# Plant Agriculture Pest Control: A Study Manual for Applicators



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Photo "Winter smother crop of yellow mustard," Clyde Elmore
Photo "Plastic mulch in an olive orchard," Paul M. Vossen

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# Plant Agriculture Pest Control: A Study Manual for Applicators

# Introduction

*Plant Agriculture Pest Control*, number 10 in the University of California's Pesticide Application Compendium, is meant to be studied along with *The Safe and Effective Use of Pesticides*, 3rd Edition. Taken together, they contain information you must know to pass the Plant Agriculture (Category D) exam for a qualified pesticide applicator certificate (QAC) or license (QAL) from the State of California. Category D covers application of pesticides to food, feed, fiber, or ornamental crops, grasslands and other noncrop areas, and rice and similar crops grown in wet or flooded fields. Fumigation, aerial applications, or applications to running or standing water are not covered.

Knowledge expectations (KEs) are short statements that describe what you need to know. They will help you focus on what you must learn to pass the Plant Agriculture category examination. KEs appear at the end of this introduction, as well as throughout the book, to guide you as you read. They cover material found in

- *The Safe and Effective Use of Pesticides*, 3rd Edition
- The UC IPM Pest Management Guidelines
- Plant Agriculture Pest Control

Pesticide regulations require that people with a Category D license show practical knowledge of

- California crop and pest combinations that people often treat with restricted-use pesticides (RUPs)
- Soil and water problems resulting from pesticide applications
- Required preharvest intervals (PHI)
- Required re-entry intervals (REI)
- Phytotoxicity that may result from using pesticides
- Potential for environmental contamination, nontarget injury, and community problems resulting from pesticides applied in agricultural areas.

The Plant Agriculture study guide is a companion to California's basic principles study guide, *The Safe and Effective Use of Pesticides*, which covers the core knowledge needed by all State-licensed applicators. All page numbers and chapter references provided in this book are from the 3rd Edition of *The Safe and Effective Use of Pesticides*. KEs for the Plant Agriculture category and related material cover

- Some key pests in California's important crops and other agricultural areas
- Pest and crop life stages, and why they are key to effective pest management
- Components of an IPM program, including nonchemical pest control options that work in agricultural areas
- Effective selection of pesticides in specific situations
- Application methods and equipment used in plant agriculture
- Precision farming tools that increase application effectiveness and safety
- Factors that affect the outcome of pesticide applications

- Timing pesticide applications to maximize positive outcomes and minimize effects on nontarget organisms, especially honey bees
- Fate of pesticides in the environment
- Safety information as it relates to offsite movement and application errors in agricultural areas.

To pass your exam, you will also need to review *The Safe and Effective Use of Pesticides* and the UC IPM Pest Management Guidelines published by the University of California Statewide IPM program. The recommended Pest Management Guidelines can be found at [URL to be determined]. You can order a copy of *The Safe and Effective Use of Pesticides* from ANR Communication Services. To order, call (800) 994-8849, or visit http://anrcatalog.ucanr.edu/.

This study guide is not meant to be a comprehensive resource for the application of pesticides in agricultural settings. Use it along with *The Safe and Effective Use of Pesticides* and UC IPM's Pest Management Guidelines to study for the California Department of Pesticide Regulation (DPR) licensing exams in this category.

## Knowledge Expectations for Category D, Plant Agriculture

### Pest Management

1-1. Explain the relationships among the components of an effective Integrated Pest Management program.
1-2. Describe nonchemical pest management practices.
1-3. Describe the ways nonchemical pest control methods work with an organism's biology.
1-4. Describe host plant resistance in relation to disease management.
1-5. Describe host plant resistance in relation to nematode management.
1-6. Explain how planting transgenic crops can affect a weed management plan.
1-7. Explain how planting transgenic crops can affect a pest management plan targeting insects or mites.
1-8. Explain how pest-related transgenic crops fit into an IPM program.
1-9. Explain why monitoring both before and after pesticide application is critical to effective pest management.

**Pest Biology and Pest Identification**

2-1. Explain why it is important to know how living organisms are classified and named, and name the two components that make up an organism's scientific name.

2-2. Explain why understanding the life history, including accurate identification of life stages, of both pests and crops is critical to effective pest management.

2-3. Describe the ways pesticides work with an organism's biology, including the biological factors that may alter a pesticide's effectiveness.

2-4. List important California pests and describe:
   a. Crop(s) they damage
   b. Management techniques

2-5. Describe the anatomical difference between insects and mites.

2-6. Describe the life cycle/life stages of
   a. insects with complete metamorphosis
   b. insects with incomplete (simple) metamorphosis
   c. mites
   d. annual, biennial, and perennial weeds
   e. nematodes
   f. vertebrate pests
   g. pathogens

2-7. Describe common sources of
   a. insects and mites
   b. inoculum
   c. weeds
   d. nematodes

2-8. Describe different types of characteristic damage (symptoms and signs) caused by
   a. insects and mites
   b. plant disease
   c. weeds
   d. abiotic factors
   e. nematodes
   f. vertebrate pests

2-9. Define the three parts of the disease triangle and explain why they must all be present for disease to occur.

2-10. Describe the differences between broadleaf weeds, grasses, and sedges.

2-11. Describe how nematodes can spread.

2-12. List the major groups of vertebrates and describe how they can become pests.

2-13. Explain how to identify vertebrate pests using direct and indirect methods.

**Pesticides**

3-1. Describe the factors to consider when making pesticide use decisions.
3-2. Discuss types of insecticides/miticides and describe which type works best in a given situation.
3-3. Discuss types of herbicides and describe which type works best in a given situation.
3-4. Describe the importance of selecting pesticides with varying modes of action, including the management, prevention, or delay of resistance development in target organisms.
3-5. Discuss types of pesticides used for disease control and describe which type works best in a given situation.
3-6. Discuss types of nematicides and describe which type works best in a given situation.
3-7. Discuss types of pesticides used to manage vertebrate pests and describe which type works best in a given situation.
3-8. Describe methods for making poison baits more selective.

**Safe and Effective Use of Pesticides**

4-1. Explain the various fates of pesticides in the environment, and how understanding these fates affect pesticide selection and application.
4-2. Explain how to determine if weather conditions at the application site will cause off-site movement.
4-3. Describe the factors that can affect the outcomes of pesticide applications.
4-4. Describe the different types of resistance to pesticides, how each occurs, and how to manage each.
4-5. Explain how the proper use of pesticides contributes to the management of pesticide resistance.
4-6. Explain how pesticide resistance develops and describe ways to manage it.
4-7. Explain how to monitor and account for pesticide underperformance, and list the ways to avoid it.
4-8. Explain how weather conditions at the application site can impact the effectiveness of pesticide applications.
4-9. List common errors that can occur when applying pesticides and describe the problems that can result from these errors, including legal and economic consequences.
4-10. List the advantages and disadvantages of using multiple pesticides in one tank (tank mix).
4-11. List the indications that a tank mix of two or more formulations is incompatible.
4-12. Describe the ways to prevent incompatibility when tank mixing pesticides.
4-13. Describe methods used to time pesticide applications and increase their effectiveness.
4-14. Describe thresholds used to make treatment decisions, and explain how to use these thresholds to determine if pesticide application is needed.
4-15. List and describe the tools available for monitoring agricultural pest populations before, during, and after pesticide application.
4-16. Explain how to prevent pesticides from moving into nontarget areas.

4-17. Describe several methods that help determine whether adequate pesticide coverage is being achieved.

**Application Equipment**

5-1. Describe various pesticide application equipment used to apply pesticides in plant agriculture settings.
5-2. Define common problems with application equipment and describe how these might be remedied.
5-3. Explain how to select the right equipment for effective applications to common plant structures.
5-4. Describe various pesticide application methods.
5-5. List components of chemigation equipment, explain how they work together, and identify which components work best with which pesticide formulations.
5-6. List components of liquid application equipment, explain how they work together, and identify which components work best with which pesticide formulations.
5-7. Describe types of nozzles, including outputs, patterns, and applications that require each output or pattern.
5-8. Describe the parts of a nozzle.
5-9. Describe types of pumps and how to select the best pump for particular situations.
5-10. List the adjustments to make to improve inadequate spray coverage or pesticide placement.
5-11. Describe procedures for thoroughly cleaning
   a. Liquid sprayers
   b. Dust applicators
   c. Granular applicators
   d. Chemigation equipment
5-12. Describe procedures for storing
   a. Liquid sprayers
   b. Dust applicators
   c. Granular applicators

**Section 1: Integrated Pest Management**

**Knowledge Expectations**

1-1. Explain the relationships among the components of an effective Integrated Pest Management program.
1-2. Describe nonchemical pest management practices.
1-3. Describe the ways nonchemical pest control methods work with an organism's biology.
1-4. Describe host plant resistance in relation to disease management.
1-5. Describe host plant resistance in relation to nematode management.
1-6. Explain how planting transgenic crops can affect a weed management plan.
1-7. Explain how planting transgenic crops can affect a pest management plan targeting insects or mites.
1-8. Explain how pest-related transgenic crops fit into an IPM program.
1-9. Explain why monitoring both before and after pesticide application is critical to effective pest management.

# IPM in Plant Agriculture

Most crops are grown on large areas of land closely connected to other parts of our ecosystem. Because of this, people must reduce pesticide use and the risks linked to it when they can. You can help decrease the number of pesticide applications to all types of agricultural lands by using a variety of pest control methods in an integrated pest management (IPM) program. The following sections describe key IPM components and explain how they work together to control pests. For a definition of IPM and how an IPM plan is created, see Chapter 1 of *The Safe and Effective Use of Pesticides*.

## Parts of an IPM program

IPM programs will always have these five parts:

- Pest identification
- Monitoring and assessing pest numbers and damage
- Guidelines for management action
- Preventing pest problems
- Using a combination of biological, cultural, physical/mechanical, and chemical management tools

**Pest Identification**. Most pest management tools are effective only against certain pests. To create an effective IPM plan, then, you must identify pests currently or likely to appear at the site. Correct pest identification helps you choose the best management options. For more on how to identify pests, see Chapter 2 of *The Safe and Effective Use of Pesticides*.

**Monitoring**. Monitoring provides information on conditions at a site. Through monitoring, you can find out about pest numbers, crop health, the weather, or the type of soil at the site. You can use this information to predict and assess pests and pest damage. Because conditions vary, you should monitor each field separately. Regularly check the pest species present; the maturity and health of the crop, plant, or commodity protected; the weather; the plant environment, including soil conditions; and, when appropriate, the population levels of pest and beneficial organisms.

Keep written records of monitoring results, weather, and management activities. During the season, these records indicate whether pests or natural enemy populations are increasing or decreasing. They also aid in forecasting possible pest outbreaks. Good records can help you decide whether future control actions are needed. For more on monitoring for pests and other organisms, see "Monitoring: The Key to Successful Pest Management" in Chapter 1 of *The Safe and Effective Use of Pesticides*, p 16. For sampling methods used in specific crops for specific pests, see UC IPM's Pest Management Guidelines at http://ipm.ucanr.edu/PMG/crops-agriculture.html.

**Guidelines for management action**. Guidelines help you decide what management actions, including pesticide applications, may be needed to avoid loss from pest damage. They are useful only when combined with monitoring and accurate pest identification. Guidelines for insects and mites are generally numerical thresholds based on certain sampling techniques. Guidelines for other pests may be based on the history of a field or region, the stage of crop growth, the weather, and other field notes. See http://www.ipm.ucanr.edu/MODELS/index.html if you want help creating and using management guidelines.

**Preventing Pest Problems**. Often, preventing pests is the best way to protect crops and other agricultural lands. Host plant resistance is one of the most effective tools in an IPM program, because of its specificity and minimal disruption of the environment. Host resistance can be a long-lasting control measure, especially if properly used and if more than one gene is responsible for resistance.

Many cultural practices are used to prevent or eliminate pest populations before planting. Crop rotation and fallowing are used to manage certain nematodes, weeds, and plant pathogens that cannot move quickly from nearby areas or survive long periods without a host. In some cases, changing the planting and harvesting dates can avoid pests. Site selection can also be critical. For example, susceptible crops should not be planted in fields with a history of soilborne diseases, nematodes, or troublesome weeds. Another technique used to prevent pests and their damage is habitat modification.

Most pest control methods only eliminate a percentage of the pests present. Many are effective against one stage but ineffective against another stage. Some pest management methods may affect several different pests. Weed control, for example, may also result in fewer vertebrate pests. You must always remember that the management practices you choose can also affect nontarget organisms, especially beneficial insects such as honey bees ("Components of an IPM Program" adapted from Flint, M.L., 2012).

### Integrating Management Methods

From biological controls to chemical sprays, you have many tools available to you for addressing pest problems, each with its own strengths and weaknesses. In order to realize the greatest benefit from any one of these many tools, they must be used in combination. Using these tools together allows you to balance strengths and weaknesses to improve control of target pests. For more about building an effective integrated pest management program, see Chapters 1 and 10 of *The Safe and Effective Use of Pesticides*.

## Nonchemical Pest Control Methods

Chapter 1 of *The Safe and Effective Use of Pesticides* discusses several methods used to control pests without chemicals. These include

- Biological control
- Cultural control
- Mechanical and physical control

In the following sections, you will find a more detailed treatment of each of these methods, along with some examples of their use in Plant Agriculture. For basic definitions and general facts about nonchemical pest control methods, see pp 6-13 of *The Safe and Effective Use of Pesticides*.

### Biological Control

There are several types of biological control agents you can use to suppress pest populations in agricultural situations, including predators, parasites, herbivores, competitors, pathogens, and organisms that release substances that are toxic or repellant to pests (known as antibiosis).

#### Biological Control of Insects and Mites

There are more biological controls available for the management of insects and mites than for any other pest group. Natural enemies can play a role in the management of almost all arthropod pests. Predators and parasites are among the best-known enemies of insects and mites. Other biological control agents include *entomopathogenic nematodes* and microbial agents such as bacteria, fungi, and viruses. Vertebrates, including birds, bats, and fish, may have a significant impact on some insect populations. During the past century, more than 40 insect species have been partially, substantially, or completely controlled through classical biological control efforts in California.

**Predatory Arthropods**. Insects and mites are food for an enormous variety of predatory arthropods, with representatives from every insect order as well as spiders, mites, and centipedes. Important insect predators include green and brown lacewings, syrphid flies, robber flies, damsel bugs, big-eyed bugs, assassin bugs, minute pirate bugs, lady beetles, soldier beetles, predaceous ground beetles, wasps and ants, and predaceous mites and spiders (Figure 1-1(A)-(F)). Many predatory arthropods eat each other in addition to pests, so their effectiveness depends on the food web of the ecosystem.

**Figure 1-1** Predators of insects and mites are found in almost every insect order. A few examples are shown here. (A) minute pirate bug. (B) lacewing larva eating a lace bug. (C) sixspotted thrips and a spider mite egg. (D) gray ant attacking a peach twig borer larva. (E) syrphid fly larva attacking an aphid. (F) twice stabbed lady beetle feeding on walnut scale.

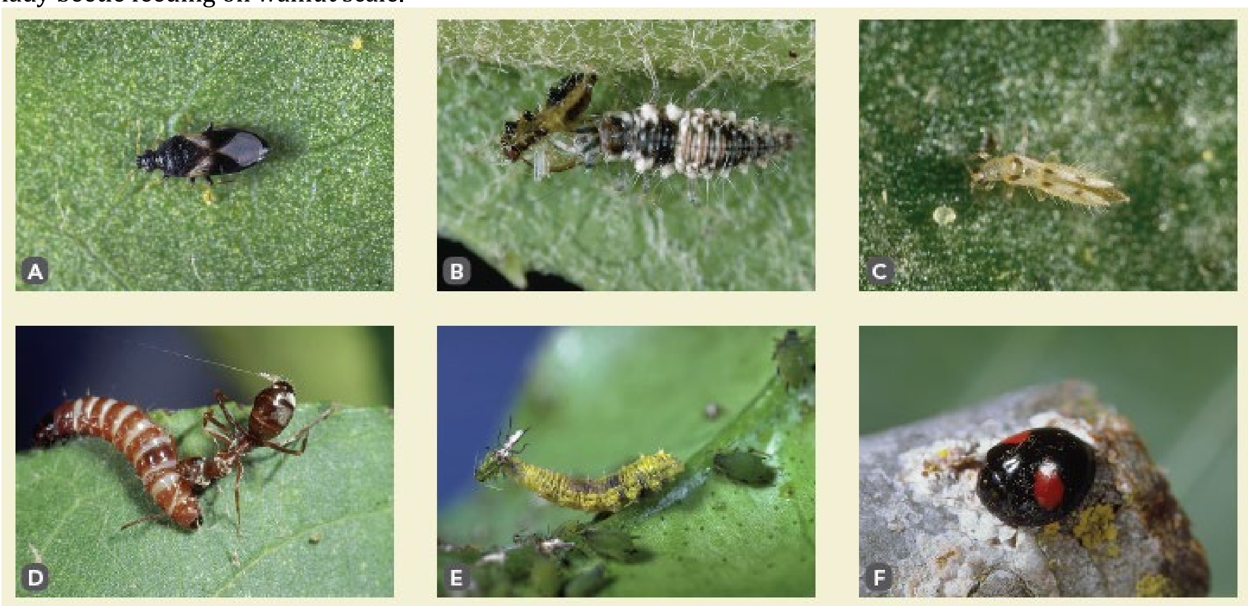
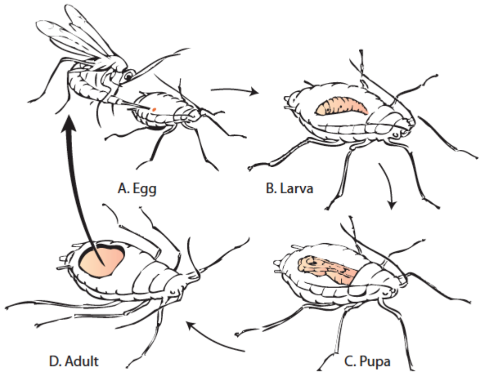



**Figure 1-2** The life cycle of a typical insect parasite, or parasitoid, illustrated using a species that attacks aphids.




**Parasitic Insects**. Wasps and flies are the insects that parasitize other insects most often. Insect parasites (parasitoids) are free living as adults but parasitic in their larval stage. Adult females lay their eggs inside or attached to the outside of the host's body. After hatching, the immature stage of the parasite completes its development on or in the host, killing it just before pupating or emerging as an adult (Figure 1-2). Only one host individual is killed during the parasite's development.

**Nematodes**. Nematodes used in insect pest management are called entomopathogenic nematodes and are packaged, sold, and applied by flooding, similar to some insecticides. Depending on the species and the formulation in which it is packaged (gel, clay matrix, or liquid flowable), the shelf life for some formulations is between 3 months and 5 months. Applications of nematodes for soil-inhabiting insects should be watered in to increase efficacy. Table 1-1 lists some commercially available nematodes and the pests they control.

**Table 1-1:** *Selected commercially available nematodes and the pests they can control. Follow the recommended application procedure.*

| Nematode scientific name | Pests controlled | Habitat | Application procedure |
|---|---|---|---|
| *Heterorhabditis bacteriophora* | Japanese beetle larvae, turf grubs, white grubs | turf | Apply as soil drench or conventional spray to the surface at a rate of 23 million per 1,000 square feet in 5 gallons of water. Soil must be warm (60°F) and moist. Irrigate every 2–3 days for 2 weeks after application. |
| | weevils, flea beetles, root maggots, and certain other soil-dwelling insects | soil | |
| *Steinernema carpocapsae* | carpenterworm, clearwing moth larvae | woody plants, typically beneath the bark | Apply with a squeeze-bottle applicator or 20-ounce oil can at a concentration of 1 million or more per 1 ounce of water. Clear tunnel entrance, insert applicator, and inject suspension until gallery is filled. |
| *Steinernema feltiae* | fungus gnat | soil | Apply as soil drench or surface application. |

**Pathogens**. Pathogens play an important role in the control of insect pests. Insect pathogens include viruses, bacteria, fungi, and other microorganisms that produce disease in their insect hosts. Many pathogens occur naturally and frequently keep insect pests below damaging levels. For example, many caterpillar species are kept under control by natural outbreaks of disease. Of those that occur naturally, viruses are most common. Caterpillars that are killed by viruses (like the cabbage looper in Figure 1-3) often turn dark. Their bodies become soft and limp as they liquefy. When the dead bodies break open, new viral particles are released, which infect other caterpillars.

**Figure 1-3** This cabbage looper has been killed by a commercially available virus.

Naturally occurring fungal disease can help control aphids. In humid conditions, aphids are very susceptible to fungal disease. Fungus-killed aphids turn orangish or brown and have a fuzzy, shriveled texture; sometimes fine, white mycelia can be seen growing over their bodies.

The use of microorganisms for the management of insects and mites is a special category of augmentation. There are several microbial pesticides, including bacteria, fungi, viruses, and protozoa, currently registered for the management of insects and mites. For more on microbial pesticides, see p 87 in Chapter 3 of *The Safe and Effective Use of Pesticides*.

**Biological Control of Weeds**

If one weed species is removed by biological control, another troublesome species is likely to take its place. As a result, classical biological control has less potential for weed management in agricultural lands. This is because agricultural land is more regularly disturbed than pastures, forests, rangelands, and aquatic systems. It is not suited to the slower pace of biological weed control. Even so, there are some organisms that are useful for controlling weeds in and around agricultural areas.

**Insects**. Insects control weeds by feeding on plants or by transmitting disease organisms that injure plants. Moths, thrips, mealybugs, scale insects, wasps, certain beetles, leafminers, gall midges, and other insects have been moderately successful in biological control programs for weeds.

**Pathogens**. Pathogens have extremely rapid generation times, can cause severe damage rapidly under proper environmental conditions, have methods for efficient dispersal, and exhibit a high degree of specificity toward the plant species they attack. However, because many weeds are closely related to desirable species, any release of pathogens must be done with care. One of the few successful cases of the introduction and establishment of a pathogen for biological control of a weed involved the introduction of the rust pathogen *Puccinia chondrillina* against rush skeletonweed in Australia in the 1970s. The rust was also introduced into California and the Pacific Northwest but achieved less success. Unlike release of insects for biological control, all pathogenic microorganisms applied for biological control of weeds must be registered as pesticides. Although presently no pathogens are being used as bioherbicides in California, two fungi have been registered for use in other states against stranglevine and northern jointvetch.

**Vertebrates**. Vertebrates will eat most plants, including desirable species, since they rely heavily on leaves, seeds, fruit, roots, seedlings, and other plant parts for food. When used as biological control agents, they require active management to confine their feeding to target weeds. Among vertebrates, fish, birds, and mammals have the greatest potential for biological weed control. For instance, sterile grass carp can be used in certain well-contained water bodies to manage aquatic weeds.

Geese have been used as selective grazers to control weedy grasses in cotton, orchards, and vineyards. (Figure 1-4A). Geese prefer grasses, but they will turn to broadleaves when grass species are gone. If not properly managed, geese will feed on crop plants.

**Figure 1-4** Geese and sheep are used in a variety of agricultural situations to control weeds.


Sheep and goats are sometimes used for weed control in vineyards and orchards (Figure 1-4B), as well as in noncrop agricultural lands such as grasslands, and rangelands. Sheep will effectively remove all weeds down to ground level. Goats are browsers and must be carefully managed to avoid damage to trees or vines. Both sheep and goats are generally used during the time when trees and vines are dormant. Goats have been used successfully in rangelands and grasslands to control yellow starthistle in both its bolting and spiny stages. Overall, it is best to use grazing animals for weed control before plants have produced viable seed, especially if the target plant's seeds can pass through the animal unharmed.

**Allelopathy**. Allelopathy occurs when a plant releases chemicals (allelochemicals) that impair growth of other plants nearby. An example of a plant with allelopathic qualities is the black walnut tree, which produces a toxin that inhibits growth of most plant species around the base of the tree. Other crop plants with well-demonstrated allelopathic effects on weeds include barley, rye, and sudangrass.

**Competition**. Weeds decrease crop yields and harm plants in noncrop agricultural areas by competing for light, water, and nutrients. Tilting any of these resources in favor of desirable plants can help them outcompete weeds. For instance, using transplants can give the desirable plant an advantage by shading certain weed species out. Managing water and nutrients can also effectively increase the competitiveness of desirable plants. Banding and side-dressing of fertilizer applications, for instance, favors crops over weeds. Revegetation of rangelands and other noncrop agricultural lands is also an effective way to suppress invasive weeds.

**Figure 1-5** Solarization has been used to increase bacteria that are the natural enemies of soil-dwelling lettuce disease pathogens.

### Biological Control of Plant Pathogens

Organisms that kill or inhibit growth of plant pathogens and other microorganisms are called antagonists. They may act as predators, parasites, pathogens, or competitors, or they may have repellent or antibiotic effects. In some cases, soil solarization, crop rotation, or incorporating compost, green manure, or other amendments can increase activities of beneficial soil organisms and reduce disease occurrence. For example, solarization has been used to increase bacteria that are the natural enemies of soilborne pathogens that attack lettuce (Figure 1-5).

**Table 1-2:**
*Selected commercially available mycopesticides.*

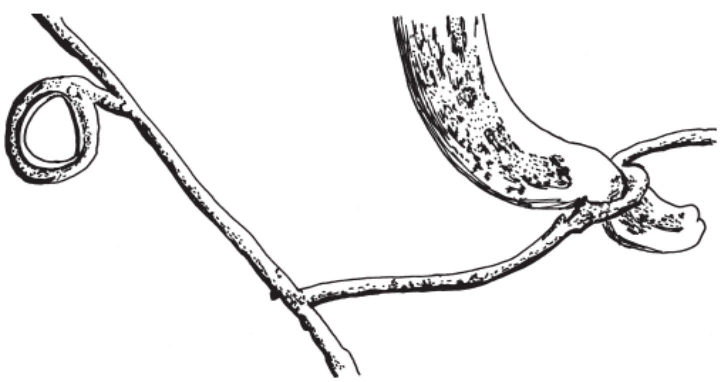
| Mycopesticide organism | Pathogens controlled | Example application methods |
|---|---|---|
| *Agrobacterium radiobacter* strains | crown gall (*Agrobacterium tumefaciens*) | preplant preventive as cutting, root, or seed dip |
| *Ampelomyces quisqualis* | powdery mildew | preventive foliar spray |
| *Bacillus subtilis* | damping-off pathogens, such as *Pythium* spp., and foliar diseases such as powdery mildew | seed inoculant or foliar spray |
| *Burkholderia cepacia* | Fusarium and Rhizoctonia root rots and certain nematodes | preventive application prior to planting as cutting, seed, or seedling dip |
| *Candida oleophila* | postharvest fruit decay | preventive application to harvested fruit |
| *Gliocladium virens* | *Pythium* and *Rhizoctonia* spp. | incorporation in soil or media and incubation before planting |
| *Pseudomonas cepacia, P. fluorescens* | fire blight and frost of pears | foliar spray |
| *Pseudomonas syringae* | postharvest fruit decay | postharvest preventive application to certain fruits before storage |
| *Streptomyces griseoviridis* | root decay fungi, e.g., *Alternaria*, *Fusarium*, and *Phomopsis* spp. | preventive as dip, drench, or spray for seeds and container-grown plants |
| *Streptomycin* from *Streptomyces griseus* | bacterial blights, cankers, leaf spots, and wilts; crown gall | curative as cutting dip or foliar spray |
| *Trichoderma harzianum, T. polysporum* | *Pythium* spp. and other soilborne pathogens | seed and bulb dip, soil drench, tree wound dressing |

Mycopesticides must be labeled and registered in accordance with pesticide regulations of the U.S. EPA (and in California with DPR). Check labels for permitted uses and methods. Many of these microorganisms are also available in commercial amendments or inoculants, which are largely unregulated, and information on their use may be less reliable than the information for registered mycopesticides.

*Mycopesticides* are commercially available beneficial microorganisms or their by-products that control plant pathogens. Other than disease-suppressive composts and amendments, mycopesticides are currently the most effective biological control against plant diseases. For instance, the competitive bacterium *Pseudomonas fluorescens* A506 has been used effectively in combination with antibiotics to control fire blight disease of pears in California. Table 1-2 lists some commercially available mycopesticides.

**Disease-Suppressive Soils**. Disease-suppressive soils are soils in which disease incidence remains low even though a pathogen, a susceptible host, and environmental conditions that favor disease development are present. Most soils possess some ability to limit disease, but disease-suppressive soils are known to have a much lower rate of disease. Among the best-known examples of disease-suppressive soils are soils suppressive to Fusarium wilt and take-all decline of wheat.

**Figure 1-6** Certain fungi (such as *Arthrobotrys brochopaga* and *A. dactyloides*) produce these looplike structures in spaces among soil particles where nematodes commonly travel. When a nematode enters, the loop contracts like a noose. Fungal hyphae then grow into the captured nematode and consume its body. Other trapping fungi use sticky nets (*A. oligospora*), sticky knobs (such as *Dactylaria haptoyla* and *Nematoctonus* spp.) or sticky spores (*Drechmeria coniospora* and *Hirsutella rhossiliensis*).



### Biological Control of Plant-Parasitic Nematodes

Nematodes have many types of natural enemies that regulate their numbers. These include predatory insects and nematodes, pathogenic microorganisms, competitors, and organisms that secrete harmful or repellent substances. Some of the best-studied natural enemies are fungi that capture nematodes in various forms of traps (Figure 1-6). At present, there are no practical applications of biological control for nematodes. ("Biological Control" adapted from Flint, M.L., 2012)

## Cultural Control

### Smother Crops and Cover Crops

Smother crops are grown for their ability to suppress weeds and for their cash value. They are planted at high densities in crop rotations following the main crop. Cereals, sorghum, safflower, field corn, and domestic sunflowers have been effectively used as smother crops (Figure 1-7).

**Figure 1-7** Planting a winter smother crop of yellow mustard minimizes weed growth in this vineyard.

Cover crops are noncrop plant species grown either along with the host crop (usually perennial plants) or in rotation with annual crops; they are generally not harvested. Cover crops can suppress weeds; provide nutrients to the soil; and provide food and shelter to beneficial insects, mites, and spiders. They can also help improve soil texture, increase organic matter, increase water infiltration rates, reduce pesticide runoff into surface water, and reduce soil erosion. Successful cover crop varieties often planted in orchards and vineyards in California include strawberry clover, annual clover, cereal grasses, annual grasses, and vetches.

**Table 1-3:** *Advantages and disadvantages of cover cropping.*

ADVANTAGES

- ☐ decreases soil erosion
- ☐ increases organic matter
- ☐ improves soil structure and water infiltration
- ☐ decreases water and pesticide runoff
- ☐ may add or conserve nitrogen
- ☐ may suppress weed growth
- ☐ may attract or provide nectar source for beneficial insects, spiders, and mites

DISADVANTAGES

- ☐ depletes soil moisture
- ☐ may decrease availability of plant nutrients, especially nitrogen
- ☐ may require additional irrigation and nitrogen applications
- ☐ may increase weeds
- ☐ may attract arthropod and rodent pests
- ☐ may increase nematode populations
- ☐ increases danger of frost damage to trees or vines
- ☐ increases associated costs

Adapted from Ingels et al. 1998.

An example of a cover crop improving biological control is the use of vetch to improve biological control of mealybugs in vineyards. Vetch supplies ants with nectar which keeps them from moving into vines, thereby reducing ants' interference with the natural enemies of grape pests—especially parasitic wasps that control mealybugs. However, in some vineyards cover crops can increase early populations of the caterpillar pest omnivorous leafroller by providing it with an alternate food source.

In some cases, cover crops may compete with crops or may become weeds if not properly managed. See Table 1-3 for advantages and disadvantages of using cover crops.

**Figure 1-8** In new orchard plantings, intercropping is sometimes used to produce income prior to the maturing of the trees, as in this peach orchard, planted with beans.

**Intercropping**. Intercropping involves growing more than one crop in a field at the same time: multiple crops are planted in alternating strips or intersown into a main crop. Intercropping is sometimes used to reduce pests. For instance, older stands of alfalfa can be overseeded with oats to reduce weed pressure, and the harvested alfalfa-oat mix is sold as a forage crop. In cotton, a trap crop of alfalfa can be planted in strips to keep damaging lygus bugs out of the crop. In new orchard plantings, intercropping is sometimes used to produce income prior to the maturing of the trees (Figure 1-8).

Problems can arise in intercropping systems if pesticide applications are needed. A pesticide registered for one crop in the system may not be registered for the other crop. You must make sure that the pesticides you will apply are compatible with both crops.

### Crop Rotation

Crop rotation is the intentional planting of specific crop sequences to improve crop health. It is one of the oldest cultural practices in use. It can increase organic matter, improve soil properties, conserve water, and manage pests. Crop rotations have provided effective control for certain host-specific plant pathogens, nematodes, and insects by disrupting the pests' life cycle and by changing environmental conditions to deter certain species. For instance, a combination of crop rotation and fallowing can be used to control nematodes, but only when the site is completely cleared of susceptible plants.

Pests that can be successfully controlled with crop rotation are those that originate in the field and are not likely to move in from nearby areas. These pests tend to be soil-borne and immobile. The host range of the pest should be relatively narrow, allowing you to easily find a suitable alternate crop. Pests that attack only one or a few closely related crops are the best candidates. Also, the pest population should not be able to survive after a 1- or 2-year absence of the living host.

**Table 1-4:** *Selected crops in which rotation with small grains is combined with other management practices to reduce nematode and disease populations.*

| Pest type | Suggested rotation cycle in years | Nonhost crop options and other comments |
|---|---|---|
| **Diseases** | | |
| Verticillium wilt | 3 | Small grains, corn |
| Phytophthora root rot | 1 | Cereals for severe infestations |
| Bacterial spot | 1 or more | Nonsolanaceous crops |
| Bacterial canker | 1 or more | Nonsolanaceous crops |
| Fusarium wilt | 2 or more | Crops other than tomato |
| Southern blight | 3 | Small grains |
| Corky root rot | 2 or more | Small grains, corn |
| **Other pests** | | |
| Root knot nematode | — | Use resistant tomato varieties and other nonhosts |
| Weeds | 1 or more | See SPECIAL WEED PROBLEMS |
| Dodder | — | Use tolerant tomato varieties or grass crops |

Good candidates for management by crop rotation include soil- and root-dwelling nematodes and soilborne pathogens that do not produce airborne spores and have limited host ranges. When rotation is used for disease and nematode management, alternate weed hosts must be controlled as well, especially those present along fencerows and field edges, or in nearby uncultivated or noncrop areas. Weeds are sometimes controlled with a combination of rotation and herbicide management by rotating to a crop that allows the use of a more effective herbicide. Rotating to a flooded crop, like rice, or a highly competitive crop, like alfalfa, can also help reduce a variety of troublesome pest species. Various crops can be used as part of a rotation sequence to reduce nematode and soil pathogens as well as provide additional benefits in broadleaf crops (Table 1-4). For more specific recommendations based on your situation, check www.ipm.ucanr.edu for Pest Management Guidelines that discuss crop rotation.

### Planting and Harvest Dates

Planting and harvest dates should be chosen to favor crops over pests. For weed management, choose a planting time that favors germination of the crop over key weed species. For instance, in many parts of California, fall alfalfa planting can be adjusted to avoid both late-germinating summer weeds and late fall-germinating winter weeds. However, crops planted too late in fall will germinate and grow slowly, allowing winter weeds to become well established. If fields are infested with field bindweed, perennial grasses, or nutsedge, planting in early fall will ensure that alfalfa is established and growing well when these perennials reemerge in spring.

Adjustments in the timing of planting can also aid in insect and disease management. Winter-grown carrots and potatoes in California can be planted when the potato cyst nematode is not active, avoiding exposure in early crop development stages when the pest is most damaging. In sugarbeets, beet yellow virus and beet mosaic virus have been kept under control by following strict planting programs that allowed no early-spring plantings in or next to growing districts where sugarbeets were overwintered in the field. Certain seedling diseases, such as black root rot and damping-off, can be avoided in cotton by planting later to reduce the chance of infection. Timing spring row crop planting to allow sufficient time for winter row crop residues to decompose is an important cultural practice used in coastal row crop production to prevent seedcorn maggot damage to seeds and seedlings. Using a chain drag behind the seed shanks on the planter also helps to camouflage the seed row from adult egg-laying flies.

Harvest can also be timed to limit or avoid pest damage. Early harvest can reduce the number of generations of nematodes that can damage a root crop. In northern California potato fields, early harvest effectively reduces the incidence of nematode damage to tubers by shortening the time nematodes have available to reproduce. Early harvest is also beneficial in the management of various insect pests. Early harvest of coastal avocados can help control greenhouse thrips on tough-skinned varieties by minimizing crop-to-crop overlap and removing much of the insect population before it has time to move to a new crop. In some situations, early harvest of alfalfa hay can eliminate need for treating alfalfa weevil or alfalfa caterpillar.

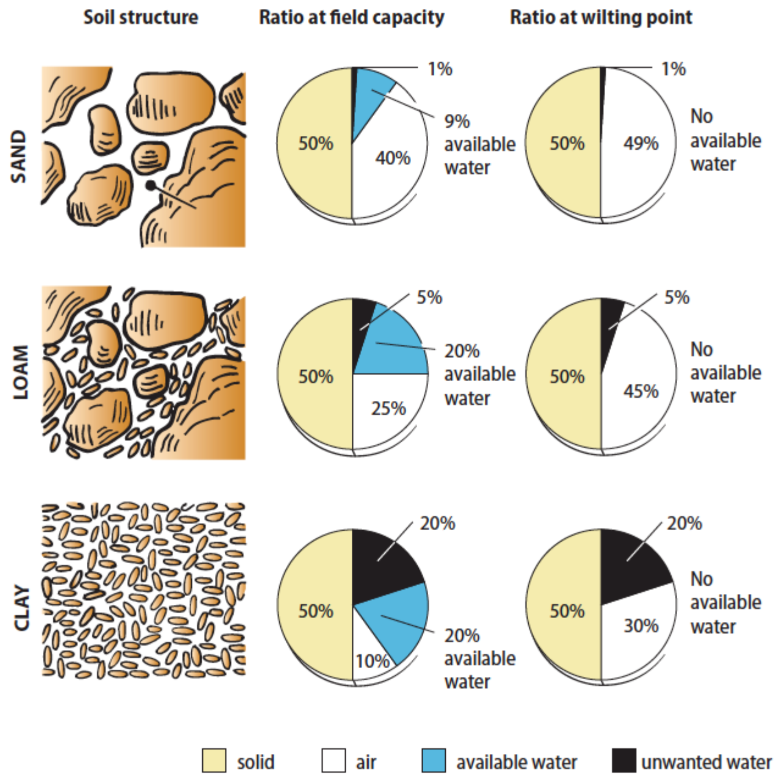
**Irrigation and Water Management**

Poor water management is a major contributor to many pest problems. Too much soil water excludes oxygen that plant roots need to survive. It is a primary factor in the development of many root and crown diseases, such as Phytophthora root rot. The fungi causing these diseases are present in many soils but only become damaging when excessive moisture favors them. Excess water and poor drainage in low areas of fields, grasslands, or noncrop agricultural lands also favor numerous hard-to-control weeds such as nutsedge and barnyardgrass.

Underwatering, or drought stress, on the other hand, may cause wilting, sunburn, sunscald, and branch cracking that can allow invasion of pathogens and attract boring insects. It can also stress plants so that they cannot overcome attack by pests. Underwatering reduces crop competitiveness and can encourage weeds to invade.

Certain types of irrigation systems are both positively and negatively associated with pest populations. Droplets from overhead irrigation can dislodge, drown, or drive off some insect and mite pests, reduce successful mating of moth pests such as the diamondback moth, and reduce powdery mildew of grapes. However, increased moisture on plant surfaces can encourage fruit or foliar diseases. Flood irrigation, while inexpensive, can contribute to root diseases and weeds. Drip irrigation systems deliver water only to sites where it is needed, reducing root diseases and weeds.

**Figure 1-9** Pore spaces are the openings between soil particles that contain water and air. Sandy soils have big pore spaces that contain large amounts of air and allow water to drain quickly. Clay soils have smaller pore spaces and retain more water, resulting in poor drainage and often insufficient oxygen for roots. Loamy soils are a mixture of sand, silt, and clay that are not compacted; loam provides the best balance between water-holding ability and adequate air.




To avoid problems associated with over- or underwatering, learn the water requirements of the plants and find out how much available water the soil can hold. Available water is that portion of the soil water that can be withdrawn by plants (Figure 1-9). During the growing season, irrigation is needed when a certain amount of the available water has been used. Soil type, stage of plant growth, total amount of available water, weather conditions, and irrigation cost affect when and if irrigation is appropriate.

**Fertilizers and Soil Amendments**

Fertilizers and soil amendments are used to promote healthy plants and increase yields. Although not a pest management practice, applying fertilizers and soil amendments can change the activity of many pest species. While healthy plants can tolerate pest attacks and damage better than weaker plants, using too much fertilizer may attract or speed the growth of certain pests. For example, excess nitrogen on nectarines results in increased levels of brown rot, oriental fruit moth, and peach twig borer. Aphids, leafhoppers, lace bugs, and other sucking insects are associated with the lush growth that results from applying too much nitrogen. When you add the right amounts of soil nutrients at the right time, you can boost pest management efforts while limiting environmental contamination.

**Resistant Cultivars**

Host resistance takes advantage of the genetic attributes of certain plant cultivars that allow the plants to resist or tolerate pest attack. Host resistance is one of the most successful and environmentally friendly pest management techniques. It is used in the management of plant pathogens, nematode pests, and to a more limited extent, arthropod pests. For example, there are tomato cultivars that are resistant to root knot nematodes, *Verticillium*, *Fusarium*, tomato spotted wilt, and tobacco mosaic virus. Cultivars resistant or tolerant to downy mildew of lettuce and crucifers, celery Fusarium yellows, white mold of beans, cucumber mosaic virus of cucumber, root rots of peas, and tobacco mosaic virus of pepper are commonly used in California. Successful examples of resistance or *tolerance* to insect pests include the use of phylloxera-resistant grape *rootstock*, apple rootstocks resistant to woolly apple aphid, and varieties of alfalfa resistant to blue alfalfa aphid, pea aphid, and spotted alfalfa aphid.

**Table 1-5:** *Some common plant diseases managed in annual crops in California through the use of resistant cultivars.*

| Crop | Disease | Causal agent |
|---|---|---|
| beans | bean anthracnose | *Colletotrichum lindemuthianum* |
| | bean common mosaic | bean common mosaic virus (BCMV) |
| | bean yellow mosaic | bean yellows mosaic virus (BYMV) |
| | curly top | beet curly top gemini virus (BCTV) |
| | Fusarium wilt (blackeye and garbanzo beans) | *Fusarium oxysporum* |
| | halo blight | *Pseudomonas syringae* pv. *phaseolicola* |
| cole crops | downy mildew | *Peronospora parasitica* |
| | Fusarium yellows (cabbage) | *Fusarium oxysporum* |
| corn | common rust | *Puccinia sorghi* |
| | Fusarium ear rot | *Fusarium moniliforme* |
| | Fusarium stalk rot | *Fusarium moniliforme* |
| | head smut | *Sphacelotheca reiliana* |
| | maize dwarf mosaic | maize dwarf mosaic virus (MDMV) |
| cucurbits | angular leaf spot | *Pseudomonas syringae* pv. *lachrymans* |
| | anthracnose (some varieties of watermelon and cucumber) | *Collectotrichum lagenarium* |
| | downy mildew | *Pseudoperonospora cubensis* |
| | Fusarium wilt (cantaloupe and watermelon) | *Fusarium oxysporum* |
| | powdery mildew | *Sphaerotheca fuliginea, Erysiphe cichoracearum* |
| | Verticillium wilt | *Verticillium dahliae* |
| lettuce | downy mildew | *Bremia lactucae* |
| | lettuce mosaic | lettuce mosaic virus (LMV) |
| | corky root | *Rhizomonas suberifaciens* |
| small grains | barley yellow dwarf (barley and wheat) | barley yellow dwarf virus (BYDV) |
| | leaf rust of wheat and barley | *Puccinia* spp. |
| | leaf scald of barley | *Rhynchosporium secalis* |
| | net blotch of barley | *Pyrenophora teres* |
| | powdery mildew (barley and wheat) | *Blumeria graminis* |
| | Septoria tritici blotch | *Septoria tritic* |
| | stem rusts of wheat, barley, oats | *Puccinia graminis* |
| | stripe rusts | *Puccinia striiformis* |
| tomatoes | Alternaria stem canker | *Alternaria canker* |
| | bacterial speck | *Pseudomonas syringae* pv. *tomato* |
| | Fusarium wilt | *Fusarium oxysporum* |
| | Verticillium wilt (race 1) | *Verticillium dahliae* |

**Host Plant Resistance.** Pest-resistant plants, when available, are one of the most effective and least expensive pest management tools (Figure 1-10). Resistant plant cultivars and rootstocks have inherited characteristics that result in less pest damage or infestation than other varieties of that species. Although the terms *variety* and *cultivar* are frequently used interchangeably, plants produced through breeding programs are most accurately called

**Figure 1-10** Cotton cultivars resistant to the root knot nematode (outside rows) show little damage from nematodes compared with the susceptible cultivars in the center rows.

cultivars; *variety* can also refer to naturally occurring variants in a subspecies. Plant cultivars bred to resist pests are a major tool in management of plant pathogens and nematodes and have also been used effectively against a number of insect pests, including the species listed above. Examples of some plant pathogens managed through the use of resistant cultivars in a few California annual crops are given in Table 1-5.

Although extremely valuable, the use of pest-resistant plants is not foolproof. Occasionally a resistant plant can become more susceptible to pest pressure as a reaction to physical stress such as variations in moisture, evaporation, plant and soil nutrition, and temperature. Also, a plant that is resistant to one pest may still be damaged by another pest.

Pest organisms overcome host plant resistance in the same way that plants develop pesticide resistance. It is best to use pest-resistant plants in combination with a variety of management techniques, such as crop rotation and fallowing, that reduce the chance that a pest population will overcome host plant resistance through constant exposure over many generations. ("Cultural Controls" adapted from Flint, M.L., 2012).

**Transgenic (Genetically Modified) Crops**

Transgenic technology offers many opportunities for developing new cultivars for pest management purposes. For instance, transgenic crops, often called genetically modified crops, are now available with inserted genes which allow them to tolerate certain herbicides, produce proteins toxic to certain insects (*endotoxins*), or be antagonistic to plant disease (for a general definition of transgenic plants, see p 13 in Chapter 1 of *The Safe and Effective Use of Pesticides*). While this technology holds much promise, transgenic crops are not a "magic bullet" solution to pest problems, and people often worry about their use. Introduction of a gene from the bacterium *Bacillus thuringiensis* (Bt) into a plant host, for instance, raises concerns about increasing the chances of insect resistance to the Bt endotoxin. Some biologists worry that widespread use of plants with altered genes could dilute the gene pool of wild species, threaten diversity, and upset the natural balance of an ecosystem. In addition, research shows that when used as the primary means of pest management, the benefits of transgenic crops do not last. Because of these and other concerns, transgenic crops must be part of an integrated pest management program (IPM), which helps the benefits of the added genes last longer.

Some genetic modifications make plants resistant to herbicides. This type of transgenic crop has several benefits, including simpler and safer chemical weed control, the ability to switch to conservation tillage systems that preserve topsoil and reduce erosion, and the ability to apply herbicides when the need arises during the crop's life cycle. Drawbacks include the possibility of increased pesticide use (since they can be applied as needed), reliance on a single herbicide, and the development of weeds that evolve to resist the same pesticide as the crop.

A major benefit of planting an insect-resistant transgenic crop is that you may need to apply fewer pesticides. It also means that there will be a greater number of nontarget organisms remaining, since less pesticide is being applied. Drawbacks include secondary pest problems that emerge when primary pest populations have been reduced.

In cases of transgenic insect- and disease-resistant crops, because genes have been engineered with a particular pest in mind, other pests are left unharmed. When there are not enough natural enemies and competition has been reduced, these secondary pests can reach injury thresholds, requiring pesticide application. In addition, you cannot use transgenic crops exclusively to manage pests, or you risk losing the advantages conveyed by the addition of resistant genes. The problem arises when pest resistance relies on a gene-for-gene change in the host plant. For example, when a gene to help plants resist a particular pathogen is inserted, natural selection will enable the pathogen to develop ways of circumventing the resistance, making the innovation less and less effective as time passes. To avoid this problem, farmers often plant conventional plants within or along the borders of a field to encourage interbreeding between pests that have developed resistance and those that have not. This strategy is called refuge or reservoir planting. Reservoirs help lengthen the beneficial life of transgenic crops by delaying the development of resistance in pests.

Some genetically modified plants employ a method of virus suppression called *cross protection*. Plants are exposed to a mild strain of a virus, much like vaccinations in people, which stimulates the plant's natural defenses. When these plants are exposed to the full-strength strain of the virus, cross protection defends the plant against the virus. Another type of genetic modification causes viral genes to be suppressed as they begin to infect the plant. In trials, some crops have increased yields as much as 80% over their unaltered counterparts. These modifications can help lessen dependence on preventative spraying to suppress insect vectors.

Ultimately, transgenic crops change pest management plans by highlighting the need to use a variety of pest control tools. Employing several tools at once not only increases the useful life of inserted genes, but also improves the productivity of agricultural systems.

## Mechanical and Physical Control

### Land Preparation

Adequate land preparation prior to planting can avoid many potential pests. Well-prepared fields and noncrop lands are easier to irrigate and manage, resulting in better weed control and fewer diseases.

Proper site preparation reduces soil compaction and contributes to good drainage. When planning how to prepare the site, consider soil depth, texture, and topography. Survey the site for the presence of troublesome weeds and potential vertebrate pests. Evaluate the surrounding habitat as well; nearby sites may harbor vertebrates and other pest organisms that could contribute to future pest problems. Many pests, if detected before planting, can be overcome by preplant treatments such as cultivation or pesticide application.

### Soil Tillage

Tillage, or cultivation, kills weeds, disrupts the life cycle of some insect pests, and buries disease inoculum. Tillage is often combined with other management practices to turn under crop debris, incorporate fertilizer, improve water penetration, or enhance growing conditions for the crop. Cultivation is the most important and widely used weed management tool in many crops and, with proper timing, kills annual weeds, biennial weeds without a taproot, and seedlings of annual and perennial weeds. Mature perennial weeds can be controlled by repeated cultivations when soil is dry. Tilling at the wrong time, however, can increase perennial weeds. It can also bring annual weed seeds to the surface, resulting in germination flushes. Some perennial weeds, such as johnsongrass, bermudagrass, and field bindweed, can increase due to regrowth from chopped-up underground stems. Tillage is not typically used on noncrop agricultural and grassland areas, such as rangelands.

**Figure 1-11** Row plowing in vineyards in early spring before new growth be-gins buries the mummies of the omni-vorous leafroller, a major pest of grapes.

Different types of cultivation are often used to manage different pests. For instance, moldboard plowing is used in specific situations because it buries weed seeds deeply, reducing germination and establishment. The French plow is used in vineyards for weed management and to bury the overwintering larvae of the omnivorous leafroller and their overwintering diet of dried berries and vineyard debris (Figure 1-11). Sclerotinia drop of lettuce can be managed, in some instances, by burying the propagules 10 to 12 inches (25 to 30 cm) beneath the soil by deep plowing. However, in fields with high inoculum density, deep plowing may actually increase disease incidence by spreading sclerotia and increasing the number of plants likely to be infected.

All cultivation techniques have their advantages and disadvantages; their impacts on the ecosystem should be carefully weighed. Tillage can destroy soil structure and contribute to soil erosion, loss of fertilizer, increased compaction, disruption in the life cycle of beneficial organisms, and air pollution. For this reason, some growers have adopted *conservation tillage*. Conservation tillage retains a plant residue cover of at least 30% from the previous crop on the soil surface and includes no-till, ridge-till, strip-till, mulch-till, and other tillage systems that meet this requirement. However, conservation tillage has its disadvantages as well: soils do not warm as rapidly due to the insulating effect of the residues, and weeds and plant diseases can increase.

### Mowing

Mowing is an effective weed management tool, particularly when used in combination with other management methods. It is the most common method of nonchemical weed control used along private roads and other noncrop agricultural areas, and orchard or vineyard floors (Figure 1-12). Proper timing and site conditions are very important. Mowing should be completed before weeds set seed or before seeds mature, and it should be done when soil moisture is low. Also, mowing a cover crop can result in mass migration of arthropod pests such as thrips or mites to trees or vines, so mowing should be avoided when these pests can be most harmful, such as during bloom. In most situations, follow-up mowing is necessary, depending on the growth and flowering pattern of the weed species present. You can use mowing to effectively control annual weeds in many places, including grasslands, field edges, and other uncultivated areas.

**Figure 1-12** Vegetation is controlled by mowing between rows in this no-till vineyard.

As a component of a long-term management plan, mowing has been particularly effective in managing yellow starthistle populations. After 2 years of mowing treatments, flower head and seedling production are significantly reduced when mowing is timed for the early flowering stage (when about 5% of the flower heads are in bloom). In addition, mowing can help balance the number of species growing in areas where livestock forage by increasing light for low-growing plants like legumes.

### Flaming

Flaming is a weed management technique that has been used in row crops, orchards, and vineyards. Flaming commonly uses special propane burners, but equipment employing hot water, steam, or infrared light is also available. Flaming requires only brief plant contact and extremely high temperatures; treated weeds wilt and die within a few days. Proper use of flaming should not heat weeds so long that they smolder, char, or burn.

Flaming is most effective on young annual dicot weeds. Young perennial weeds are also susceptible but require more than one treatment. Repeated flaming eventually starves the roots, killing the weeds. Flaming has also been successfully used as a spot treatment for dodder, and to control weeds and weevils in alfalfa. In late fall or winter, when alfalfa plants are dormant, flaming destroys the adult and egg stages of weevils.

**Mulches**

A mulch is a layer of material covering the soil surface. Mulches are used in some vegetable, orchard, and strawberry plantings. The use of plastic mulches is a standard practice in strawberry production. Mulches discourage weed growth, conserve soil moisture, enhance the water-holding capacity of light, sandy soils, and help maintain a uniform soil temperature.

Composts used as mulches in nursery crops have been shown to reduce Phytophthora root rots and other diseases. A number of mulching materials are available, including bark and wood chips, composted green waste, and plastics such as polyesters and polyethylenes. Different materials are sometimes used together. For instance, a woven weed mat or plastic sheet may be laid down and wood chips spread on top.

The type of mulch and the timing of its application depend on the cultivar, planting and harvest seasons, and other management practices. Various types of mulches are used in vegetable, vineyard, and orchard crops (Figure 1-13). Plastic mulches have been used successfully in noncrop agricultural lands to manage annual weeds occurring in small areas. Silver polyethylene mulches used in the production of cucurbits can repel aphids and whiteflies and reduce the incidence of some of the diseases they carry. When plastic mulches are installed to protect crops, special care must be taken to use drip irrigation beneath them, since these mulches don't allow air or water penetration. Buried drip irrigation will avoid waterlogging of roots that can lead to root disease.

**Figure 1-13** Black plastic used as mulch in an olive orchard.

Where weeds are severe, organic mulches are most successful when applied in the spring after the soil is weed-free to a depth of 2 to 6 inches (5 to 15 cm). It is also important that mulching materials be weed-free. Fertilizer can be added to organic mulches that are not completely decomposed to prevent the material from robbing the soil of nitrogen.

Mulches should be regularly inspected; they can provide hiding places for other pest species. Snails, slugs, earwigs, ants, sowbugs, and other invertebrate pests can be found hiding in mulched areas. In addition, mice, gophers, and other vertebrate pests may seek out mulches for protection and food.

**Table 1-6:** *Selected pathogens and pests controlled by soil solarization.*

| Type of pest | Scientific name | Common name or disease |
|---|---|---|
| **Pathogens or Pests Largely Controlled** | | |
| fungi | *Fusarium oxysporum* | Fusarium wilt |
| | *Phytophthora* spp. | Phytophthora root rot |
| | *Rhizoctonia solani* | seed or seedling rot |
| | *Verticillium dahliae* | Verticillium wilt |
| bacteria | *Agrobacterium tumefaciens* | crown gall |
| | *Clavibacter michiganensis* | canker |
| | *Streptomyces scabies* | potato scap |
| nematodes | *Criconemella xenoplax* | ring nematode |
| | *Heterodera schachtii* | sugarbeet cyst nematode |
| | *Paratylenchus* spp. | pin nematode |
| | *Pratylenchus* spp. | lesion nematode |
| | *Xiphinema* spp. | dagger nematode |
| weeds | *Abutilon theophrasti* | velvetleaf |
| | *Amaranthus* spp. | pigweed |
| | *Amsinckia douglasiana* | fiddleneck |
| | *Brassica nigra* | black mustard |
| | *Convolvulus arvensis* | field bindweed (seed) |
| | *Cynodon dactylon* | bermudagrass (seed) |
| | *Malva parviflora* | cheeseweed |
| | *Solanum* spp. | nightshade |
| | *Sorghum halepense* | johnsongrass (seed) |
| **Pathogens or Pests Partially Controlled** | | |
| fungi | *Macrophomina phaseolina* | charcoal rot |
| bacteria | *Pseudomonas solanacearum* | bacterial wilt |
| nematodes | *Meloidogyne incognita* | southern root knot nematode |
| weeds | *Convolvulus arvensis* | field bindweed (plant) |
| | *Cynodon dactylon* | bermudagrass (plant) |
| | *Cyperus* spp. | yellow and purple nutsedge |
| | *Sorghum halepense* | johnsongrass (plant) |
| | *Malva niceanis* | bull mallow |

Adapted from Elmore et al. 1997.

### Soil Solarization

Soil solarization involves covering moist soil with clear plastic and allowing the soil to heat up. This practice reduces or eliminates many soil-inhabiting pests by raising the temperature in the top 2 to 3 inches (5 to 7.5 cm) of soil to levels that kill these organisms. Solarization favors beneficial organisms in the soil by creating changes in the soil microflora that the beneficials are able to exploit. In some situations, solarization can help to increase yields and improve crop quality following treatment.

Soil solarization has been effective in controlling certain soilborne pathogens and many weed species, and in partially controlling many other pests (Table 1-6). To be effective, a clear plastic tarp is placed over bare, moistened soil for 3 to 6 weeks during the hottest part of the year. Weed control is enhanced if fields are irrigated prior to being covered because moisture helps conduct heat under the tarp. In cooler areas, solarization may not be as effective. It is not typically used in noncrop agricultural areas or grasslands.

**Traps**

Mechanical traps are used to control many vertebrate and invertebrate pests. Traps are especially important in the management of vertebrate species such as ground squirrels, moles, meadow voles, pocket gophers, rats, mice, and some species of large animals. Insect traps used for control include fly traps, roach traps, and other types of sticky traps. Some of these traps are regularly used for monitoring but can also be used to assist in management efforts. For more on trapping, see *The Safe and Effective Use of Pesticides, 3rd Ed.,* Chapter 1, p 10. (adapted from Flint, M.L., 2012)

## Section 2: Biology and Pest Identification

### Knowledge Expectations

2-1. Explain why it is important to know how living organisms are classified and named, and name the two components that make up an organism's scientific name.

2-2. Explain why understanding the life history, including accurate identification of life stages, of both pests and crops is critical to effective pest management.

2-3. Describe the ways pesticides work with an organism's biology, including the biological factors that may alter a pesticide's effectiveness.

2-4. List important California pests and describe:
   a. Crop(s) they damage
   b. Management techniques

2-5. Describe the anatomical difference between insects and mites.

2-6. Describe the life cycle/life stages of
   a. insects with complete metamorphosis
   b. insects with incomplete (simple) metamorphosis
   c. mites
   d. annual, biennial, and perennial weeds
   e. nematodes
   f. vertebrate pests
   g. pathogens

2-7. Describe common sources of
   a. insects and mites
   b. inoculum
   c. weeds
   d. nematodes

2-8. Describe different types of characteristic damage (symptoms and signs) caused by
   a. insects and mites
   b. plant disease
   c. weeds
   d. abiotic factors
   e. nematodes
   f. vertebrate pests

2-9. Define the three parts of the disease triangle and explain why they must all be present for disease to occur.

2-10. Describe the differences between broadleaf weeds, grasses, and sedges.

2-11. Describe how nematodes can spread.

2-12. List the major groups of vertebrates and describe how they can become pests.

2-13. Explain how to identify vertebrate pests using direct and indirect methods.

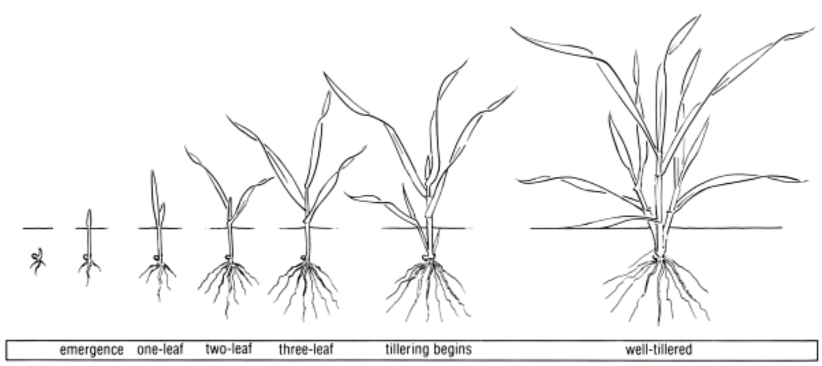
## Pest Biology in Plant Agriculture

Effective applications of pesticides depend on your knowledge and skill. Important facts to know before beginning any application include biological markers that help you identify pests, recognize vulnerable life stages of both crops and pests, and predict problems using conditions at the application site. Of course, the first step is to correctly identify the pest and name it in your pest control records.

Living organisms are classified and named by the scientific community so they can be clearly identified, studied, and discussed by people anywhere in the world. For content addressing the scientific names of insects, plants, and other pest organisms you may encounter in agricultural settings, see *The Safe and Effective Use of Pesticides* Chapter 2, Pest Identification, and read "How Plants and Animals Are Named" on pages 20-22.

After identifying the pest, the next step is to determine the life history, and current life stage of both the target pest and the crop you are trying to protect. In agriculture, successful control of a pest depends upon your ability to pinpoint the most vulnerable life stage of both the pest and the crop. Recognizing life stages allows you to time your control efforts effectively to take advantage of both pest and crop biology. For illustrations of various pests' life cycles, see pp 27-63 of *The Safe and Effective Use of Pesticides*. A drawing of the life stages of a monocot crop appears in Figure 2-1. The life stages of a dicot are shown in Figure 2-7 on p 27 of *The Safe and Effective Use of Pesticides*.

**Figure 2-1** Growth stages of wheat, a monocot.




Timing your pesticide application to coincide with a pest's most vulnerable stage is one way you can use knowledge of a pest's biology to control it. Some pesticides are formulated to work with an organism's biology, taking advantage of characteristics like grooming habits, metabolism, organ functions, circulatory systems, and reproductive systems.

The biological factors of pests to consider when applying pesticides include

- Life stage
- Physical characteristics, strengths, and weaknesses
- Environmental conditions required for reproduction
- Sources of food and shelter

Pesticide applications can be very effective, but so can many nonchemical pest control methods. For a general treatment of various ways you can control pests without spraying, see “Pest Management Methods” in Chapter 1 of *The Safe and Effective Use of Pesticides*. In addition, UC IPM’s Pest Management Guidelines provide detailed information about how to control specific pests in a wide variety of crops. See http://ipm.ucanr.edu/PMG/crops-agriculture.html and select your crop to find both Year-Round IPM Program recommendations and Pest Management Guidelines for a range of pests on that crop.

## Important Crops and Pests in California Agriculture

In this section, you will find information about important crops and pests in California agriculture that are frequently treated with restricted-use pesticides. They were selected using data from the California Pesticide Use Report, statistics on pest management information accessed on the University of California Integrated Pest Management webpage, and consultation with pest management experts in the state. What follows is a selection of economically important pests, rather than an exhaustive list. They represent a large affected area, a large amount of restricted pesticide use, and a variety of commodities grown in the state. Each crop features an illustration of its growth stages, as well as the common and scientific names of selected pests for that crop. The URLs provided after the pest name refer to the Pest Management Guidelines, which contain a variety of pest management strategies. You must understand and be able to recall these strategies; however, you are not required to remember the pesticides recommended to manage individual pests.

Because the Plant Agriculture category excludes application of fumigants, you will not see pests treated primarily with fumigants in this list.

### Alfalfa

### Pests of Alfalfa

#### Vertebrate Pests

http://ucipm.ucdavis.edu/PMG/C001/m001spvertmon.html

#### Cowpea Aphid
**Scientific Name:** ***Aphis craccivora***

http://ucipm.ucdavis.edu/PMG/r1301511.html - MANAGEMENT

#### Alfalfa Weevil, Egyptian Alfalfa Weevil

**Alfalfa Weevil:** ***Hypera postica***
**Egyptian Alfalfa Weevil:** ***Hypera brunneipennis***

http://ucipm.ucdavis.edu/PMG/r1300511.html - MANAGEMENT

**Alfalfa Caterpillar**
**Scientific Name:** ***Colias eurytheme***

http://ucipm.ucdavis.edu/PMG/r1300611.html - MANAGEMENT

**Aphids ( Blue Alfalfa, Pea)**
**Blue alfalfa aphid:** ***Acyrthosiphon kondoi***
**Pea aphid:** ***Acyrthosiphon pisum***

http://ipm.ucanr.edu/PMG/r1302311.html#MANAGEMENT

http://ipm.ucanr.edu/PMG/r1302211.html#MANAGEMENT

**Beet Armyworm**
**Scientific Name:** ***Spodoptera exigua***

http://ucipm.ucdavis.edu/PMG/r1300711.html - MANAGEMENT

**Leafhopper (Garden, Potato, Mexican)**
**Garden leafhopper:** ***Empoasca solana***
**Potato leafhopper:** ***E. fabae***
**Mexican leafhopper:** ***E. mexara***

http://ucipm.ucdavis.edu/PMG/r1301211.html - MANAGEMENT

**Small Grains**

**Pests of Wheat**

**Russian Wheat Aphid**
**Scientific name:** ***Diuraphis noxia***

Key to Identifying Aphids: http://ucipm.ucdavis.edu/TOOLS/KEYAPHIDGRAIN/

http://ucipm.ucdavis.edu/PMG/r730300211.html - MANAGEMENT

**Bird Cherry-Oat Aphid**
**Scientific name: *Rhopalosiphum padi***

http://ucipm.ucdavis.edu/PMG/r730300311.html - MANAGEMENT

**Weeds** (Annual Broadleaf Weeds, Annual Grass Weeds, Field Bindweed, Johnsongrass)

http://ucipm.ucdavis.edu/PMG/r730700211.html

**Mites** (Brown Wheat, Winter Grain, Banks Grass)
**Brown wheat mite: *Petrobia latens***
**Winter grain mite: *Penthaleus major***
**Banks grass mite: *Oligonychus pratensis***

http://ucipm.ucdavis.edu/PMG/r730400111.html - MANAGEMENT

**Stripe Rusts of Wheat and Barley**
**Pathogen: *Puccinia striiformis***

http://ucipm.ucdavis.edu/PMG/r730100511.html - MANAGEMENT

**Barley Yellow Dwarf**
**Pathogen: Barley yellow dwarf virus**

http://ucipm.ucdavis.edu/PMG/r730101911.html - MANAGEMENT

**Cotton**

**Pests of Cotton**

**Sweet Potato/Silver Leaf Whitefly**
**Scientific Name: *Bemisia tabaci* Biotype B, (formerly *B. Argentifolii)***

http://ucipm.ucdavis.edu/PMG/r114300311.html - MANAGEMENT

**Pink Bollworm**
**Scientific Name: *Pectinophora gossypiella***

http://ucipm.ucdavis.edu/PMG/r114301511.html - MANAGEMENT

**Cotton Bollworm**
**Scientific Name:** ***Helicoverpa zea***

http://ucipm.ucdavis.edu/PMG/r114300511.html - MANAGEMENT

**Cotton Aphid**
**Scientific Name:** ***Aphis gossypii***

http://ucipm.ucdavis.edu/PMG/r114300111.html - MANAGEMENT

**Lygus Bug**
**Scientific Name:** ***Lygus hesperus***

http://ucipm.ucdavis.edu/PMG/r114301611.html - MANAGEMENT

**Webspinning Spider Mites** (Strawberry Spider, Pacific Spider, Twospotted Spider, Carmine Spider)
**Strawberry spider mite:** ***Tetranychus turkestani***
**Pacific spider mite:** ***Tetranychus pacificus***
**Twospotted spider mite:** ***Tetranychus urticae***
**Carmine spider mite:** ***Tetranychus cinnabarinus***

http://ucipm.ucdavis.edu/PMG/r114400111.html - MANAGEMENT

**Corn**

**Corn Earworm**

http://ucipm.ucdavis.edu/PMG/r113300911.html - MANAGEMENT

**Corn Leaf Aphid, Greenbug, Green Peach Aphid**
**Corn leaf aphid:** ***Rhopalosiphum maidis***
**Greenbug:** ***Schizaphis graminum***
**Green peach aphid:** ***Myzus persicae***

Key to Identifying Aphids: http://ucipm.ucdavis.edu/TOOLS/KEYAPHIDGRAIN/

http://ucipm.ucdavis.edu/PMG/r113300611.html - MANAGEMENT

**Weeds (Barnyardgrass and Volunteer Cereals, Nutsedge, Johnsongrass, Broadleaves, Resistant Weed Management Issues)**

http://ucipm.ucdavis.edu/PMG/r113700211.html

**Spider Mites (Twospotted Spider, Banks Grass, Strawberry Spider, Pacific Spider)**
**Twospotted spider mite: *Tetranychus urticae***
**Banks grass mite: *Oligonychus pratensis***
**Strawberry spider mite: *Tetranychus turkestani***
**Pacific spider mite: *Tetranychus pacificus***

http://ucipm.ucdavis.edu/PMG/r113400111.html - MANAGEMENT

**Armyworm, Beet Armyworm, Western Yellow Striped Armyworm**
**Armyworm: *Mythimna (= Pseudaletia) unipuncta***
**Beet armyworm: *Spodoptera exigua***
**Western yellowstriped armyworm: *Spodoptera praefica***

http://ucipm.ucdavis.edu/PMG/r113300811.html - MANAGEMENT

**Wireworms**
**Scientific names: *Limonius* spp. and others**

http://ucipm.ucdavis.edu/PMG/r113300211.html - MANAGEMENT

## Tree and Vine Crops

**Citrus**

**Citrus Leafminer**
**Scientific Name: *Phyllocnistis citrella***

http://ucipm.ucdavis.edu/PMG/r107303211.html - MANAGEMENT

**Scales (California Red, Yellow)**
**California red scale: *Aonidiella aurantii***
**Yellow scale: *Aonidiella citrina***

http://ucipm.ucdavis.edu/PMG/r107301111.html - MANAGEMENT

**Citrus Thrips**
**Scientific Name: *Scirtothrips citri***

http://ucipm.ucdavis.edu/PMG/r107301711.html - MANAGEMENT

***Phytophthora Gummosis***
**Pathogen:** ***Phytophthora* spp.**

http://ucipm.ucdavis.edu/PMG/r107100411.html - MANAGEMENT

**Mealybugs (Itrus, Citrophilus, Longtailed, Comstock)**
**Citrus mealybug:** ***Planococcus citri***
**Citrophilus mealybug:** ***Pseudococcus calceolariae***
**Longtailed mealybug** ***Pseudococcus longispinus***
**Comstock mealybug:** ***Pseudococcus comstocki***

http://ucipm.ucdavis.edu/PMG/r107300511.html - MANAGEMENT

**Cottony Cushion Scale**
**Scientific Name:** ***Icerya purchasi***

http://ucipm.ucdavis.edu/PMG/r107301611.html - MANAGEMENT

**Various Vertebrate Pests**

http://ucipm.ucdavis.edu/PMG/r107601111.html (management only)

**Grapes**

**Powdery Mildew**
**Pathogen:** ***Erisiphe necator***

http://ucipm.ucdavis.edu/PMG/r302100311.html - MANAGEMENT

**Leafhopper (Western grape, variegated)**
**Western grape leafhopper:** ***Erythroneura elegantula***
**Variegated leafhopper:** ***Erythroneura variabilis***

http://ucipm.ucdavis.edu/PMG/r302300111.html - MANAGEMENT

**Vine Mealybug**
**Scientific name:** ***Planococcus ficus***

http://ucipm.ucdavis.edu/PMG/r302301911.html - MANAGEMENT

**Pierce's Disease**
**Pathogen:** ***Xylella fastidiosa***

http://ucipm.ucdavis.edu/PMG/r302101211.html - MANAGEMENT

**Mealybugs (grape, obscure, longtailed)**
**Grape mealybug:** ***Pseudococcus maritimus***
**Obscure mealybug:** ***Pseudococcus viburni***
**Longtailed mealybug:** ***Pseudococcus longispinus***

http://ucipm.ucdavis.edu/PMG/r302301811.html - MANAGEMENT

**Botrytis Bunch Rot**
**Pathogen:** ***Botrytis cinerea***

http://ucipm.ucdavis.edu/PMG/r302100111.html - MANAGEMENT

**Almond**

**Navel Orangeworm**
**Scientific name:** ***Amyelois transitella***

http://ucipm.ucdavis.edu/PMG/r3300311.html - MANAGEMENT

**Peach Twig Borer**
**Scientific name:** ***Anarsia lineatella***

http://ucipm.ucdavis.edu/PMG/r3300211.html - MANAGEMENT

**Alternaria Leaf Spot**
**Pathogen:** ***Alternaria alternata***

http://ucipm.ucdavis.edu/PMG/r3101611.html - MANAGEMENT

**Anthracnose**
**Pathogen:** ***Colletotrichum acutatum***

http://ucipm.ucdavis.edu/PMG/r3101111.html - MANAGEMENT

**Shot Hole**
**Pathogen:** ***Wilsonomyces carpophilus***

http://ucipm.ucdavis.edu/PMG/r3100211.html - MANAGEMENT

**Brown Rot Blossom Blight**
**Pathogen:** ***Monilinia laxa;*** **rarely** ***Monilinia fructicola***

http://ucipm.ucdavis.edu/PMG/r3100111.html - MANAGEMENT

**Weeds (undefined, Roundup resistant varieties?)**

http://ucipm.ucdavis.edu/PMG/r3700211.html

**Avocado**

**Avocado Root Rot (Phytophthora Root Rot)**
**Pathogen:** ***Phytophthora cinnamomi***

http://ucipm.ucdavis.edu/PMG/r8100111.html - MANAGEMENT

**Persea Mite**
**Scientific name:** ***Oligonychus perseae***

http://ucipm.ucdavis.edu/PMG/r8400211.html - MANAGEMENT

**Avocado Thrips**
**Scientific name:** ***Scirtothrips perseae***

http://ucipm.ucdavis.edu/PMG/r8300311.html - MANAGEMENT

**Anthracnose**
**Pathogen:** ***Colletotrichum gloeosporioides***

http://ucipm.ucdavis.edu/PMG/r8100711.html - MANAGEMENT

**Armillaria Root Rot (Oak Root Fungus)**
**Pathogen: *Armillaria mellea***

http://ucipm.ucdavis.edu/PMG/r8100211.html - MANAGEMENT

**Branch Canker and Dieback (previously known as Dothiorella Canker)**
**Pathogen: *Botryosphaeria* spp. and *Fusicoccum* spp.**

http://ucipm.ucdavis.edu/PMG/r8100611.html - MANAGEMENT

**Walnut**

**Codling Moth**
**Scientific Name: *Cydia pomonella***

http://ucipm.ucdavis.edu/PMG/r881300211.html - MANAGEMENT

**Walnut Husk Fly**
**Scientific Name: *Rhagoletis completa***

http://ucipm.ucdavis.edu/PMG/r881301211.html - MANAGEMENT

**Walnut Blight**
**Pathogen: *Xanthomonas campestris* pv. *juglandis***

http://ucipm.ucdavis.edu/PMG/r881100111.html - MANAGEMENT

**Crown Gall**
**Pathogen: *Agrobacterium tumefaciens***

http://ucipm.ucdavis.edu/PMG/r881100211.html - MANAGEMENT

**Phytophthora Root and Crown Rot**
**Pathogen: *Phytophthora* spp.**

http://ucipm.ucdavis.edu/PMG/r881100411.html - MANAGEMENT

**Aphid (Walnut, Dusky-veined)**
**Walnut aphid: *Chromaphis juglandicola***
**Dusky-veined aphid: *Callaphis juglandis***

http://ucipm.ucdavis.edu/PMG/r881300511.html - MANAGEMENT

## Vegetables and other Row Crops

**Tomato**

**Tomato Yellow Leaf Curl**
**Pathogen: *Tomato yellow leaf curl virus* (TYLCV)**

http://ucipm.ucdavis.edu/PMG/r783103311.html

**Whiteflies (Silverleaf, Greenhouse, Bandedwinged)**
**Silverleaf whitefly: *Bemisia argentifolii***
**Greenhouse whitefly: *Trialeurodes vaporariorum***
**Bandedwinged whitefly: *Trialeurodes abutilonia***

http://ucipm.ucdavis.edu/PMG/r783301211.html - MANAGEMENT

**Tomato Fruitworm**
**Scientific name: *Helicoverpa (Heliothis) zea***

http://ucipm.ucdavis.edu/PMG/r783300111.html - MANAGEMENT

**Stink Bug ( Consperse, Redshouldered, Say's Stinkbug complex, Southern green)**
**Consperse stink bug: *Euschistus conspersus***
**Redshouldered stink bug:*Thyanta pallidovirens (= T. accerra)***
**Say's stink bug complex: *Chlorochroa sayi* and *Chlorochroa uhleri***
**Southern green stink bug: *Nezara viridula***

http://ucipm.ucdavis.edu/PMG/r783300211.html - MANAGEMENT

**Leafminers**
**Scientific names: *Liriomyza sativae, L. trifolii,* and *L. huidobrensis***

http://ucipm.ucdavis.edu/PMG/r783300911.html - MANAGEMENT

**Fusarium Wilt**
**Pathogen:** ***Fusarium oxysporum*** **f. sp.** ***lycopersici***

http://ucipm.ucdavis.edu/PMG/r783101011.html - MANAGEMENT

**Rice**

**Rice Blast (no pix in repository)**
**Pathogen:** ***Pyricularia grisea***

http://ucipm.ucdavis.edu/PMG/r682100611.html - MANAGEMENT

**Rice Water Weevil**
**Scientific Name:** ***Lissorhoptrus oryzophilus***

http://ucipm.ucdavis.edu/PMG/r682300511.html - MANAGEMENT

**Tadpole Shrimp**
**Scientific Name:** ***Triops longicaudatus***

http://ucipm.ucdavis.edu/PMG/r682500111.html - MANAGEMENT

Armyworm (Western Yellowstriped Armyworm)
**Armyworm:** ***Mythimna (= Pseudaletia) unipuncta***
**Western yellowstriped armyworm:** ***Spodoptera praefica***

http://ucipm.ucdavis.edu/PMG/r682300411.html - MANAGEMENT

**Rice Leafminer**
**Scientific Name:** ***Hydrellia griseola***

http://ucipm.ucdavis.edu/PMG/r682300211.html - MANAGEMENT

**Aggregate Sheath Spot of Rice**
**Pathogen:** ***Rhizoctonia oryzae-sativae***

http://ucipm.ucdavis.edu/PMG/r682100311.html - MANAGEMENT

**Weeds (undefined)**

There is no central page for rice like there is for other crops…
Weed gallery: http://ucipm.ucdavis.edu/PMG/r682700999.html

**Strawberry**

**Spider Mites (Twospotted Spider, Carmine Spider)**
**Twospotted spider mite:** ***Tetranychus urticae***
**Carmine spider mite:** ***Tetranychus cinnabarinus***

http://ucipm.ucdavis.edu/PMG/r734400111.html - MANAGEMENT

**Lygus Bug**
**Scientific Name:** ***Lygus hesperus***

http://ucipm.ucdavis.edu/PMG/r734300111.html - MANAGEMENT

**Cyclamen Mite**
**Scientific Name:** ***Phytonemus pallidus***

http://ucipm.ucdavis.edu/PMG/r734400211.html - MANAGEMENT

**Aphid (Green Peach, Melon, Potato, Strawberry)**
**Green peach aphid:** ***Myzus persicae***
**Melon aphid:** ***Aphis gossypii***
**Potato aphid:** ***Macrosiphum euphorbiae***
**Strawberry aphid:** ***Chaetosiphon fragaefolii***

http://ucipm.ucdavis.edu/PMG/r734300211.html - MANAGEMENT

**Verticillium Wilt**
**Pathogen:** ***Verticillium dahliae***

http://ucipm.ucdavis.edu/PMG/r734100811.html - MANAGEMENT

**Phytophthora Crown Rot**
**Pathogens:** ***Phytophthora cactorum, P. citricola, P. parasitica,*** **and** ***P. megasperma***

http://ucipm.ucdavis.edu/PMG/r734100911.html - MANAGEMENT

**Carrots**

**Alternaria Leaf Blight**
**Pathogen:** ***Alternaria dauci***

http://ucipm.ucdavis.edu/PMG/r102100711.html - MANAGEMENT

**Root Knot Nematode, Stubby Root Nematode, Needle Nematode**
**Root knot nematodes:** ***Meloidogyne incognita, M. javanica, M. hapla,*** **and** ***M. arenaria***
**Stubby root nematode:** ***Paratrichodorus*** **sp.**
**Needle nematode:** ***Longidorus africanus***

http://ucipm.ucdavis.edu/PMG/r102200111.html - MANAGEMENT

**Cotton (Melon) Aphid**
**Scientific Name:** ***Aphis gossypii***

http://ucipm.ucdavis.edu/PMG/r102300411.html - MANAGEMENT

**Cavity Spot**
**Pathogens:** ***Pythium sulcatum*** **and** ***P. violae***

http://ucipm.ucdavis.edu/PMG/r102100411.html - MANAGEMENT

**Cercospora Leaf Blight**
**Pathogen:** ***Cercospora carotae***

http://ucipm.ucdavis.edu/PMG/r102100211.html - MANAGEMENT

**Bacterial Soft Rot**
**Pathogen:** ***Pectobacterium carotovorum ssp. carotovorum***

http://ucipm.ucdavis.edu/PMG/r102101011.html - MANAGEMENT

**Cole Crops**

**Cabbage Aphid**
**Scientific Name:** ***Brevicoryne brassicae***

http://ucipm.ucdavis.edu/PMG/r108300811.html - MANAGEMENT

**Cabbage Looper**
**Scientific Name:** ***Trichoplusia ni***

http://ucipm.ucdavis.edu/PMG/r108301011.html - MANAGEMENT

**Imported Cabbageworm**
**Scientific Name:** ***Pieris rapae***

http://ucipm.ucdavis.edu/PMG/r108301111.html - MANAGEMENT

**Alternaria Leafspot**
**Pathogens:** ***Alternaria brassicae, A. brassicicola***

http://ucipm.ucdavis.edu/PMG/r108100911.html - MANAGEMENT

**Diamondback Moth**
**Scientific Name:** ***Plutella xylostella***

http://ucipm.ucdavis.edu/PMG/r108301311.html - MANAGEMENT

**Cabbage Maggot**
**Scientific Name:** ***Delia radicum***

http://ucipm.ucdavis.edu/PMG/r108300111.html - MANAGEMENT

**Important Pests in Rangelands/Grasslands/Noncrop Agricultural Lands**

**Weeds:**

- Barb Goatgrass: http://anrcatalog.ucanr.edu/pdf/8315.pdf
- Black Medic: http://ipm.ucanr.edu/PMG/WEEDS/black_medic.html
- Brooms: http://ipm.ucanr.edu/PMG/PESTNOTES/pn74147.html

- Burning and stinging nettles: http://ipm.ucanr.edu/PMG/PESTNOTES/pn74146.html
- California burclover: http://ipm.ucanr.edu/PMG/WEEDS/california_burclover.html
- Fiddlenecks: http://ipm.ucanr.edu/PMG/WEEDS/fiddlenecks.html
- Hare barley and wild oats: http://ipm.ucanr.edu/PMG/WEEDS/hare_barley.html and http://ipm.ucanr.edu/PMG/WEEDS/wild_oat.html
- Invasive plants: http://ipm.ucanr.edu/PMG/PESTNOTES/pn74139.html
- Perennial pepperweed: http://ipm.ucanr.edu/PMG/PESTNOTES/pn74121.html#RANGELAND
- Ripgut brome: http://ipm.ucanr.edu/PMG/WEEDS/ripgut_brome.html
- Yellow starthistle: http://ipm.ucanr.edu/PMG/PESTNOTES/pn7402.html
- Wild blackberries: http://ipm.ucanr.edu/PMG/PESTNOTES/pn7434.html

**Vertebrates:**

- Ground squirrel: http://ipm.ucanr.edu/PMG/PESTNOTES/pn7438.html
- Wild pig: http://ipm.ucanr.edu/PMG/PESTNOTES/pn74170.html
- Deer mouse: http://ipm.ucanr.edu/PMG/PESTNOTES/pn74161.html

**Insects*:**

- Grasshopper: http://ipm.ucanr.edu/PMG/PESTNOTES/pn74103.html

*Note that most insects are considered pests of crops that are adjacent to grasslands or rangelands, rather than being pests of grasslands or rangelands. These include false chinch bugs (http://ipm.ucanr.edu/PMG/PESTNOTES//pn74153.html) and stink bugs.

**Section 3: Pesticides**

**Knowledge Expectations**

3-1. Describe the factors to consider when making pesticide use decisions.
3-2. Discuss types of insecticides/miticides and describe which type works best in a given situation.
3-3. Discuss types of herbicides and describe which type works best in a given situation.
3-4. Describe the importance of selecting pesticides with varying modes of action, including the management, prevention, or delay of resistance development in target organisms.
3-5. Discuss types of pesticides used for disease control and describe which type works best in a given situation.
3-6. Discuss types of nematicides and describe which type works best in a given situation.
3-7. Discuss types of pesticides used to manage vertebrate pests and describe which type works best in a given situation.
3-8. Describe methods for making poison baits more selective.

# Factors to Consider when Making Pesticide Use Decisions

## Choosing the Right Pesticide

Pesticides can provide cost-effective control of pests that cause damage to crops. In an IPM program, you only use pesticides when observation indicates they are needed.

Pesticides are organized in several ways, most commonly by type of pest controlled (insecticides, herbicides, fungicides, rodenticides, nematicides). They may also be sorted according to mode of action (for example, growth regulator herbicides) or according to chemical class (amides, pyrethroids) or source of material (botanicals, microbials). Pesticides are systemic (translocated throughout the organism) or nonsystemic (contact). The tables in Chapter 3 of *The Safe and Effective Use of Pesticides* provide several examples of pesticides organized in all of these different ways.

In choosing a pesticide, consider not only its effect on the target pest, but also the effect it may have on other pests, natural enemies, honey bees and other pollinators, people, the environment, and the crop. Consider special attributes of the site such as soil type, nearby crops, surface water and groundwater, wildlife, people's homes, and the potential for worker exposure. You should also make sure that the pesticide you select works within constraints of legally established restricted-entry intervals and the allowable days before harvest.

This section discusses the criteria to consider when choosing different types of pesticides—insecticides, herbicides, nematicides, fungicides, bactericides, and vertebrate control materials. Factors to consider when choosing a pesticide include its

- selectivity
- toxicity

- available formulations
- persistence in the environment
- cost and efficacy
- ease of use and compatibility
- effects on beneficial organisms
- restricted entry intervals and harvest restrictions
- movement in and impact on the environment

For more information about pesticides, their toxicity, and how they are organized see Chapter 3; for effects of pesticides on human health, see Chapter 5; and for the environmental impacts of pesticide applications see Chapter 4 in *The Safe and Effective Use of Pesticides*. For a general treatment of what goes into the typical pesticide use decision and the pesticide selection process, see pp 287-290.

**Insecticides**
Key to choosing an insecticide for an IPM program is identifying the species causing the damage, determining the life stage most effectively controlled, and timing the application to match that life stage. Many insecticides are fairly broad-spectrum poisons. It is therefore equally important to consider the potential impact of the insecticide on nontarget organisms such as pollinators and natural enemies, animals, and people in the area, as well as its potential for moving off-site and posing hazards elsewhere.

All insecticides should be chosen based on crops or the plans for noncrop agricultural areas along with the pest. Emphasis should be placed on choosing the least-toxic material that will effectively manage the pest population. In an IPM program, preserving natural enemies is a high priority. You should choose selective materials and time their applications to control pests without seriously impacting these important beneficial insects. Formulations and application methods can further improve control and selectivity, and can reduce hazards to people and the environment (Table 3-1). See Chapters 3, 7, and 10 of *The Safe and Effective Use of Pesticides* for ways you can increase a pesticide's safety and selectivity.

Contact insecticides provide control when target pests come in to physical contact with it. Stomach poisons must be ingested to affect the pests. For instance, if a pest feeds on the underside of leaves, an application of contact or stomach poison to the upper surface will not be effective. Many insecticides have both contact and stomach activity.

Systemic insecticides are taken up after application by the crop, plant, or animal and move to other tissues within the organism. On plants, systemics may be applied to foliage and transported to the leaves and stems, or they can be soil-applied to be taken up by the roots where they kill feeding insects. Sometimes beneficial insects or pollinators feeding on nectar from treated plants may also be affected.

**Table 3-1:** *Insecticides/miticides by chemical name, method of effect, selectivity, and typical uses.*

| **Chemical Name** | **Method of Effect*** | **(S)elective or (B)road-spectrum** | **Uses** |
|---|---|---|---|
| Kaolin | C | B | Protects plants from insect and mite feeding damage by coating leaves and preventing insects from feeding. |
| Phosmet | C | B | Kills insects and mites on contact, and when they feed on sprayed plants, used during dormant periods to destroy overwintering pests, as well as during fruiting season. |
| Carbaryl | C & slight S | B | Kills insects by contact, and when pests take baits or eat coated plants. Dangerous to pollinators and other beneficial insects. |
| Diazinon | C | B | Kills insects on contact, affects nontarget insects and wildlife. Apply to dormant trees to control insect pests, avoid applying when weeds are blooming and pollinators are active. |
| Chlorpyrifos | C | B | Controls insects that eat, contact, or inhale it. Dangerous to pollinators and other beneficial insects. |
| Imidacloprid | S | S | Controls insects in many agricultural settings, as well as in structures to prevent termite damage. |
| Permethrin | C | B | Controls mites and insects on contact. Effective on a variety of crops, and as an impregnate on clothing and netting. |
| Dicofol | C | S | Controls mites on contact. Applied to foliage in agricultural settings and in or around domestic and agricultural buildings to control mites. |

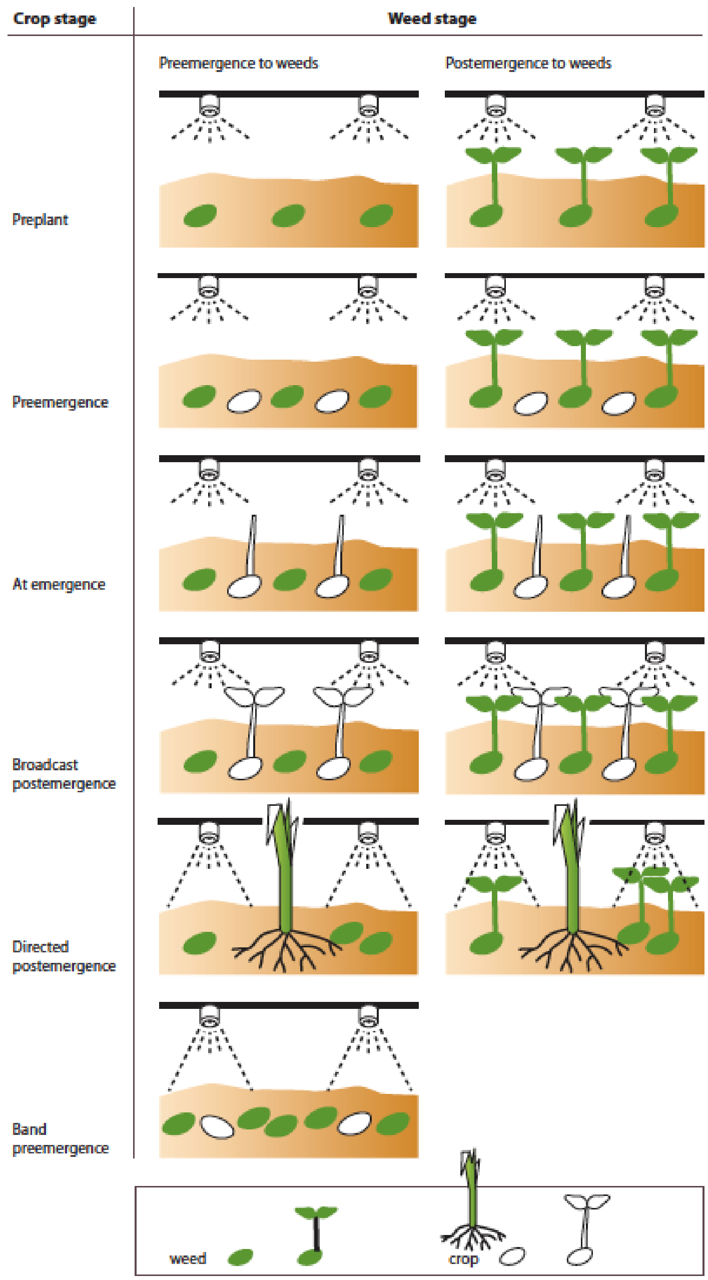
*Key: C = Contact; S = Systemic
*Some a.i.'s or products listed here may not be currently registered as pesticides, or may have their registration cancelled.

The chemical family (also sometimes referred to as class), provides clues to the material's specificity, toxicity, and mode of action. However, a number of insecticides do not fit into chemical families because they are not closely related to other insecticides. (For classification of insecticides according to chemical family and mode of action, see the Insecticide Resistance Action Committee website, www.irac-online.org.) On the other hand, some materials can be grouped according to other common features, such as origin or mode of action. Some common insecticide groups include soaps and oils (fatty acids), abrasive dusts, botanicals, insect growth regulators, and microbials.

**Herbicides**

Herbicides are chemicals that kill plants. When combined with good cultural practices, herbicides control many weed species and are an important component of an integrated weed management program. Application method and timing are critical for the success of herbicide applications. To help you understand the importance of application timing, Figure 3-1 shows the stages of weed growth which are most affected by different types of herbicide applications.

**Figure 3-1** Terms used in describing application timing of herbicides in relationship to crop growth and weed emergence. Adapted from Fryer and Evans, 1968.




Herbicides are organized in several ways, generally relating to how they affect plants or which types of plants they affect. Selective herbicides only kill certain types of plants (such as broadleaf or grass weeds); nonselective (broad-spectrum) herbicides kill all types of vegetation. Contact herbicides kill only the plant parts touched directly by the herbicide. Systemic herbicides are absorbed by the roots or aboveground plant tissue and are moved throughout the plant so that all its parts are affected.

Proper choice of herbicide depends on the weed species, the susceptibility of the weeds to the material, and the tolerance of the crop and surrounding desirable vegetation to the material. Weed infestations are usually composed of several different species. Use a weed susceptibility chart to help select an herbicide or mix of herbicides that offers the most effective control. Figure 3-2 is an example of a weed susceptibility chart for weed species found in stone fruits. Plant-back or *crop rotational restrictions* should also be considered when selecting herbicides. Some pesticides remain in soil for a long time and can affect the next crop planted at that site. The pesticide label will tell you if crop rotational restrictions apply in your case. Follow the label instructions regarding use and crop rotational restrictions. See p 108 of *The Safe and Effective Use of Pesticides* for more on crop rotational (plant-back) restrictions.

Before deciding on an herbicide, always consider its mode of action, selectivity, persistence, site of action, toxicity, resistance issues, and environmental concerns (Table 3-2). In addition, soil type and site preparation affect the action of many herbicides. Specifics for individual herbicides can be found in the Weed Science Society of America's *Herbicide Handbook*.

**Mode of Action**. Herbicides kill plants by interfering with vital plant processes. For example, they may interfere with photosynthesis, inhibit root or shoot growth, or cause abnormal plant tissue development. Often, closely related herbicides have the same mode of action, but there are exceptions. Knowing the mode of action lets you rotate herbicides in order to reduce the development of resistance in the weeds you treat. In addition, knowing the material's mode of action helps you recognize damage symptoms caused by a specific herbicide on target weeds and nontarget plants. Modes or mechanisms of action for specific herbicides can be found on the Herbicide Resistance Action Committee website, at www.hracglobal.com, or from the Weed Science Society of America. See p 298-299 of *The Safe and Effective Use of Pesticides* for more about how mode of action affects the development of pesticide resistance.

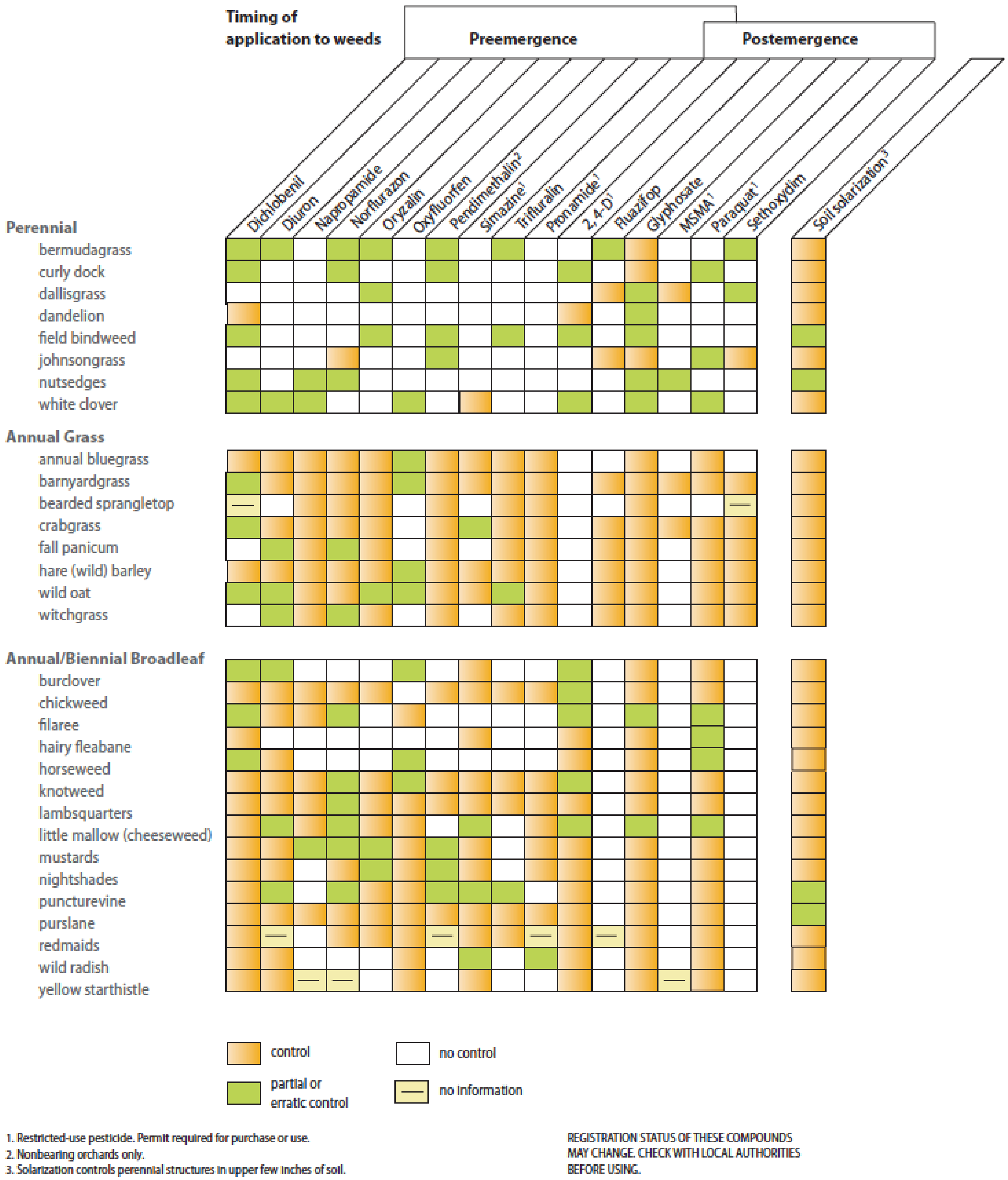
**Table 3-2:** *Herbicides by chemical name, method of effect, selectivity and typical uses.*

| Name** | Method of Effect* | (S)elective or (B)road-spectrum | Uses |
|---|---|---|---|
| Glyphosate | S | B | Spot treatment to control weeds or clumps of weeds. Foliar applied. |
| Trifluralin | S | S | Controls most annual weeds in lawns and gardens when applied after garden plants are established. Soil applied or applied via chemigation. |
| Benefin | S | S | Controls many annual weeds, as well as crabgrass in lawns. Soil applied or applied via chemigation. |
| Dithiopyr | S | S | Controls crabgrass, annual bluegrass, oxalis, spurge, and others. Soil applied. |
| Dicamba | S | S | Controls broadleaves (including clover and other broadleaf weeds in lawns). Foliar applied. |
| Fluazifop | S | S | Controls grasses including bermudagrass in broadleaf groundcovers or landscape beds. Apply when grass weeds are actively growing. Foliar applied. |
| 2,4-D | S | S | Controls broadleaves (including dandelion and other broadleaf weeds in lawns). Foliar applied. |
| Atrazine | S | S | Controls weeds in annual and established perennial crops. Foliar applied. |
| Glufosinate ammonium | C | B | Spot treatment to control weeds or clumps of weeds. Foliar applied. |

*Key: C = Contact; S = Systemic

**Some a.i.'s or products listed here may not be currently registered as pesticides, or may have their registration cancelled.

**Figure 3-2** Example herbicide selectivity table for stone fruits. You can also find up-to-date herbicide efficacy tables at the UC IPM website, www.ipm.ucanr.edu.



**Selectivity**. Herbicides that kill weeds but leave desirable plants unharmed are called selective. For instance, certain herbicides kill most broadleaf weeds but leave grassy plants such as turf or grain crops unharmed. Become familiar with the identity of the weed species to take advantage of herbicide selectivity.

If you must choose a less selective herbicide, it can be made more selective through the use of particular application techniques. For methods used to make pesticides more selective, see pp 294-299 of *The Safe and Effective Use of Pesticides*.

**Persistence.** Herbicide persistence varies widely. Many soil-applied herbicides are designed to remain toxic to weeds for several weeks or months after application to provide weed control over an extended time. The residue of such a material may pose a hazard if susceptible crops are planted before the material degrades or if the herbicide accumulates in groundwater or surface water supplies. For these reasons it is critical that you abide by crop rotational restrictions listed on the pesticide label.

Soil type can affect both the persistence and the effectiveness of many herbicides. Some herbicides are held tightly in soils that have high clay content or high levels of organic matter so they are not as available for weed control. As a result, higher rates may be required on these soils for effective weed management or their use may not be recommended at all (Table 3-3). Herbicide labels specify these differential rates. For more about how soil affects persistence, see pp 101 and 292-293 of *The Safe and Effective Use of Pesticides*.

**Table 3-3:** *Preemergence broadcast application rates per acre for sample herbicide. Some herbicide labels recommend different application rates based on soil texture and the percentage of organic matter in the soil.*

| | Brand X 80W herbicide applied (lb) taking into account % organic matter in soil | | | | | |
|---|---|---|---|---|---|---|
| **Soil texture** | **Less than 1%** | **1%** | **2%** | **3%** | **4%** | **Over 4%** |
| coarse<br>(sand, loamy sand, sandy loam) | do not use | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 |
| medium<br>(loam, silt loam, silt, sandy clay, loam) | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 |
| fine<br>(silty clay loam, clay loam, sandy clay, silty clay, clay) | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
| peat or muck | not recommended | | | | | |

*Source:* Ross and Lembi 1999.

**Site of Entry and Movement Through the Plant**. Soil-applied herbicides can enter plants through roots, shoots, seeds, rhizomes, bulbs, or tubers. The primary site of entry for foliar-applied herbicides is the leaf. Once inside the plant, the herbicide must reach a specific susceptible site. Contact herbicides typically kill only the part of the plant that is sprayed. Understanding the site of entry and whether (and how) herbicides move through the plant (translocate) is essential when choosing herbicides. This knowledge also aids in determining appropriate application timing and herbicide placement.

**Toxicity**. Most herbicides have quite low acute toxicity to people and animals; they are relatively safe to the user, wildlife, and the environment. However, there are notable exceptions, such as paraquat. The acute toxicity of paraquat is very high, and, as a result, you should use it with caution.

**Environmental Concerns**. A hazard associated with most herbicides is the potential for drift or runoff onto other areas, where nontarget plants may be damaged. Some herbicides are quite persistent or are easily leached into groundwater or rinsed into surface water where they may harm plants and wildlife. Leaching is influenced by the characteristics of the herbicide and the soil type. For instance, coarse-textured soils, such as sandy loam, are prone to leaching. California regulations restrict the application of certain herbicides in some growing areas where leaching to groundwater has been a problem. You must consider the potential for all types of offsite movement when selecting herbicides and application methods. Always check with your County Agricultural Commissioner for local regulations. See Chapter 4 of *The Safe and Effective Use of Pesticides* for a more detailed treatment of environmental problems caused by herbicides.

### Fungicides and Bactericides

Pesticides used for disease control fall primarily into three categories: bactericides, fungicides, and fumigants. A few bactericides are available to control bacterial plant diseases. They consist primarily of copper compounds and certain antibiotics, such as streptomycin. Natural bactericides are also available, such as *Agrobacterium radiobacter* strain K84 for the control of crown gall in fruit trees, *Pseudomonas fluorescens* strain A506 for the control of fire blight in pears, and *Bacillus subtilis* used against a range of fungal pests including those causing powdery mildew and Alternaria leaf blights.

Many fungicides are available to aid in managing a variety of fungal diseases. New products are developed every year. An up-to-date list of fungicides and modes of action is maintained by the Fungicide Resistance Action Committee at www.frac.info.

Fungicides can be grouped into two basic classes: *eradicants* and *protectants*. Most fungicides are surface protectants that must be applied before the fungal spores germinate and enter the plant. Their presence usually prevents spores from germinating or kills spores once they germinate. If infection occurs, protectants cannot prevent disease.

Eradicants directly affect pathogens after they have invaded the plant tissue by killing the fungus inside the host or by suppressing the reproduction of the fungus. Many eradicant fungicides are systemics that are absorbed into plant tissue and translocated to other parts of the plant; they can control established infections to a limited extent. Systemics are not as susceptible to weathering as surface protectants, but because they usually act on specific metabolic processes, they are more susceptible to resistance. Because of their effectiveness as eradicants, systemic fungicides are beginning to replace protectants.

Antibiotics are substances produced by microorganisms that inhibit growth and are toxic to other microorganisms. A number of antibiotics, such as streptomycin and tetracycline, have been formulated as bactericides and are registered only on a few crops. They act on the host or pathogen. Antibiotics are absorbed by the plant and, to a limited extent, may be translocated systemically.

When selecting a fungicide or bactericide, it is important to choose the most effective material for the situation (Table 3-4). For instance, protectants have limited usefulness once an infection has started. Precise timing of pesticide applications is probably more important in the control of plant pathogens than with any other type of pest. Keep track of weather, especially temperature and moisture, because disease epidemics can build rapidly after changes in the weather. Repeated applications are often required, depending on the persistence of the material. Systemic fungicides reduce the need for repeated applications. For more about pathogens and their life cycles, see pp 58-65 in *The Safe and Effective Use of Pesticides*.

To date, fungicides have not been identified as sources of environmental problems nearly as much as insecticides and herbicides have. This is partially because most fungicides break down rapidly in the environment, with the exception of copper compounds. Also, fungicide modes of action against microorganisms make them less likely to impact mammals, fish, birds, and higher plants. Few fungicides have high acute mammalian toxicity. However, some have been identified as potential carcinogens and have raised consumer concerns because they can persist on harvested food crops for some time. Processors and certain markets do not allow the use of some of these materials.

**Table 3-4:** *Bacteriacides and fungicides by scientific and/or common name, method of effect, selectivity and typical uses.*

| Name | Method of Effect* | (S)elective or (B)road-spectrum | Uses |
|---|---|---|---|
| Mancozeb | C | B | Protects sprayed plants from fungal infections. Foliar applied. Benefits from adding a surfactant. |
| Azoxystrobin | S | B | Controls most fungal diseases – the broadest of the fungicides available. |
| Streptomycin | S? | S | Controls fireblight bacteria, but is a restricted material and is allowed only in specified circumstances. Usually mixed with terramycin to help mitigate resistance in California. |
| *Agrobacterium radiobacter* | S | S | Controls crown gall, but only as a preventative. Applied as a root dip or spray before heeling-in or planting. |
| Bordeaux mixture | C | B | Protects sprayed plants from fungal infections. |
| Ziram | C | S | Protects sprayed plants from fungal infections. |

*Key: C = Contact; S = Systemic
*Some a.i.'s or products listed here may not be currently registered as pesticides, or may have their registration cancelled.

## Nematicides

The number of nematicides available is very limited (Table 3-5). Effective nematicides must be able to move throughout the soil profile where nematodes reside. Soil texture, moisture, organic matter, pH, and temperature, soil profile variability, adsorptive characteristics of the chemical, application methods, and application rates also influence successful control. As broad-spectrum pesticides, most of the available nematicides have substantial potential for environmental and human hazard if not used with great care. Some nematicides have been linked to groundwater contamination, and others are volatile organic compounds (VOCs) that can contribute to smog.

**Table 3-5:** *Nematicides by chemical name, method of effect, selectivity, and typical uses.*

| Chemical Name | Method of Effect* | (S)elective or (B)road-spectrum | Uses |
|---|---|---|---|
| Aldicarb | S | B | Controls nematodes in certain crops and other pests in many situations. Applied at planting, it can remain in the plant's root system for 6-8 weeks. |
| 1,3-Dichloropropene | C | B | Controls nematodes and other pests. Applied as a preplant fumigant in agricultural settings. |
| Chloropicrin | C | B | Controls nematodes and other pests as a fumigant, often in conjunction with methyl bromide and 1,3-Dichloropropene. |

*Key: C = Contact; S = Systemic
*Some a.i.'s or products listed here may not be currently registered as pesticides, or may have their registration cancelled.

Nematicides can be generally classified as fumigants or nonfumigants. Fumigants have been increasingly restricted because they can be sources of VOCs and also pose health concerns. In California, you are required to pass a separate certification exam for soil fumigation in order to apply these pesticides. Nonfumigants, such as fenamiphos and sodium tetrathiocarbonate, may be applied at or after planting. Irrigation or rain to disperse the material into the soil profile must follow application. Materials can also be applied directly in irrigation water using a chemigation system. See p 222-229 in *The Safe and Effective Use of Pesticides* to learn more about chemigation systems and their components.

Before deciding to use a nematicide, it is critical to learn which nematode species are present and to have estimates of their populations. Species of nematodes differ in their sensitivity to nematicides, and certain life stages are more sensitive than others. For example, juveniles and stages during a molt are more sensitive than adults to fumigation, while eggs are less sensitive than adults. For more about nematodes and their life cycles, see pp 48-51 in *The Safe and Effective Use of Pesticides*.

### Rodenticides and Other Chemicals to Control Vertebrate Pests

The most commonly used pesticides available for vertebrate pest control include burrow fumigants, strychnine, anticoagulants, chemosterilants, and repellents (Table 3-6).-The key to selecting and using the appropriate pesticide for vertebrate control is accurate identification and knowledge of the habits and biology of the animal causing the damage. Often, the pest is not present when damage is noticed, so identification must be made from symptoms such as chewed bark or from other signs of the pest's presence such as droppings, tracks, burrows, nests, or food caches. For more about vertebrate pests and their habits, see pp 52-55 in *The Safe and Effective Use of Pesticides*. To learn about the difference between first and second generation anticoagulants, see pp 85-86.

**Table 3-6:** *Vertebrate Control Substances by scientific and/or common name, method of effect, selectivity and typical uses.*

| Name | Method of Effect* | (S)elective or (B)road-spectrum | Uses |
|---|---|---|---|
| Sulfuryl Fluoride | C | B | Used as a fumigant to prevent a rodent from accessing stored body fat. |
| Rotenone | C | B | Used as a piscicide in water, interferes with cellular respiration. |
| 4-Aminopyridine | S | S | Used to cause convulsions that cause birds to emit distress calls that frighten other birds away. |
| Bromadiolone | S | B | Used to control rodents by reducing blood clotting, eventually resulting in death. |

*Key: C = Contact; S = Systemic
*Some a.i.'s or products listed here may not be currently registered as pesticides, or may have their registration cancelled.

You should choose a pesticide that is appropriate to the location, time of year, and the environmental conditions at the site. You must also think about the potential for poisoning people and nontarget species and secondary poisoning of predators and domestic animals. When using pesticides to control vertebrate pests, consider the effectiveness of the material compared to other methods. For instance, pesticides should be combined with appropriate habitat modification techniques whenever possible. Check with the local county Agricultural Commissioner to find out about vertebrate pest control materials that can legally and effectively be used at each site. Vertebrate control materials can pose special hazards for endangered vertebrate species. In California the Department of Pesticide Regulation provides online maps indicating what endangered species are located in a given area. Consult DPR's PRESCRIBE at www.cdpr.ca.gov/docs/endspec/. ("Factors to Consider when Making Pesticide Use Decisions" adapted from Flint, M.L., 2012)

## Section 4: Safe and Effective Use of Pesticides

### Knowledge Expectations

4-1. Explain the various fates of pesticides in the environment, and how understanding these fates affect pesticide selection and application.
4-2. Explain how to determine if weather conditions at the application site will cause off-site movement.
4-3. Describe the factors that can affect the outcomes of pesticide applications.
4-4. Describe the different types of resistance to pesticides, how each occurs, and how to manage each.
4-5. Explain how the proper use of pesticides contributes to the management of pesticide resistance.
4-6. Explain how pesticide resistance develops and describe ways to manage it.
4-7. Explain how to monitor and account for pesticide underperformance, and list the ways to avoid it.
4-8. Explain how weather conditions at the application site can impact the effectiveness of pesticide applications.
4-9. List common errors that can occur when applying pesticides and describe the problems that can result from these errors, including legal and economic consequences.
4-10. List the advantages and disadvantages of using multiple pesticides in one tank (tank mix).
4-11. List the indications that a tank mix of two or more formulations is incompatible.
4-12. Describe the ways to prevent incompatibility when tank mixing pesticides.
4-13. Describe methods used to time pesticide applications and increase their effectiveness.
4-14. Describe thresholds used to make treatment decisions, and explain how to use these thresholds to determine if pesticide application is needed.
4-15. List and describe the tools available for monitoring agricultural pest populations before, during, and after pesticide application.
4-16. Explain how to prevent pesticides from moving into nontarget areas.
4-17. Describe several methods that help determine whether adequate pesticide coverage is being achieved.

## Fate of Pesticides in the Environment

As soon as you release a pesticide into the environment, it begins to move and change. These changes can be positive or negative, depending on the chemical, the target pest, and environmental conditions during and after its release. For instance, when targeting weeds, a certain amount of leaching is required so that herbicides reach the weed's site of uptake: its roots. Too much leaching due to heavy rain or irrigation, however, means that the herbicide moves through the soil and away from targeted weeds into groundwater. Pesticides also change – breaking down or, in some cases, becoming more toxic because of factors like heat, sunlight, and amount of organic matter in the soil, among others. Natural processes can reduce the effectiveness of pesticide applications, pollute water, and negatively impact people, nontarget plants, and nontarget animals in the surrounding environment. To learn more about chemical changes that affect pesticides, see pp 301-302 in *The Safe and Effective Use of Pesticides*.

Natural processes that impact pesticides consist of those that transfer, or move chemicals and those that break chemicals down, or *degrade* them. Movement of chemicals in the environment can occur via leaching and runoff, as well as adsorption, absorption, volatilization, and drift caused by wind or temperature inversions. The breakdown of chemicals happens through the action of microbes, the normal action of the chemical, and sunlight (known as *photodegradation*).

**Adsorption** is the binding of chemicals to soil particles. The amount and persistence of adsorption varies with pesticide properties, soil moisture content, soil pH, and soil texture. Soils high in organic matter or clay are the most adsorptive. Coarse, sandy soils with little organic matter or clay are much less adsorptive. Certain pesticides used on highly adsorptive soils may require higher rates or more frequent applications. Read the label carefully to find the proper application rate for the soil type at the application site.

The adsorptive nature of soil influences the other processes that determine pesticide fate. A pesticide tightly held by soil particles is less likely to be taken up by plants, volatilize, leach, or be degraded by microorganisms. However, soil-adsorbed pesticides readily move when soil particles are blown by wind or washed away by water.

**Volatilization** occurs when a solid or liquid turns into a gas. Volatilization of pesticides increases with higher air temperature, higher temperature at the treated surface, increased air movement, low relative humidity, and small spray droplet size. Pesticides volatilize more readily from coarse textured (sandy) soils that are dry, and from medium to fine textured soils with high moisture content. It is extremely important that you identify the soil type prior to applying pesticides on both crop and noncrop agricultural lands to ensure that you are meeting all label requirements for safe application of that material.

Once in a gaseous state, a pesticide can be carried away from a treated area by air currents. The movement of pesticide vapors in the atmosphere is called vapor drift. Unlike spray drift or dusts that can sometimes be seen during an application, vapor drift is invisible.

The vapor pressure rating of a pesticide is a measure of its capacity to volatilize. The higher the vapor pressure, the more volatile the pesticide. Volatilization can be reduced if you use low volatile formulations and soil incorporation. Avoid applying volatile pesticides when conditions favor volatilization. When applying in noncrop agricultural areas, be aware of your surroundings and avoid spray contact with impervious surfaces such as concrete or rocks.

**Runoff** occurs as water moves over a sloping surface, carrying pesticides either mixed in the water or bound to eroding soil. The amount of pesticide runoff depends on the grade or slope of an area, the erodibility and texture of the soil, the soil moisture content, the amount and timing of irrigation or rainfall, and the properties of the pesticide. For instance, a pesticide application made to a heavy clay soil already saturated with water is highly susceptible to runoff. Established vegetation or plant residues retain soil and moisture and tend to reduce runoff.

Runoff from both crop and noncrop agricultural areas can pollute streams, ponds, and lakes. Once in these surface waters, pesticides can injure the aquatic ecosystem; contaminate groundwater; cause livestock injury and crop loss; and damage sensitive plants downstream.

The risk of pesticide runoff is greatest when heavy rainfall occurs shortly after application. Always check the forecast before any outdoor application; if heavy rain is expected, then you should delay treatment. Irrigation should be applied in accordance with label instructions and monitored to avoid runoff and accumulation of excess surface water.

No-tillage, low-tillage cropping systems, and soil incorporation methods reduce pesticide runoff. Adjuvants that promote pesticide retention on treated surfaces can reduce the pesticide content in runoff water. In addition, surface grading, drainage ditches and dikes, and the use of border vegetation can help reduce the amount and control the movement of runoff waters.

**Leaching** occurs as water moves down through the soil, potentially reaching groundwater. Several factors influence pesticide leaching:

- *The water solubility of the pesticide*. A pesticide that dissolves in water can move readily as the solution leaches through the soil.
- *Soil permeability* (how fast water percolates through soil). Permeability is affected by soil structure, texture, and management practices. For example, sandy soils are more permeable, so are more likely to lead to leaching.
- *The degree of pesticide adsorption*. Adsorption is probably the most important factor influencing leaching. In Sidebar 3-1, a higher Groundwater Ubiquity Score (GUS) indicates an increased potential for leaching – the pesticide is less likely to stick to surfaces and remain in the area.
- *Persistence*. Pesticide persistence indicates how long a pesticide resists degradation. Persistence is usually measured by half-life—the time it takes for one-half of the amount of pesticide to degrade. A pesticide with a long half-life may persist in the soil long enough to leach even if it adsorbs fairly well.
- *Pesticide rate and rainfall or irrigation*. The greater the amount of pesticide used, and the closer the time of application to a heavy rainfall or irrigation, the greater its likelihood of leaching.
- *The method of application.* Pesticides applied directly to the soil or incorporated in the soil are available for leaching in higher concentrations than foliage applied treatments.

**Sidebar 3-1**

The Groundwater Ubiquity Score (GUS) is a methodology used to estimate the potential of pesticides to contaminate groundwater. Persistence of pesticides and binding ability of pesticides to soil particles are used to obtain GUS values. The tables below contain some common fungicides, herbicides, and insecticides to help you determine the consequences of pesticide application in the environment.

| **GUS Value** | **Leaching Potential** |
|---|---|
| < 0.1 | Extremely Low |
| 0.1-1.0 | Very Low |
| 1.0-2.0 | Low |
| 2.0-3.0 | Moderate |
| 3.0-4.0 | High |
| > 4.0 | Very High |

Potential for Groundwater Contamination Based on GUS — Fungicides
Common name of fungicides are used; GUS value in parenthesis

| **Extremely Low - Low** | **Intermediate** | **High-Very High** |
|---|---|---|
| Chloroneb (1.65) | Azoxystrobin (2.43) | Fenarimol (3.12) |
| Chlorothalonil (1.27) | Flutolanil (2.26) | Triticonazole (3.08)* |
| Cyazofamid (0.75)* | Mycobutanil (2.37) | |
| Etridiazole (1.30) | Propiconazole (2.04) | |
| Fludioxonil (1.79) | Triadimefon (2.15) | |
| Fluoxastrobin (1.51)* | Vinclozolin (2.60) | |
| Iprodione (1.32) | | |
| Mancozeb (1.29) | | |
| Pyraclostrobin (- 0.06)* | | |
| Trifloxystrobin (0.56) | | |

Potential for Groundwater Contamination Based on GUS — Herbicides
Common name of herbicides are used; GUS value in parenthesis

| **Extremely Low – Low** | **Intermediate** | **High-Very High** |
|---|---|---|
| Aminopyralid (1.41) | 2,4-D amine (2.70) | Bromacil (4.44) |
| Bispyribac-sodium(1.69)* | 2,4-D ester (2.00) | Clopyralid (5.46) |
| Clethodim (1.43) | Bensulide (2.08) | Dicamba (3.78) |
| Diquat dibromide (-6.00) | Dimethenamid (2.19)* | Imazapyr (3.91) |
| Fluazifop (0.69) | Diuron (2.58) | MCPP (3.57) |
| Glyphosate (- 0.69) | Fluoxypyr (2.65) | Nicosulfuron (3.34) |
| Mesotrione (1.47)* | Halosulfuron (2.29) | Prometon (4.95) |
| Oxadiazon (0.88) | Norflurazon (2.70) | Quinclorac (7.39) |
| Pendimethalin (0.59) | | Simazine (3.35) |
| Prodiamine (0.24) | | Sulfosulfuron (3.42)* |
| Oryzalin (1.59) | | Triclopyr (5.63) |
| Paraquat (-5.58) | | Atrazine (4.40) |
| | | Bentazon (1.45 to 3.38)* |

*A range of values comes from a change in absorption rates and half-life based on conditions at the application site.

Potential for Groundwater Contamination Based on GUS — Insecticides
Common name of insecticides are used; GUS value in parenthesis

| Extremely Low – Low | Intermediate | High-Very High |
| --- | --- | --- |
| Acequinocyl (0.36)* | Azadiractin (2.59) | Clothianidin (4.91)* |
| Bifenazate (0.00)* | Clofentezine (2.06)* | Dinotefuran (4.95)* |
| Buprofezin (0.73) | Fipronil (2.13) | Imidacloprid (3.76)* |
| Chlorpyrifos (0.32) | Halofenozide (2.08) | Trichlorfon (3.00) |
| Malathion (0.00) | | |
| Permethrin (-1.48) | | |
| Pyrethrins (-1.08) | | |
| Spinosyn(s) (- 0.35 & 0.09)* | | |
| Bifenthrin (-2.72) | | |
| Permethrin (-0.88) | | |
| Diazinon (1.28) | | |
| Cypermethrin (-2.27 to -1.38)* | | |

*A range of values comes from a change in absorption rates and half-life based on conditions at the application site.

**Absorption** occurs when pesticides are taken up by plants or other organisms. Once absorbed into a plant, most pesticides degrade. Some residues may persist, however, and enter the environment when the plant tissues decay. Certain pesticides are so persistent in soil that they can be absorbed by plants years after the application, so pay careful attention to label instructions regarding crop rotational or plant-back restrictions. (Adapted with permission from "Pesticide Education Manual: A Guide to Proper Use and Handling," Orono, ME: University of Maine Cooperative Extension, 2006.)

**Pesticide Degradation**
**Microbial degradation** is a process that destroys pesticides in the soil and occurs when microorganisms such as fungi and bacteria use a pesticide as food. It is the most common form of herbicide degradation. Microbial degradation can be quite rapid and thorough under favorable soil conditions—warm temperatures, proper pH, adequate soil moisture, oxygen, and fertility. Certain pesticides may actually require higher application rates to compensate for the loss when used in soils with these characteristics. After testing your soil, check the pesticide label for specific application rates for your soil type. Also be aware that repeated applications of certain pesticides in an area can result in enhanced degradation of those pesticides as the microbe populations build up.

**Chemical degradation** is the breakdown of pesticides by processes that do not involve living organisms. The breakdown products are usually nontoxic or nonpesticidal. Soil adsorption, pH levels, temperature, and moisture influence the rate and type of chemical reactions that occur. Chemical degradation is a slow process for most pesticides and is driven by chemical reactions such as hydrolyzation (when the material reacts with water) or oxidation (when the material reacts with oxygen). Many pesticides, especially the organophosphate insecticides, are susceptible to chemical degradation in high pH (alkaline) soils or spray mixes.

**Photodegradation** is the breakdown of pesticides by sunlight. Pesticides vary considerably in their stability when exposed to natural light. For instance, the herbicides most commonly applied to noncrop agricultural areas like grasslands and rangelands are resistant to breakdown by sunlight. Photodegradation of pesticides applied to active croplands is reduced by soil incorporation or by irrigation or rainfall following application.

## Factors that Affect the Outcome of Pesticide Applications

There are many factors other than pesticide formulations and properties that can affect the outcome of a pesticide application. These factors range from simple human error, to soil temperature, to pest and crop biology. Much of what happens after a pesticide is released into the environment is out of our control, but with careful planning, the outcome of your application can be improved. Understanding how the following factors affect pesticide applications to crops, grasslands, fencerows, field edges, and rangelands will help you increase success rates.

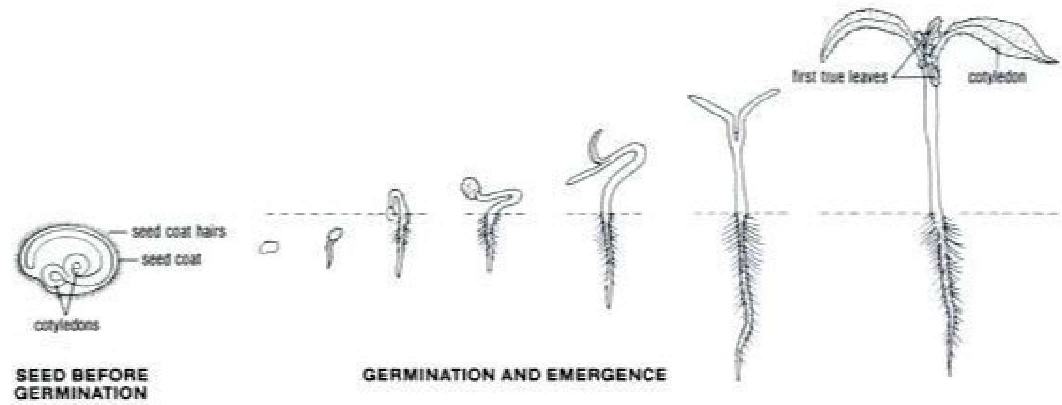
**Pest Identification**
Misidentification of pests is the most common reason that a pesticide application fails. Chapter 2 of *The Safe and Effective Use of Pesticides* covers methods for identifying pests that are causing damage to the crops you may treat. The section on biology of pests (online at [URL to be determined]) goes into detail regarding pests prevalent in California crops. In addition, The University of California's Integrated Pest Management website (http://ipm.ucanr.edu) provides Pest Management Guidelines to help guide you through the identification process based on the organisms, symptoms, and signs you observe.

**Life Stage of Pests**
Most pests have one or more stages in their life cycle when they are most vulnerable to pesticides. Applications made during a pest's most vulnerable life stage can increase a pesticide's overall effectiveness. Applications made at other stages in a pest's life cycle may be less effective. For example, most insects are easiest to control in the larval or nymph stages, and hardest to control as eggs, pupae, and adults. Weeds are most vulnerable before they emerge or as seedlings. Pathogens require preventative measures, since it is often impossible to get rid of them once they are established. For more information about pest life stages, see Chapter 2, *The Safe and Effective Use of Pesticides*.

In addition, you can often find pests on specific parts of a plant during particular life stages. For instance, adult leafhoppers can be found on the underside of sugarbeet leaves, or white, powdery fungal growth can be seen on the lower leaves of peppers infected with powdery mildew. Phenology models and records of past infestations can help you determine when certain life stages will occur, so you can time pesticide applications correctly.

**Life Stage and Health of Crops**
Pesticides can be toxic to the crops they are meant to protect, especially if plants are at a vulnerable life stage (Figure 4-1), have a nutrient deficiency, or are water or heat stressed. In addition, certain stages of crop growth are more vulnerable to pest damage, so it is important to track the crop's life stage in addition to that of the pest to determine the most effective time to apply pesticides, should they be required.

**Figure 4-1** A plant's seedling stage is typically the most vulnerable to herbicides.




**Pesticide Resistance**
Pesticide resistance has become a serious problem, limiting the number of effective pesticides available in many cropping systems. More than 500 species of insects and mites are known to be resistant to at least one pesticide. Resistance has been documented in over 200 weed species, over 100 species of plant pathogens, and in rodents. Repeated application of the same or similar pesticides has led to the development of populations of pest species that are resistant to pesticides that once controlled them. Once resistance begins to develop, higher rates of the same pesticide are necessary to achieve the same amount of control. Eventually, little or no control is achieved despite repeated applications at maximum rates. For more about pesticide resistance and how to combat it, see Chapter 10, *The Safe and Effective Use of Pesticides,* pp 303-306. More specific information about a pesticide and the pests that may be resistant to it can be found at any of the following websites:

- Fungicide Resistance Action Committee (www.frac.info)
- Insecticide Resistance Action Committee (www.irac-online.org)
- Herbicide Resistance Action Committee (www.hracglobal.com)

In addition, UC IPM's Pest Management Guidelines (http://ipm.ucanr.edu) may mention pesticides that have been compromised due to the development of resistance in target pests, and http://weedscience.org updates its list of resistant weeds regularly (adapted from Flint, M.L., 2012).

**Physical and Chemical Properties of the Soil**

The effectiveness of many soil-applied and soil-incorporated pesticides depends on the physical and chemical properties of the soil – its texture, pH, and the organic matter content. Each of these properties must be considered before applying any pesticide to maximize positive outcomes and reduce problems like offsite movement, chemical breakdown, and pesticides that do not reach their intended target. Soil analysis can be performed on samples gathered from an application site. There may also be soil maps of your area available from the Natural Resources Conservation Service (see soils.usda.gov for details) that will help you determine the soil texture prior to pesticide application. Check for on-line soil maps and information via the Gridded Soil Survey Geographic Database (gSSURGO), at http://datagateway.nrcs.usda.gov. You can also check the UC Davis Soil Resource Lab at http://casoilresource.lawr.ucdavis.edu. Labels provide application rates based on various soil properties (see an example in Figure 4-2). Check labels carefully once you know the makeup of soil at the application site.

**Figure 4-2** Sample of rates recommended for particular soil types in apples from a Diuron 4L label.

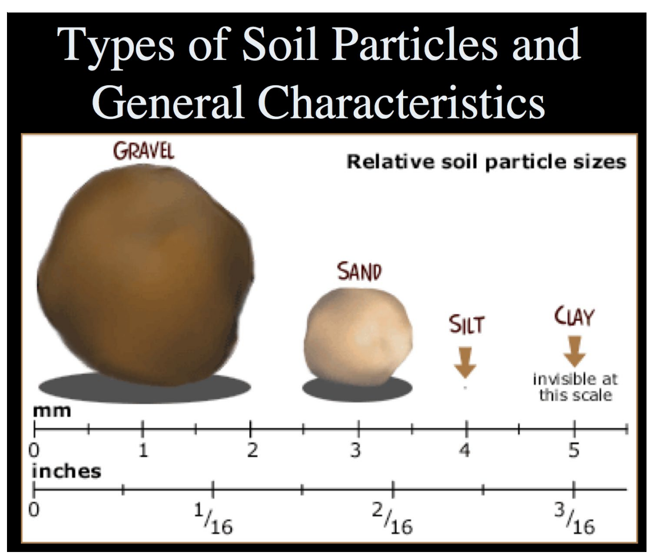
| Soil Texture | Rate per Acre | |
|---|---|---|
| | 1 to 2% Organic Matter This Product plus Sinbar | More than 2% Organic Matter This Product plus Sinbar |
| Sandy loam | 0.8 qt. + 1 lb. | 1.2 qts. + 1.5 lbs. |
| Loam, Silt loam, Silt | 1.2 qts. + 1.5 lbs. | 1.6 qts. + 2 lbs. |
| Clay loam, Clay | 1.6 qts. + 2 lbs. | 1.6 qts. + 2 lbs. |

**Soil Texture**. Soil texture is determined by analysis of its component parts: sand, silt, and clay (Figures 4-3, 4-4). Depending upon the percentage of each part within the soil sample provided, you may have soil that is:

1. Light or coarse (made up mostly of sand)
2. Medium (made up mostly of silt)
3. Heavy or fine (made up mostly of clay)
4. A combination of two or more of these textures

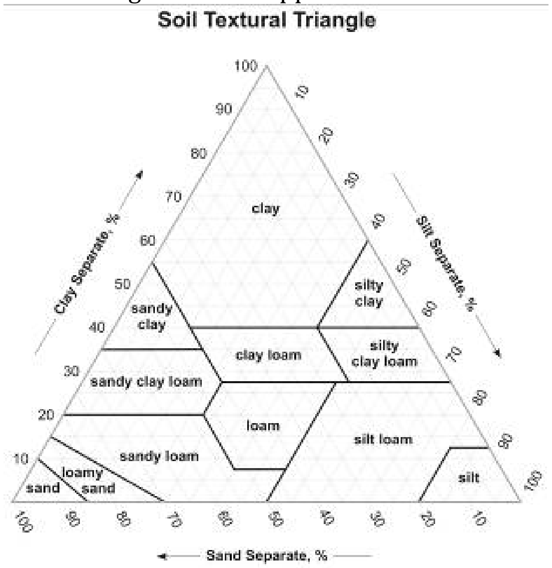
Light or coarse-textured soils contain more sand particles than other types. Sand particles are large and course and the pore openings between each soil particle are large. Combined, these characteristics mean that soils with light or coarse textures are the least adsorptive and most permeable. In these soils, water and pesticides move downwards (or percolate)

**Figure 4-3** Relative size of gravel, sand, silt, and clay particles.



rapidly. Because of their permeability, pesticide applications to sandy soils have the potential to enter and contaminate groundwater more easily than applications to medium or heavy soils.

**Figure 4-4** Soil texture is determined by analysis of its component parts: sand, silt, and clay. A soil texture triangle can help you determine what type of soil you are working with at an application site.




Medium soils contain more silt than sand or clay. Particles of silt are finer and have more adsorptive capacity than sand particles. Soils with a high silt content are less permeable than sandier soils. Water and pesticide move more slowly through this soil type, which helps reduce leaching. However, access to pesticides by pests may be reduced somewhat because the pesticide binds to silty soil particles and is not available for uptake by pests or crops.

Soils with more clay than silt or sand are referred to as heavy or fine-textured. Clay particles are finer and more adsorptive than silt. Heavy or fine soils tend to hold on to water and pesticides rather than allowing them to percolate down through the soil. Pesticides bind more tightly (adsorb) to particles in this type of soil, and are less available to root systems and pests that reside in the soil. Some soil-applied pesticides require distribution evenly throughout the soil to be effective, so applications made in this soil type may require more pesticide to control pests. Clay soils are also more prone to runoff than other soil types.

**Table 4-1:** *Relationship between soil texture and physical and chemical properties.*

| | Physical and chemical properties | | | | | |
|---|---|---|---|---|---|---|
| Soil type | Particle size (mm) | Water infiltration | Water-holding capacity | Nutrient- holding capacity | Aeration | Workability |
| sand | 2–0.05 | good | poor | poor | good | good |
| silt | 0.05–0.002 | medium | medium | medium | medium | medium |
| clay | 0.002 and less | poor | good | good | poor | poor |
| loam | mix of sizes | medium | medium | medium | medium | medium |

The labels of soil-active pesticides will provide dosage levels that account for the adsorptive capacity of soil at your application site. Labels may indicate higher rates for soils high in clay, and lower rates for soils that contain a greater percentage of sand, for instance (Table 4-1).

**Organic Matter**. Soil rich in organic matter has a higher rate of adsorption than soil with little or no organic matter. Because soil rich in organic matter holds onto pesticides so strongly, the pesticides are not available to be taken up by weed roots, germinating seeds, nematodes, or insects. In addition, soil with a high organic content will host many microbes that can break available pesticides down quickly. The label will advise how much pesticide you will have to use to overcome these issues (see Figure 4-2).

### Weather

Rain, wind, temperature, and sunlight all have effects on pesticides during and after application, both positive and negative. Some pesticides require moisture to enhance their action, so applying one of these just before a long dry spell will adversely affect your results, whereas the opposite is true for pesticides that easily wash off leaf surfaces during rain or irrigation activity. Too much wind can blow pesticides off target, but a little wind can help pesticides penetrate dense canopies and improve deposition. Knowing the rainfastness levels of the pesticides you apply is especially important for applications made in noncrop agricultural areas, especially grasslands and rangelands, because these areas are so large. They are also often located closer to natural areas which can be negatively impacted by pesticides washed off of foliage when it rains.

Soil and air temperatures are also important factors, affecting phytotoxicity, degradation, uptake by pests, and volatility. Most labels indicate upper and lower temperature limits so you can avoid applying a pesticide while temperatures are unfavorable. Sunlight can also be a problem for certain pesticides, because ultraviolet light breaks them down so rapidly, that less of the active ingredient reaches its target. Low humidity – a common condition in many California locations -- can accelerate spray droplet evaporation between the sprayer and the target, increasing drift. For more on drift, leaching, pesticide degradation, runoff, and other losses related to weather, see Chapters 4 and 7 in *The Safe and Effective Use of Pesticides*.

### Water Quality

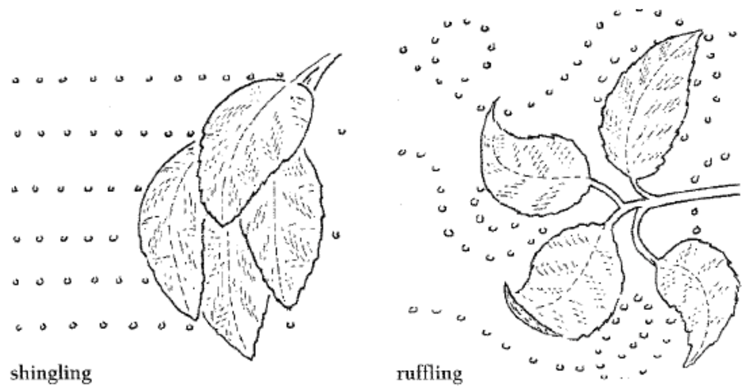
If water used for mixing pesticides contains soil particles or other impurities, the effectiveness of the pesticide may be reduced. Chemicals in the water can alter the active ingredient of a pesticide, changing its toxicity or making it ineffective against the target pest. If the water contains soil particles, the pesticide may bind to these particles, making it unavailable for uptake by target pests. See Chapter 10, pp 301-302 of *The Safe and Effective Use of Pesticides* for more information about problems that occur when the water used for mixing contains impurities.

### Uniformity of Pesticide Coverage

Pesticide coverage often must be uniform to be effective. There are several factors that affect the uniform distribution of pesticides at an application site, including the density of plants or plant foliage and the condition of the soil.

Before starting to spray, it is important to assess crop plants to determine the density of foliage. This step is important because penetration of pesticide into the canopy can mean the difference between the success or failure of your application. For example, to control some plant-feeding pests, the pesticide spray must coat both sides of leaf surfaces. If you improperly deliver the spray to the foliage it may cause *shingling*. This is a condition in which leaves clump together and prevent droplets from reaching some leaf surfaces (Figure 4-5). Using an air blast sprayer or oscillating boom sprayer produces *ruffling* of the plant foliage. This allows spray droplets to contact all surfaces, resulting in improved control of the target organism. (*The Safe and Effective Use of Pesticides*, 2nd ed. p. 195)

**Figure 4-5** Spray that is improperly delivered to foliage causes leaves to stick together and prevents proper coverage – a condition known as shingling. Ruffling foliage can improve distribution of pesticide droplets.




Uniformity can also be affected by the condition of the soil – whether particles are relatively uniformly distributed or clumped together. When soil is clumpy or cloddy, uniform application becomes difficult, because some surfaces get covered with pesticide, and others are only partially covered or missed completely. The result of uneven distribution in clumpy soil is that pesticide will not reach the target organism and control will be reduced.

### Mistakes

Application mistakes are a frequent cause of the failure of a pesticide to control pests. Mistakes you can make that can adversely affect your application include applying a mixture containing less than the recommended pesticide rate for the target pest, applying pesticide at the wrong time, repeating applications too frequently or not frequently enough, placing a soil applied pesticide incorrectly, failing to fully incorporate a pesticide into the soil, and applying pesticides unevenly.

**Mixing Errors.** Adding less than the required amount of active ingredient can cause a number of problems, one of which is the development of resistance in target pests because of reduced efficacy. Adding too much active ingredient can cause costly problems like wasted pesticide and residues that exceed tolerance thresholds on produce. Avoid these mistakes by reading the label carefully for instructions and calculations to make that ensure your mixture contains the correct amount of pesticide. Before making calculations check application records to see what rates have worked in the past. Make an estimate you can use to check your math when you calculate rates for the current application (see Chapter 9 in *The Safe and Effective Use of Pesticides* for more information about common rate calculations for both liquid and dry formulations). Do not rush through the mixing or application process. Cutting corners to increase productivity often leads to costly errors and wasted pesticide.

Mixing errors can also occur when you are preparing tank mixes of two or more pesticides and do not carefully check to make sure the pesticides are compatible. See Chapter 10, pp 299-303 for information about effective methods for mixing two or more pesticides, including how to test for incompatibility. For advantages and disadvantages of using a tank mix, see pp 94-95.

**Timing Errors.** The label will also indicate whether the pesticide should be applied before or during planting, or after plants or fruits have emerged, as well as when during a pest's life cycle the pesticide should be applied. If you don't take the time to read the label carefully regarding the proper timing of your application, you may destroy the plants you are trying to protect or miss the opportunity to suppress the pest you mean to control. Poor timing can also result in the death of honey bees and other pollinators. Labels on pesticides known to affect pollinators outline ways to avoid this problem during applications. For more about how to time pesticide applications properly, see Chapter 10, p 298.

**Application Frequency Errors.** Outcomes of a pesticide application can be affected by the number of times a pesticide is used at a site. Problems can be caused by applying a pesticide too frequently or not frequently enough. Label instructions prescribe how often to apply a pesticide. Applying more often than the label allows is illegal. Manufacturers recommend a particular application frequency to maintain adequate control of the pest being treated. Reducing the frequency of a pesticide application below label recommendations may result in inadequate control; so before reducing application frequency, carefully monitor the pest population. For more information on creating and implementing a monitoring program see Chapters 1 and 10 in *The Safe and Effective Use of Pesticides*.

Increasing the frequency of applications may actually contribute to secondary pest outbreaks or a resurgence of the pest, because additional pesticide may disrupt beneficial insects. Besides, it is expensive to use unneeded pesticides. In addition, making pesticide applications more often can lead to pest resistance, as well as an increase in biological agents in the soil that break pesticides down quickly so that they cannot reach target pests. It may also lead to unsafe residues on crops, resulting in the destruction of the crop when the residues are detected.

**Application Accuracy Errors.** Some pesticides only work when they're deposited in a particular place. Failing to place a pesticide correctly means it cannot reach the target pest – either the pest will not come in contact with the pesticide, or the plant cannot access the pesticide to translocate it. For more about how to increase accuracy during pesticide applications, see Chapter 10, pp 294-297 in *The Safe and Effective Use of Pesticides*.

**Soil Incorporation Errors.** Many soil-incorporated pesticides will not work properly unless they are mixed thoroughly into the soil (using mechanical incorporation or water) to form a solution. There are several reasons you must thoroughly mix these pesticides into the soil. First, some soil-incorporated pesticides must be taken up by plants through their roots in order to control them or to protect them from pest organisms. Second, certain soil-dwelling pests must come in contact with the pesticide in order to be controlled, so the more thoroughly the pesticide is incorporated into soil, the more effective it will be. Lastly, some pesticides volatilize quickly when exposed to air, so a timely and thorough incorporation is necessary for them to be effective.

**Uneven Application.** Uneven application is a serious problem that can cause poor control of target pests. Apply too much pesticide in any one place and runoff, drift, or phytotoxicity can result. Apply too little, and the pest will not be controlled. When applications are not uniform, there is a chance the pest will develop resistance to the pesticide. Uneven application can result from a failure to

- match spray volume delivery with canopy density
- assess the application site accurately
- recognize and replace blocked, worn, or damaged nozzles
- calculate the area to be sprayed accurately
- turn off spray when reaching row ends, maneuvering around obstacles, or shifting from row to row
- mark the place where spraying should begin again after refilling the tank or taking a break.

For more about how to ensure even application of pesticides, see Chapter 10, pp 294-296 in *The Safe and Effective Use of Pesticides*.

Your skill in assessing the application site, developing an efficient application pattern, and maintaining and operating pesticide application equipment affect the even distribution of pesticides in the field. Since problems can occur whether too much or too little pesticide is delivered to the application site, successful outcomes depend on your ability as an applicator to plan ahead, as well as to see and correct problems as they occur. For more on application patterns and ensuring uniform delivery of pesticides, see Chapter 7, pp 182, 184 in *The Safe and Effective Use of Pesticides*.


**Figure 4-6** Use a tractor-mounted GPS to help you apply pesticides evenly, without overlaps or gaps.

Developments in technology available to applicators can help even the most experienced practitioners ensure a more uniform distribution of pesticides. These technologies include system controllers that bundle GPS data with rate controllers and sensors that track terrain, boom movement, nozzle output, plant height and density, and speed, and adjust spray rate and pressure as you go. A system controller with GPS can also guide you back to the exact location where spraying stopped so you can begin again without overlaps or gaps (Figure 4-6).

Electronic devices take the guesswork out of the application process, while also providing detailed records of application patterns so that results can be studied and application methods improved for the next season. See "Precision Farming Tools" on p 99 of this supplement to learn more about electronic devices that work with a variety of pesticide application equipment.

Regardless of the spray technology used to apply pesticides, you must be familiar with the system and be able to recognize and correct errors if and when they occur. For additional information about errors and how to correct or mitigate them, see pp 345-346 of *The Safe and Effective Use of Pesticides*.

### Maintenance and Calibration of Application Equipment

Application equipment failure and poor calibration contribute to the poor performance of pesticides. Every piece of application equipment must be inspected and maintained regularly to assure safe, consistent operation, and most require periodic calibration to ensure the uniformity of pesticide output. Powered equipment has multiple components that can fail without proper maintenance. An equipment failure such as a burst fitting or a split hose can drench an applicator or contaminate a large area in a matter of seconds, and blocked nozzles can cause uneven distribution of pesticides, disrupting your pest control efforts.

Calibration is the only way to know that a particular piece of equipment is applying the correct amount of pesticide. Improperly calibrated equipment can result in misuse because of overapplication, or ineffective treatment because of underapplication. Equipment must be recalibrated regularly to compensate for wear in pumps, nozzles, and metering systems and to adjust settings thrown off by vibration and use. Calibration methods are treated more fully in *The Safe and Effective Use of Pesticides*, Chapter 9.

## Timing Pesticide Applications to Maximize Effectiveness

In the previous sections, as well as in Chapters 1, 7, and 10 of *The Safe and Effective Use of Pesticides*, proper timing has been emphasized as a key to maximizing positive outcomes of pesticide applications. Therefore, it is important that you understand not only why you must apply pesticides at the right time, but also how to determine the best time to apply them. Below you will find methods you can use to accurately time pesticide applications.

### Traps

Traps are used to sample the mobile life stages of insects. Changes in trap counts over time can signal changes in pest life cycle development that may be used to time pest control practices such as pesticide sprays. Traps can be designed to attract insects or randomly catch them. Trap attractants include food bait or sex pheromone(s). Bait traps use the

**Figure 4-7** Use a black egg trap baited with a mixture of almond press cake and almond oil to monitor navel orangeworm egg laying.

pest's food source to attract the pest. Examples of bait traps include navel orangeworm egg traps baited with ground almond meal (Figure 4-7), codling moth traps baited with kairomone lures and driedfruit beetle traps in fig baited with culled fruit, water and yeast. (Figure 4-8) When trap counts begin to drop off, it may mean that the beetles are being attracted to the fruit and should be controlled. Bait traps are also used for moth pests, such as oriental fruit moth. Using bait traps for oriental fruit moth monitors population changes over time as with pheromone traps, except that both males and females are caught. Pheromone traps allow managers to determine when reproductive adults are in the field, aiding in the timing of management actions (Figure 4-9). Sticky tape traps are wrapped tightly around small branches before scale crawlers emerge in the spring. When crawlers hatch and begin searching for sites to settle, large numbers of them get stuck on the tape, signaling appropriate treatment time.

**Figure 4-8** A bait trap consists of a large container that is baited with culled fruit, water, and yeast.

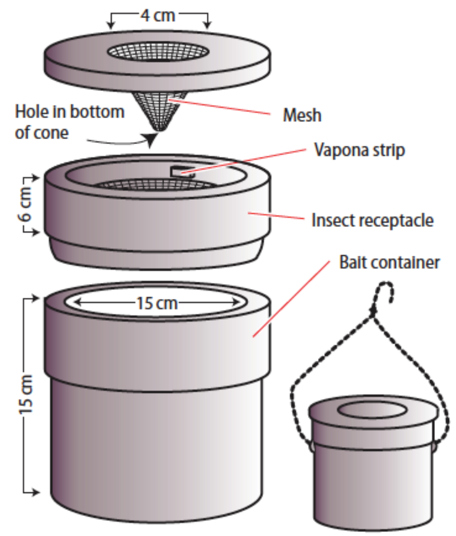



**Figure 4-9** Wing-type pheromone traps are used to monitor for insects such as peach twig borer and coddling moth, among others.


### Phenology Models

Phenology models predict time of events in an organism's development. An organism that cannot internally regulate its own temperature depends on temperatures in the environment to develop. Plants and invertebrates, including insects and nematodes, require a certain amount of heat to develop from one point in their life-cycle to another, e.g., from eggs to adults. Because of yearly variations in weather, calendar dates cannot reliably help you make management decisions. Measuring the amount of heat accumulated over time, however, provides a physiological time scale that is more accurate than calendar days. Trap count data can be used to start phenology model calculations.

**Developmental thresholds.** Two parameters are used when referring to the effect of temperature on growth and development. The **lower developmental threshold** for a species is the temperature below which development stops. The **upper developmental threshold** is less well defined, but is often taken as the temperature at which the rate of growth or development begins to slow. For many organisms, the upper thresholds are not used because people do not have enough data to obtain such estimates. Both lower and upper thresholds are determined through carefully controlled research and are unique for a specific organism.

**Physiological time**. The amount of heat needed by an organism to develop is known as **physiological time**. The amount of heat required to complete a given organism's development does not vary—the combination of temperature (between thresholds) and time will always be the same. Physiological time is often expressed in units called degree-days. For instance: if a species has a lower developmental threshold of 52° F, and the temperature remains at 53°F (or 1° above the lower developmental threshold) for 24 hours, one degree-day is accumulated.

**Developmental stages**. Each stage of an organism's development has its own total heat requirement. Development can be estimated by accumulating degree-days between temperature thresholds throughout the season. The accumulation of degree-days from a starting point can help predict when a developmental stage will be reached. Degree-day monitoring does not tell you when you need to make a pesticide application, but rather when a pest will reach susceptible life stages. If pests are abundant, monitoring degree-days helps you more effectively time any control action you might take.

Most computerized environmental monitoring and control equipment has a built-in ability to calculate degree-days and can continuously record temperatures and calculate degree-day accumulations. Degree-day calculators linked to the UC IPM Program's Weather database can be accessed online at the UC Statewide IPM Program's website, http://ipm.ucanr.edu. Degree-day software that uses local weather data is also available. Site-specific input is often required to accurately track pest populations in a particular field. For example, pheromone trap catch data are used to begin degree-day accumulations for certain pests.

**Sidebar 1:**
**Factors that Affect Insecticide & Miticide Applications**

- Monitoring techniques specific to insects/mites (like pheromone trapping, using sweep nets, sticky paper) that help determine when to apply
- Use of phenology models that help determine when to apply
- How dense the crop's foliage is at the time of application
- Spray coverage
- Leaf shape and texture
- The location of insects or mites (on top of leaves, on undersides of leaves, on stems, on roots)
- Timing of applications to when insects/mites are most active

* Many of these factors apply broadly to all pesticides, however, the points included are particularly important in insecticide and miticide applications.

**Sidebar 2:**
**Factors that Affect Herbicide Applications**

- Soil textures (such as clay and/or organic matter,) that adsorbs chemicals and prevents target plants from accessing the pesticide
- Uniformity of deposition (breaking up soil can help with this issue)
- Density of leaves, as well as leaf shape and texture of pest plants
- Density of a crop's canopy
- Volatility under certain conditions (wet soil, high soil temperatures, air movement)
- Number of weeds present – if there are many weeds, it is possible that the amount of pesticide absorbed by any one plant will be reduced
- Growth stage of the weed

* Many of these factors apply broadly to all pesticides, however, the points included are particularly important in herbicide applications.

**Sidebar 3:**
**Factors that Affect Nematicide Applications**

- Correct identification of the nematode present
- Timing of application (most nematicides work best if applied before planting)
- Soil incorporation or tarping procedures
- Soil moisture level

* Many of these factors apply broadly to all pesticides, however, the points included are particularly important in nematicide applications.

**Sidebar 4:**
**Factors that Affect Fungicide and Other Disease Control Applications***

- Regular coverage of vulnerable plant surfaces as they grow (frequency of application)
- Tracking of disease progress using phenology models, pesticide use records, and advice from reliable local sources (like your county cooperative extension)
- Uniformity of coverage
- Application rate (using more or less pesticide than is recommended)

* Many of these factors apply broadly to all pesticides, however, the points included are particularly important in disease control applications.

### Computerized Systems

**Disease forecasting** systems use weather, host, and pathogen data to predict times when disease outbreak is likely. Initially developed in table form (for example, Figure 4-10), these models have gained wider acceptance with the development of computers, desktop, and now mobile units (laptops, tablets, and phones) as tools to deliver pest models.

In many areas and for specific crops, networks of weather stations allow you to receive the latest temperature, rainfall, relative humidity, and leaf wetness readings on which to base pesticide application decisions. In-field weather stations automatically transmit weather data to a central computer that gathers the data. The potential for an outbreak of specific diseases is calculated based on past weather patterns and disease incidence.

**Figure 4-10** The Mills and La Plante Table: temperature and hours of wetting requirements for apple scab infection. The need for preventive fungicide treatment for apple scab can be determined by keeping track of daily average temperatures and hours that leaves are wet each day. The Mills Chart indicates how many hours leaves must remain wet at various temperatures for infection to occur. Treatment is warranted if wetting hours are exceeded. Shown here are apples damaged by scab.

| Average required temperature (°F) | Hours of wetting for infection |
|---|---|
| 78 | 13 |
| 77 | 11 |
| 76 | 9.5 |
| 61–75 | 9 |
| 60 | 9.5 |
| 57–59 | 10 |
| 55–56 | 11 |
| 54 | 11.5 |
| 52–53 | 12 |
| 51 | 13 |
| 50 | 14 |
| 49 | 14.5 |
| 48 | 15 |
| 47 | 17 |
| 46 | 19 |
| 45 | 20 |
| 44 | 22 |
| 43 | 25 |
| 42 | 30 |
| 33–41 | * |

* Not known

A plant disease model is a mathematical description of the interaction among the environment, hosts, and pathogens that can result in disease (see Chapter 2 of *The Safe and Effective Use of Pesticides* for more about the disease triangle, and http://ipm.ucanr.edu/WEATHER/index.html#PESTPLANTMODELS for pest models).

**Plant mapping** is a useful tool for certain crops where appropriate support research has been conducted, enabling you to monitor the status of plants in their fields. Plant mapping systems are computer programs that use plant data from field samples to provide an indication of crop health and development. Cumulative field measurements track plant growth throughout the growing season and alert managers to signs of stress. In cotton, for instance, plant mapping measurements include plant height, number of vegetative branch nodes, number of fruiting branch nodes, and first-position boll retention in the top and bottom five nodes. These measurements are recorded and calculated on a plant monitoring form or entered into a computer containing a plant-mapping program. By knowing precisely the stage of crop development, you are better able to predict when certain types of pests will be damaging (e.g., bud or seed feeders), when to apply a certain plant growth regulator, or predict harvest and so time preharvest pesticide application to match preharvest interval for the pesticide selected. (“Timing Pesticide Applications to Maximize Effectiveness” adapted from Flint, M.L., 2012)

**Section 5: Application Methods and Equipment**

**Knowledge Expectations**

5-1. Describe various pesticide application equipment used to apply pesticides in plant agriculture settings.
5-2. Define common problems with application equipment and describe how these might be remedied.
5-3. Explain how to select the right equipment for effective applications to common plant structures.
5-4. Describe various pesticide application methods.
5-5. List components of chemigation equipment, explain how they work together, and identify which components work best with which pesticide formulations.
5-6. List components of liquid application equipment, explain how they work together, and identify which components work best with which pesticide formulations.
5-7. Describe types of nozzles, including outputs, patterns, and applications that require each output or pattern.
5-8. Describe the parts of a nozzle.
5-9. Describe types of pumps and how to select the best pump for particular situations.
5-10. List the adjustments to make to improve inadequate spray coverage or pesticide placement.
5-11. Describe procedures for thoroughly cleaning
  a. Liquid sprayers
  b. Dust applicators
  c. Granular applicators
  d. Chemigation equipment
5-12. Describe procedures for storing
  a. Liquid sprayers
  b. Dust applicators
  c. Granular applicators

## Application Methods and Equipment

Selecting, using, maintaining, and properly calibrating application equipment helps to ensure that pesticides are applied safely, accurately, and effectively. In this section, you will learn about the application methods and equipment used most often in agricultural settings, including an in-depth treatment of nozzles and their selection. You will also read about precision farming tools – electronic systems that help you target pesticides far more precisely than you can through traditional means.

## Selecting Application Equipment

Table 5-1 describes various application methods, such as spot, banded, and broadcast treatments. The situation in which you might use a particular method, the method's benefits and drawbacks, and the equipment used to make such applications is also included. For a general description of liquid, dry, and chemigation application equipment, see Chapter 8 in *The Safe and Effective Use of Pesticides*.

**Table 5-1.** *Pesticide application methods and equipment commonly used in agricultural settings.*

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Band and Directed Spray Applications | Used in row crops for insect, disease, and weed management. Used in noncrop agricultural areas and grasslands to prevent the spread of weeds. | Benefits:<br>Uses less pesticide than other methods, so reduces cost per treatment.<br><br>Can be targeted very effectively as directed spray, shielded spray, or hooded spray applications.<br><br>Can be used at different times in a crop's life cycle.<br><br>Drawbacks:<br>Requires special equipment to make applications more targeted.<br><br>The nozzles on some systems are arranged with drop hoses or thin metal strips that can twist and rotate the nozzles as the applicator moves through the field. This accidental twisting can decrease spray pattern uniformity and may cause drift. | Hydraulic (liquid) sprayers<br>Low pressure boom sprayers<br>Front-mounted boom sprayers<br>Granule spreaders<br>Spinning disc sprayers<br>Air shear sprayers |

| **Application Method** | **Situations** | **Benefits/Drawbacks** | **Equipment** |
|---|---|---|---|
| Spot Treatments, Spray-to-wet Treatments, Drizzle Treatments | Early treatment of mite and insect infestations that are concentrated in just a few areas, and have yet to spread to other parts of a field.<br><br>Treatment of patches of weeds scattered throughout crop or noncrop lands, or weeds that are taller than crop/desired plants.<br><br>Treatment of field edges/noncrop areas with herbicide or insecticide to prevent field infestation.<br><br>Sometimes used to apply fungicides to limited areas. | Benefits:<br>Small, hand-carried sprayers can reach areas that tractor-mounted or self-propelled sprayers cannot reach.<br><br>Small sprayers keep pesticides on target and reduce environmental contamination when calibrated and used correctly.<br><br>Can reduce the amount of pesticide required to control pests from 70 to 90% over broadcast applications.<br><br>Drawbacks:<br>Backpack (knapsack) sprayers are tiring to carry and operate, and can treat only a small area.<br><br>Walking pace for carried sprayers must remain steady to ensure proper coverage, even over small areas. A steady walking pace may be difficult to maintain, depending on the terrain.<br><br>You cannot control the spray volume delivered from spot to spot, so some areas may receive more material than necessary, and some may receive less. | Syringe sprayers<br>Hand-operated backpack or knapsack sprayers (lever-operated, trigger pump, mistblowing, hose-end, push-pull hand pump, compressed-air)<br>Nonpowered and powered wheelbarrow sprayers<br>Powered backpack sprayers<br>Estate sprayers<br>Rope wick or canvas wiper applicators<br>Drizzle applicators |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Precision (Patch) Spraying, Spray-to-wet Treatments, Drizzle Treatments | Early treatment of mite and insect infestations that are concentrated in just a few areas, and have yet to spread to other parts of the field.<br><br>Treatment of patches of weeds scattered throughout crop or noncrop areas, or weeds that are taller than crop/desired plants.<br><br>Treatment of field edges/noncrop areas with herbicide or insecticide to prevent field infestation.<br><br>Sometimes used to apply fungicides to limited areas. | Benefits:<br>For sprayers with GPS and rate controllers installed, pesticides can be targeted accurately to precise areas.<br><br>Can reduce the amount of pesticide required to control pests from 70 to 90% over broadcast applications.<br><br>Drawbacks:<br>System controllers can be expensive up front, and require the operator to understand how to program such systems.<br><br>These sprayers require more maintenance over their lifetime than other types of sprayers. | Boom sprayers equipped with VRA systems<br>Spinning disc sprayers<br>Drizzle applicators |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Basal | Treatment of weeds growing around the base of established trees and vines.<br><br>Treatment of insects infesting the base of established trees and vines.<br><br>Removal of problem woody plants that are less than 8 inches in diameter, or that have very thin bark. | Benefits:<br>Pesticide applied to bark for removal of woody pest plants moves systemically throughout the plant to kill it.<br><br>Causes little or no damage to surrounding plants when spray is accurately targeted.<br><br>Can be used for weed and insect control in vineyards and orchards where plants are well-established, allowing the applicator to precisely target pesticides to affected areas and reduce the amount of pesticide needed to control pests.<br><br>Drawbacks:<br>Treatments cannot be made in rainy weather or if rainy weather is predicted.<br><br>People and animals are easily exposed to pesticides on treated bark in areas of animal and human activity.<br><br>Protection activity may be short-lived, depending on the product applied.<br><br>The effectiveness of treatment depends on the temperature during and just after application, as well as the age of the plant and corkiness /thickness of the bark. | Syringe sprayers<br>Trigger pump sprayers<br>Low-volume backpack sprayers<br>Wick applicators |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Broadcast | Treatment of insects and disease in areas of dense foliage.<br><br>Treatment of pests in orchards.<br><br>Treatment of large areas where there are numerous insects or weeds (a high density of pests).<br><br>Used in noncrop agricultural areas and grasslands when weeds have crowded out sensitive desirable plants. | Benefits:<br>Provides good penetration and coverage of plant surfaces, especially in dense foliage.<br><br>Large tanks on some equipment allow many acres to be treated in just one application.<br><br>Can be used in many different situations.<br><br>Drawbacks:<br>May cause drift hazards if droplet size is too small for conditions at the site.<br><br>Conditions at the application site can cause uneven deposit of pesticide.<br><br>Pests are not usually uniformly distributed throughout the field so making this type of application may waste some pesticide. | Backpack mistblowers<br>Air-sleeve sprayers<br>Tunnel sprayers (using hydraulic nozzles)<br>Air blast sprayers<br>Orchard sprayers using hydraulic nozzles, air shear nozzles (on machines with centrifugal fans), or rotary nozzles (mounted in front of propeller fans)<br>Oscillating boom sprayers<br>High-pressure hydraulic sprayers<br>Air-assist sprayers<br>Electromagnetic sprayers<br>Spreaders<br>Tractor-mounted airflow granular applicators<br>Power dusters |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Rope-wick or canvas-type wiper | Treatment of weeds in crop and noncrop areas | Benefits:<br>Equipment reduces drift by targeting herbicides extremely accurately – the pesticide is deposited directly onto pest plants.<br><br>Wick applicators allow the selective application of broad-spectrum pesticides.<br><br>Drawbacks:<br>Rope wicks must be watched carefully to avoid oversaturation and dripping or having too dry a wick.<br><br>Wicks can accumulate dirt on their surfaces, keeping pesticide from reaching target plants.<br><br>Weedy species must be taller than desirable plants. | Rope wick applicator<br>Canvas wiper<br>Enclosed boom rotating wiper<br>(All of these can be on a boom attached to an ATV or tractor. Booms can also be hand carried.) |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Soil injection | Treatment of nematodes, insects, weeds and pathogens prior to planting. | Benefits:<br>Addresses problems before crop is planted, which is especially important for long-term crops like trees or vines.<br><br>Tines along the toolbar can be adjusted to penetrate the soil at varying depths, so the system is flexible.<br><br>Drawbacks:<br>This method is expensive.<br><br>Many chemicals used in soil injection are environmentally problematic and require Restricted Use Permits and special pesticide licenses or certifications for applicators. | Vehicle mounted or towed toolbar fitted with chisel tines. |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Tree Injection and Implants, Cut Stump/Basal Cut Stump | Treatment of disease and insects by injection of pesticides under the bark of trees.<br><br>Treatment of chewing and sucking insects that feed on shoots and leaves.<br><br>Treatment for removal of unwanted trees. | Benefits:<br>Highly targeted pesticide applications reduce environmental contamination.<br><br>Pesticides are distributed throughout the tree efficiently by using the tree's water-conducting system.<br><br>Can be applied in any type of weather.<br><br>Equipment needed to perform injections is simple to use.<br><br>Uses less pesticide than sprays or soil treatments.<br><br>Drawbacks:<br>Time and labor-intensive.<br><br>May cause injury to the tree during application (some methods are more injurious than others).<br><br>Reapplications cannot be made to the same tree too frequently, even if damage continues (trees heal slowly, so you should allow at least a year between tree injection treatments). | Drill (to make holes in trunks)<br><br>High pressure drilled-hole injector<br><br>No-pressure system using container and tubing<br><br>Pressurized capsule-injection system<br><br>Pressurized tubing and reservoir system<br><br>Direct-inject system (syringe with needle that is inserted through the bark)<br><br>Single-nozzle sprayer, squirt bottle, paint brush |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Dip | Treatment for root disease prior to transplanting.<br><br>Treatment for nematodes prior to transplanting.<br><br>Treatment of insects that affect roots prior to transplanting. | Benefits:<br>Prevents the spread of pests through soil contamination caused by transplanted crops.<br><br>Systems can be mechanized to reduce exposure risks for workers and increase efficiency.<br><br>Controlled application means pesticide is targeted very accurately to affected parts of the plant.<br><br>Drawbacks:<br>Can be expensive and time consuming.<br><br>Not all dip treatments have been proven to work effectively.<br><br>Exposure risk is elevated when systems are not mechanized. | Vats for dipping<br><br>Mechanical systems that work with pesticide vats to dip plants |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Foliar | Used in insecticide and fungicide applications on crops.<br><br>Used in herbicide applications to control weeds after they have emerged (best to use when weeds are small and actively growing, or, when more established, in the early bloom stage or during active growth in the fall). | Benefits:<br>Applied directly to affected area of plants.<br><br>Flexible – can treat many different problems during a variety of stages of pest development.<br><br>Drawbacks:<br>Depending on the application method, drift can be a problem.<br><br>Can affect nontarget species.<br><br>Runoff can become a problem. | Coldfogger<br>Air-assisted electrostatic handgun<br>Pulsefogger<br>Low-volume hydraulic sprayers<br>High-volume hydraulic sprayers<br>Electrostatic sprayers<br>Rope wick and canvas wiper applicators<br>Power dusters<br>Rear-mounted boom sprayers<br>Tunnel sprayers<br>Drizzle applicators |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Soil Application:<br>Drench<br>Soil Incorporation<br>Furrow | Treatment of weeds, insects, nematodes, or pathogens prior to or during planting.<br><br>Treatment of weeds, insects, or pathogens before and after planting. | Benefits:<br>Can be used to treat many different pest problems at various stages of development.<br><br>Can be used to prevent problems with nematodes and pathogens – may be the only viable way to get rid of nematode pests, especially in tree and vine crops.<br><br>Drench treatments are highly targeted to the plants or trees that are affected by the pest.<br><br>Furrow treatments are precisely targeted and use low volumes of pesticide, reducing environmental hazards.<br><br>Soil incorporated pesticides mix thoroughly with soil, so are not as prone to drift (though leaching can be a problem – always read the label for precautions)<br><br>Drawbacks:<br>In soil incorporation treatments, pesticide must be evenly distributed within the soil in order for it to reach the target pest or be taken up by the roots of plants as they grow.<br><br>Drench treatments can be time, water, and labor-intensive.<br><br>Leaching can be a problem, especially in sandy soils. | Low-volume microtube in-furrow sprayers<br>Vehicle mounted or towed toolbar fitted with chisel tines that allow for the mixing of pesticide into the soil as the application proceeds<br>Granule spreaders<br>Low-volume boom sprayers |

| Application Method | Situations | Benefits/Drawbacks | Equipment |
|---|---|---|---|
| Chemigation | Treatment of weeds, insects, or pathogens to large areas before and after planting. | Benefits:<br>Can use existing irrigation equipment to apply pesticides.<br><br>Very efficient.<br><br>Uses precise amounts of pesticides metered by control systems.<br><br>Drawbacks:<br>Specialized equipment must be purchased and set up, which can be expensive.<br><br>Systems are complex and must meet all State and local regulatory requirements for the protection of groundwater.<br><br>Can result in uneven applications if system is not maintained adequately or if rolling or uneven soils are treated. | Setup depends on irrigation systems available at the site. See *The Safe and Effective Use of Pesticides,* p 222-229 for more information about chemigation system setups. |

## Selecting Nozzles

Picking the best nozzle for your particular application method, site conditions, and equipment can increase the safety and effectiveness of your pest control efforts. This section explains the various nozzles used in Plant Agriculture, and methods used to select the right nozzle for the job.

**Figure 5-1** Most pesticides are applied with a nozzle type designed to produce a tapered flat-spray pattern, like this one.

The spray nozzle you choose directly affects droplet size, spray uniformity, spray coverage, and drift potential, which directly impacts pest control, economics, and environmental quality. Although nozzles have been developed for practically every kind of spray application, only a few nozzle types are commonly used to apply pesticides and fertilizer-pesticide combinations. Most pesticides are applied with a nozzle type designed to produce a tapered flat-spray pattern (Figure 5-1). These nozzle types are extended range flat-fans, turbo or chamber style flat-fans and flooding flat-fans, and air-injection/venturi flat-fans of various designs. Table 5-2 compares a sampling of popular spray tips used used to apply pesticides in agricultural areas and illustrates their spray patterns. Figure 5-2 shows the color codes that represent standardized droplet sizes used by nozzle manufacturers to make nozzle selection easier. Figure 5-3 illustrates how the classification colors are used in a nozzle catalog.

**Figure 5-2** Droplet-size categories for nozzles with symbols and color codes.

| Category | Symbol | Color Code | Approx. VMD Range (microns) |
|---|---|---|---|
| Extremely Fine | XF | Purple | <60 |
| Very Fine | VF | Red | 60-145 |
| Fine | F | Orange | 145-225 |
| Medium | M | Yellow | 226-325 |
| Coarse | C | Blue | 326-400 |
| Very Coarse | VC | Green | 401-500 |
| Extremely Coarse | EC | White | 501-650 |
| Ultra Coarse | UC | Black | >650 |

**Figure 5-3** HARDI ISO 110* flat fan nozzle sample demonstrating use of color codes.

## HARDI® ISO LD-110

LowDrift nozzles

| PSI | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|
| ISO size/color | GPM | | | | | |
| 01-Orange | 0.071 | 0.087 | 0.100 | 0.112 | 0.122 | 0.132 |
| 015-Green | 0.106 | 0.130 | 0.150 | 0.168 | 0.184 | 0.198 |
| 02-Yellow | 0.141 | 0.173 | 0.200 | 0.224 | 0.245 | 0.265 |
| 025-Lilac | 0.177 | 0.217 | 0.250 | 0.280 | 0.306 | 0.331 |
| 03-Blue | 0.212 | 0.260 | 0.300 | 0.335 | 0.367 | 0.397 |
| 04-Red | 0.283 | 0.346 | 0.400 | 0.447 | 0.490 | 0.529 |
| 05-Brown | 0.354 | 0.433 | 0.500 | 0.559 | 0.612 | 0.661 |

## HARDI® ISO MINIDRIFT

Air inclusion nozzles

| PSI | 20 | 30 | 40 | 50 | 60 | 70 |
|---|---|---|---|---|---|---|
| ISO size/color | GPM | | | | | |
| 015-Green | 0.106 | 0.130 | 0.150 | 0.168 | 0.184 | 0.198 |
| 02-Yellow | 0.141 | 0.173 | 0.200 | 0.224 | 0.245 | 0.265 |
| 025-Lilac | 0.177 | 0.217 | 0.250 | 0.280 | 0.306 | 0.331 |
| 03-Blue | 0.212 | 0.260 | 0.300 | 0.335 | 0.367 | 0.397 |
| 04-Red | 0.283 | 0.346 | 0.400 | 0.447 | 0.490 | 0.529 |
| 05-Brown | 0.354 | 0.433 | 0.500 | 0.559 | 0.612 | 0.661 |

**Spray quality:** Fine | Coarse | Medium | Very coarse

In addition to the nozzles described in *The Safe and Effective Use of Pesticides*, Chapter 8, pp 204-209 you may find the following nozzles particularly useful in agricultural pesticide applications.

**Flooding Nozzles**

Flooding nozzles produce a wide-angle, flat-fan pattern, and are used for applying herbicides and mixtures of herbicides and liquid fertilizers. Nozzle spacing should be 40 inches or less. These nozzles are most effective in reducing drift when they are operated within a pressure range of 8 to 25 psi. Pressure changes affect the width of the spray pattern more with the flooding nozzle than with the extended range flat-fan nozzle. In addition, the distribution pattern usually is not as uniform as that of the extended range flat-fan tip. The best distribution is achieved when the nozzle is mounted at a height and angle to obtain at least double coverage or l00 percent overlap. Uniformity of application depends on the pressure, height, spacing, and orientation of the nozzles. Pressure directly affects droplet size, nozzle flow rate, spray angle, and pattern uniformity. At low pressures, flooding nozzles produce large spray drops; at high pressures, these nozzles actually produce smaller drops than flat-fan nozzles at an equivalent flow rate.

The spray distribution of flooding nozzles varies greatly with changes in pressure. At low pressures, flooding nozzles produce a fairly uniform pattern across the swath, but at high pressures the pattern becomes heavier in the center and tapers off toward the edges. The width of the spray pattern also is affected by pressure. To obtain an acceptable distribution pattern and overlap, you should operate flooding nozzles within a pressure range of 8 to 25 psi.

Nozzle height is critical in obtaining uniform application when using flooding nozzles. Flooding nozzles can be mounted vertically to spray backwards, horizontally to spray downwards, or at any angle between vertical and horizontal. When the nozzle is mounted horizontally to spray downwards, heavy concentrations of spray tend to occur at the edges of the spray pattern. Rotating the nozzles 30 to 45 degrees from the horizontal will usually increase the pattern uniformity over the recommended pressure range of 8 to 25 psi. For uniform distribution over a range of pressures, mount the nozzles to obtain double coverage at the lowest operating pressure.

**Extended Range Flat-Fan**

Extended range flat-fan nozzles are frequently used for soil and foliar applications when better coverage is required than can be obtained from the flooding or turbo flooding nozzles. Extended range flat-fan nozzles are available in both 80- and 110-degree fan angles. The spray pattern from this nozzle type has tapered edges. Because the outer edges of the spray pattern have reduced volumes, it is necessary to overlap adjacent patterns along a boom in order to obtain uniform spray coverage.

The 80-degree fan nozzles are usually mounted on 20-inch centers at a boom height of 17 to 19 inches. The 110-degree nozzles could be mounted on 30-inch centers at a boom height of 20 to 22 inches or kept on 20-inch centers and lowered to 16 to 18 inches. Regardless of the spacing and height, for maximum uniformity in the spray distribution, the spray patterns should overlap about 50 to 60 percent of the nozzle spacing (25 to 30 percent on each edge of the pattern).

Extended range nozzles maintain their droplet size and spray distribution pattern over a wider range of pressure than typical nozzles. They are best suited for use with electronic controllers that will control the spray rate either by adjusting the spray pressure or pulse width modulation.

For soil applications, the recommended pressure range is from 10 to 30 psi. For foliar application when smaller drops are required to increase the coverage, higher pressures from 30 to 60 psi may be required. However, an increase in the likelihood of drift may result when pressures above 25 psi are used. Because of the potential for increased drift with this nozzle type and with newer more drift resistant nozzle designs, this nozzle type is not as highly recommended as it was when first introduced.

**Turbulence Chamber (Turbo) Flood Nozzles**

Turbulence chamber flood nozzles are nozzles that combine the precision and uniformity of extended range flat spray tips with the clog resistance and wide-angle pattern of flooding nozzles. The design of the turbulence chamber flood nozzle increases droplet size and distribution uniformity by incorporating a preorifice and chamber internally and a more refined exit orifice. The increased turbulence in the spray tip causes an improvement in pattern uniformity over existing flooding nozzles. At operating pressures of 8 to 25 psi, turbulence chamber flood nozzles, because of the pre-orifice, produce larger droplets than standard flooding nozzles. Having larger droplets reduces the number of fine, drift-prone droplets in the spray pattern, so Turbulence chamber flood nozzles work well in drift-sensitive applications. Turbulence chamber flood nozzles, because of their improved pattern uniformity, probably need at least 50 percent overlap to obtain proper application uniformity. Turbo Flood nozzles are highly recommended for soil application of crop protection products. Both this nozzle type and the Turbo Flat-Fan nozzles described below help reduce spray drift by 94%-99%.

**Turbulence Chamber (Turbo) Flat-Fan**

The turbulence chamber flat-fan nozzle is designed similar to the turbulence chamber flood, incorporating the preorifice and chamber. It has been adapted to fit in a flat-fan style nozzle body with a greatly improved (uniform) wide angle spray pattern when compared to the extended range flat-fan and other drift-reduction flat-fan nozzles. This nozzle was originally designed for use in the application of postemergence products, but can be used in any application to reduce drift. Turbulence chamber flat-fan nozzles are wide-angle preorifice nozzles that create larger spray droplets across a wider pressure range (15 to 90 psi) than comparable low-drift tips, reducing the number of drift-prone particles. The wide spray angle will allow for a 20 or 30-inch nozzle spacing and requires 50 to 60 percent overlap to achieve uniform application across the boom. Position the tip so that the preset spray angle is directed away from the direction of travel. The Turbo flat-fan nozzle is excellent for use with electronic spray controllers where speed and pressure changes occur regularly.

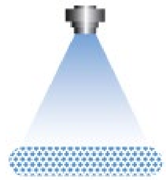
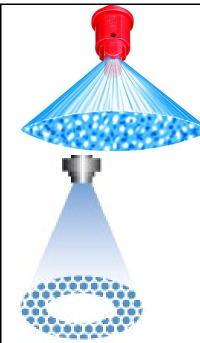
**Air-Injection/Air-Induction/Venturi Nozzles**

Nozzle manufacturers are increasingly focused on designs for maximum drift reduction. These designs involve the use of air incorporated into the spray nozzle to produce a larger droplet size. Several designs are on the market and are commonly referred to as air-induction, air-injection or venturi nozzles. Air is entrapped into the spray solution at some point (typically a venturi section) within the nozzle. To accomplish the mixing, some type of inlet port and venturi is typically used to draw the air into the tip under a reduced pressure. The air-solution combination forms a larger spray droplet. By increasing the size of the spray droplets, a reduction in spray drift occurs by minimizing the smaller, drift-prone fine droplets typically created in a spray tip. Current design of these tips calls for a higher pressure (70-80 psi) to perform adequately. Most all venturi nozzles are designed to spray a wide-angle flat spray pattern.

Venturi nozzles, which are more expensive, dramatically reduce drift potential. In addition to providing good protection against drift, research data on venturi nozzles indicates that they can provide adequate efficacy when used at the higher pressure. Before using, understand coverage needs (systemic vs. contact) for the crop protection products being used in order to ensure adequate droplet formation. These nozzles work better with systemic products, but can also work with contact products if the spray volume is high (>40 GPA). It is also important to maintain at least 40 psi as an operating pressure to maintain uniform pattern development while properly atomizing the spray solution. Adding deposition aids or drift-reducing products to tank mix solutions sprayed using venturi nozzles also can have a major impact on pattern quality.

Please note special calibration requirements for the venturi nozzles. For example, Greenleaf, designer of the TurboDrop venturi two-piece nozzle, requires the exit orifice to be two times the size of the venturi orifice. Otherwise the exit orifice may create a negative pressure effect in the venturi area resulting in failure of the nozzle to create the proper spray quality (actually reversing flow from the air inlets). Select and calibrate the TurboDrop nozzle based on the venturi orifice, which is color-coded to standard. A chart is available from the manufacturer for this purpose. Other venturi nozzle styles are one piece and do not have this precaution. ("Selecting Nozzles" is adapted from *Agricultural Plant Pest Control*, Kansas State University, Frannie L. Miller, et al., July 2011.)

**Table 5-2: Nozzle selection guide, with spray pattern illustrations**

| |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
| | **Extended range flat-fan** | **Standard flat-fan** | **Even flat-fan** | **Turbo flood** | **Solid (full) cone** | **Hollow cone** | **Disc-core** | **Flooding** | **Venturi/ Air induction/ air injection** |
| **Herbicides** | | | | | | | | | |
| Soil-incorporated | Good | — | — | Very Good | Very Good | — | — | Good | Good |
| Pre-emerge | Very Good (on low pressure) | Good | Very Good | Very Good | Good to Very Good | — | — | — | Good |
| Post-emerge contact | Good | Good | Good | — | — | Very Good | — | — | — |
| Post-emerge systemic | Very Good (on low pressure) | Good | Very Good | Very Good | — | — | — | — | Good |
| **Fungicides** | | | | | | | | | |
| Contact | Very Good | Good | Good | — | — | Good | Very Good | — | — |
| Systemic | Very Good (on low pressure) | — | Very Good | Very Good | — | — | Good | — | — |
| **Insecticides** | | | | | | | | | |
| Contact | Good | Good | — | — | — | Very Good | Very Good | — | — |
| Systemic | Very Good (on low pressure) | — | Very Good | Very Good | — | — | Good | — | — |

Adapted from http://pubs.ext.vt.edu/442/442-032/442-032_pdf.pdf

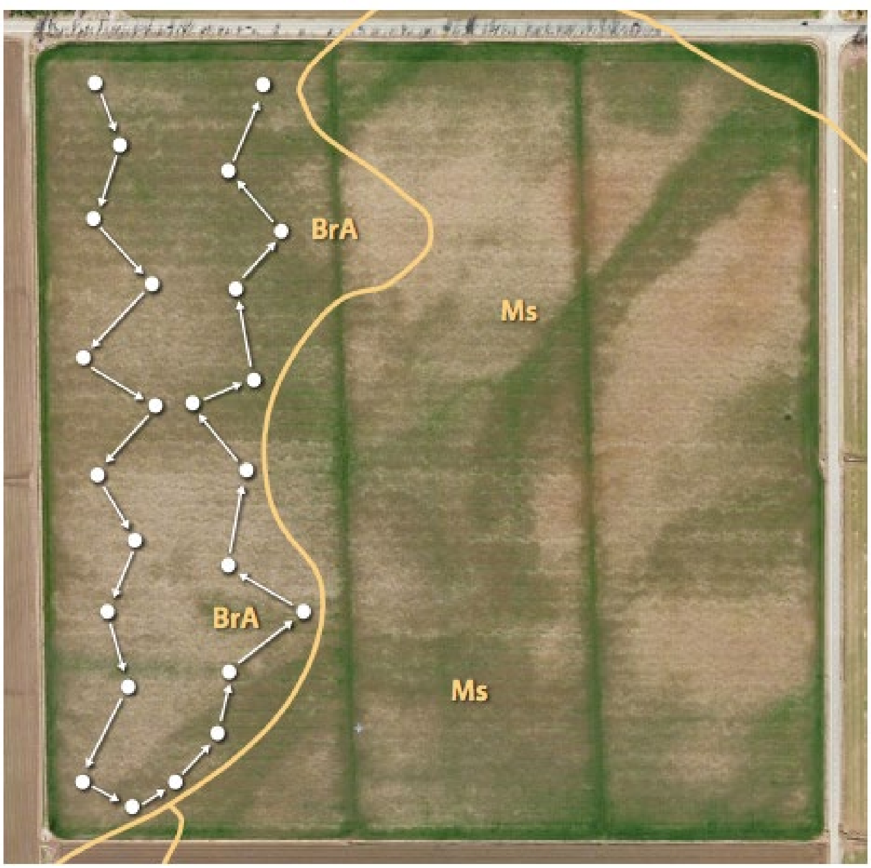
## Precision Farming and Variable-Rate Application Systems

### Precision Farming Tools

*Precision farming* uses computers and electronics to produce a site-specific approach to crop management. It provides a set of tools based on the measurement of variability between and within fields, supplying more information to make better decisions. Precision farming systems use global positioning systems (GPS) to collect data and geographic information systems (GIS) to manage it.

The first step in implementing precision farming is the production of yield maps and soil samples (Figure 5-4). Yield maps are data files that show the variability of the crop yield across a field. GPS units are used to precisely identify locations in a field; the maps are linked to yield data. This type of precision can be used to plan more accurate pest management programs. For instance, using GPS, the application rate of a pesticide can be varied in different parts of the field according to known differences in soil type or known pest populations preprogrammed into the system.

**Figure 5-4** Soil sampling plan to obtain a representative sample from a field or management area. The sampling points are shown on a Google map using the SoilWeb application (available at casoilresource.lawr.ucdavis.edu/soilweb/).



The data produced through the use of a GPS unit are managed through the GIS, a data management program designed to manipulate and display data on computerized maps. A GIS organizes, statistically analyzes, and displays data; links each set of data to precise GPS locations; and produces new sets of data by combining overlays. Examples of overlays include soil type, topography, and cover crop. Other features recorded include crop management inputs such as seed, pesticides, and fertilizer. The advantage of this system is that by combining these maps, you get more precise information on the ways that yield, pest damage, and treatment history affect one another. The record-keeping system maintained with GIS systems can be especially valuable for IPM programs.
Variable rate application systems can help you apply pesticides more precisely than relying solely on conventional methods. Using variables collected directly from the site, such as canopy density, soil moisture, and air temperature, among others, these systems control application rates and sprayer placement to give thorough and accurate coverage. The following sections describe these electronic systems and how you can use them to increase the effectiveness of a pesticide application.

### Variable Rate Application Systems

A *Variable rate application* (VRA) system can help you apply pesticides more efficiently and effectively by adjusting application rates automatically according to inputs that you control or that are acquired by or uploaded to the system. A VRA system utilizes many of the same components as a conventional spraying system but changes the application system output across a field based on preloaded or on-the-fly data regarding pest populations, crop conditions or other variables across the field. VRA systems are made up of a task computer and a system for controlling application rates, sometimes called a rate controller. VRA systems may also include a GPS. There are three types of VRA systems:

- Map-based systems
- Sensor-based systems
- Combination systems

**Map-based Systems**. A map-based system uses an electronic map, sometimes called a *prescription map*, along with a GPS receiver to deliver particular rates as the sprayer moves through the field. You program this system by entering the desired application rates for each area of the prescription map prior to application, and use the GPS to ensure the accuracy of the sprayer's field position while applying the pesticide.

**Sensor-based Systems**. Sensor-based systems do not require a map or a GPS. These units rely on sensors mounted on the sprayer that gather data through direct contact or *remote sensing*. These sensors can measure soil properties, presence and thickness of foliage, and height of plants as the sprayer moves through a field, uploading data to the task computer. The computer analyzes this data and delivers that analysis to the control system. The control system can then calculate the proper pesticide delivery rate and adjusts on the go to deliver the right amount of pesticide for given conditions. Sprayers using sensor-based systems may move more slowly than equipment using map-based systems, but they are very accurate, which helps keep pesticides on target.

**Combination Systems**. A combination system uses both sensor data and prescription maps to ensure proper application rates. The task computer uses sensor data acquired during the initial application to develop a prescription map. This map is saved and uploaded to the rate controller before future pesticide applications at the same site, making these applications more efficient as well as accurate.

**Rate Controllers Used in VRA Systems.** Rate controllers can be one of the following types:

- Flow control
- Chemical-injection control
- Modulated spraying-nozzle control

**Flow Control Systems**. Flow-based rate controllers are used with liquid pesticide mixtures carried in a tank mounted on the sprayer. They are the simplest of the controllers, made up of just three parts: a flow meter, a groundspeed sensor, and an electronically controlled valve (servo valve). The controller receives instructions from the task computer, using information you enter about sprayer width and prescribed gallons per acre, and then matches this data with sensed ground speed to change the flow rate on the go. It takes about 3-5 seconds for any change in flow rate to reach the boom.

One drawback of these systems is that the calculated rate based on sensed data may be outside the optimum operating range of the nozzles you are using. Some systems will warn you if this problem occurs, but others may not, so you must pay attention to what is happening as you spray. Another problem with flow-based systems occurs because of the variation in pressure rates. This variation can alter droplet size enough to cause increased drift or runoff, poor coverage, and irregular spray pattern. Flow-based systems may also leave some pesticide in the tank after the application, which you will have to dispose of properly before cleaning and storing the sprayer. See *The Safe and Effective Use of Pesticides* Chapter 7, p 187 for proper disposal of surplus diluted pesticide.

**Chemical-injection Control Systems**. In a chemical-injection control system, the controller works with a chemical pump to regulate the injection of pesticide into the carrier (usually water) as the sprayer moves through the field. Unlike flow control systems, chemical-injection control systems use all the mixed pesticide during the application so there is nothing left over. Chemical-injection rate controllers vary application rates by increasing or decreasing the amount of pesticide injected rather than changing pressure delivered to the nozzles. This control method keeps droplet size constant throughout the application, reducing drift and runoff that may occur when droplets get too small or too large.

The major drawback of chemical-injection rate controllers is the time it takes for the old mixture to be flushed out of the sprayer as the new mixture works its way to the boom and nozzles. In some field trials of boom sprayers using chemical-injection VRA systems, it took nearly 100 feet for the new mixture to completely replace the old mixture, causing an uneven, “Christmas tree” application pattern. In some VRA systems, this problem has been addressed by the addition of a carrier control device, which works in tandem with the chemical-injection controller to vary both the rate of chemical injected and the pressure delivered to the nozzles. However, these combination systems are more complex and expensive than the others, and they reintroduce the problems that come from varying droplet size.

**Pulse Width Modulated Control Systems**. Pulse width modulated control (PWM) systems are the most flexible, but also the most complex of the rate controllers. A PWM system controls spray at the nozzle, changing the timing and duration of spray by opening and closing high-speed solenoid valve assemblies mounted directly to conventional nozzle assemblies. Commands are delivered by the control system, based on data collected by sensors and uploaded to the task computer during the application.

One of the major benefits of the PWM-based VRA system is performance speed as it switches from one application rate to another. The action of opening a closed valve (or closing an open valve) takes 8 milliseconds, or a little less than 1/10$^{th}$ of a second, to complete. The system can also reduce pressure to increase droplet size on the go if conditions change and suddenly favor drift.

Certain types of nozzles are required for these systems, so they cannot be used in every situation. In order to preserve the uniformity of the spray pattern, and reduce the likelihood of gaps or overlaps, you must use wide spray-angle (110-degree angle versus more-common 80-degree angle) nozzles. You also must pay attention to the pressure rates produced by PWM systems, since errors do sometimes occur, resulting in rates that exceed nozzle capacity.

## Review Questions

**Section 1: Integrated Pest Management**

1. In what ways can insects be used to control weeds?
   a. They can be encouraged to lay eggs on or inside plants.
   b. They are vectors, transmitting disease organisms to plants.
   c. Their presence attracts the type of animal that eats plants.

2. How does crop rotation help control nematode populations?
   a. Populations will fall if the nematode species has a narrow host range and requires a living host to survive in the soil.
   b. Nematodes will latch onto the new plants, and will be removed when plant debris is removed before the next planting.
   c. The effect of crop rotation on nematodes is not well understood and only works when combined with chemical control methods.

3. Select the drawbacks of planting transgenic crops on a pest management plan (choose all that apply).
   a. The ability to apply pesticide as needed
   b. An increase in pesticide usage
   c. The emergence of secondary pest problems
   d. Repeated use of the same pesticide in an area
   e. The planting of reservoir crops in addition to transgenic crops
   f. A drop in spraying to control disease vectors
   g. Weeds that develop resistance to the same pesticide as the crop

4. Which of the following statements are *true* about host-plant resistance to nematode infestation (select all that apply)?
   a. Nematode-resistant plants are best used in combination with other management techniques, such as crop rotation and fallowing.
   b. Good water management, fertilization, and other cultural practices make little difference in a plant's ability to resist nematodes.
   c. A plant that is resistant to nematode pests may be susceptible to one or more alternate pests that live and breed nearby.
   d. Nematode-resistant plants are a very cost-efficient way to manage pest nematode species in fields, orchards, or vineyards.

5. A disease-resistant cultivar may still become infected when:
   a. conditions favor infection, and disease vectors are numerous in the area.
   b. it rains frequently, and soil contains a high level of organic matter.
   c. plants become physically stressed by overwatering or nutrient deficits.

6. Using transgenic plants without employing other IPM methods may increase a pest's:
   a. resistance to the inserted genes.
   b. ability to reproduce and spread.
   c. available sites for overwintering.

7. Why do integrated pest management programs work better than programs relying on just one management method?
   a. The additional complexity of the system confuses pests, making them easier to control or eliminate.
   b. Using a number of pest control methods at once takes far less effort than employing them individually .
   c. A diversity of approaches to managing pests increases the long-term effectiveness of each individual control measure.

8. Match the nonchemical pest management method with its main use or uses.

| | |
|---|---|
| 1. Soil solarization | a. Used to increase species of bacteria known to be natural enemies of soilborne pathogens. |
| 2. Fungal diseases | b. Used to suppress weeds and yield a cash crop at the same time |
| 3. Geese | c. Used to kill weeds, disrupt the life cycle of some insect pests, and bury disease inoculum |
| 4. Smother crops | d. Usually occurs naturally and helps control aphids |
| 5. Tillage or cultivation | e. Used for controlling weedy grasses in cotton, orchards, and vineyards |

9. Which of the following are considered benefits of pest monitoring (select all that apply?
   a. Observing seasonal changes in pest populations
   b. Proper timing of pesticide applications
   c. Assessing the effectiveness of pest control measures
   d. Ability to use more pesticides and apply these more frequently

**Section 2: Pest Biology and Pest Identification**

1. Which of the following is a disadvantage of using common names for identifying organisms?
   a. They usually describe one characteristic of the pest but leave others out.
   b. They provide little information about the relationship of one organism to another.
   c. Pesticide labels list common names of pests rather than scientific names.

2. What is *most* likely to cause your pest control efforts to fail?
   a. Making pesticide applications when crop plants are in their dormant stage.
   b. Spraying a pesticide prior to the pest's most vulnerable life stage.
   c. Delaying pesticide applications until action thresholds are reached.

3. A stomach poison applied to the upper surface of leaves will fail to control insects if:
   a. they feed on all areas of the leaf.
   b. they feed on the edges of the leaf.
   c. they feed on underside of the leaf.

4. Match the pests listed below with the crop(s) they damage.

| | |
|---|---|
| 1. Mexican leafhopper (*Empoasca mexara*) | a. Avocado |
| 2. Banks grass mite (*Oligonychus pratensis*) | b. Cole crops |
| 3. Dothiorella canker (*Botryosphaeria* spp. and *Fusicoccum* spp.) | c. Small Grains and Corn |
| 4. Bandedwinged whitefly (*Trialeurodes abutilonia*) | d. Alfalfa |
| 5. Alternaria Leafspot (*Alternaria brassicae, A. brassicicola*) | e. Tomato, Alfalfa, and Cotton |

5. Which of the following body parts distinguish mites from insects? Select all that apply.
   a. thorax
   b. abdomen
   c. idiosoma
   d. number of legs
   e. wings
   f. gnathosoma
   g. antennae

6. Match the typical life cycle/life stages with the type of pest.

| | |
|---|---|
| 1. Egg, nymph, adult | a. Fish |
| 2. Seed, seedling, vegetative growth, reproductive period, post-reproductive period | b. Insect, complete metamorphosis |
| 3. Egg, juvenile, adult | c. Nematode |
| 4. Egg, larva, fry, juvenile, adult | d. Weed |
| 5. Egg, larva, pupa, adult | e. Insect, incomplete metamorphosis |

(answer: 1. e; 2. d 3. c; 4. a; 5. b)

7. Which statement is *true* regarding common sources of viral disease in plants?
   a. Viruses are spread from plant to plant as vertebrate pests feed on leaves.
   b. Viruses are spread from one plant to another by insect or nematode vectors.
   c. Viruses enter plants either through their root structure or through wounds.

8. Match the plant's symptoms/signs with the pest that is most likely causing them.

| | |
|---|---|
| 1. Plants become waterlogged due to clogged drainage ditches. | a. Grasshoppers |
| 2. Alfalfa leaves show chewing damage. | b. Fungi |
| 3. Roots of carrots split or become stubby. | c. Insufficient water reaching certain areas |
| 4. Roots of plants down a single row have been eaten away. | d. Nematodes |
| 5. Sudden wilting of plants in random patches. | e. Weeds |
| 6. Powdery accumulations on leaves and fruit. | f. Pocket gophers |

9. In order for disease to occur, a susceptible host must live in the right environment and come into contact with:
   a. insect vectors.
   b. alternate hosts.
   c. pathogens.

10. Match the type of weed with its distinguishing characteristics.

| | |
|---|---|
| 1. Sedge | a. This weed produces two seedling-leaves (cotyledons) and can be herbaceous or woody. |
| 2. Grass | b. This weed has elongated, V shaped leaves arising from solid, triangular stems. |
| 3. Broadleaf | c. This weed has a hollow stem and a thin outgrowth or fringe of hairs (ligule) that occurs at the collar region |

11. Movement of nematodes over long distances primarily occurs from the transport of:
   a. nursery plants.
   b. irrigation water.
   c. farm equipment.

12. Mammals become pests when they:
   a. consume stored produce.
   b. prey on reptiles and insects.
   c. live on or near farms.

13. What is the difference between direct and indirect damage caused by vertebrate pests?
    a. Direct damage can be used to identify a vertebrate pest definitively; indirect damage can never positively identify the vertebrate pest that caused the injury.
    b. Direct damage consists of a vertebrate's teeth marks and burrows; indirect damage consists of a vertebrate's tracks and fecal droppings
    c. Direct damage is the injury to crops made by the pest as it feeds; indirect damage consists of burrows, nests, and fecal droppings left behind by the pest.

**Section 3: Pesticides**

1. Which type of pesticide should you avoid if pollinators are active in the area?
   a. Granular herbicides
   b. Contact acaricides
   c. Systemic insecticides

2. Which type of pesticide should you use if you want to reduce the number of applications that are needed to control fungal disease?
   a. Systemic fungicides
   b. Contact fungicides
   c. Persistent fungicides

3. Weed seeds have been found in the soil of a recently plowed field. Which type of pesticide would you use in this situation?
   a. Preemergent silvicide
   b. Postemergent herbicide
   c. Preemergent herbicide

4. Nematodes have been discovered in a field where crop plants are actively growing. Which of the following nematicide applications will be most effective at this site?
   a. Soil injection of fumigants
   b. Soil incorporation of microbial pesticides
   c. Chemigation of nematicides

5. Match the situation with the factor(s) that must be considered before deciding which pesticide to use.

| | |
|---|---|
| 1. An insect pest has reached the action threshold in a strawberry field. | a. Restricted-entry and preharvest intervals |
| 2. Pests have become resistant to the pesticide normally applied at a site. | b. Available adjuvants and formulation type |
| 3. A pest requires treatment and the crop will need to be picked by workers within the next two weeks. | c. Mode of action and chemical family |
| 4. You are spraying near a sensitive area, so drift reduction is critical. | d. Type of pest controlled and crop/site restrictions |

6. What information must you have before you can select a pesticide to use for vertebrate control?
   a. An accurate identification of the pest species causing damage and a knowledge of its habits and biology
   b. A list of the pesticide's hazards to nontarget animals and humans in the area where it will be applied
   c. A history of weather trends and vertebrate pest population density in the area

7. Which of the following statements are *true* about poison baits (select all that apply)?
   a. You can use specially designed bait stations to prevent other animals and children from accessing poison baits.
   b. Some baits attract target pests, eliminating the need for widespread pesticide application.
   c. Well-targeted baits are formulated to reach the target pest, and leave the pest's predators unharmed.
   d. Manufacturers often color grain baits to make them less attractive to birds

8. Which of the following signs indicate an incompatibility developing in a tank mix? Select all that apply.
   a. Flakes forming in the tank
   b. Foaming in the tank
   c. Crystals precipitating in the tank
   d. Clouding of the mixture
   e. Oily clumps appearing in the tank
   f. Severe separation

9. To avoid the development of resistance in agricultural pests, you should use pesticides with differing:
   a. toxicity.
   b. modes of action.
   c. application methods.

**Section 4: Safe and Effective Use of Pesticides**

1. Match the pesticide characteristic(s) with the way(s) it is most likely to move in the environment.

| | |
|---|---|
| 1. Pesticide is persistent in soil | a. Runoff |
| 2. Pesticide is soluble in water | b. Leaching |
| 3. Pesticide mixture is thin and watery | c. Spray drift |
| 4. Pesticide is volatile | d. Particle drift |
| 5. Pesticide is persistent and adsorbs tightly to soil particles. | e. Vapor drift |

2. Which of the following weather conditions, if detected at the application site, should result in a postponement or cancellation of the pesticide application? Select all that apply.

a. Temperature is above label limit
b. Winds are light, less than 5 mph
c. A temperature inversion has been observed
d. The day is clear and sunny, and temperatures are rising rapidly
e. Fog is rolling into the area
f. The day is sunny and temperatures are mild

3. Match the mistake with the description of resulting problem(s).

| | |
|---|---|
| 1. Adding less than the required amount of active ingredient to the tank mix. | a. Pesticide cannot reach the target pest |
| 2. Making applications when flowers are in bloom. | b. Causes vapor drift when the pesticide comes into contact with air |
| 3. Applying pesticides too frequently in an area. | c. Aids in the development of resistance |
| 4. Applying pesticides to places where pests do not usually breed, live, or feed. | d. Contributes to secondary pest outbreaks or a resurgence of the pest |
| 5. Failing to mix volatile pesticides thoroughly into soil. | e. May result in the death of pollinators |

4. What can you do to reduce the likelihood of pesticides settling out or clumping after mixing?

a. Contact the pesticide dealer to find out which compatibility agent to add to the tank.
b. Decrease agitation to reduce excessive turbulence and foaming in the tank.
c. Decrease dilution rates so there is less diluent (water or oil) in the tank.

(answer: a)

5. Three factors that make for effective pesticide use are:
   a. Hot weather, adequate rainfall or irrigation, and concentration of the spray mixture
   b. Timing application to optimal weather conditions, pest susceptibility to the pesticide, and ability to protect natural enemies
   c. Volume of spray used, method of application, and capacity of the spray tank

6. Which of the following is a benefit of using more than one pesticide in the spray tank?
   a. You can treat a larger area using a single tank mix.
   b. You can decrease environmental contamination by making a single application.
   c. You can save time by treating two or more pests during a single application.

7. To reduce the possibility of building up a pest's resistance to a pesticide, you can:
   a. Use only pesticides that have very long persistence
   b. Use a pesticide that is selective to the pest
   c. Make frequent spot treatments with the same pesticide

8. Which of the following actions will help to *decrease* pesticide resistance (select all that apply)?
   a. Use less than the label-recommended amount of pesticide in the tank.
   b. Use pesticides from the same chemical class repeatedly at a site.
   c. Apply pesticides with varying modes of action over time.
   d. Apply the same pesticide to pests that reproduce multiple times in a season.
   e. Implement an IPM program that uses a variety of pest control methods.
   f. Limit the number of pesticide applications in a season.

9. What can you do to find out if your pesticide application has been successful in an area?
   a. Return to the site one day after the application to see if pest damage has been reduced or has stopped.
   b. Leave water-sensitive paper cards at the site and check to see if there has been a color change.
   c. Walk through the site immediately after the application to see if spray has reached target surfaces.

10. The threshold that defines the time during crop development when losses from weed interference are most likely to occur is called the:
   a. damage threshold.
   b. economic threshold.
   c. period threshold.

11. Match the monitoring tool with its uses and targets.

| | |
|---|---|
| 1. Visual inspection | a. Shake plants or beat branches over a drop cloth to collect adults and larvae/nymphs of easily dislodged insects and mites. |
| 2. Knockdown techniques | b. May require a hand lens or other magnifier to check the outer surface of plants for surface-feeding invertebrates and the damage they cause. |
| 3. Sweep nets | c. Check to see if temperature development thresholds and rates have been determined for the pest being monitored. |
| 4. Pitfall traps | d. Use to capture adult weevils, predaceous ground beetles, ground-dwelling spiders, Collembola, and possibly others such as squash bugs. |
| 5. Degree-day phenology | e. Use to collect adults and larvae or nymphs of invertebrate species that are free-living on foliage. |

12. Physiological time is often expressed in units called:

a. Degree-days
b. Heat-days
c. Life-days

13. Different weather conditions can affect a pesticide's phytotoxicity, degradation, uptake by pests, and volatility. Which one can affect all four?

a. Fog
b. Temperature
c. Wind

14. What must you do to protect surface water near the field where you are applying a pesticide?

a. Spray less pesticide than the label recommends in areas next to the water.
b. Create a buffer zone near the water, and avoid spraying pesticides there.
c. Use a water-soluble pesticide that breaks down quickly in the environment.

15. When a pest has several distinct mechanisms to withstand pesticide chemicals, allowing them to tolerate several classes of pesticides that are not related to each other chemically, they have developed:

a. cross-resistance.
b. chemical resistance.
c. multiple resistance.

16. How can you tell if pesticide coverage is adequate in an area?
    a. Check foliage for visible residue.
    b. Check plants to see if pest damage is continuing.
    c. Count the number of dead or dying pests.

**Section 5: Application Methods and Equipment**

1. Which of the following equipment types can be used to treat insects and disease in areas of dense foliage?
   a. Trigger pump sprayers
   b. Spinning disc sprayers
   c. Tunnel sprayers

2. You must use an agitator at all times when spraying:
   a. wettable powders.
   b. soluble powders.
   c. soluble liquids.

3. If you are using a formulation that has a high drift potential, it is best to use a boom sprayer equipped with:
   a. aluminum nozzles.
   b. spray shields.
   c. a system controller.

4. Manufacturers make nozzles out of which of the following materials? Select all that apply.
   a. Rubber
   b. Copper
   c. Coated steel
   d. Plastic
   e. Brass
   f. Tungsten carbide

5. Match the pump type with the appropriate application situation.

| | |
|---|---|
| 1. Diaphragm | a. Used to make low-pressure applications (between 20 and 100 psi) of oil sprays or emulsifiable concentrates. |
| 2. Gear | b. Used for herbicide applications of flowable, emulsifiable concentrate, soluble powder, or other nonabrasive formulations. |
| 3. Centrifugal | c. Used in both low- and high-pressure applications of abrasive or corrosive chemicals. |
| 4. Piston | d. Used for high-pressure applications or if you use both high and low pressures, as when using a VRA-equipped sprayer. |
| 5. Roller | e. Used in a wide variety of situations requiring a range of application pressures (from 5 to 200 psi), especially when spraying abrasive materials. |

6. Match the nozzle type with the application method that requires it.

| | |
|---|---|
| 1. Turbulence chamber flood | a. Used in situations where you cannot use a spray boom but need a wide swath. |
| 2. Venturi | b. Used for soil and foliar applications when better coverage is required than can be obtained from flooding or turbo flooding nozzles. |
| 3. Extended range flat-fan | c. Used for applying herbicides and mixtures of herbicides and liquid fertilizers. |
| 4. Flooding | d. Used for applying insecticides and fungicides to dense foliage. |
| 5. Broadcast | e. Recommended for soil application of crop protection products; used especially when making drift-sensitive applications. |
| 6. Disc-core | f. Used most often with systemic products, but can also work with contact products if the spray volume is high (>40 GPA). |
| 7. Cone | g. Used when applying separate bands of spray that should not overlap. |
| 8. Even spray | h. Suitable for high-pressure and high flow rate applications of insecticides and fungicides. |

7. Procedures for thoroughly cleaning application equipment after use should start with reading the:
   a. equipment's instruction manual.
   b. label of the last pesticide applied.
   c. agricultural commissioner's equipment cleaning booklet.

8. The first step to take before storing any application equipment is to:
   a. decontaminate and clean it thoroughly.
   b. inspect it carefully for damage and wear.
   c. check tanks or hoppers for leftover pesticide.

9. Match the sprayer malfunction with the problem causing it.

| | |
|---|---|
| 1. Sprayer pressure too high | a. The nozzles are positioned too far from the target. |
| 2. Sprayer pressure too low | b. The agitator is not working properly. |
| 3. Nozzles clog repeatedly | c. The bypass system has become restricted. |
| 4. Excessive drift | d. The pressure setting does not match the operating range of nozzles. |
| 5. Uneven spray pattern | e. The nozzles have become worn. |

10. Which of the following chemigation systems should you use if you want to reduce drift and increase accuracy of pesticide application?
   a. Center pivot systems
   b. Furrow irrigation systems
   c. Micro-irrigation systems

11. An easy way to reduce pesticide drift is to discontinue spraying when wind speeds exceed:
   a. 3 mph
   b. 5 mph
   c. 7 mph

12. When treating weeds or insects infesting the base of established trees or vines, you should use which of the following application methods?
   a. Basal
   b. Broadcast
   c. Drench

13. Which application method is used to deposit pesticide directly onto pest plants?
   a. Soil injection
   b. Rope-wick
   c. Precision spraying

## Review Question Answer Key

**Section 1**
1. b
2. a
3. b, c, d, g
4. a, c, d
5. c
6. a
7. c
8. (1) a, (2) d, (3) e, (4) b, (5) c
9. a, b, c

**Section 2**
1. b
2. b
3. c
4. (1) d, (2) c, (3) a, (4) e, (5) b
5. c, d, f
6. (1) e, (2) d, (3) c, (4) a, (5) b
7. b
8. (1) e, (2) a, (3) d, (4) f, (5) c, (6) b
9. c
10. (1) b, (2) c, (3) a
11. a
12. a
13. c

**Section 3**
1. c
2. a
3. c
4. c
5. (1) d, (2) c, (3) a, (4) b
6. a
7. a, b, d
8. a, c d, e, f
9. b

**Section 4**
1. (1) b, (2) a, (3) c, (4) e, (5) d
2. a, c, d, e
3. (1) c, (2) e, (3) d, (4) a, (5) b
4. a
5. b
6. c
7. c
8. c, e, f
9. a
10. c
11. (1) b, (2) a, (3) e, (4) d, (5) c
12. a
13. b
14. b
15. c
16. a

**Section 5**
1. c
2. a
3. b
4. d, e, f
5. (1) c, (2) a, (3) e, (4) d, (5) b
6. (1) e, (2) f, (3) b, (4) c, (5) a, (6) h, (7) d; (8) g
7. b
8. a
9. (1) c, (2) e, (3) b, (4) a, (5) d
10. c
11. c
12. a
13. b

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