulated as baits; an example is methiocarb, which is very effective against snails and slugs in ornamental plantings. Metaldehydes are one of the oldest and most successful molluscides.

8.2.6 MITICIDES

Miticides are pesticides designed to kill mites.

8.2.7 AVIACIDES

Aviacides are pesticides designed to kill birds. They are commonly included in grain and used as bait. Strychnine is an aviacide.

8.3 Growth Regulators in Pest Control

Plant growth regulators are used to manipulate plant height, promote rooting, and reduce fruiting, among other uses. A high concentration of certain plant hormones can reduce infection by some pathogens. This effect has been observed in tomato with respect to *Fusarium* and in potato with respect to *Phytophthora.* Viral and mycoplasma infections are known to cause reduced vigor and stunting in plants. However, an application of gibberellic acid spray overcomes stunting and axillary bud suppression. Sour cherry yellows is a common viral infection of cherries that is commercially controlled by the application of gibberellic acid on a significant scale.

8.4 Choosing a Pesticide

8.4.1 STEPS IN THE DECISION-MAKING PROCESS OF PEST CONTROL

The following are general steps that may be followed in the development and implementation of a pest-control strategy (Figure 8–1). Depending on whether the pest problem is new, as well as the experience of the person making the decisions, some of the steps may be skipped.

1. *Detection.* A pest-control program always starts with a problem. The pest must first be detected. The presence of a pest may be detected by visual observation of the organism or the damage it causes. While certain pests can be identified from a distance, some pests have hiding places (e.g., the underside of the leaf, under stones, or under debris) and require the grower to make an effort to search at close quarters. The key to successful pest control is early detection. It is advisable, therefore, that the grower routinely inspect the plants and look for pests and disease organisms known to be associated with the production operation and those prevalent in the area.
2. *Identification.* When a problem has been observed, it is important to make a positive identification of the insect or pathogen. Without knowing the organism involved, no sound control measure can be developed. Trial and error is wasteful. If the grower does not have the expertise to positively identify an insect or disease organism, a sample of an infected plant or the organism itself should be collected and sent to an appropriate identification center, such as the department of agriculture at a land grant institution or the U.S. Department of Agriculture (USDA) Extension Office. County extension agents should be consulted before contacting the national office.
3. *Biology and habits.* An organism has a life cycle. In insects that undergo a complete metamorphosis, there is a dramatic change from one stage of

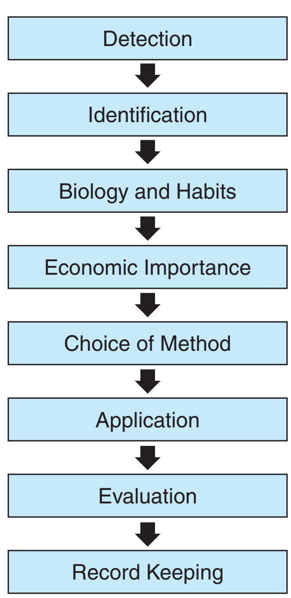

FIGURE 8–1 Steps in the decision-making process for pesticide application.

development to another. Each of these stages has its unique characteristics and habits. One stage may be more vulnerable than another to a particular control measure. The most vulnerable stage should be targeted for controlling the organism. It is important to know the habits of the organism in order to plan a control strategy. Certain insects hide on the undersides of leaves. Others inhabit the soil, and still others live on plant materials. Some insects are nocturnal in feeding habit, and others feed during the daytime. It has already been stated that certain insects have chewing mouthparts and others have piercing mouthparts. Some organisms have or secrete a protective covering, whereas others do not. These and other biological characteristics and habits are important in designing effective pest-control strategies.

4. *Economic importance.* It is economically wasteful of resources and time if it costs more to control a pest than the returns expected from the enterprise without protection. In other words, if the pest incidence does not pose an economic threat, the grower should ignore the pest. Certain pests can completely wipe out a production operation and must therefore be controlled immediately at the sign of their presence.
5. *Choice of method of control.* The most effective, economic, safe, and environmentally sound method of control should be selected after identifying the pest and assessing the potential damage. It may be found that a combination of methods rather than one particular method may be most effective. Some methods are easier to apply than others. Further, some methods may require the use of special equipment or the hiring of professional applicators.
6. *Application.* If chemicals are to be used, they must be applied at the correct rate. Premixed chemicals are available for purchase in certain cases. Otherwise, the user must follow the instructions provided with the chemical to mix the correct rate. Timeliness of application is critical to the success of a pest-control method.
   To eradicate a pest, it is important to know its life cycle. Certain applications may destroy the adults without damaging the eggs. By knowing when eggs hatch, an appropriate schedule can be developed to implement repeated application of the pesticide for more complete control. The environmental conditions under which application of a pesticide occurs is critical to its effectiveness. Pesticides should not be applied if rainfall is expected soon after the application. Further, a calm day is required to contain chemicals applied as sprays and dusts within the area of intended use.
7. *Evaluation.* The effectiveness of an application should be evaluated within a reasonable period after application to determine whether a repeat application is necessary. Evaluating the impact of pest control on the total operation is important. Controlling pests is expected to significantly increase productivity and returns on investment. If this is not the case, the grower should review the operation and make necessary changes.
8. *Record keeping.* Keeping records of one's operations is critical. The only way to make alternative choices is to have data for comparison. Such a record should include the type of pesticide, rate of application, cost of application, yield, and net returns.

8.4.2 ENVIRONMENTAL AND SAFETY CONCERNS

To avoid indiscriminate use of pesticides and to protect the environment, laws and guidelines that govern the use of pesticides are enforced. These laws vary from place to place. Pesticide manufacturers and governmental agencies conduct extensive tests on pesticides before they are approved for use. That a pesticide is approved for use does not mean it may be used in any situation desired. Regional and local factors such as climatic factors, soil characteristics, and agricultural production may preclude the use of approved chemicals in certain situations. It is imperative that only legally approved chemicals (with respect to the particular area) be used. Such information is available through the local extension service. Local nurseries and vendors often carry only state-approved pesticides. For the inexperienced grower, it pays to seek expert advice on the correct pesticide to use. This kind of information is usually only a phone call away and free of charge.

In a competitive industry, a variety of pesticides abound for the same problem. Some are more effective than others; some are safer than others. Pesticides also vary in their ease of use and *formulation*. Some pesticide formulations are suited for outdoor use only. In fact, the utmost care should be taken when using pesticides in the home. When you purchase a pesticide, be sure—at the very least—to read the label and understand the recommendations for its safe use. You may also let the seller know whether the problem is indoors or outdoors.

In sum, the chemical selected should be

1. Legally approved for use in the area.
2. Effective against the pest.
3. Appropriate for the conditions under which it will be used.
4. Accompanied by detailed instructions about its proper use.
5. Relatively safe (to humans, the environment, and the economic parts of the plant). Certain chemicals can be applied only by certified personnel.
6. One that the grower can apply safely (based on available equipment, location of a problem, and other factors).

8.4.3 IMPORTANCE OF PESTICIDE LABELS

A *label,* the piece of paper (or other suitable material) affixed by the manufacturer to the container of a product, provides certain specific information about the product (Figure 8–2). The information is not arbitrary and must meet specific governmental guidelines. A label is much more than an advertisement. Several categories of information are provided on a label, including the following:

1. Name of the product, which may include a trademark name and chemical name
2. Company name, address, and logo (where applicable)
3. Type of pesticide (e.g., fungicide or insecticide)
4. Product chemical analysis and characteristics: active ingredients and proportions (common and/or chemical names of ingredients) and formulation of substances (e.g., dust, emulsion, and wettable powder)
5. Pests it controls
6. Directions for proper use and any restrictions
7. Hazard statements (appearing as *caution, warning, danger,* or *poison*)
8. Storage and disposal directions
9. Governmental administrative stipulations (e.g., Environmental Protection Agency [EPA] approval and EPA number)
10. Net content

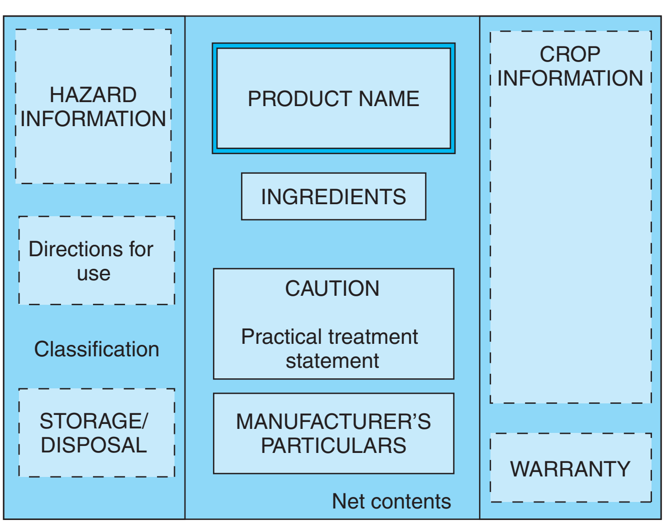

FIGURE 8–2 A typical pesticide label.

Typically, the trade name of the chemical, the type of chemical, and the company name are most visible. The hazard term is also quite conspicuous. Much of the other information is often in fine print. However, the user must endeavor to *read and follow all directions* very carefully. Understanding the warning signs of toxicity should be a high priority, since pesticides are generally very toxic to humans. As more research information becomes available on various aspects of the chemical product and also its impact on the environment, the governmental regulatory agencies may require additional information to be included on the product label.

8.4.4 PESTICIDE TOXICITY

Toxicity
The relative capacity of a substance to be poisonous to a living organism.

Lethal Dose (LD_{50})
The milligrams of toxicant per kilogram body weight of an organism that is capable of killing 50 percent of the organisms under the test conditions.

It is wise to treat all chemicals and especially pesticides (designed to kill) as poisonous until information to the contrary is clearly available. A measure of the danger associated with pesticides is the *hazard* rating, which is a function of **toxicity** and *exposure*. Toxicity is a measure of the degree to which a chemical is poisonous to the organism. A pesticide that is very toxic as a concentrate may not be hazardous when formulated as a granule. On the other hand, a pesticide of low toxicity may become very hazardous when used at high concentrations. Apart from formulation, the frequency of use and the experience of the operator may increase or decrease the hazard level.

The standard way of measuring toxicity is by determining the **lethal dose (LD_{50})** of the chemical. LD_{50} represents the dose sufficient to kill 50 percent of laboratory test animals, usually rats. Since the test is performed on mammals, the LD_{50} is sometimes described as *mammalian toxicity*. The higher the LD_{50} value, the less poisonous the chemical. LD_{50} is measured in units of milligrams of substance per kilogram of animal body weight. It follows, therefore, that children (low total body weight) could be killed by a dose that would only make an adult very sick. The LD_{50} values for selected garden chemicals are presented in Table 8–2. Since a pesticide may be ingested, inhaled, or absorbed through the skin, toxicity is sometimes broken down into three kinds—*oral toxicity, toxicity on inhalation,* and *dermal toxicity.*

TABLE 8–2 LD_{50} Values (Oral) of Selected Pesticides

Pesticide	*LD_{50}*
Fungicides	
Captan	9,000–15,000
Maneb	6,750–7,500
Thiram	780
Zineb	8,000
PCNB	1,550–2,000
Insecticides	
Carbaryl	500–850
Dursban	97–279
Malathion	1,000–1,375
Pyrethrum	820–1,870
Rotenone	50–75
Herbicides	
DCPA	3,000
EPCT	1,600
Simazine	5,000
Oxyzalin	10,000

Source: Extracted (and modified) from extension bulletin B-751, Farm Science Series, Michigan State University, University Cooperative Extension Service.

Chemicals gain access to humans through ingestion, touching, or inhaling. Some chemicals are highly corrosive and burn the skin upon contact. Chemicals that produce fumes or are formulated as dusts or powders are easily inhaled. Certain chemicals have strong odors that alert the user to their potential danger if inhaled.

8.4.5 USING PESTICIDES SAFELY

A first rule to using pesticides safely is to treat them as health hazards. After all, they are designed to *kill* pests. Use them as the last resort for controlling pests. If pesticides are necessary, the user should

1. Choose the correct one. Look for safer or less toxic alternatives of pesticides.
2. Purchase or mix only the quantities needed. Do not store excess chemicals, since it poses a serious health hazard, especially in homes where children live. Leftover chemicals also create disposal problems.
3. Read the label and act accordingly. Be very familiar with the manufacturer's directions for safe use. Note and observe all warnings. Use *only* in the way prescribed by the manufacturer. Follow directions for use. Be sure to use the correct concentration.
4. Wear protective clothing and avoid contact with the skin. Wear gloves or at least wash your hands thoroughly and immediately after using any chemical. Protect your eyes and cover your nose and mouth with a mask to prevent inhalation or ingestion of chemicals.
5. Do not eat food, drink, or chew anything while handling chemicals, and do not eat afterward until you have washed your hands with soap.
6. Apply chemicals under the best conditions possible. Do not spray on a windy day. If a light wind prevails, do not spray into it, proceeding such that the wind is behind you as you move along. If rain (or irrigation) occurs after application, much of the chemical will be lost to the ground. When applying chemicals outdoors, it pays to listen to the weather report to know the best time for application. When applying chemicals indoors, avoid spraying onto cooking utensils and food. All such items should be covered before spraying. Children, especially, should leave the house for a period of time if extensive spraying is to be done. Moving a diseased plant outside of the house rather than spraying it indoors is recommended. Chemicals should be applied in conditions of adequate ventilation. A closed area such as a greenhouse should be adequately ventilated before people return to work in the area.
7. Apply with extreme care. Certain pesticides are injurious to both pests and humans and will kill indiscriminately. Plants can be damaged through accidental splashing or drifting during a spraying operation. The operator can be injured through carelessness. Premixed chemicals are less concentrated and safer to handle. Concentrated chemicals should be handled with extra care.
8. Know what to do in case of an accident. The label should indicate proper actions in case of a spill, ingestion, or inhalation. Water and a detergent should be readily available to wash any body part that comes in direct contact with the chemical. Cleaning certain spills requires more than water.
9. Clean all applicators thoroughly after use and store them in a safe place.
10. Store chemicals as directed by the manufacturer. A cool, dry place is often required for chemical storage. Keep *all* chemicals out of the reach of children and pets. It is best to store unused chemicals in their original containers for ease in recognizing the chemicals and avoiding accidents through misidentification.
11. Be very careful of using pesticides near the time of produce harvest. Pesticide poisoning may occur if produce is harvested before the pesticide effect wears off. Where applicable, produce grown with pesticides should be washed before being eaten or fed to animals.

8.4.6 METHODS OF PESTICIDE APPLICATION

Pesticides may be applied to plants, products, or the growing medium, according to need. The general ways in which pesticides are used are as follows:

1. *Foliar application.* Pesticides may be applied to plant foliage in the form of a liquid or dust (powder).
2. *Soil treatment.* A soil may be fumigated (by treating with volatile chemicals) to control nematodes and other soilborne diseases. Sometimes various formulations including drenches, granules, and dusts may be applied.
3. *Seed treatment.* Planting materials (e.g., seeds, bulbs, corms, and tubers) may be treated with a pesticide to control soilborne diseases that cause seed decay or damping-off of young seedlings.
4. *Control of postharvest pests.* Fruits may be dipped in dilute solutions of fungitoxic chemicals to protect them from rotting in storage.

8.5 INTEGRATED PEST MANAGEMENT

Integrated Pest Management (IPM)
An approach to pest control that attempts to use all the best management methods available to keep pest populations below the economic and/or aesthetic injury level, with least damage to life and the environment.

Integrated pest management (IPM) is a pest-control strategy whose goal is not to eradicate but to manage a pest such that its population is maintained below that which can cause economic loss to a production enterprise or aesthetic injury. In this strategy, human health and the general environment are paramount considerations. By nature, IPM depends on a broad and interdisciplinary approach to pest control, incorporating various aspects of the basic control methods (cultural, biological, legislative, and chemical) (Figure 8–3).

8.5.1 GOALS OF IPM

The goals of IPM may be summarized as follows:

1. *Improved control of pests.* Methods of pest control should be reviewed regularly so that the best strategy is always used. As scientific knowledge abounds and technology advances, new and improved alternative measures will become available. Strategies should draw on the strengths of all of the basic control methods in a truly interdisciplinary fashion to develop the best control package. Improvements in control should consider the fact that nature has built-in means of controlling population growth by the presence of natural enemies of organisms in the environment. Preference should be given to natural methods of control over the use of chemicals.

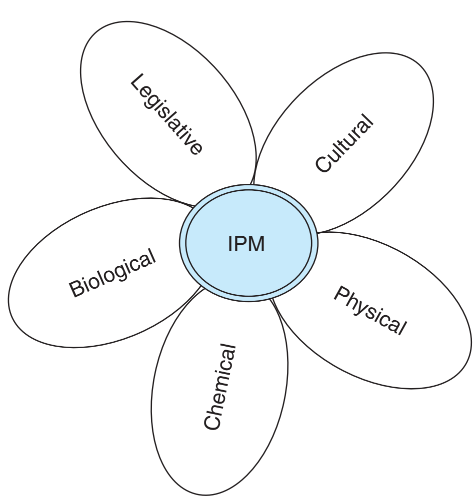

FIGURE 8–3 The components of an integrated pest management (IPM) system. *(Source: G. Acquaah, Principles of Crop Production)*

2. *Pesticide management.* Controlling pests should be a planned activity such that pesticides are used judiciously. Pesticides should be used so that natural enemies of plant pests are not destroyed in the process. Further, pesticides should be contained and applied only when absolutely necessary. Care must be taken to minimize the side effects of chemical application.
3. *Economic protection of plants.* As previously stated in this module, the mere sight of a pest does not necessarily mean that it constitutes a threat to economic production. A control measure should be enforced only when its necessity has been determined. When needed, IPM ensures that a control package includes the bare minimum for effectiveness. By using minimal quantities of pesticides (through reduced rate of application and reduced frequency of application), the cost of protection can be reduced significantly.
4. *Reduction of potential hazards.* A paramount objective of IPM is the responsible use of pesticides. When pesticides are deemed necessary, they should be used at the lowest effective level to prevent adverse environmental impact. IPM strategies are aimed at maintaining ecological stability and protecting the health of the grower (or user), the consumer, and the general environment. Hazardous chemicals should be prevented from entering the *food chain* (the sequence of transfer of food from producers through several levels of consumers in the biological community). Excess pesticides and other agricultural chemicals seep into the groundwater and also pollute the general environment, posing serious health problems to humans and wildlife.

8.5.2 DECISION-MAKING PROCESS IN DEVELOPING AN IPM PROGRAM

An IPM program is developed by following the basic principles for a conventional pest-control program, but with certain modifications. It is important to remember that an IPM program is broad based and interdisciplinary, including strategies involved with the basic methods of control. The general decision-making steps are as follows:

1. Identify the pest and the beneficial organisms in the area of interest. IPM uses natural enemies to control pests. By knowing these two groups of organisms, one can make the appropriate choices of control method that will selectively kill the pest while protecting the beneficial insects.
2. Know the biology of the organisms involved and how the environment influences them.
3. Select an appropriate cultural practice that will be detrimental to the pest while favoring the desirable organisms. Cultural control is usually considered first because the method of plant production plays a role in the pest problems encountered in cultivation. Cultural practices include selecting cultivars that are resistant to pests in the production area, preparing the soil properly, planting at the right time, providing adequate nutrition and water, and so forth.
4. Develop a pest-monitoring schedule for the production enterprise to record the kinds and populations of various organisms. This step requires some expertise to be successful.
5. Determine tolerable threshold levels of pest populations. Since one of the goals of IPM is economic pest control, it is important to know what level of pest population constitutes an economic threat. When this threshold is reached, an appropriate control strategy should be implemented. The strategy should take into account the pest plant species, the stage of plant development, the economic product, and the general environment. Whereas a threshold may be deemed an economic threat when it occurs in the early stages of plant growth, the same threshold may not be economically threatening when the plant is approaching maturity.
6. If an economic threat is deemed eminent, decide on a definite course of action to forestall the danger. Sometimes the best decision is to wait a while.

If intervention is delayed, the grower must increase monitoring of the population dynamics of the pest to avoid any surprise disaster.

7. Evaluate and follow up on the IPM program to make appropriate strategic adjustments for increased effectiveness and efficiency of control.

8.5.3 TOOLS FOR AN IPM PROGRAM

Tools used to implement an IPM program reflect the basic methods of pest control. Using these tools in an informed and responsible manner results in a successful pest-control program with minimal adverse environmental impact.

1. *Cultural tools.* Cultural tools include proper soil preparation, proper time of planting, and use of resistant cultivars.
2. *Biological tools.* Biological tools include use of natural enemies of the pests and pheromones as sex traps.
3. *Chemical tools.* Chemical tools include the use of pesticides and improved methods of application.
4. *Legislative tools.* Legislative tools include the use of laws to restrict the transport of plant materials that may be contaminated.

SUMMARY

Diseases and pests can be controlled by implementing certain preventive measures such as observing phytosanitation, using quality disease-resistant seeds, and planting adapted cultivars. If diseases and pests become a problem, they may be controlled by one of four strategies: biological, cultural, chemical, or governmental controls. A fifth strategy, integrated pest management, uses a combination of all four strategies. Pesticides that control weeds are called herbicides. Nonplant pests may be controlled by one of several specifically designed pesticides including insecticides, fungicides, nematicides, miticides, rodenticides, and molluscides. Pesticides are toxic to humans and should be handled with care. Pesticide labels should be read very carefully and the directions followed meticulously. In pest control, the first step is to identify the specific pest and determine its potential for damage as well as the damage already caused.

MODULE 2

BIOLOGICAL, CULTURAL, LEGISLATIVE, PHYSICAL, AND MECHANICAL CONTROL OF PLANT PESTS

8.6 RATIONALE OF BIOLOGICAL CONTROL

Nature has built into its dynamics a variety of mechanisms whereby it maintains a state of equilibrium. Whenever a destabilizing force comes into effect, this natural balance shifts in the direction of the force. Unaided by humans, nature effectively maintains this desirable state of balance, or equilibrium. Unfortunately, when humans interface with nature, they tend to nudge it to their advantage and in the process often wind up destroying the delicate balance, which may lead to serious environmental consequences.

Every organism has its natural enemies. Unless a disaster or a drastic change occurs in their living conditions, the danger of extinction of organisms is minimized, in part because one organism does not dominate nature through overpopulation. This natural means of mutual control makes **biological control** the oldest method of pest control. Biological control is the control of diseases and pests by the direct activities of living organisms or the indirect activities of their products.

Biological Control
The use of other organisms to control populations of pathogens.

Industrialization and technical advancement have been major contributors to the destabilization of natural balance. Such advancements changed the lifestyles of people and caused consumers to be more demanding in terms of product quality. Subsistent agriculture was gradually replaced by mechanized farming of large tracts of land. Instead of allowing the farmland to lay idle (fallow) for a period of time to rejuvenate, the same tract of land was repeatedly farmed, predisposing it to depletion of plant growth nutrients. This practice ushered in the era of artificial soil amendments with fertilizers (Chapter 4). Instead of *mixed cropping,* which is closer to what occurs in nature, *monocropping,* which encourages the buildup of pests associated with one particular species, is common today. To curb this disproportionate increase in the population of one pest, farmers use more chemicals (pesticides) to control pests. As previously indicated, an unfortunate aspect of chemical use is that these toxins often kill indiscriminately, depleting the population of both pests and desirable organisms.

8.7 Strategies of Biological Control

A variety of strategies may be adopted to control diseases and pests biologically. In fact, biological control involves the exploitation of natural defense mechanisms and managing and controlling them to increase their effectiveness. The natural systems exploited in biological control are discussed in the following sections.

1. *Structural.* Some species have characteristics that condition resistance to certain pests and disease-causing organisms. Certain species, for example, have hairs (pubesence) on their leaf surfaces and other parts that interfere with oviposition in insects. In this way, the multiplication of insects is impeded, thus hindering their spread and devastation to the plant. Other plants have genetically conditioned structural features such as a thick cuticle that sucking and chewing insects have difficulty penetrating.
2. *Chemicals.* Certain chemicals extracted from plants have insecticidal action. Common ones include the widely known *pyrethrum* extracted from plants in the chrysanthemum family, *rotenone,* and *nicotine* (rotenone being more common). Other species, including the neem tree, mamey, and basil, contain a chemical that repels insect pests or hinders their growth and development into adults.
3. *Phytoallexins.* In nature, certain plants exude toxins from their roots into the soil. These toxins prevent the growth of other species in the immediate vicinity. The species hence maintains a kind of territorial boundary similar to that which occurs in the animal kingdom.
4. *Parasitism.* The Japanese beetle *(Tiphia),* for example, is attacked by the larvae of a beetle, while the adult alfalfa weevil is a host for the eggs of the stingless wasp *(Microstomus aethipoides),* which hatches inside the weevil, eventually destroying it. Cyst nematodes (*Heterodera* and *Globodera*) are parasitized by certain fungi (e.g., *Catenaria auxilianis*), and the root-knot nematode (*Meloidogyne* spp.) is parasitized by the fungus *Dactylella oviparasitica.* Similarly, bacteriophages are viruses that destroy bacteria. These viral parasites occur in the environment.
5. *Prey-predator relationships.* Birds may prey on insects and rodents. Snakes also prey on rodents that destroy horticultural plants. Carabid beetles (ground beetles)

prey on aphids, caterpillars, slugs, and others. Lacewings *(Chrysopa)* prey on aphids, spiders prey on flying insects, and social wasps prey on caterpillars.

Antagonism
The phenomenon of one organism producing toxic metabolic products that kill, injure, or inhibit the growth of some other organism in close proximity.

6. ***Antagonism.*** As described previously in this chapter, nature has built-in mechanisms for maintaining balance so that no single organism dominates. If an organism is introduced into a new environment where its antagonizing organism is not present, the organism can multiply rapidly and pose a great economic threat to vulnerable cultivated crops in the area. In olive orchards, for example, the olive parlatoria scale, an economic pest, can be controlled effectively by biological means if its antagonistic organism, the parasitic wasp, is introduced into the environment. Antagonistic plants that exude toxins against nematodes are known to occur in nature.
7. *Repellents.* Some plant species exude strong scents that are repulsive to certain insects. Onion, garlic, and leek have been known to repel aphids, and mint repels cabbage butterflies and flea beetles. Horseradish repels potato bugs, and sage repels cabbage pests and carrot flies. Marigolds repel root nematodes. By planting the appropriate combinations of plants in a particular area, the grower can gain some degree of crop protection from a specific pest.
8. *Alternative host (trap plants).* Pests have preference for the plant species they attack. If two hosts are available, one may be preferentially attacked. Slugs prefer lettuce to chrysanthemums, and, as such, a good crop of the latter can be produced in the field by planting lettuce among them as "decoy" plants, or trap plants. Similarly, nematodes may be controlled by planting certain species that prevent the development of larvae into adults. This practice has the effect of decreasing the population of nematodes in the soil. *Clotalaria* plants are used to trap the larvae of root-knot nematodes (*Meloidegyne* spp.).
9. *Biocontrol.* In the storage of horticultural produce, *biocontrol* is employed in the postharvest control of diseases in stone fruits such as peach and plum. This control is effected by treating fruits with a suspension of the bacterium *Bacillus subtilis,* which is found to delay brown rot caused by the fungus *Monilinia fruticola.* Biocontrol measures involving other bacteria and fungi exist. Bacteria damage certain frost-sensitive plants by aiding in the formation of ice (called *ice nucleation*). Ice-nucleated active bacteria (e.g., *Pseudomonas syringae*) are replaced by applying non-ice-nucleated bacteria, which reduces bacteria-mediated frost injury.
10. *Microbial sprays (biopesticides).* Scientists have identified and cultured natural enemies of certain horticultural plants. An infected field is sprayed with large populations of laboratory-cultured microbes. For example, aerial application of spores of the fungus *Collectotrichum gloesporiodes* has been successfully used to control the northern jointvetch in rice fields. Also, the fungus *Talaromyces flavius,* when applied to the soil, is effective in controlling soilborne diseases such as wilts of potato (potato wilt) and eggplant (verticilium wilt). Through breeding efforts, more aggressive and effective strains of these microbes are being developed, as in the case of plant cultivars. Another commercially available microbial spray is the *Bacillus thuringiensis* spray, which is effective against caterpillars or cutworms, corn borers, cabbage worms, and others. The effect on caterpillars starts upon ingestion of the bacteria.

8.7.1 ADVANTAGES AND DISADVANTAGES OF BIOLOGICAL CONTROL

Advantages

The advantages of biological control include the following:

1. Pesticides are harmful to the environment and are hazardous to humans and wildlife. Biological control uses organisms already present in the environment.
2. Seeds of improved cultivars (resistant cultivars) are cheaper to use than spraying against pests with chemicals.
3. Biological control is safer to apply than chemicals.

TABLE 8–3 Selected Examples of Biological Control of Horticultural Pests

Biological Agent	*Some Pests Controlled*
Ladybug	Aphid
Bacillus thuringiensis	Colorado potato beetle and caterpillar
Bacillus popillise	Japanese beetle
Green lacewing	Aphid and mealybug
Parasitic wasp	Tomato hornworm and cabbage looper
Nedalia beetle	Citrus cottony scale
Tilleteopars	Powdery mildew
Talaromyces flavius	Potato wilt and verticillium wilt

In addition to these organisms, the use of resistant cultivars, plants with repellent scents, and crop rotation are other nonchemical methods of pest control.

Disadvantages

The major disadvantages of biological control include the following:

1. Availability and application are limited to relatively few crop species.
2. Handling of organisms is less convenient than chemicals, often requiring special care.

8.7.2 OTHER EXAMPLES OF BIOLOGICAL CONTROL

A variety of beetles have been identified as predators of pests of cultivated crops:

1. The European seven-spotted lady beetle *(Coccinella septempunctata)* preys on aphids.
2. The ladybug *(Crystalaemus montrocizieri)* destroys mealybugs.
3. The larvae of the Japanese beetle feed on the larvae of other beetles.

In addition to beetles, the bacterium *Bacillus thuringiensis* is known to infest and kill a variety of insects, including the larvae of butterflies, moths, and corn borers, while being harmless to plants. Other examples are presented in Table 8–3. Figure 8–4 presents examples of various organisms in effecting biological control. These exhibits represent only a select few examples.

8.8 CULTURAL CONTROL

A variety of strategies are employed to implement cultural control of diseases and pests in plants.

8.8.1 CROP ROTATION

As indicated in the introduction to this chapter, monoculture and repeated cultivation of one species on the same area of land encourages the buildup of the diseases and pests that plague the cultivated species. Crop rotation is a strategy whereby no one species is perpetually planted on the same plot of land (Figure 8–5). Additionally, a species is not followed by its relative. Instead, species with different soil requirements or use are rotated in a definite cycle (e.g., corn to tomato to bean to corn, or a four-year rotation). Note that the rotation has a cereal, a solanaceous species, and a legume. A rotation consisting of, for example, potato, tomato, and eggplant (all solanaceous species) certainly violates the rule of not following a species with its relative. Similarly, cruciferous plants (e.g., cabbage, broccoli, mustard), leguminous plants (e.g., beans, peas), onions (e.g., garlic, leek), and Curcubitaceous plants (watermelon, squash) are groups of plants affected by similar diseases. Rotation of crops is effective in reducing the populations of

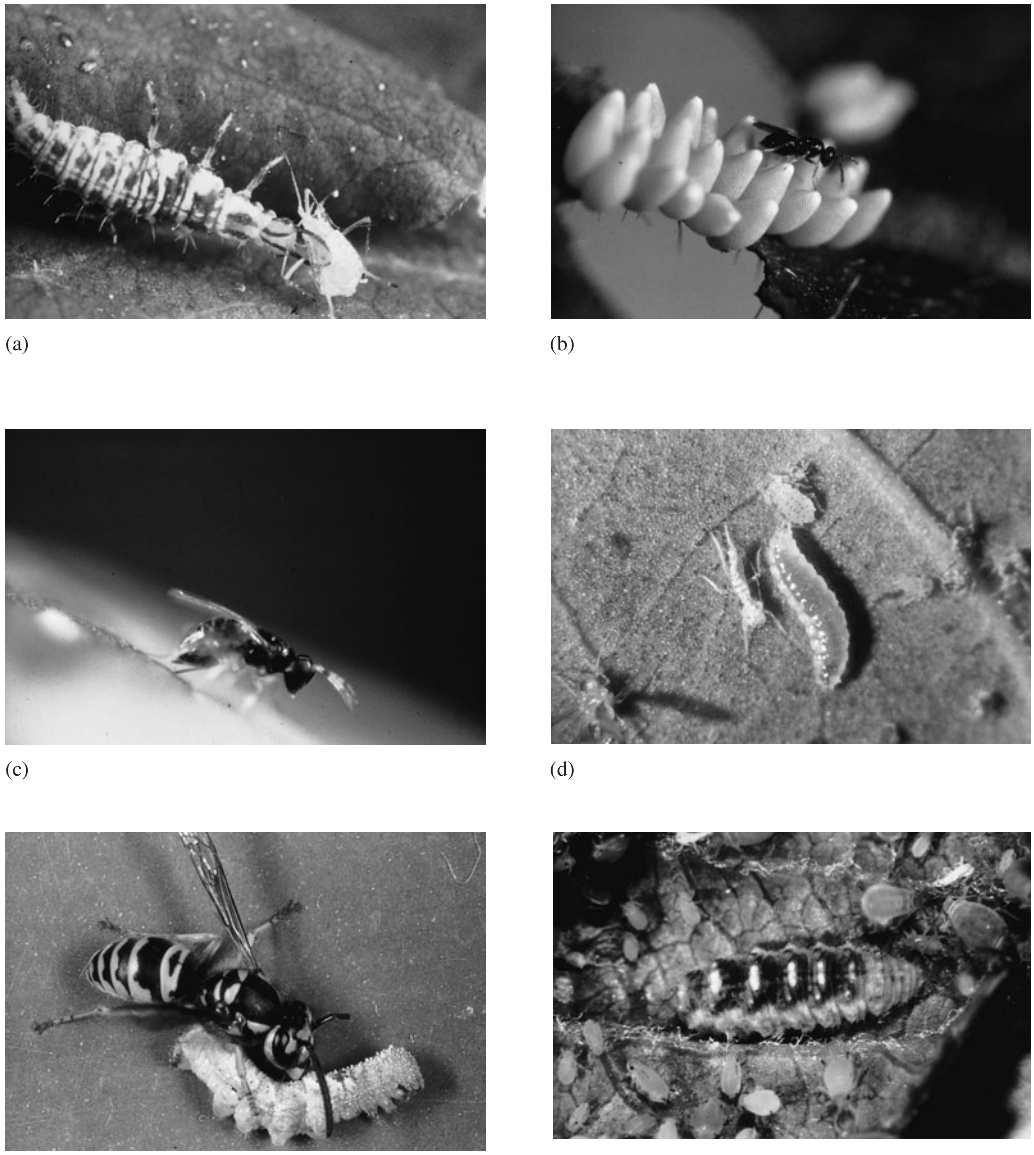

FIGURE 8–4 Selected examples of biological control. (a) A lacewing attacking prey. (b) *Tetrastichus gallerucae* attacking elm leaf beetle eggs. (c) Female *Aphytis* piercing scale insect with ovipositor. (d) Predaceous midge larva eating aphid. (e) Yellow jacket attacking a caterpillar. (f) Flower fly larva eating aphids. (*Source:* Photos provided courtesy of Oklahoma Cooperative Extension Service, Oklahoma State University)

certain soilborne diseases such as tomato wilts. The causal organisms of such diseases need the host plant in order to thrive and consequently cannot persist in the soil if the host is absent for about two to three years. Rotations are particularly effective in controlling diseases and pests whose causal organisms do not travel long distances (such as nematodes, weevils, certain wilts, and phytophthora).

8.8.2 SANITATION

Disease-causing organisms and insects remain in the field if infected plant debris is left on the ground. Sometimes infected plant remains have to be incinerated to kill the pathogens. Uninfected plant remains may harbor insects and disease organisms.

8.8.3 USE OF RESISTANT CULTIVARS

Plant breeders genetically manipulate the genotypes of plants to the advantage of humans. Through scientific inquiry, some of the protective strategies of plants in the wild have been discovered and studied. Some species resist certain diseases and pests because they have genes that condition such characteristics. Through breeding, scientists are able

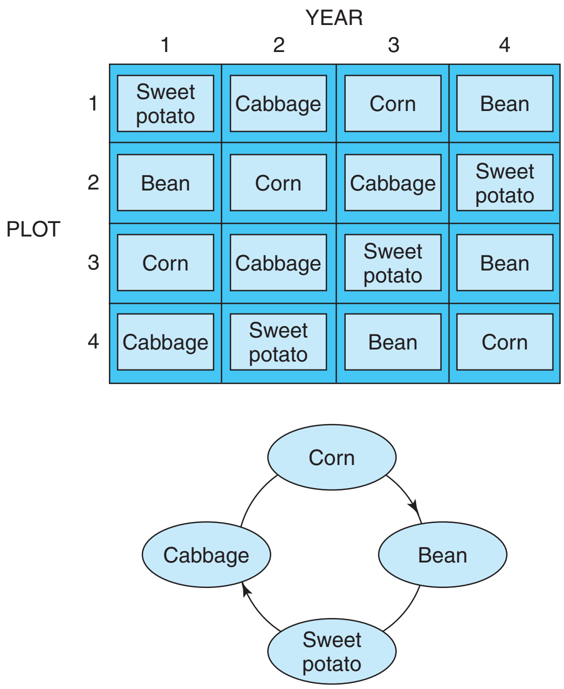

FIGURE 8–5 A crop rotation cycle.

to transfer the ability to resist diseases and pests from the wild into cultivated species and from cultivar to cultivar within the species. Sometimes resistance is even transferred across species and genus boundaries (see biotechnology). Resistant cultivars exist for most of the major pests of horticultural plants.

8.8.4 HOST ERADICATION

Host eradication is often a drastic preemptive method of pest control that involves the elimination of all susceptible hosts when a pathogen is known to have been introduced into the production area. This tactic is used to forestall an eminent disease epidemic. For example, all citrus trees in a production area where a pathogen has been introduced may be completely eradicated. On a small scale, host eradication is conducted in nurseries and greenhouses by rouging (removing off types) infected plants. Certain pathogens require two alternative hosts to complete their life cycles. In such a case, the less economically important host should be eliminated to interrupt the developmental cycle of the pathogen. For example, *Cronartium ribicola* requires pine and currant plants to complete its life cycle.

8.8.5 MULCHING

Plastic mulching has the capacity to trap heat, which causes the soil temperature to increase. The high temperature destroys some soil pathogens, including *Verticilium.*

8.9 Legislative Control

Various regulatory or legislative restrictions are placed on the movement of live plants and produce from one place to another. Controlling the spread of plant pests through laws is called **plant quarantine.** The purpose of such laws is to prevent the importation and spread of pathogens and insect pests into areas where they do not already occur. In the United States, the Plant Quarantine Act of 1912 established the laws that govern such restricted movement of materials. International and local (with and between states) restrictions are designed to curb the spread of diseases and pests that are associated with specific plants. Enforcement is especially strict with regard to plants that are of high economic importance.

Plant Quarantine
The use of legislation to control the import and export of plants or plant materials to prevent the spread of plant pests and diseases.

Plant breeding efforts may succeed in developing resistant cultivars to certain pests and diseases. However, the production enterprise can be wiped out with the introduction of a new strain of the pathogen from another country or region. When imports are detained in quarantine procedures, the inspectors observe the materials over a period of time (at least for the duration of the incubation period of the insect or pathogen), after which plants are released, treated, or destroyed, depending on the results during the detention.

Quarantines are not foolproof since their success depends on the experience of the inspectors. Further, pathogens may escape detection if they exist in less conspicuous stages in their life cycles, such as eggs or spores. Where plants are treated, certain latent infections may exist in seeds and other plant materials even after a period of growing plants in the field.

8.10 Mechanical and Physical Control

Pests may be controlled by a variety of mechanical or physical methods, as outlined here:

1. *Traps.* A number of mechanical control measures may be adopted to control pests in the greenhouse and field. A fly catcher is a strip of paper or polyethylene (commonly yellow in color) that has been coated on both surfaces with a sticky substance. Insects that land on the paper get stuck to it and eventually die (Figure 8–6). Larger mechanical traps are used to catch rodents. Certain lights are designed to attract insects, which then become trapped by other devices installed for that purpose.
2. *Handpicking.* In a small garden, caterpillars and other large bugs may be handpicked (not necessarily with bare hands) and destroyed.
3. *Barriers.* Rodents can be kept out of a garden by fencing it. A band of sticky paper (similar to a fly catcher) wrapped around the base of a tree prevents crawling insects on the ground from climbing up the tree.
4. *Tillage.* As a pest-control measure, tillage (cultivation) is used to remove weeds from the area.
5. *Mulching.* Mulching can be a method of mechanical control because a material such as plastic prevents weeds from growing through the material.

FIGURE 8–6 Polyethylene trap. *(Source: George Acquaah)*

6. *Heat treatment.* In the greenhouse, soil and other growing media are routinely sterilized before use. Depending on the temperature, sterilization may kill nematodes and water mold (at 50°C [122°F]). To kill bacteria, fungi, and worms, the temperature should be about 72°C (162°F). Weed seeds and some bacteria and viruses are killed at temperatures of about 82°C (180°F). When soil is oven sterilized, beneficial microbes (e.g., bacteria involved in the nitrogen cycle) may be killed, and toxic levels of salts (e.g., that of magnesium) may occur.

   Hot water is used in the greenhouse to clean certain dormant planting materials (e.g., seeds and bulbs) to remove pathogens. Heat treatment by hot air is used to dry cut surfaces of vegetative plant materials such as tubers to accelerate healing and thus prevent rot. For example, sweet potato may be air dried at 28 to 32°C (82 to 90°F) for about two weeks. Drying of grains and nuts is required before long-term storage. Fruits such as grapes and plums can be dried to produce raisins and prunes, respectively. The latter products can be stored for long periods without decay.
7. *Cold treatment.* Most postharvest protection of fresh produce is achieved through cold storage to maintain quality. Cold storage does not kill pathogens but slows their activity.
8. *Radiation.* Exposure of harvested products to the appropriate dose of radiation (e.g., gamma radiation) is known to prolong shelf life. Similarly, it is known that certain pathogenic fungi (e.g., *Botrytis* and *Alternaria*) produce spores only under conditions in which the light received contains ultraviolet (UV) radiation. Some greenhouses are glazed with UV-absorbing material so that radiation with a wavelength below 390 nanometers is not received within the greenhouse. Vegetables may be produced without infection by these pathogens.

Summary

Every organism has natural enemies. Biological control exploits natural defense mechanisms, managing and controlling them to increase their efficiency. Some plants have structural features that confer upon them resistance to particular pests. Certain plants contain chemicals such as pyrethrums that repel pests. Parasitism and prey-predator relationships occur in nature. Plant breeders are able to breed resistance to pests and diseases into cultivars. Diseases and pests can be controlled by adopting crop rotation practices. Some microbial sprays are available for use against a number of pests. Governments enact legislation to restrict the movement of live biological material from one place to another to limit the spread of contagious diseases. Such quarantine laws differ from place to place. Sometimes pests have to be physically or mechanically removed by, for example, trapping or handpicking.

Module 3

Chemical Control of Plant Pests: Insecticides

8.11 Insecticides and Their Use

Insecticides are chemicals used to control insect pests. They are classified in several standard ways.

8.11.1 CLASSIFICATION BASED ON KILLING ACTION

Chemicals used to control insect pests vary in the way they kill, which thus provides a basis for classifying insecticides. This method of classification is outmoded. Since insects differ in morphology and feeding habits, for example, it is critical that the insecticide attack the pest where it is most vulnerable. The various action modes under which insecticides may be classified are as follows:

1. *Contact action.* Insecticides that kill by contact action are also called *contact poisons.* They are effective when sprayed directly onto the pests or when the pests come into contact with poisons as they move on plant parts that have been sprayed. Once in contact with the pest, contact poisons attack the respiratory and nervous systems, with lethal consequences. Most insects succumb to contact poisons (e.g., malathion). Insects that hide on the undersides of leaves are hard to hit directly by contact poisons.
2. *Stomach action. Stomach poisons* must be ingested by the pest to be effective. As such, chewing insects (e.g., grasshoppers, beetles, and caterpillars) are effectively controlled by this class of poisons. Once ingested, the poison (e.g., rotenone) is absorbed through the digestive tract.
3. *Systemic action. Systemic insecticides* permeate the entire plant so that any insects that suck or chew are exposed to the poisons. They may be applied as foliar sprays or directly to the soil to be absorbed by roots. Insects cannot hide from this chemical since once they feed (whether by sucking or chewing) they ingest the toxin. The caution to observe with systemic poisons is that when applied to food crops, the produce must not be eaten until the toxin (e.g., orthene) has broken down to a safe level.
4. *Fumigation. Fumigants* are volatile chemicals that enter the target pest through its respiratory system. They are effective when used in closed systems such as storage houses and greenhouses. The soil can also be fumigated to control soilborne diseases such as root-knot nematodes. Though gaseous, fumigants have contact action. The fine particles settle on the body of the insect before entering through the pores.
5. *Repellent action.* Most insecticides are designed to kill pests. However, some chemicals, called *repellants* (e.g., Bordeaux mixture), repel insects (e.g., leaf hopper and potato flea beetle) from plants without any killing action.
6. *Attractant action.* Females of many insect species secrete certain chemicals called *pheromones* that attract male partners. Scientists have successfully synthesized these chemicals for use in luring male insects to traps, where they are caught and destroyed. The Japanese beetle moth and gypsy moth are easily baited by the use of pheromones. By baiting males and destroying them, most females are left unfertilized, thus reducing the population of the insects.
7. *Suffocation.* Scale insects are widely controlled by spraying oils that plug the breathing holes in their bodies and suffocate them.

8.11.2 CLASSIFICATION BASED ON CHEMISTRY OF ACTIVE INGREDIENT

Modern classification of insecticides is based on chemical composition, since many modern insecticides have both contact and stomach actions. The two broad classes of insecticides are based on the chemistry of the **active ingredient** (the compound responsible for the killing action).

Active Ingredient (A.I.)
The amount of actual pesticide in a formulation that is toxic or inhibiting to the pest.

Inorganic Compounds (Inorganics)

Insecticides made up of inorganic compounds or minerals are becoming increasingly less common. They are usually designed to kill by stomach action and include compounds such as arsenic (lead arsenate or calcium arsenate), sulfur, and fluorine.

Organic Compounds (Organics)

Organic insecticides may be *natural* or *synthetic.*

Natural (Botanicals) Botanicals are products from plants that have insecticidal effects. Many plant species produce organic compounds that are toxic to insect pests that feed on them. Plant organic substances are usually safe and nontoxic to humans. An example of a botanical is *pyrethrum,* which is obtained from chrysanthemum. Another organic substance is *nicotine,* which is obtained from tobacco plants and is an addictive substance found in cigarettes. Other botanicals are rotenone, ryania, and sabadilla. Many organic compounds act as stomach or contact poisons.

Synthetic Organic Compounds Synthetic organic chemicals are artificially compounded and are effective against a wide variety of insects and pests. On the basis of the active ingredients in chemicals, several classes of synthetic organic insecticides are identified:

1. *Organochlorines (chlorinated hydrocarbons).* Organochlorines are most readily associated with dicarbo-, dihydrotetrachloride (DDT), which is one of the earliest and most successful to be developed. It has wide application, being effective against horticultural field pests, mosquitoes, fleas, and flies. It has a long residual effect, working long after initial application. Organochlorines are not readily biodegradable, which contributes to their rapid buildup in the environment in the soil and water, as well as in the tissues of plants and animals and their products. They are thus not only toxic to humans through their action on direct contact but also through the ingestion of food that has been contaminated, such as dairy and meat products (i.e., through a cow eating contaminated feed) and fish from contaminated waters. Consequently, DDT (as well as its close relatives) has been banned in many parts of the world. Other organochlorines are chlordane, lindane, methoxychlor, heptachlor, and aldin.
2. *Organophosphates.* Unlike chlorinated hydrocarbons, organophosphates (or organic phosphates) have shorter residual action (breakdown within thirty days) and are more readily biodegradable. As such, they do not build up in the environment. However, certain types (e.g., parathion) are extremely toxic to humans. Organophosphates are generally effective insecticides. Malathion is less toxic and widely used as a horticultural spray. Other organophosphates include diazinon, phorate, dameton, and chlorpyrifos.
3. *Carbamates.* Carbamates are relatively safer to use than those previously described. They have somewhat low mammalian toxicity and short residual action (breakdown within seven days). They are effective against sucking and chewing insects. One of the earliest and most successful was carbaryl (trade named Sevin). Others are carbofuran, aldicarb, and propoxur.
4. *Pyrethroids.* Pyrethroids are synthetic equivalents of natural pyrethrins found in species such as chrysanthemum. They are less toxic to humans and effective against a broad spectrum of insects.

Fumigants Fumigants act in the gaseous state and are best used in closed environments (e.g., as storage pesticides) or injected into the soil. One of the most common types is methyl bromide, an odorless and colorless gas that is highly toxic to humans but is used widely to fumigate stored vegetables, seeds, fruits, and grains. It is also used to chemically sterilize soil mixes for use in greenhouses. Malathion is one of the most widely used fumigants of stored grain.

Spray Oils Spray oils are obtained by specially distilling and refining crude oils. They are used to combat scale insects and mites in orchard plants and ornamentals. A common form is called dormant spray.

Biologicals (Microbial Insecticides) Biologicals are commercially produced pathogens (e.g., bacteria, fungi, and viruses) that are applied to the foliage of plants to prey on specific insect pests. For example, commercial preparations of the bacterium *Bacillus thuringiensis* are applied to foliage to control several species of *Lepidoptera* (caterpillars).

8.11.3 FORMULATIONS OF INSECTICIDES

Formulation
The form in which a pesticide is offered for sale.

The chemical that actually controls the target pest *(active ingredient)* is not marketed or utilized directly but mixed with an inert ingredient to create what is called a **formulation.** Although some formulations are ready to use, others require diluting with a solvent or water before use. The two general types of formulations are dry and liquid.

Dry Formulations

Dusts Dusts are chemicals formulated as powders and applied as such without mixing or diluting. They usually contain low concentrations of the active ingredient or ingredients (about 1 to 10 percent) mixed with fine-powdered inert material (e.g., chalk, clay, or talc). Dusts are applied by using simple equipment called *dusters.* They are easy to apply but leave unsightly residue on foliage. Further, when applied in even the slightest wind condition, **drift** (blowing away in the wind) may be a problem. Drifting of a pesticide onto plants not intended to be sprayed may result in collateral damage.

Drift
The movement by air of pesticide particles outside the intended target area during or shortly after application.

Wettable Powders Wettable powders are concentrated chemicals formulated as dusts or powders that require dilution before use. Wettable powders are usually formulated to a high concentration of active ingredient (about 50 percent or greater). The addition of water decreases drift, but since the powders, even in solution, tend to settle, care should be taken to stir the mixture frequently so that the chemical is applied uniformly and at the desired rate. To increase the effectiveness of pesticides that require mixing with water before use, they are mixed with surfactants (agents that help pesticides to stick or spread better by lowering surface tension). This mixing is necessary because the plant surface naturally repels water to a varying extent. Wettable powders require constant agitation during use.

Granules Sometimes insecticides are formulated as coarse particles called granules. Granules are applied to the soil in the same way as granular fertilizer formulations are applied. They may require dissolution in water before roots can absorb the chemicals. Some may have to be incorporated into the soil. Systemic herbicides may be formulated this way. Other granules are designed to act like fumigants and thus need no water to initiate their effects. Granules are ready to use and pose little danger to the user. There is no danger of drift, and application requires only simple equipment such as a spreader.

Pellets Pellets differ from granules in that the former consists of particles that are uniform in size and of specific weight. Unlike granules, pellets can be applied by precision applicators.

Baits When an active ingredient is mixed with food or some other substance that attracts pests, the formulation is called a bait. Pests are attracted to baits and die when they ingest the poisons. Baits are usually low in active ingredient (less than 5 percent). They are commonly used to control indoor pests including mice and cockroaches.

Liquid Formulations

Aerosols Aerosols contain one or more active ingredients in a solvent. Household chemicals are frequently formulated as aerosols. These insecticides are contained in pressurized cans and are ready for use. They are very convenient to use but still require adherence to the safety measures that apply to all insecticides. The insecticides are propelled by special gases (propellants) including fluorocarbons (e.g., freon), isobutane, and isopropane. Aerosols may be formulated for use as smoke or fog in special generators under enclosed conditions (e.g., warehouses or greenhouses). The advantage of this formulation is that the entire space is filled with the pesticide. However, because aerosols are difficult to confine to the target, everything in the area is exposed to the pesticide. Injury due to inhalation is possible if aerosols are used without proper protection.

Emulsifiable Concentrates Emulsifiable concentrates consist of an active ingredient mixed in a petroleum solvent and an **emulsifier.** The emulsifier is an *adjuvant* that allows the formulation to be mixed with water. Emulsifiable concentrates are used widely in horticultural applications. They are adaptable to a variety of methods of application and equipment, including mist blowers, aerial applicators, and portable sprayers. Emulsifiable concentrates are desirable for several reasons, including the fact that, unlike wettable powders, they do not separate out in solution and hence do not require frequent stirring in the tank as dusts. They are mixed with water to the required concentration and leave very little residue on plants and fruits. However, mixing errors may occur, leading to a high potential for *phytotoxicity* (plant damage from chemicals).

Emulsifier
A surface-active agent that facilitates the suspension of minute droplets of one liquid in another to form a stable emulsion.

Flowables Flowables are suspensions of active ingredients. They are easy to use but may leave some residue on plants.

Fumigants Fumigants are formulations that produce gases during application. They may be liquids or solids. Fumigants are best applied in closed environments such as granaries, warehouses, and greenhouses. They are used in controlling some soilborne pests. A major advantage of fumigants is their ability to invade any space in the areas of application (such as cracks and crevices). A single application is usually effective in controlling the pest. The disadvantages include the need for special equipment, limitation to use in enclosed areas, and a high potential for human respiratory injury.

Solutions Sometimes, by including special additives in the formulation, the active ingredient may become soluble in water. Solutions have the advantage of leaving no residue on surfaces and requiring no agitation during use.

8.11.4 APPLICATION EQUIPMENT

The type of equipment used in insecticide application depends on several factors, including the area to be treated, the kinds of plants to be treated, and the formulation. Some equipment is mechanically operated, and others are motorized. Although some are handheld, others require the use of tractors and other means of transportation. Common insecticide applicators are described in the following sections.

Small-Scale Applicators

Pressurized Cans Aerosols come ready to use in pressurized cans (Figure 8–7). Special equipment is not needed. The pesticide is released by simply pressing down on the nozzle to deliver a fine, misty spray.

Compressed-Air Tank Spray A compressed-air tank is a much larger version of the handheld aerosol can, but the principle of operation is the same (Figure 8–8). The tank is partially filled with the correctly prepared chemical solution. The remainder of the space is occupied by air, which is compressed in a variety of ways depending on the design of the equipment. A handle may be used to mechanically pump air into the tank. The tank is attached with a flexible tube fitted at the tip with a nozzle for delivering fine sprays in patterns according to its design. The flexible tube enables the operator to spray hard-to-reach places. The design of the compressed-air tank sprayer may allow the equipment to be carried as a knapsack on the back or hung on the shoulder in a sling.

Atomizer Sprayer An atomizer sprayer is a simple handheld implement with a plunger that is pushed to draw air into the tube for dispersing the chemical solution in a fine spray at each stroke.

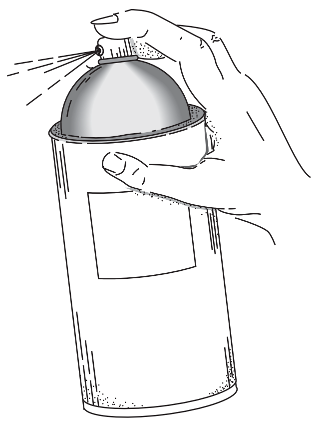

FIGURE 8–7 Pressurized can used for spraying aerosols.

FIGURE 8–8 Compressed-air tank sprayer. *(Source: George Acquaah)*

Dusters Pesticides formulated as dust are applied with the aid of dusters that may have plungers similar to those of atomizers. Some dusters have a squeezable bulb.

Large-Scale Applicators

Motorized Ground Applicators Motorized ground applicators work on the same principle as those for small-scale applications, except that certain functions that are manually performed in small applicators are automated in large applicators. The designs and sizes of the equipment vary:

1. *Portable (usually on the back of the operator).* Some compressed tanks are small enough to be carried around. They are fitted with small motors so that the operator needs only control the delivery tube and direct the spray at desired targets.
2. *Tractor-mounted.* The power take-off of the tractor may be used to provide the source of power for operating large sprayers, which are drawn or attached to the rear of tractors (Figure 8–9).
3. *Truck-mounted.* Some trucks are equipped with tanks and other devices for spraying or spreading (granular) pesticides, such as the fan jet applicator for orchards.

Aerial Applicators Where very large acreages must be treated, using airplanes or helicopters equipped with sprayers may be most economical. Some commercial companies specialize in aerial applications (Figure 8–10).

8.11.5 EQUIPMENT CALIBRATION

Chemicals used to control insects are very toxic to both pests and humans and as such should be used very carefully, only if needed, and also in the minimum strength or concentration needed to be effective. Overapplication is not only wasteful but may damage the plants and produce being protected and may be injurious to operators and consumers of the produce.

FIGURE 8–9 A tractor-mounted sprayer for trees. *(Source:* USDA)

FIGURE 8–10 Aerial application of pesticides. *(Source:* USDA)

Insecticide manufacturers provide adequate instructions with their products for their correct and safe use. The recommended rate of application should be adopted. Premixed insecticides are available for easy and ready application and are especially recommended for the novice.

Small applicators are usually not calibrated beyond that for which the manufacturer designed them, and as such the operator should be careful to deliver just the right quantity of the correctly mixed chemical. When liquid chemicals are used, a good application is one that covers the leaf surface to a point where dripping is about to occur. Dusts should similarly cover the leaf surface uniformly in one round of application. The amount applied depends on the distance between the leaf and the applicator.

Large applicators need calibration beyond the manufacturer's settings. Factors to take into account in calibration include the rate of application; the speed of the tractor, truck, or airplane; the nozzle type at the end of the sprayer; and the distance of the nozzle from the plants.

8.11.6 STRATEGIES FOR EFFECTIVE AND SAFE APPLICATION

Identify Pest

Treatment is most successful if the disease is identified in its early stages. In horticulture, then, the grower should visit the field or inspect the plants regularly. Certain insects are known to be perpetual pests at certain times in the growing season and should be anticipated. In insect control, the grower should determine whether the problem is caused by chewing or sucking insects. Chewing insects chew away the leaves especially, leaving holes, a network of veins, whitish patches, or partly eaten leaves. Stomach and contact poisons are effective for their control. It is more difficult to detect the presence of sucking insects. Plants are deprived of nutrients and may appear weak, grow less vigorously, or show rolled leaf edges. Sometimes, as in the case of aphids, these sucking pests can be found by turning over the leaf to examine the underside. Systemic and contact insecticides are effective against sucking insects.

Determine Economic Damage Potential

Certain insects are unable to inflict enough damage to cause the grower any significant economic loss. Since chemicals are not only expensive but hazardous to health, they should be applied only when the grower has determined that the potential loss is significant enough to warrant their use.

Insect Biology

Knowing the biology of the insect enables the timely application of insecticides for effectiveness. Insects must be controlled before they reach the stage where they cause devastation to the crop and before they have a chance to multiply. Insect pests are more susceptible when they are active than when they are in the egg or pupa stages. If, upon examination of the field or garden, only dormant stages are observed, chemical control should be delayed until the eggs hatch or adults emerge. Immediate control measures are required when mixed stages occur. In such a situation, a follow-up application should be made as appropriate (with respect to the life cycle of the insect) to coincide with the hatching of eggs.

8.11.7 HOUSEPLANT PESTS AND THEIR CONTROL

Common houseplant pests and their means of control are presented in Table 8–4.

8.11.8 VEGETABLE PESTS AND THEIR CONTROL

A selected number of vegetable pests and their means of control are summarized in Table 8–5.

TABLE 8–4 Suggestions for Control of Selected Houseplant Pests

Pest	*Plants Attacked*	*Control*
Mite	African violet, begonia, cyclamen, gloxinia, palm, geranium, and English ivy	Spray with dicofol
Mealybug	Begonia, African violet, gardenia, palm, dracaena, and gloxinia	Use malathion, diazinon, or orthene or remove by hand
Aphid	Gloxinia and begonia	Use malathion or remove by hand
Whitefly	Geranium, coleus, and begonia	Use malathion, rotenone, or orthene
Scale	Philodendron, azalea, citrus, fern, and palm	Remove by hand or use nicotine sulfate
Fungus gnat	Philodendron, fuchsia, and fern	Use nicotine sulfate

It is recommended, whenever possible, to use pesticides on plants on which they are registered and to follow the manufacturer's directions.

TABLE 8–5 Suggestions for Control of Selected Vegetable Pests

Pest	*Plants Attacked*	*Control*
Aphid	Cole crops (cabbage, broccoli, cauliflower, and brussels sprout)	Use diazinon or malathion
Mite	Bean (dry, lima, and snap) and tomato	Use malathion, diazinon, or kelthane
Caterpillar	Cole crops	Use Sevin, malathion, or thiodan
Cutworm or white grub	Cole crops	Use Sevin or diazinon
Earworm or fruitworm	Corn and tomato	Use Sevin or diazinon
Damping-off	Eggplant, pepper, cucumber, muskmelon, pumpkin, and tomato	Use captan or thiram
Downy mildew	Cole crops and beans	Use zineb or maneb
Powdery mildew	Bean, pumpkin, and squash	Use sulfur or benomyl
Wilt	Tomato, eggplant, and pepper	No chemical control
Cercospora leaf spot	Beet and carrot	Use zineb or maneb

It is recommended, whenever possible, to use pesticides on plants on which they are registered and to follow the manufacturer's directions.

8.11.9 LANDSCAPE PESTS AND THEIR CONTROL

A selected number of landscape pests and their means of control are presented in Table 8–6.

TABLE 8–6 Common Landscape Pests and Control

Pest	*Description and Suggested Control*
Lawn Pests	
Ants	Inhabit the soil in nests and destroy vegetation, leaving denuded spots in the lawn; their mounds are unsightly Control: Drench nests with pesticides (e.g., diazinon, Sevin, and malathion)
Chigger	Also called red bug, it is the larval stage of a small mite; it sucks sap from stems and causes stunted growth Control: Apply insecticide dusts and sprays (e.g., durban, Sevin, and diazinon)
Billbug	Also called a snout beetle, it damages the roots and crowns of grasses Control: Apply diazinon or carbaryl
Armyworm	Feeds on stems and leaves Control: Apply diazinon or carbaryl
Sod webworm	Also called a grass moth; as it feeds, it spins threads that bind soil and leaves into tubelike structures on the soil surface Control: Spray carbaryl, aspon, or diazinon
Japanese beetle	Destructive in both larval and adult stages; destructive also to trees, fruits, and other ornamentals Control: Apply diazinon
Leaf bug	Damaged leaf shows yellow dots initially and eventually yellows and dies Control: Apply malathion or diazinon
General Landscape Pests (Annuals, Perennials, Trees, and Shrubs)	
Aphid	Sucking insect found on the underside of leaves; causes puckering or curling of leaves; it secretes honeydew that attracts other pests (e.g., flies, mites, and ants) Control: Apply orthene, diazinon, or malathion
Caterpillar	Larva of many insect pests (e.g., cankerworm, gypsy moth, eastern tent caterpillar, webworm, California orange dog, and sawfly) feed on the foliage of landscape plants Control: Use diazinon, Sevin, or orthene
Borer	Larvae of certain insects (e.g., peach twig borer and other wood borers) damage flowering fruit trees and other ornamental trees Control: Apply dimethoate, bendiocarb, or lindane
Beetle	Adult and larva may inflict damage to plant foliage Control: Apply methoxychlor or carbaryl
Mite	Presence characterized by discolored patches on leaf as a result of feeding (sucking) from underneath the leaf; affected plants are less vigorous and may eventually brown and die Control: Apply dicofol, malathion, or kelthane
Gall	May occur on stems, branches, twigs, or leaves; leaf galls usually cause less damage, being primarily unsightly and reducing aesthetic value Control: Apply carbaryl, diazinon, or malathion
Scale	Scale insects overwinter as eggs or young. They may be armored or unarmored according to scale characteristics. They suck plant juice by using their piercing mouthparts. Control: Apply dormant oil, acephate, or carbaryl

SUMMARY

Chemicals used to control insect pests are called insecticides. On the basis of killing action, they are classified as contact poisons, stomach poisons, systemic insecticides, fumigants, repellents, attractants, and those that kill by suffocation. Active ingredients of insecticides may be organic or inorganic. Organic insecticides may be created from natural or synthetic compounds. Synthetic organic compounds have several classes: chlorinated hydrocarbons (e.g., DDT), organophosphates (e.g., malathion), carbamates (e.g., Sevin), pyrethroids (synthetic pyrethrins), and others. Insecticides may be formulated as dusts, wettable powders, emulsifiable concentrates, granules, or aerosols. Insecticide applicators vary in size from handheld to aerial sprayers.

MODULE 4

CHEMICAL CONTROL OF PLANT PESTS: HERBICIDES

OVERVIEW

Herbicides are chemicals used to control weeds. Chemicals are the method of choice in killing weeds in large-scale plant production operations. Although their use facilitates plant production, the collateral damage to the environment and health hazard they pose to humans often detract from their role in agricultural production. Herbicides are also convenient for controlling weeds in the landscape and along railroads and highways. They work by interfering with the metabolic processes of the plant. The challenge in their design and application is to minimize damage to cultivated plants while killing unwanted plants. Indiscriminate use of herbicides should be avoided. Certain chemicals are restricted for use by professionals (licensed or certified applicators). As with all toxic chemicals, strict adherence to the directions for their safe use minimizes the danger to the health of humans and cultivated plants.

8.12 CLASSIFICATION OF HERBICIDES

Herbicides may be grouped in one of several ways—by selectivity, how they kill (mode of action—by contact or systemic [translocation]), timing of application, and chemistry.

8.12.1 SELECTIVITY

On the basis of selectivity, there are two types of herbicides: selective and nonselective.

Selective Herbicides

Selectivity
The ability of a pesticide to kill some pests and not others without injuring related plants or animals.

True **selectivity** is achieved when an herbicide applied at the proper dose and timing is effective against only certain species of plants but not against others. *Selective herbicides* are designed to kill only certain plants without harming others. Generally, they are designed to discriminate between broadleaf and narrowleaf (grasses) morphologies. Selective herbicides are the most widely used because most situations require only certain plants to be killed but not others. For example, in lawn (grass), broadleaves of any kind are not desired. Broadleaf weeds such as dandelions and wild mustards can be safely eliminated by spraying the lawn with a selective herbicide such as (2,4-dichlorophenoxy acetic acid), which kills only broadleaf plants. Certain chemicals can be manipulated to be selective by changing the concentration at which they are applied. At a high rate of application, a particular herbicide may kill a certain species but fail to do so at a lower concentration. However, even at lower concentrations, these chemicals remain toxic and should be handled with care. As such, by spraying older cultivated plants with low application rates, younger weeds may be controlled without harming the desired crop plants.

Nonselective Herbicides

Nonselective herbicides literally kill all plants exposed to them—weeds and crops alike. These nondiscriminating herbicides are used to control weeds in areas where no plant growth is desired, such as driveways, parking lots, and along railroad tracks. Examples of nonselective herbicides are Roundup and atrazine. Nonselective herbicides may be made selective through manipulation of the concentration or rate of application. For example, using atrazine at low concentrations decreases its killing action to certain plant types.

8.12.2 CONTACT VERSUS TRANSLOCATED

Some chemicals use two modes of action. *Contact herbicides* kill by direct contact with plants and are very effective against annual weeds. To be most effective, the application must completely cover the plant parts. **Systemic (translocated) pesticides** are absorbed through either roots or leaves. Those applied to the soil have residual action and thus are most suitable for controlling perennial weeds. Complete coverage is not necessary when using these chemicals.

Systemic Pesticide (translocated)
One that is absorbed and moved from the site of uptake to other parts of the plant.

8.12.3 TIMING OF APPLICATION

Regarding crop (or weed) growth cycle, three stages are important for herbicide application.

Preplant

Preplant herbicides are applied to the soil before planting the crop. Depending on the kind, it may or may not require incorporation into the soil to be effective. Preplant applications are made at low rates or concentrations and have the advantage of damaging weeds when they are in the most vulnerable seedling stage.

Preemergence

Like preplant herbicides, preemergence herbicides are applied after planting the crop, either before crops or weeds emerge or after crop emergence but before weed emergence. These herbicides kill only germinating seedlings and not established plants. Whenever soil is disturbed, weeds arise. A newly planted ground cover may be sprayed with a preemergence herbicide to suppress weeds that may have been stirred up.

Postemergence

Herbicide application after cultivated plants have emerged is described as postemergence treatment. In several situations, such as occurs in orchards, the grower has no choice but to adopt postemergence application. However, the grower may choose to apply a herbicide before weeds emerge (preemergence). It is important, therefore, that emergence always be in reference to either the weed or the crop plant.

8.12.4 CHEMISTRY

Herbicides may be classified according to their chemical nature as either organic or inorganic.

Organic Herbicides

The various classes of organic herbicides include organic arsenicals and phenoxy herbicides.

Organic Arsenicals Organic arsenicals are translocated herbicides and thus are effective against plant species with underground structures (e.g., rhizomes and tubers), as occurs in nutsedges and johnsongrass. They are relatively less toxic than inorganic chemicals and are salts of arsenic and arsenic acid derivatives.

Phenoxy Herbicides Phenoxy herbicides are also referred to as hormone weed killers. One of the most common phenoxy herbicides is 2,4-D. Another is 2,4,5-trichlorophenoxy acetic acid, which is used in the control of woody perennials and is associated with the Agent Orange episode in Vietnam, where it was used to defoliate large forest areas. The latter has been banned by the EPA.

Diphenyl Ethers An example is Fusilade.

Substituted Amide These herbicides are readily biodegradable by plants and in the soil. An example is Diphenamid.

Substituted Ureas Selective preemergence herbicides, substituted ureas have strong residual effects in the soil. An example is Siduron.

Carbamates This class of herbicides is formulated generally for preemergence application. An example is EPTC.

Triazines An example of this class of herbicides is Simazine. It is used in driveways and around patios.

Aliphatic Acids An example is Dalapon, used to control grasses.

Arylaliphatic Acid An example is DCPA.

Substituted Nitriles These herbicides are fast acting and also have broad action. An example is Dichlobenial.

Bipyridyliums Examples are diquat and paraquat, called contact herbicides.

Inorganic Herbicides

Inorganic herbicides have great residual effects and thus are strictly regulated by the EPA. They are not recommended for use around the house.

8.13 Formulations

Herbicides are formulated to be applied as either *liquids* or *granules.*

8.13.1 LIQUIDS

Liquid formulations are applied as either wettable powders or water-dispersible granules in water. Most herbicides are applied as sprays, making the sprayer the most important implement in herbicide application. Sprayers come in a variety of designs and may be hand or power operated. Sprayers may be mounted on trucks or tractors. Sprayer application may also be at low volume (high herbicide concentration delivered in small amounts per unit area) or high volume (low concentration of a herbicide applied in large amounts per unit area).

8.13.2 GRANULES

When granules are used, they may be applied at low or high rates. When applying at low rates (small amounts of granules), a carrier material such as sand may be mixed with the granules to increase the bulk for more effective and uniform application. Granular formulations are more expensive than others because of the bulk and shipping costs.

Further, they do not provide uniform application. However, the equipment for application is less expensive and there is no need to haul large amounts of water to the field during application.

8.14 Methods of Application

Depending on the areas to be treated and the distribution of vegetation, herbicides may be applied in several ways, including broadcast, band, and spot application.

1. *Broadcast application.* When the entire area is to be treated, the herbicide may be broadcast without fear of damaging other plants. Liquids and granules may be broadcast. Aerial application by aircraft is a form of broadcasting.
2. *Band application.* In orchards and vineyards, the paths between rows may be readily cultivated, but the plant canopy may not permit the equipment to get close enough to clear all of the weeds from around the stem. Herbicides may be applied by band application to control the narrow strips of weeds around plants.
3. *Spot application.* Weeds that break through gaps in the driveway or walkway and masses of weeds concentrated in a small or hard-to-reach area are often spot treated.

8.15 Factors Influencing Herbicide Effectiveness

Herbicides are applied directly to plants or the soil. As such, plant and soil conditions, coupled with the conditions in the general environment in which application occurs, influence the effectiveness of herbicides. Although some of these factors are environmental, the effectiveness of herbicide application depends largely on the operator. Some sources of error in application are discussed in the following paragraphs.

1. *Weed identification and assessment of infestation.* Since a weed is simply a plant out of place, a volunteer corn plant in an orchard is a weed. The presence of a few plants of corn in a tomato field does not warrant chemical control. The corn (the weed) may be cut down or uprooted by hand. The weeds to be controlled must be correctly identified for the correct treatment to be prescribed.
2. *Herbicide selection.* Since most herbicides are selective, it is important that the correct plant species be identified so that the appropriate chemical is used.
3. *Time of application.* Certain weeds are extremely difficult to eradicate. However, their spread may be slowed if the weeds are controlled before they flower so that they do not bear seed. Also, since herbicides may be applied as preplant, preemergence, or postemergence herbicides, it is important that they be applied at the correct time in relation to the emergence of the crop or weed. If one is depending on rainfall to wash the herbicide into the soil, the operator should follow the weather forecast to ensure that rain will fall within about a week after application or make provisions for irrigation. Not all herbicides require rainfall (water) after application to be effective.
4. *Correct rate of application (equipment calibration).* The recommended rate of application should be adopted in a weed-control program. The equipment used should be properly calibrated to deliver the desired rate. If the chemical is overdiluted, the application will be a waste of time and money since the weed will not be controlled. On the other hand, too high a rate of application may injure desired crops and also waste money.
5. *Good ground coverage.* If the ground is not completely covered during an application, weeds may germinate and survive at untreated spots. This result may necessitate an additional spot application or manual removal of weeds, increasing production costs.

6. *Weather factors.* Although little rainfall may be unsatisfactory in some situations, excessive rain may wash granules away. Spraying in windy conditions causes excessive drift that may damage crop plants.
7. *Age of weeds.* Herbicides are more effective on younger plants than older ones. Weed-control measures should be effected before weeds are mature.
8. *Soil characteristics.* Herbicides such as Dacthal are readily absorbed by the soil organic matter, making them less effective on soils that are high in organic matter. Clay soils also absorb certain herbicides. In such situations, a higher rate of application may be necessary for better results.

8.16 Indoor Weed Control

Weeds should not become a problem indoors, especially in the home. Most houseplants are planted in pots or suitable containers. Weeds may occasionally arise because of the source of the growing medium. Such unwanted plants should be uprooted by hand. There is absolutely no need to use chemicals to control weeds in the home. In greenhouses without concrete floors, weeds could become a problem if neglected. Weeds could also arise through cracks in the concrete. Such weeds may be spot treated with chemicals. Certain herbicides are approved for use in greenhouses.

8.17 Suggested Herbicides for the Landscape

Common herbicides used in ornamental plant culture are presented in Table 8–7.

8.18 Suggested Herbicides for the Home Garden

Weed control in the home garden can be accomplished without chemicals. Annual weeds (e.g., purselane, pigweed, and crabgrass) and perennial weeds (e.g., bindweed and quackgrass) can be controlled by hoeing, mulching, cultivating, or pulling by hand. Chemicals such as Dacthal may be used if necessary.

TABLE 8–7 Suggested Herbicides for the Landscape

Problem Weeds	*Suggested Herbicides*
Lawn	
Annual grass weeds	Trifluralin
	Dacthal (DCPA)—apply as preemergent
Annual broadleaf weeds	Bromoxynil
Perennial and other weeds	Glyphosate—as spot treatment; use for nonselective control or as preemergent for new lawns
General control of broadleaf weeds	2,4-D amine
Flower beds	
Annual weeds	Dacthal
Perennial weeds	Eptam (EPTC)
Around shrubs and trees	
Annual weeds	Dacthal, Bensulide
Perennial grass weeds	Eptham, Glyphosate

Summary

Herbicides are chemicals used to control weeds. They may be classified according to selectivity (as selective herbicides, which kill only certain plants, or nonselective herbicides), timing of application (as preplant, preemergence, or postemergence herbicides), mode of action (as either contact or translocated), and chemistry (as either organic or inorganic herbicides). Herbicides may be formulated as liquids or granules. They are applied by either broadcast, or band application. Sometimes they are applied as a spot application to control highly localized weed infestation. The effectiveness of herbicide application depends on several factors, including plant species, type of herbicide, time of application, weather factors, age of weeds, and soil factors.

Module 5

Greenhouse Pest Control

Greenhouses are enclosed structures and hence have environmental conditions that are different from the general open environment. Further, the greenhouse environment can be controlled, and thus the pest incidence can be controlled to some extent. However, even with best efforts, certain pests occur in greenhouses.

8.19 Common Greenhouse Insect Pests

Some of the most common and economically important greenhouse pests are described in the following list.

1. *Aphids.* The most common aphid found in greenhouses is the green peach aphid *(Myzus persicae)*. They may be winged or wingless. Whereas the winged green peach aphids are brown in color, the wingless ones are yellowish-green or pink. Aphids attack a wide variety of greenhouse plants. Younger leaves that are attacked become distorted, and older leaves show chlorotic patches.
2. *Fungus gnats.* Important species of the fungus gnat are *Bradysia* spp. and *Seiara* spp. Gnats are gray-colored, long-legged flies. They live on the soil. The stage in their life cycle that constitutes a pest problem is the larva stage. Gnat larvae are white worms with black heads. They prefer soils that are rich in organic matter, feeding on soil fungi and decaying organic matter. However, they can also feed on underground storage organs and the roots of young seedlings.
3. *Leaf miners.* Leaf miners are insects that in the larval stage tunnel between the outer layers of leaves. Their activity blemishes leaves severely. Chrysanthemums are particularly susceptible to leaf miner attack; the chrysanthemum leaf miner is called *Phytomyza atriconis.* Other species exist.
4. *Mealybugs.* Mealybugs (*Pseudococcus* spp.) are oval-shaped piercing insects that secrete a waxy covering over their bodies, causing them to appear white. This waxy layer forms a protective covering that makes pesticidal control of bugs difficult. To be most effective, mealybugs are controlled by spraying the nymphs. The economic damage they cause to plants is similar to aphid attack. Mealybugs also secrete honeydew, which attracts black mold to grow on the plant.
5. *Mites.* Mites belong to the spider or scorpion family (Arachnida). They are very tiny in size and develop well under conditions of high humidity and low temperatures of about 16°C (60°F). A common species is the *Steneotarsonemus pallidus* (Cyclamen

mite). However, the most important mite in greenhouse production is the two-spotted mite (or red spider) *(Tetranychus urticae)*. Mites usually hide on the undersides of leaves. The red spiders may spin unsightly webs over leaves and flowers.

6. *Scale insects.* Scale insects are similar to mealybugs. Some of them also secrete honeydew and thus cause black mold growth to appear, as in mealybug attack. They may be armored and have rubbery outer coatings or be without such a coating and armor.
7. *Slugs and snails.* Slugs and snails are mollusks (which include shell animals such as oysters). These pests chew tender seedlings and leaves. They are nocturnal in feeding habit and thus hide during the day under stones, leaves, and other objects; they prefer very damp environments. Slugs and snails gain access to the greenhouse area through growing media and attachment to plants and containers.
8. *Thrips.* Thrips are very tiny insects. They feed on a wide variety of greenhouse plants, usually congregating on buds, petals, or leaf axils. A gentle tap on the hiding place causes aphids to become dislodged. During feeding, aphids scrape the surface of the leaf, resulting in whitish streaks that may eventually turn brown. They excrete brown droplets that eventually turn black.
9. *Whiteflies.* Whiteflies are also tiny insects. The greenhouse whitefly *(Trialeurodes vaporariorum)* is covered with a white, waxy powder. Greenhouse plants most affected by whiteflies include petunia, poinsettia, ageratum, chrysanthemum, and tomato. Since they are attracted to the color yellow, sticky strips are usually suspended over benches to trap these flies. Whiteflies also secrete honeydew.
10. *Caterpillars.* Caterpillars, or the worm stage of some moths, are a menace to greenhouse production. Examples are corn earworms (which attack buds and succulent parts of plants such as chrysanthemum), European corn borers (bore through stems), cutworms (attack shoots), and beet armyworms (attack plants such as geranium, chrysanthemum, and carnation).

8.20 Common Greenhouse Diseases

8.20.1 VIRUSES

Viruses, as previously indicated, cause stunting of affected plants and discoloration of leaves in the form of streaks, rings, or blocks. They are seldom transmitted by seed, exceptions including tomato ring spot and tobacco ring spot, which affect geraniums. Other greenhouse viruses include carnation mottle, carnation mosaic, chrysanthemum stunt, and chrysanthemum mosaic.

8.20.2 BACTERIA

Few greenhouse bacterial diseases exist. Major diseases include bacterial blight of geranium *(Xanthomonas pelargonium);* bacterial leaf spot of geranium and English ivy *(Xanthomonas hederae);* bacterial wilt of carnation *(Pseudomonas caryophylli);* and crown gall of rose, chrysanthemum, and geranium *(Agrobacterium tumifasciens).*

8.20.3 FUNGI

Major greenhouse fungal diseases include the following:

1. *Powdery mildew.* Mildew occurs under conditions of high humidity. Plants affected by powdery mildew have a whitish, powdery growth on plant parts. Some plants (e.g., rose) are susceptible at an early stage and thus become very distorted. In other species, such as zinnia and dahlia, powdery mildew occurs on older plant parts. In the latter scenario, the economic damage is blemishing, which makes plants less aesthetically desirable and thus not usable as cut flowers.

Sulfur may be applied for both prevention and control, along with monitoring the humidity and temperature of the greenhouse to prevent high humidity levels.

2. *Botrytis blight. Botrytis* blight is known to affect numerous species of plants. The species *Botrytis cinerea* (common gray mold) causes rots and blights of many greenhouse plants, including carnation, chrysanthemum, rose, azalea, and geranium. Depending on the species, the stem, leaf, flower, or other tissue may be affected. Observing greenhouse sanitation reduces the incidence of *Botrytis.* Ample ventilation is required, as is preventing irrigation water from splashing on plants.
3. *Root rot.* Three important causal agents of root and basal rots are *Rhizoctonia, Phythium,* and *Thielaviopsis.* These fungi are soilborne and transmitted by mechanical means such as splashing of water during irrigation and contamination of tillage tools and containers. They are controlled by soil pasteurization and sterilization of tools, containers, and greenhouse bench tops. Root media should be well drained. Observance of good sanitation is necessary to control this pest.
4. *Damping-off.* When damping-off occurs before germination of seeds, the seeds tend to rot in the soil. Postemergence infection causes young seedlings to topple and eventually die. Preemergence damping-off is caused by *Phythium,* and *Rhizoctonia* causes damping-off of seedlings. Since the fungi are soilborne, damping-off is controlled largely by planting seeds in a pasteurized soil or medium that is well drained. Also, care should be taken when watering to prevent splashing.
5. *Verticillium wilt. Verticillium* wilt is caused by a fungus that inhabits the soil. It affects a wide variety of plants including rose, geranium, begonia, and chrysanthemum. The symptoms vary from one species to another and depend also on the stage of plant development. Some plants may not show any symptoms until they reach the reproductive stage, at which time the flower buds wilt. Generally, affected plants show wilting and yellowing of leaf margins, starting from the lower and older leaves. Once infected through the soil, the fungus grows upward in the plant through the xylem tissue. Thus, cuttings from infected plants also spread the disease. Soil pasteurization is effective in controlling the disease.

8.20.4 NEMATODES

Nematodes (eelworms) are soilborne organisms, one of the widely known species being the root-knot nematode (*Meloidogyne* spp.). Infected plants have knotted roots and amorphous growth of the roots. The knots in the roots interrupt vascular flow, and affected plants soon experience stunted growth. Soil pasteurization and general aeration help to control this pest.

Certain nematodes cause leaf spots and eventually leaf drop. The spots start on the lower sides of leaves as light-colored brown spots that eventually turn black. Leaf nematodes require plant materials to survive in the soil. Thus good sanitation, including removal of plant debris, helps to control these organisms. Spraying the affected plant foliage with appropriate pesticides (e.g., parathion or diazinon) is an effective control measure.

8.21 Control Methods

The common methods of pest control in the greenhouse include:

1. *Pesticide spray.* Most greenhouse pest problems are controlled by spraying appropriate chemicals. The pesticides may be emulsifiable concentrates or wettable powders. Certain pesticide formulations are approved for use in greenhouses.
2. *Aerosol.* Aerosols are usually applied in the greenhouse when immediate killing of pests is desired, since very little residue is left on the plant, and, even then, only the upper surfaces of leaves show residue. Aerosols should be applied to dry

leaves on a calm day to prevent the material from being drawn out of the greenhouse through openings. The greenhouse must usually be kept closed overnight after an aerosol application.

3. *Dust.* Dusts are not commonly used to control pests in the greenhouse.
4. *Fog.* Fogs are applied by using fogging equipment. Fogs are oil based and usually prepared to 10 percent strength of the regular insecticide or fungicide. The fogging equipment heats up the pesticide, which breaks down into a white fog that spreads throughout the facility. However, leaks in the greenhouse may cause uneven distribution of the gas.
5. *Smoke.* Unlike fogs, dusts, and sprays, smokes do not require special equipment for application. Instead, a combustible formulation of the pesticide packaged in containers is placed in the center isle of the greenhouse and ignited. Smokes are generally not as phytotoxic to foliage as other gas applications. When in use, all vents and doors must be closed.
6. *Application to root media.* Soilborne diseases and pests may be controlled by drenching the soil with pesticides. Granules or powder formulations may be applied to the soil surface and washed down in irrigation water.

8.22 Control Strategies

To be effective, the timing of application of the pesticide is critical. Three factors should be considered regarding the intervals between pesticide applications:

1. The residual life of the pesticide
2. The life cycle of the pest
3. The killing action of the pesticide

It is important to know the life cycle of the insect to be controlled and the developmental stage at which it is most susceptible to the pesticide. For example, if the insect has a seven-day life cycle and the pesticide to be applied (e.g., smokes and aerosols) is not effective against eggs, the pesticide should be applied at six-day intervals. The rationale is that the first application will kill most of the adults. Since aerosols and smoke leave no residue, the eggs will hatch on schedule. However, before they develop to adult stage, when they can lay a new batch of eggs, the next round of treatment kills that population, along with any that survived the first treatment. The survivors of the first round of treatment have a chance to lay eggs, which will be missed by the second application. However, the eggs will hatch within six days, in time for the third application. This third application is usually adequate in completely eradicating the pest within twelve days. Usually, as temperatures increase, the life cycle of the pest increases in length. Spraying intervals of between five and seven days are generally effective in controlling many greenhouse insect and mite attacks.

When controlling mites, keep in mind that mites are known to develop resistance to pesticides rapidly. They are also known to occur as a heterogeneous mixture in a given population. A three-miticide cycle of control is recommended. First, one miticide should be selected for use at one time until the mites develop resistance to it. A second miticide should then be selected and used repeatedly until resistance against it has also been developed, followed by use of the third pesticide. When resistance to the third pesticide has been developed, the first should be reintroduced, since by this time the population would have lost its resistance to the first pesticide. The three-miticide cycle is then repeated.

Certain pesticides are specially formulated or approved for greenhouse application. Pesticides are also registered for use on certain plants. States may have preferred chemicals for use under various circumstances. It is important to check with appropriate local authorities such as the cooperative extension service to find out which pesticide is best for use on a particular occasion.

8.23 Preventing Greenhouse Diseases

The greenhouse is an enclosure in which plant growth factors are under artificial control. The conditions are often ideal for plant production and similarly favor greenhouse pests associated with the specific production. Diseases can be prevented by adopting several cultural practices: environmental control; strict observance of sanitation; use of clean, healthy plant materials; and use of sterilized soil.

8.23.1 ENVIRONMENTAL CONTROL

One problem associated with environmental control that is a frequent source of diseases is condensation. This problem is caused by the combination of temperature and moisture content of the greenhouse atmosphere. During the daytime, the sun causes air inside of the greenhouse to warm. Warm air holds more moisture than cold air. Thus, during the night when it is cooler, the warm air is progressively cooled until it reaches the dew point. At this stage, water starts to condense on the surfaces of plants and greenhouse structures. Drops of water on plant leaf surfaces provide the condition needed for spores of pathogens to germinate and thus promote the incidence of diseases such as *Botrytis* blight caused by the gray mold fungus.

To reduce condensation, the greenhouse should be equipped with exhaust fans and ventilation that will circulate air by bringing in fresh, cooler air periodically. If the vents are closed, still air can be avoided by using a horizontal airflow system to move the air through the greenhouse and reduce the incidence of cold spots, which cause condensation of moisture.

Greenhouse structures, including floors, have surfaces that can retain water over a period of time. High humidity levels favor diseases such as mildews. When plants are watered in the morning, the moisture on solid surfaces has enough time to evaporate. With appropriate ventilation, excessive humidity is eliminated. Excessive moisture in rooting media can be avoided by using well-drained media and also watering only when needed.

8.23.2 SANITATION

Weeds are known to harbor insects and disease-causing organisms, apart from being unsightly. They may be mechanically removed or controlled by using approved herbicides.

Debris remaining after a crop harvest should be promptly removed and disposed of. Plant material from horticultural practices such as pinching and disbudding should be gathered during the operation and discarded outside of the greenhouse. Decaying plant materials provide a fertile medium in which disease organisms thrive.

Greenhouse containers—flats, pans, and pots—should be sterilized before reuse. Clay pots may be steam sterilized. Pots can be chemically sterilized by soaking containers in a formaldehyde solution (1 part formalin [40 percent formaldehyde] to 100 parts water) for thirty minutes, followed by rinsing and air drying. Apart from containers, all greenhouse tools should be cleaned and sterilized after use. First, the dirt should be scraped off and the tools washed with water; the tools should then be dipped in household bleach (sodium hypochlorite) at 1 part bleach (5.25 percent sodium hypochlorite) to 9 parts water. Watering hoses should not be left on the greenhouse floor such that the ends touch the floor; they should be hung with the ends turned upward.

Greenhouse benches should be sterilized periodically. All workstations should be cleaned and wiped with disinfectant or bleach after use. Wooden benches and flats may be painted or dipped in a 2 percent solution of copper naphthenate. Soil and growing media used in the greenhouse should be sterilized. If bulk root media are purchased, they should be stored such that they will not become contaminated by unsterilized soil or water.

Restricted access to parts of the greenhouse where preparation takes place (e.g., media and seeds) should be enforced to prohibit the general public from entering those areas. Visitors and customers come from a variety of places and may carry infected soil on the soles of their shoes. It is important to routinely clean and disinfect the floor at frequent intervals.

Summary

Because of their enclosed nature, greenhouses have specific pest problems. The most common insect pests include aphids, fungus gnats, leaf miners, mealybugs, mites, scale insects, slugs, snails, thrips, whiteflies, and caterpillars. Common diseases include a variety of viral and bacterial problems and fungal diseases (e.g., powdery mildew, *Botrytis* blight, root rot, damping-off, *Verticillium* wilt, and nematodes). Because of the enclosed condition, pesticide formulations for greenhouses such as smokes, fogs, and aerosols are suitable for use.

When controlling pests, it is important to know the life cycle of the organism, the residual life of the chemical to be used, and the pesticide's mode of action. The environment in the greenhouse can be controlled and monitored to reduce pest incidence. Further, observance of good sanitation and hygiene, as well as sterilizing growing media, tools, and other greenhouse structures, reduces the incidence of disease.

References and Suggested Reading

Bohmont, B. L. 1997. *The standard pesticide user's guide,* 4th ed. Englewood Cliffs, N.J.: Prentice Hall.

Boodley, J. W. 1996. *The commercial greenhouse,* 2d ed. Albany, N.Y.: Delmar.

Cravens, R. H. 1977. *Pests and diseases.* Alexandria, Va.: Time-Life.

Dixon, G. R. 1981. *Vegetable crop diseases.* Westport, Conn.: AVI Publishing.

Klingman, G. C., F. M. Ashton, and L. J. Noordhoff. 1982. *Weed science: Principles and practices,* 2d ed. New York: John Wiley & Sons.

Nelson, P. V. 1985. *Greenhouse operation and management,* 2d ed. Retson: Retson Publishing.

Prone, P. 1978. *Diseases and pests of ornamental plants,* 5th ed. New York: John Wiley & Sons.

Outcomes Assessment

1. In disease control, prevention is better than cure. Discuss, giving specific examples, how diseases may be prevented in horticultural production.
2. Discuss specific methods that may be used to reduce or eliminate the presence of a pathogen's inoculum during horticultural production.
3. Discuss the concept of integrated pest management as a pest-control strategy.
4. Discuss the pros and cons of the use of pesticides in crop production. What can a producer do to minimize the adverse effects of the use of pesticides?
5. Describe the information one can obtain from a pesticide label.
6. If a producer does not want to use pesticides in crop production, suggest an alternative approach that may be adopted to control pests.