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Alternatives in Insect Management

Biological and Biorational Approaches

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CONTENTS

Introduction

Synthetic chemical insecticides have played important and beneficial roles in the control of agricultural pests and the reduction of insect-borne diseases for nearly 50 years. Their use will remain essential for many more years. Nonetheless, insecticides also pose real hazards. Some leave undesirable residues in food, water, and the environment. Low doses of many insecticides are toxic to humans and other animals, and some insecticides are suspected to be carcinogens. As a result, many researchers, farmers, and homeowners are seeking less hazardous alternatives to conventional synthetic insecticides.

This publication provides background information and evaluations of the safety and effectiveness of several alternative products and practices that are available for use in insect pest management. It focuses on microbial insecticides; botanical insecticides and insecticidal soaps; attractants and traps; and beneficial insects and mites (natural enemies of pests). Although these topics comprise a core of important alternatives in insect pest management, they by no means represent a complete picture of all available alternatives. Readers are encouraged to consult additional references for information on the use of resistant varieties, crop rotations, sanitation, and other practices for specific crops or situations (see Olkowski et al. 1991; Henn et al. 1991; Pedigo 1989; and Metcalf and Luckmann 1982). Each chapter of this publication also lists references that contain additional information.

Appropriate and effective alternative methods of insect management are not necessarily “nonchemical” or “nontoxic.” For example, although they are derived from plants, the botanical insecticides that are used commonly by some producers of organic foods certainly are chemicals, and some are moderately to highly toxic to humans and other mammals. Popular microbial insecticides also contain chemical toxins. Because the terms nonchemical, nontoxic, and natural are themselves often artificial and misleading simplifications, the alternatives described in this publication are termed biological or biorational. Biological control is the use of predators, parasitoids, pathogens, or competitors to control pests. The term biorational is less clearly defined. Specific insecticides, insect growth regulators, and attractants are often called biorational because they affect or attack biochemical systems that are unique to arthropods, insects, or even specific groups of insects. Terminology aside, the intent of this publication is to provide information on pest management products and practices that pose reduced risks to the environment and human health. It will be successful if it helps readers to choose and use safer and effective methods of insect control.

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CHAPTER 1
Microbial Insecticides

Microbial insecticides are composed of microscopic living organisms (viruses, bacteria, fungi, protozoa, or nematodes) or the toxins produced by these organisms. They are formulated to be applied as conventional insecticidal sprays, dusts, or granules. Each product's specific properties determine the ways in which it can be used most effectively. This chapter describes the types of microorganisms formulated for insect control, summarizes the strengths and weaknesses of products available commercially (and a few currently under development), and lists the most promising uses for microbial insecticides.

With the exception of insecticidal products containing nematodes, all the microbial insecticides discussed in this chapter are regulated by the United States Environmental Protection Agency (U.S. EPA). (Nematodes used for insect control are multicellular parasites, and parasites and predators are not regulated as pesticides by the U.S. EPA.) Although this chapter provides background information on microbial insecticides, readers should consult product labels for specific application directions. All insecticides should be used only in the manner specified on the product label.

ADVANTAGES OF MICROBIAL INSECTICIDES

Individual products differ in important ways, but the following list of beneficial characteristics applies to most microbial insecticides.

> The organisms used in microbial insecticides are essentially nontoxic and nonpathogenic to wildlife, humans, and other organisms not closely related to the target pest.
>
> The toxic action of most microbial insecticides is specific to a single group or species of insects, and this specificity means that most microbial insecticides do not directly affect beneficial insects (including predators or parasites of pests) in treated areas.
>
> If necessary, most microbial insecticides can be used in conjunction with synthetic chemical insecticides because in most cases the microbial product is not deactivated or damaged by residues of conventional insecticides. (Follow label directions concerning any limitations.)
>
> Because their residues present no hazards to humans or other animals, microbial insecticides can be applied even when a crop is almost ready for harvest.
>
> In some cases, the pathogenic microorganisms can become established in a pest population or its habitat and provide control during subsequent pest generations or seasons.

DISADVANTAGES OF MICROBIAL INSECTICIDES

The limitations or disadvantages listed below do not prevent the successful use of microbial insecticides. Understanding how these limitations affect specific microorganisms will help users to choose effective products and take necessary steps to achieve successful results.

> Because a single microbial insecticide may be toxic to only a specific species or group of insects, each application may control only a portion of the pests present in a field, garden, or lawn. If other types of pests are present in the treated area, they will survive and may continue to cause damage. Conventional insecticides are subject to similar limitations because they too are not equally effective against all pests. Nonetheless, the negative aspect of selectivity is often more noticeable for microbials.
>
> Heat, desiccation (drying out), or exposure to ultraviolet radiation reduces the effectiveness of several types of microbial insecticides. Consequently, proper timing and application procedures are especially important for some products.

Special formulation and storage procedures are necessary for some microbial pesticides. Although these procedures may complicate the production and distribution of certain products, storage requirements do not seriously limit the handling of microbial insecticides that are widely available. (Store all pesticides, including microbial insecticides, according to label directions.)

Because several microbial insecticides are pest-specific, the potential market for these products may be limited. Their development, registration, and production costs cannot be spread over a wide range of pest control sales. Consequently, some products are not widely available or are relatively expensive (several insect viruses, for example).

BACTERIA

Bacterial pathogens used for insect control are spore-forming, rod-shaped bacteria in the genus *Bacillus*. They occur commonly in soils, and most insecticidal strains have been isolated from soil samples. Bacterial insecticides must be eaten by target insects to be effective; they are not contact poisons. Insecticidal products composed of a single *Bacillus* species may be active against an entire order of insects, or they may be effective against only one or a few species. For example, products containing *Bacillus thuringiensis* var. *kurstaki* kill the caterpillar stage of a wide array of butterflies and moths. In contrast, *Bacillus popilliae* var. *popilliae* (milky disease) kills Japanese beetle larvae but is not effective against the closely related annual white grubs (masked chafers in the genus *Cyclocephala*) that commonly infest lawns in much of the Midwest.

The microbial insecticides most widely used in the United States since the 1960s are preparations of the bacterium *Bacillus thuringiensis* (abbreviated as *Bt*). *Bt* products are produced commercially in large industrial fermentation tanks. As the bacteria live and multiply in the right conditions, each cell produces (internally) a spore and a crystalline protein toxin called an endotoxin. Most commercial *Bt* products contain the protein toxin and spores, but some are cultured in a manner that yields only the toxin component.

When *Bt* is ingested by a susceptible insect, the protein toxin is activated by alkaline conditions and enzyme activity in the insect's gut. The toxicity of the activated toxin is dependent on the presence of specific receptor sites on the insect's gut wall. This necessary match between toxin and receptor sites determines the range of insect species killed by each *Bt* subspecies and isolate. If the activated toxin attaches to receptor sites, it paralyzes and destroys the cells of the insect's gut wall, allowing the gut contents to enter the insect's body cavity and bloodstream. Poisoned insects may die quickly from the activity of the toxin or may die within 2 or 3 days from the effects of septicemia (blood-poisoning). Although a few days may elapse before the insect dies, it stops feeding (and therefore stops damaging crops) soon after ingesting *Bt*.

Bt does not colonize or cycle (reproduce and persist to infect subsequent generations of the pest) in the environment in the magnitude necessary to provide continuing control of target pests. (See Figure 1-1.) The bacteria may multiply in the infected host, but bacterial multiplication in the insect does not result in production of abundant spores or crystalline toxins. The usual result is that few infective units are released into the environment when a poisoned insect dies. Consequently, *Bt* products are applied much like synthetic insecticides. *Bt* treatments are inactivated fairly rapidly (within one to a few days) in many outdoor situations, and repeated applications may be necessary for some crops and pests.

Until the early 1980s, commercial *Bt* products were effective only against caterpillars. In recent years, however, additional isolates that kill other types of pests have been identified and developed for insecticidal use. The nature of the crystalline protein endotoxin differs among *Bt* subspecies and isolates, and the characteristics of these specific endotoxins determine what insects will be poisoned by each *Bt* product. *Bt* formulations that are now commercially available fall into one of the following broad categories.

Bt Formulations That Kill Caterpillars.

The best-known and most widely used *Bt* insecticides are formulated from *Bacillus thuringiensis* var. *kurstaki* isolates that are pathogenic and toxic only to larvae of the butterflies and moths. Many such *Bt* products have been registered with the U.S. EPA. The most common trade names for these commercial products include Dipel, Biobit, Javelin, Full-Bac, Thuricide, Worm Attack, and Caterpillar Killer, but many small companies sell similar products under a variety of trade names. These products are commercially successful and widely available as liquid concentrates, wettable powders, and ready-to-use dusts and granules. They are used to control many common leaf-feeding caterpillars, including caterpillar pests on vegetables (especially the “worms” that attack cabbage, broccoli, cauliflower, and Brussels sprouts), bagworms and tent caterpillars on trees and shrubs, larvae of the gypsy moth and other forest caterpillars, and European corn borer larvae in field corn. Several of these products are used to control Indianmeal moth larvae in stored grain. A related product with a very specific target is Certan, formulated from *Bacillus thuringiensis* var. *aizawai*, and used exclusively for the control of wax moth larvae in honeybee hives.

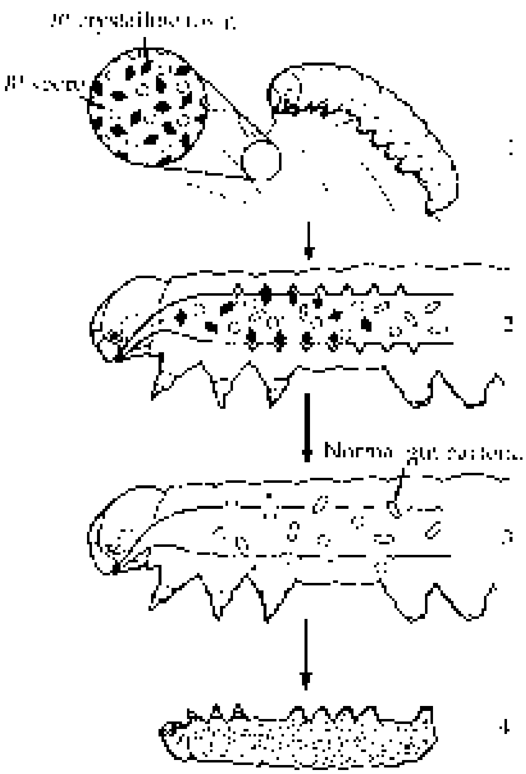

Figure 1-1. Action of* Bacillus thuringiensis *var.* kurstaki *on caterpillars.

(1) Caterpillar consumes foliage treated with* Bt *(spores and crystalline toxin). (2) Within minutes, the toxin binds to specific receptors in the gut wall, and the caterpillar* stops feeding*. (3) Within hours, the gut wall breaks down, allowing spores and normal gut bacteria to enter the body cavity; the toxin dissolves. (4) In 1 to 2 days, the caterpillar dies from septicemia as spores and gut bacteria proliferate in its blood. (Adapted from Abbott Laboratories, “Mosquito Control: Taking the Bite Out of Summer.”)

Bt products that kill caterpillars are *not* effective against other types of pests; they will not control aphids, beetles, flies, or additional pests other than caterpillars. Even certain caterpillars are not effectively controlled by *Bt*, especially those that live in the soil or bore into plant tissues without consuming a significant amount of the *Bt* applied to plant surfaces. (Again, *Bt* is a stomach poison that must be ingested to be effective.) The peach tree borer in stone fruits, corn earworm in corn, and the cutworms that clip off field crops or garden plants are examples of caterpillars seldom controlled by *Bt* treatments. Most *Bt* products are not registered for the control of codling moth larvae that attack apples and pears because these larvae do not feed much (if at all) on treated surfaces.

Bt Formulations That Kill Mosquito, Black Fly, and Fungus Gnat Larvae.

Production of a second group of *Bt* insecticides began in the early 1980s. These products use *Bacillus thuringiensis* var. *israelensis* (*Bti*), a subspecies that kills the larvae of certain Diptera (the insect order containing the flies and mosquitoes). The main targets for *Bti* are the larval stages of mosquitoes, black flies, and fungus gnats; it does not control larval stages of “higher” flies such as the house fly, stable fly, or blow flies. Mosquitoes that are most susceptible to *Bti* include species in the genera *Aedes* and *Psorophora*. *Anopheles* and *Culex* species are controlled only when higher than normal rates of *Bti* are applied. *Bti* products that are available commercially include Vectobac, Teknar, Bactimos, Skeetal, and Mosquito Attack. Gnatrol is a *Bti* formulation labeled for fungus gnat control.

Bti is most effective for mosquito or black fly control when it is used on a communitywide basis by mosquito abatement district personnel. In general, any attempts to reduce the prevalence of mosquito-breeding sites and treat remaining sites are most effective when undertaken on such a scale. For most homeowners or farmers, eliminating sites that periodically serve as sources of standing water (such as tires and empty containers) and controlling weeds around stagnant ponds or drainage lagoons is more effective than applying *Bti*.

Bti products are formulated for spray or granular applications. *Bti* formulated on corn cob granules is effective against mosquito larvae developing in tires and other artificial containers. (The “Asian tiger mosquito,” *Aedes albopictus*, develops in these containers.) The corn cob granules can be blown into tire piles to provide good penetration and uniform treatment; residual control is also greater when corn cob granules are used. *Bti* is not very effective for the control of mosquito larvae in turbid water or waters containing high levels of organic pollutants.

Bti has also been used effectively for the control of fungus gnat larvae in greenhouses and in mushroom culture beds. For these uses, *Bti* is applied as a drench to potting soils or culture media. Not all *Bti* products are labeled for fungus gnat control.

Although not a *Bt*, another bacterium that is pathogenic to certain mosquitoes is *Bacillus sphaericus*. *Bacillus sphaericus* is especially active against larvae of mosquitoes in the genera *Culex*, *Psorophora*, and *Culiseta*. Effectiveness against larvae of *Aedes* species varies. *Aedes vexans* is very susceptible, but *Aedes aegypti* (the yellow fever mosquito) and *Aedes albopictus* are not. *Bacillus sphaericus* kills *Anopheles* larvae in laboratory tests, but field results have not been promising. Because *Anopheles* mosquitoes are true surface feeders, the bacterium would have to remain on the water surface for an extended period to be effective. *Bacillus sphaericus* formulations tested up to now do not remain at the surface long enough to be effective.

In addition to infecting a different group of mosquito species than *Bti*, *Bacillus sphaericus* is a potentially valuable insecticide because it remains effective in stagnant or turbid water. Although *Bacillus sphaericus*, as it occurs naturally, does cycle and maintain itself in the environment, insecticidal formulations currently under development do not cycle in water to infect subsequent generations of mosquito larvae. EPA registration of *Bacillus sphaericus* is pending.

Caterpillar Targets for Bt:

Common caterpillar pests that are controlled effectively with *Bacillus thuringiensis* var. *kurstaki* (Bt) include

- European corn borer in corn
- Indianmeal moth in stored grain
- cabbage looper
- imported cabbageworm
- diamondback moth
- tomato/tobacco heartworm
- gypsy moth
- spruce budworm
- tent caterpillars
- fall webworm
- mimosa webworm
- bagworms
- spring and fall cankerworm

Common caterpillar pests that are *not* controlled by normal applications of Bt include

- corn earworm (on corn)
- codling moth
- peach tree borer
- squash vine borer

Bt Formulations That Kill Beetles.

Another group of *Bt* isolates, including those from *Bacillus thuringiensis* var. *san diego* and *Bacillus thuringiensis* var. *tenebrionis*, are toxic to certain beetles. Within the order Coleoptera (the beetles), species exhibit great differences in susceptibility to these isolates, presumably because of differences in the insects' gut wall receptor sites where the bacterial toxins must attach. Consequently, the range of susceptible hosts for the beetle-targeted *Bt* formulations does not include all beetles, or even all of the species within a beetle family or subfamily.

In 1988, *Bacillus thuringiensis* var. *san diego*, sold under the trade name M-One, was first registered for use against larvae of the Colorado potato beetle. This product also kills adults and larvae of the elm leaf beetle and willow leaf beetle, but it is not pathogenic or toxic to some other key beetle pests, such as the corn rootworms and other related species. Trident II, a very similar product containing *Bacillus thuringiensis* var. *tenebrionis*, has also been registered for control of Colorado potato beetle larvae. Foil, a microbial insecticide containing a *Bt* conjugate that produces toxins effective against caterpillars and the Colorado potato beetle, is another recently developed product. Its uses are few, however, because the assembly of pests in common crops rarely calls for this combination of insecticidal action. Considerable research effort is now directed to identifying and developing additional *Bt* isolates that are active against more or different beetle species. Although entomologists and consumers alike will need to consider the specific target insect when judging the potential for these new products, *Bt* formulations effective against beetles seem to offer great promise.

Using *Bt* Insecticides.

Insecticides containing *Bt* can be very effective for insect control in a variety of situations. Reviewing a few key facts about these products can help users obtain the best results possible. Each *Bt* insecticide controls only certain types of insects; therefore, it is essential to identify the target pest and to confirm that the *Bt* product label states that the insecticide is effective against that pest. Separate stages of insects differ in their susceptibility to *Bt;* isolates that are effective against larval stages of butterflies, moths, or mosquitoes will not kill adults. Because susceptible insects must consume *Bt* to be poisoned, treatments must be directed to the plant parts or other material that the target pest will eat. Where this is not possible (for example, where pests bore into plant tissue without feeding much on the surface of foliage or fruits), *Bt* is usually not very effective. *Bt* does not kill susceptible insects immediately. Poisoned insects normally remain on plants for a day or two after treatment, but they do not continue feeding and will die soon.

Where *Bt* is applied to plant surfaces or other sites exposed to sunlight, it is deactivated rapidly by direct ultraviolet radiation. To maximize the effectiveness of *Bt* treatments, sprays should thoroughly cover all plant surfaces, including the undersides of leaves. Treating in the late afternoon or evening can be helpful because the insecticide remains effective on foliage overnight before being inactivated by exposure to intense sunlight the following day. Treating on cloudy (but not rainy) days provides a similar result. Production processes that encapsulate *Bt* spores or toxins in a granular matrix (such as starch) or within killed cells of other bacteria also provide protection from ultraviolet radiation. Registration and sale of products containing encapsulated *Bt* (MVP, for example) are forthcoming.

Some *Bt* isolates (not those used in currently available insecticides) produce significant amounts of an additional toxin called thuringiensin, an exotoxin that is released outside the bacterial cell wall. Research is under way to develop commercial insecticides containing this toxin. Although thuringiensin might be lauded as “natural” because it is produced by living organisms, it is nonetheless toxic to a wide range of animal species and humans. If thuringiensin or other exotoxin-based insecticides are registered and become available, users should recognize the difference between them and other *Bt* products. Thuringiensin is much more toxic and should be handled much more cautiously.

Although the issue of thuringiensin’s toxicity to mammals is a unique characteristic that does not detract from the overall safety of registered microbial insecticides, users are advised to handle all microbial insecticides cautiously. Bacterial spores, mold spores, and virus particles become “foreign proteins” if they are inhaled or rubbed into the skin. As such, they can cause serious allergic reactions. The dusts or liquids used to dilute and carry these microorganisms also can act as allergens or irritants. These problems do not prevent the safe use of microbial insecticides, but they do mean that users should not breathe dusts or mists of microbial insecticides. Users should wear gloves, long sleeves, and long trousers during application and wash thoroughly after completing the application. These are common-sense precautions that will help to prevent unexpected reactions and minimize any effects from unknown toxicity.

Recent advances in biotechnology have resulted not only in improved prospects for developing new *Bt* insecticides but also in an ability to place *Bt* toxins within crop plants in a variety of ways. For example, genes directing the production of *Bt* toxins can be incorporated into certain plant-dwelling bacteria. When these altered bacteria grow and multiply within an inoculated host plant, the *Bt* toxin is produced within the plant. Efforts are under way to test this type of *Bt* “application” in corn to control the European corn borer. Genes coding the production of *Bt* toxins have also been inserted directly into the chromosomes of certain crop plants. Although the development of this technology may seem ideal, the season-long, high-level control it would provide would also pose a great risk for the development of insect resistance to the *Bt* toxin. As genes for production of insecticidal compounds are added to crop plants, developers must also devise methods of preventing or managing insecticide resistance in target pests.

Other Bacterial Insecticides.

Insecticides sold under the trade names Doom, Japidemic, Grub Attack, Safer Grub Killer, and the generic name “milky spore disease” contain the bacteria *Bacillus popilliae* var. *popilliae* and *Bacillus lentimorbus*. These bacteria cannot be grown in fermentation tanks; instead, they are “cultivated” in laboratory-reared insect larvae. Products containing *Bacillus popilliae* and *Bacillus lentimorbus* can be applied to turf and “watered in” to the soil below to control the larval (grub) stage of the Japanese beetle and, less effectively, some other beetle grubs. When a susceptible grub consumes spores of these bacteria, they proliferate within it, and the grub’s internal organs are liquified and turned milky white (hence the name, milky disease). These symptoms develop slowly, often over a period of 3 to 4 weeks following initial infection.

Bacillus popilliae and *Bacillus lentimorbus*, unlike *Bt*, do cycle in the environment if a substantial grub population is present at the time of application. When grubs killed by these bacteria break apart, a new batch of spores is released into the soil. These spores can survive (waiting to infect another grub) beneath undisturbed sod for a period of 15 to 20 years. Consequently, lawn applications of milky spore disease bacteria might not have to be repeated each year.

Unfortunately, *Bacillus popilliae* var. *popilliae* and *Bacillus lentimorbus* offer limited usefulness in most Midwestern states because the predominant lawn grubs in this region are annual white grubs, which are larvae of beetles called chafers (genus *Cyclocephala*). These larvae are not susceptible (or are only slightly susceptible) to milky disease caused by *Bacillus popilliae* var. *popilliae*.

VIRUSES

The larvae of many insect species are vulnerable to devastating epidemics of viral diseases. The viruses that cause these outbreaks are very specific, usually acting against only a single insect genus or even a single species. Most of the viruses that have been studied for use as potential insecticides are nuclear polyhedrosis viruses (NPVs), in which numerous virus particles are “packaged” together in a crystalline envelope within insect cell nuclei, or granulosis viruses (GVs), in which one or two virus particles are surrounded by a granular or capsule-like protein crystal found in the host cell nucleus. These groups of viruses infect caterpillars and the larval stages of sawflies.

Viruses, like bacteria, must be ingested to infect insect hosts. In sawfly larvae, virus infections are limited to the gut, and disease symptoms are not as obvious as they are in caterpillars. In caterpillars, virus particles pass through the insect’s gut wall and infect other body tissues. As an infection progresses, the caterpillar’s internal organs are liquified, and its cuticle (body covering) discolors and eventually ruptures. Caterpillars killed by virus infection appear limp and soggy. They often remain attached to foliage or twigs for several days, releasing virus particles that may be consumed by other larvae. The pathogen can be spread throughout an insect population in this way (especially when rain drops help to splash the virus particles to adjacent foliage) and by infected adult females depositing virus-contaminated eggs. Dissemination of viral pathogens is deterred by exposure to direct sunlight, because direct ultraviolet radiation destroys virus particles. Although naturally occurring epidemics do control certain pests, these epidemics rarely occur before pest populations have reached outbreak levels.

The development and use of virus-based insecticides have been limited. Unlike *Bt*, insect viruses must be produced in live host insects. Although such production practices can be cost-effective, they require different facilities than those now in use by insecticide manufacturers. Because many viruses are genus- or species-specific, each viral insecticide has a limited market. These economic factors, coupled with the fact that virus insecticides are slow-acting and often less effective than available synthetic chemical insecticides, have limited their development.

Nonetheless, though they are not well known or widely available, several insect viruses have been developed and registered for use as insecticides. Most are specific to a single species or a small group of related forest pests, for example, the gypsy moth, Douglas-fir tussock moth, spruce budworm, and pine sawfly. They are not commonly available for purchase but are produced for and used by the U.S. Forest Service. Forest pests are especially good targets for viral pathogens because the permanence of the forest environment contributes to cycling of the pathogen (transmission from one generation to the next). The forest canopy also helps to protect viral particles from destruction by ultraviolet radiation.

Other insect viruses investigated for use as insecticides include those that infect the alfalfa looper, soybean looper, armyworms, cabbage looper, and imported cabbageworm. Although some of these viruses have been formulated and applied in field tests, none has been registered or sold commercially. Both the codling moth GV (Decyde) and the *Heliothis* NPV (Elcar) have been registered by the U.S. EPA and produced commercially, but these products are not currently available.

If additional viral insecticides are registered or if currently registered products become more widely available, their effective use will depend on applicators’ remembering the following key facts: most viruses are host-specific and effective only against immature stages of the target species; users must be sure to match the pathogen and the target pest correctly. Virus particles are killed by ultraviolet radiation; treating in the evening or on cloudy days should increase their effectiveness.

FUNGI

Fungi, like viruses, often act as important natural control agents that limit insect populations. Most of the species that cause insect diseases spread by means of asexual spores called conidia. Although conidia of different fungi vary greatly in ability to survive adverse environmental conditions, desiccation and ultraviolet radiation are important causes of mortality in many species. Where viable conidia reach a susceptible host, free water or very high humidity is usually required for germination. Unlike bacterial spores or virus particles, fungal conidia can germinate on the insect cuticle and produce specialized structures that allow the fungus to penetrate the cuticle and enter the insect's body. Fungi do not have to be ingested to cause infections. In most instances, as fungal infections progress, infected insects are killed by fungal toxins, not by the chronic effects of parasitism.

Fungal pathogens differ in the range of life stages and species they are able to infect. Many important fungal pathogens attack eggs, immatures, and adults of a variety of insect species. Others are more specific to immature stages or to a narrow range of insect species.

Several factors have limited the development of fungal insecticides in the United States. Although fungal pathogens (at least some species) can be produced on artificial media, large-scale production of most pathogens has not yet been accomplished. Precise production and storage conditions must be established and maintained to ensure that infective spores are produced and stored without loss of viability before they are applied. Once applied, pathogenic fungi often are effective only if environmental conditions are favorable; high humidity or rainfall usually is important. Where fungal pathogens are incorporated into soil to control belowground pests, the adverse effects of ultraviolet radiation and desiccation are minimized, but other microorganisms that act as competitors or antagonists often alter pathogen effectiveness.

Although no fungal pathogens are currently registered or commercially available in the United States, one or more fungi are used in Great Britain, China, the Soviet Union, and additional countries in eastern Europe and South America. Fungi used as insecticides include the following:

Beauveria bassiana: This common soil fungus has a broad host range that includes many beetles. It infects both larvae and adults of many species. One or more companies currently are developing preparations of this fungus for U.S. EPA registration; the Colorado potato beetle is a key target pest in research and development efforts. Understanding the interactions between *Beauveria bassiana* and other soil microorganisms may be the key to successful use of this fungus.

Nomuraea rileyi: In soybeans (especially in the southeastern United States), naturally occurring epidemic infections of *Nomuraea rileyi* cause dramatic reductions in populations of foliage-feeding caterpillars. Research directed at predicting disease outbreaks caused by this fungus may help in determining the need for application of insecticides.

Verticillium lecanii: This fungus (once sold under the trade name Vertelec) has been used in greenhouses in Great Britain to control aphids and whiteflies.

Lagenidium giganteum: This aquatic fungus is highly infectious to larvae of several mosquito genera. It cycles effectively in the aquatic environment (spores produced in infected larvae persist and infect larvae of subsequent generations), even when mosquito density is low. Its effectiveness is limited by high temperatures.

Hirsutella thompsonii: Although preparations of this pathogen were once registered by the U.S. EPA and marketed under the trade name Mycar, it is no longer available commercially. *Hirsutella thompsonii* is a pathogen of the citrus rust mite.

PROTOZOA

Protozoan pathogens naturally infect a wide range of insect hosts. Although these pathogens can kill their insect hosts, many are more important for their chronic, debilitating effects. One important and common consequence of protozoan infection is a reduction in the number of offspring produced by infected insects. Although protozoan pathogens play a significant role in the natural limitation of insect populations, few appear to be suited for development as insecticides.

Species in the genera *Nosema* and *Vairimorpha* seem to offer the greatest potential for use as insecticides. Pathogens in these genera attack Lepidopteran larvae and insects in the order Orthoptera (the grasshoppers and related insects). The one protozoan currently available in a registered insecticidal formulation is the microsporidian *Nosema locustae*, a pathogen of grasshoppers. It is sold under such trade names as NOLO Bait and Grasshopper Attack. It is most effective when ingested by immature grasshoppers (the early nymphal stages). Infections progress slowly; where the pathogen kills the grasshopper, death occurs 3 to 6 weeks after initial infection. Not all infected hoppers are killed.

Nosema locustae has been used to reduce grasshopper populations in rangeland areas, and adequate control has been achieved when treatments were applied to large areas while hoppers were still young. Although not all grasshoppers in the treated area are killed by *Nosema locustae*, infected hoppers consume less forage and infected females produce fewer viable eggs than do uninfected females. *Nosema locustae* persists on egg pods to provide varying degrees of infection the following season. The effectiveness and use of *Nosema locustae* for rangeland grasshopper control are likely to increase as research continues.

Unfortunately, small, 1-pound packages of *Nosema locustae* preparations developed for sale to gardeners and homeowners offer much less utility (or none). The mobility of grasshoppers, coupled with the fact that infected hoppers are not killed until a few weeks after they ingest the pathogen, means that application of baits containing *Nosema locustae* to individual lawns or gardens is unlikely to reduce grasshopper densities or damage substantially. (Knowing that you infected some grasshoppers that may or may not die later in someone else's garden may be somewhat satisfying, but it doesn't help much if your goal was to prevent damage to your vegetables.)

NEMATODES

To be accurate, nematodes are not microbial agents. Instead, they are multicellular roundworms. Nematodes used in insecticidal products are, however, nearly microscopic in size, and they are used much like the truly microbial products discussed previously. Nematodes used for insect control infect only insects or related arthropods; they are called entomogenous nematodes.

The entomogenous nematodes *Steinernema carpocapsae* and *Heterorhabditis heliothidis* are the species most commonly used in insecticidal preparations. Within each of these species, different strains exhibit differences in their abilities to infect and kill specific insects. In general, however, these nematodes infect a wide range of insects. On a worldwide basis, laboratory or field applications have been effective against more than 400 pest species, including numerous beetles, fly larvae, and caterpillars.

The infectious stage of these nematodes is the third juvenile stage often referred to as the J3 stage or (less accurately) the "dauer" larva. Nematodes in this stage survive without feeding in moist soil and similar habitats, sometimes for extended periods. *Steinernema* species infect host insects by entering through body openings—the mouth, anus, and spiracles (breathing pores). *Heterorhabditis* juveniles also enter host insects through body openings, and in some instances are also able to penetrate an insect's cuticle. If the environment is warm and moist, these nematodes complete their life cycle within the infected insect. Infective juveniles molt to form adults, and these adults produce a new generation within the same host. As the offspring mature to the J3 stage, they are able to leave the dead insect and seek a new host (see Figure 1-2).

Symbiotic bacteria associated with entomogenous nematodes actually cause the death of infected insects. Once inside an insect host, nematodes empty their gut bacteria into the insect's bloodstream. The nematodes then feed on these bacteria as they multiply. The insect dies from bacterial septicemia. These entomogenous nematodes and their associated bacteria (*Xenorhabdus nematophilus* and *Xenorhabdus luminescens*) have been tested extensively for toxicity to nontarget organisms, and they are considered to be nontoxic and nonpathogenic to plants and mammals.

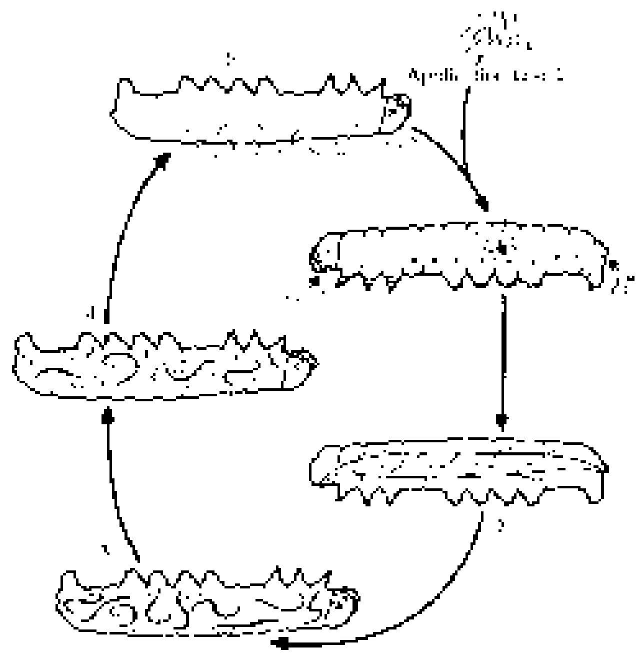

Figure 1-2. Life cycle of **Steinernema** ***sp. entomogenous nematodes.***

(1) Infective juveniles enter the gut or respiratory system through body openings (mouth, anus, and breathing pores). (2) Infective juveniles actively penetrate the gut wall, enter the body cavity, and release bacteria. (3) As bacteria multiply, host dies of septicemia; juveniles feed on bacteria and host tissues and develop into adults. (4) Adults mate and reproduce; two to three generations are produced if conditions are adequate. (5) When the food supply is exhausted, a new generation of infective juveniles exits the host and searches for a new one. (Adapted from Woodring and Kaya [1988].)

Large-scale production of nematodes has been initiated, and a few insecticides containing entomogenous nematodes are now marketed. These products contain infective juveniles (the J3 stage) and are formulated for application as sprays or drenches. Although *Steinernema* and *Heterorhabditis* species have been shown to be effective against a great number of insect species in laboratory experiments, their host range in field applications is often limited by temperature and moisture conditions in the target insect's habitat. Although controlled desiccation has been used successfully for the formulation of some insecticidal products containing nematodes, desiccation in the field usually kills entomogenous nematodes. Consequently, nematodes are most effective when applied to control insects in moist soil, plant tissues, or other protected habitats. Their viability and persistence in soil varies greatly depending upon soil moisture and temperature and other organisms present. The following examples illustrate situations in which nematodes are likely to provide effective insect control.

Research is currently targeting the use of entomogenous nematodes for the control of annual white grubs in irrigated lawns and grass sod. If applications are made when grubs are present (August or September, with correct timing dependent upon latitude and annual variations in weather), nematodes (or synthetic insecticides) need to remain active only for a period of several days to reduce grub damage. Because most homeowners and turf managers are able to irrigate, they can effectively "water in" nematode applications and keep soils moist enough to favor nematode survival and grub infection. Despite these favorable conditions, research has not yet identified formulations or preparations of nematodes that consistently provide grub control in turf evaluations. In addition, although nematodes may survive for extended periods (up to several months) in cool, moist soils, homeowners should probably expect that nematodes will persist for only 2 to 4 weeks following application for grub control.

Nematodes have been used effectively in trials against root weevil larvae and similar soil pests attacking nursery plants, ornamental plantings, garden crops, and potted plants. The ability to maintain soil moisture is an important factor in the success of these treatments.

In Midwest field crops, nematodes offer less promise for the control of major soil pests such as cutworms, corn rootworms, wireworms, and grubs. For the most part, these crops are not irrigated, and the inability to control soil moisture is a major factor limiting the success of nematode applications. Although timing applications to correspond with periods of adequate soil moisture might prove helpful, research efforts have not yet produced successful results in nonirrigated crops. For irrigated field crops, the cost of nematode products will also be an important factor that will determine whether large-scale use can be practical and economical.

Nematodes are not appropriate for termite control. Entomogenous nematodes are infectious to termites, but they are not likely to provide the long-term persistence needed in a termiticide. In soils around and under buildings, low moisture levels and the probable long-term absence of host insects would, in most cases, prevent nematode survival (persistence). Consequently, the need for long-term control would require repeated applications of nematodes at intervals not yet determined. Because repeated applications are impractical and undesirable, nematodes are not recommended for termite control.

Until further research provides data on specific pests, we recommend against the use of nematodes to control most aboveground insects. When nematodes can be placed in moist, protected environments where insects are confined (such as tunnels bored into tree trunks or other plant tissues), treatments can be effective. When nematodes are applied to exposed foliage or other locations where desiccation occurs rapidly, treatments are not likely to be effective.

Although commercial availability is likely to increase, nematodes are currently sold primarily by mail order from gardening supply houses (or wholesale to large- volume purchasers). Trade names include BioSafe, BioVector, and Scanmask; some products simply use the scientific name of the nematode. Nematodes are not considered by the U.S. EPA to be pathogens, and nematode producers are not required to complete the same U.S. EPA registration process required of producers of other microbial pesticides. This exemption means reduced start-up costs for the manufacture of products containing entomogenous nematodes, but it also means less standardization and less outside regulation of quality. As major producers of entomogenous nematodes gain a reputation for marketing high-quality products, consumers can expect these companies to practice effective quality control. Nonetheless, in the absence of extensive regulation, some suppliers are likely to market inferior products accompanied by exaggerated claims. Because of differences among nematode products and lack of regulation, buyers are urged to be careful. These products offer a great deal of potential, but their efficacy is not as unlimited as some promotions suggest.

AVERMECTINS

Any review of microbial insecticides must include a brief discussion of a group of compounds called avermectins. Commercial pesticides in this group include ivermectin and abamectin (see Table 1-1 for trade names). These compounds, produced in fermentation tanks by the soil actinomycete *Streptomyces avermitilis*, are especially toxic to a broad range of arthropods and nematodes, including important parasites of humans and domestic animals. The avermectins are toxic to invertebrates at extremely low doses (which means they can be used effectively at extremely low application rates), but they are also moderately to highly toxic to laboratory animals. Reviews by Campbell (1989) and Lasota and Dybas (1991) provide extensive details on the toxicity and uses of avermectins.

The development of ivermectin has contributed tremendously to the control of mammalian parasites, and newer products containing abamectin promise to be very useful in the control of arthropod pests of plants. Nonetheless, the broad spectrum of control provided by these compounds differs greatly from the selectivity offered by the other microbial insecticides discussed in this chapter. (In several ways, however, the avermectins are analogous to the exotoxin thuringiensin produced by some *Bt* strains.) Users who select other microbial insecticides for their low toxicity to nontarget organisms should consider the avermectins to be more like conventional synthetic insecticides than other microbial products.

SUMMARY

Microbial insecticides offer effective alternatives for the control of many insect pests. Their greatest strength is their specificity as most are essentially nontoxic and nonpathogenic to animals and humans. Although not every pest problem can be controlled by the use of a microbial insecticide, these products can be used successfully in place of more toxic insecticides to control many lawn and garden pests and several important field crop and forest insects. Because most microbial insecticides are effective against only a narrow range of pests and because these insecticides are vulnerable to rapid inactivation in the environment, users must properly identify target pests and plan the most effective application. These same qualities mean microbial insecticides can be used without undue risks of human injury or environmental damage. Consequently, microbial insecticides are likely to become increasingly important tools in insect management.

Pathogen	Product name	Host range	Uses and comments
Bacteria			
Bacillus thuringiensis var. *kurstaki (Bt)*	Bactur, Biobit, Caterpillar Killer, Dipel, Full-Bac, Futura, Javelin, MVP, Thuricide, Topside, Tribactur, Worm Attack	Caterpillars (larvae of moths and butterflies)	Effective for foliage-feeding caterpillars (and Indianmeal moth in stored grain). Deactivated rapidly in sunlight; apply in the evening or on overcast days and direct some spray to lower surfaces of leaves. Does not cycle extensively in the environment. Available as liquid concentrates, wettable powders, and ready-to-use dusts and granules. Active only if ingested.
Bacillus thuringiensis var. *israelensis (Bti)*	Bactimos, Gnatrol, Mosquito Attack, Skeetal, Teknar, Vectobac	Larvae of *Aedes* and *Psorophora* mosquitoes, black flies, and fungus gnats	Effective against larvae only. Active only if ingested. *Culex* and *Anopheles* mosquitoes are not controlled at normal application rates. Activity is reduced in highly turbid or polluted water. Does not cycle extensively in the environment. Applications generally made over wide areas by mosquito and black-fly abatement districts. Not all *Bti* products are labeled for use against fungus gnats.
Bacillus thuringiensis var. *san diego*	M-One	Larvae of Colorado potato beetle, elm leaf beetle adults	Effective against Colorado potato beetle larvae and the elm leaf beetle. Like other bacteria, it must be ingested. It is subject to breakdown in ultraviolet light and does not cycle extensively in the environment.
Bacillus thuringiensis var. *tenebrionis*	Trident II	Larvae of Colorado potato beetle	Very similar to *Bacillus thuringiensis* var. *san diego* (M-One). Foil contains a bacterial conjugate that produces toxins that act against these same beetles and caterpillars.
Bacillus thuringiensis var. *aizawai*	Certan	Wax moth caterpillars	Used only for the control of wax moth infestations in honeybee hives.
Bacillus popilliae and *Bacillus lentimorbus*	Doom, Japidemic, Milky Spore Disease, Grub Attack, Safer Grub Killer	Larvae (grubs) of Japanese beetle	The main Illinois lawn grub (the annual white grub, *Cyclocephala* sp.) is *not* susceptible to milky spore disease. The disease is very effective against Japanese beetle grubs (not a major pest in Illinois) and cycles effectively for years in the soil.
Bacillus sphaericus	(In development)	Larvae of *Culex*, *Psorophora*, and *Culiseta* mosquitoes, larvae of some *Aedes* spp.	Not registered or available commercially as of 1991. Active only if ingested. Under development for use against *Culex*, *Psorophora*, and *Culiseta* species; also effective against *Aedes vexans*. Remains effective in stagnant or turbid water. Commercial formulations will not cycle to infect subsequent generations.
Fungi			
Beauveria bassiana	(In development)	Many soil-dwelling insects	Not registered or available commercially as of 1991. Under development for control of Colorado potato beetle and several other beetle pests. High moisture requirements, lack of storage longevity, and competition with other soil microorganisms are problems that remain to be solved.

Table 1-1. (continued)

Pathogen	Product name	Host range	Uses and comments
Lagenidium giganteum	(In development)	Larvae of most pest mosquito species	Not registered or available commercially as of 1991. Effective against larvae of most pest mosquito species; remains infective in the environment through dry periods. A main drawback is its inability to survive high summertime temperatures.
Protozoa			
Nosema locustae	NOLO Bait, Grasshopper Attack	Grasshoppers, mormon crickets	Useful for rangeland grasshopper control. Active only if ingested. Not recommended for use on a small scale, such as backyard gardens, because the disease is slow-acting and grasshoppers are very mobile.
Viruses			
Gypsy moth nuclear polyhedrosis virus (NPV)	Gypchek virus	Gypsy moth caterpillars	The viral insecticides used for control of forest pests are produced for and used primarily by the U.S. Forest Service. See text.
Tussock moth NPV	TM Biocontrol-1	Tussock moth caterpillars	
Pine sawfly NPV	Neochek-S	Pine sawfly larvae	
Codling moth granulosis virus (GV)	(See comments)	Codling moth caterpillars	Commercially produced and marketed briefly, but not currently registered or available except under Experimental Use Permit (1990). Future re-registration is possible. Active only if ingested. Subject to rapid breakdown in ultraviolet light.
Entomogenous nematodes			
Steinernema carpocapsae and other *Steinernema* species	Biosafe, Scanmask, BioVector, also sold generically (wholesale and retail)	Larvae of a wide variety of soil-dwelling and boring insects	*Steinernema carpocapsae* is the main nematode species marketed retail in the United States. Because of moisture requirements, it is effective primarily against insects in moist soils or inside plant tissues. Prolonged storage or extreme temperatures before use may kill or debilitate the nematodes. Effective in cool temperatures.
Heterorhabditis spp.	Currently available on a wholesale basis for large-scale operations	Larvae of a wide variety of soil-dwelling and boring insects	Not commonly available by retail in the United States; this species is used more extensively in Europe. Available by wholesale or special order for research or large-scale commercial uses. Similar in use to *Steinernema* species but with some differences in host range, infectivity, and temperature requirements.
Avermectins			
Ivermectin	Ivomec, Eqvalan, Cardomec, Heartgard, others	Broadly toxic	See text. The avermectins, unlike other microbially produced insecticides discussed in this chapter, are toxic to a broad range of animals. They do not offer the specificity that is a strength of other products listed in this table.
Abamectin	Avid, Agri-Mek, Vertimec, Avomec	Broadly toxic	

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Requests for these publications may be sent to 110 Agricultural Building, University of Arkansas, Fayetteville, AR 72701.

CHAPTER 2

Botanical Insecticides and Insecticidal Soaps

The ideal insecticide should control target pests adequately and should be target-specific (able to kill the pest insect but not other insects or animals), rapidly degradable, and low in toxicity to humans and other mammals. Two classes of insecticides that exhibit some of these characteristics are the botanical insecticides and the insecticidal soaps. Botanical insecticides, sometimes referred to as "botanicals," are naturally occurring insecticides derived from plants. Insecticidal soaps are soaps that have been selected and formulated for their insecticidal action.

Botanical insecticides and insecticidal soaps are promising alternatives for use in insect management. However, like conventional synthetic insecticides, botanicals and insecticidal soaps have advantages and disadvantages and should be judged accordingly. Each compound should be evaluated in terms of its toxicity, effectiveness, environmental impacts, and costs.

The strengths and weaknesses of botanical insecticides and insecticidal soaps are briefly summarized in this chapter. Each compound is discussed in terms of its mode of action, mammalian toxicity, and practical uses. General information on the history and development of botanicals, insecticide toxicology, and state registration requirements is also presented. Insecticide toxicity is stressed throughout this chapter. Even though botanicals and insecticidal soaps are naturally derived and most are less toxic than many conventional insecticides, they are poisons and should be handled with the same caution as synthetic chemicals.

ADVANTAGES OF BOTANICAL INSECTICIDES AND INSECTICIDAL SOAPS

Many compounds with diverse chemical structures and different modes of action are classified as botanical insecticides or insecticidal soaps. It is therefore difficult to present a detailed list of advantages or disadvantages that apply to all of the compounds included in this category. Some general advantages shared by most of these compounds are:

Rapid degradation. Botanicals and insecticidal soaps degrade rapidly in sunlight, air, and moisture and are readily broken down by detoxification enzymes. This is very important because rapid breakdown means less persistence in the environment and reduced risks to nontarget organisms. Soaps and many botanicals may be applied to food crops shortly before harvest without leaving excessive residues.

Rapid action. Botanicals and soaps act very quickly to stop feeding by pest insects. Although they may not cause death for hours or days, they often cause immediate paralysis or cessation of feeding.

Low mammalian toxicity. Most botanicals and insecticidal soaps have low to moderate mammalian toxicity. There are exceptions, however; see "The Toxicity of Insecticides" for a general discussion of insecticide toxicities.

Selectivity. Although most botanicals have broad-spectrum activity in standard laboratory tests, in the field their rapid degradation and the action of some as stomach poisons make them more selective in some instances for plant-feeding pest insects and less harmful to beneficial insects.

Low toxicity to plants. Most botanicals are not phytotoxic (toxic to plants). Insecticidal soaps and nicotine sulfate, however, may be toxic to some ornamentals.

DISADVANTAGES OF BOTANICAL INSECTICIDES AND INSECTICIDAL SOAPS

The following disadvantages do not preclude the effective use of botanicals or insecticidal soaps, but do call attention to certain factors that must be considered when using these insecticides.

Rapid degradation. Rapid breakdown of botanicals, although desirable from an environmental and human health standpoint, creates a need for more precise timing, more frequent insecticide applications, or both.

Toxicity. Although the insecticidal soaps and most botanicals are the lesser of many "evils" in terms of general pesticide toxicities, they are toxins nonetheless. All toxins used in pest control pose some hazard to the user and to the environment. In addition, toxins are useful only when incorporated into a conscientious program of pest management that includes sanitation, cultural control, crop rotation, and use of resistant plant varieties. No insecticides, natural or synthetic, should be used as the sole means of defense against pest insects.

Cost and availability. Botanicals tend to be more expensive than synthetics, and some are not as widely available. In addition to problems of supply, the potency of some botanicals may differ from one source or batch to the next.

Lack of test data. Data on effectiveness and long-term (chronic) toxicity are unavailable for some botanicals. Tolerances for residues of some botanicals on food crops have not been established.

State registration. Several botanicals are registered by the U.S. Environmental Protection Agency (U.S. EPA) and are available by mail order, but are not registered for legal sale in specific states. (See " Registration of Botanical Insecticides" for more information on this problem.)

WHAT ARE BOTANICAL INSECTICIDES AND INSECTICIDAL SOAPS?

Botanicals are naturally occurring insecticides derived from plant sources. They are processed into various forms.

Preparations of the crude plant material. These are dusts or powders made from ground, dried plant parts that have not been extracted or treated extensively. They are marketed either full strength or diluted with carriers such as clays, talc, or diatomaceous earth. Examples include dusts or wettable powders of cubé roots (rotenone); pyrethrum flowers; sabadilla seeds; ryania stems; or neem leaves, fruits, or bark.

Plant extracts or resins. These are water or solvent extracts that concentrate the insecticidal components. Such extracts or resins are formulated into liquid concentrates or are impregnated onto dusts or wettable powders. Botanicals in this form include pyrethrins, cubé resins (rotenone), citronella and other essential oils, and neem seed extracts or oils.

Pure chemicals isolated from plants. These are purified insecticidal compounds that are isolated and refined by a series of extractions, distillations, or other processes and are formulated into concentrates. Included in this category are nicotine, d-limonene, and linalool.

Insecticidal soaps are specially formulated soaps that contain the potassium or sodium salts of insecticidal fatty acids. Soaps marketed under the Safer and M-Pede labels are most widely known; they contain the potassium salt of oleic acid, a fatty acid found in certain vegetable oils.

Crude botanical insecticides have been used for centuries and were known in tribal or traditional cultures long before being introduced into Europe or the United States. Botanicals with long histories of traditional use include neem in India, rotenone in East Asia and South America, and pyrethrum in Persia (Iran).

From the late 1800s to the 1940s, botanicals and insecticidal soaps were used extensively on certain crops. Soaps and nicotine-based insecticides were important before the turn of the century, whereas pyrethrum, rotenone, sabadilla, and ryania were popular in the 1930s and early 1940s. During that time, research on botanicals focused on efficacy, development of new formulations, and the use of synergists (compounds that enhance insecticidal action). With the development of synthetic insecticides in the mid-1940s, the use of botanicals was largely abandoned in commercial agriculture; the new synthetic compounds were less expensive, more effective, and longer lasting.

From 1945 to the early 1970s, the only botanicals remaining in widespread use were pyrethrins (used as household and industrial sprays and aerosols) and nicotine (used in greenhouses and orchards). Home gardeners continued to use rotenone on a small scale. Use of sabadilla and ryania was virtually abandoned, and for years these compounds were nearly unavailable in the United States.

In the past 10 or 15 years, interest in botanicals has increased, primarily as a result of concerns about environmental contamination and pesticide residues in foods. In a few instances, botanical insecticides have come into commercial use because a key pest has become resistant to most classes of synthetic insecticides, for example, the use of rotenone for control of the Colorado potato beetle on Long Island in New York.

Botanicals and insecticidal soaps are not widely used in conventional commercial agriculture, but small-scale organic growers and home gardeners are using them more extensively. In addition, state and federal certification programs for organic farming generally allow the use of insecticidal soaps and most botanical insecticides. As a result, botanical insecticides that for years were unavailable have been reregistered and are being produced and marketed in limited quantities. Several new botanical insecticides, such as the citrus oil derivatives and new formulations of neem also are available or are under development.

Synergists

Insects, like humans and other animals, possess enzymes that are capable of breaking down a wide variety of toxic substances. Certain natural insecticides—pyrethrins in particular, as well as several other botanicals—are readily attacked and degraded by these enzymes once inside the insect's system. In some cases, degradation occurs so rapidly that the insecticide is not active long enough to kill the insect. The insect is temporarily stunned, but then recovers. Synergists are compounds that enhance insecticidal action by inhibiting certain detoxification enzymes. The synergists used in commercial insecticides block a system of enzymes known as the multifunction oxidases (MFOs); consequently, these synergists increase the effective toxicity of those insecticides that are easily degraded by the MFOs. Insecticides that are not readily detoxified by the MFOs are not synergized by these compounds. The synergists themselves are low in toxicity, have little or no inherent insecticidal activity, and are not persistent.

The most commonly used synergist is piperonyl butoxide (PBO). PBO is found in most products that contain pyrethrins. It is also an effective synergist for rotenone, sabadilla, ryania, and the citrus oil derivatives, as well as some synthetic pyrethroids and carbamate insecticides. MGK 264 (N-octyl bicycloheptene dicarboximide) is another synergist that is sometimes used in livestock and animal shelter insecticides. Both of these compounds have low mammalian toxicity (see Table 2-1). They are usually formulated with insecticides in ratios of from 2:1 to 10:1 (synergist : insecticide). High cost is the major factor limiting more widespread use of synergists. In addition, some organic certification programs do not allow the use of PBO.

A general discussion of insecticide toxicity and a table of toxicity estimates are presented in the section, "Toxicity of Insecticides." Refer to that box and to the glossary of terms, "Terms to Understand," for further explanations of the toxicological information presented in this section.

Pyrethrum and Pyrethrins

Source. Pyrethrum is the powdered, dried flower head of the pyrethrum daisy, *Chrysanthemum cinerariaefolium* (Figure 2-1). Most of the world's pyrethrum crop is grown in Kenya. The term "pyreth*rum*" is the name for the crude flower dust itself, and the term "pyreth*rins*" refers to the six related insecticidal compounds that occur naturally in the crude material. The pyrethrins constitute 0.9 to 1.3 percent of dried pyrethrum flowers. They are extracted from crude pyrethrum dust as a resin that is used in the manufacture of various insecticidal products.

Mode of Action. Pyrethrins exert their toxic effects by disrupting the sodium and potassium ion exchange process in insect nerve fibers and interrupting the normal transmission of nerve impulses. Pyrethrin insecticides are extremely fast-acting and cause an immediate "knockdown" paralysis in insects. Despite their rapid toxic action, however, many insects are able to metabolize (break down) pyrethrins quickly. After a brief period of paralysis, these insects may recover rather than die. To prevent insects from metabolizing pyrethrins and re-

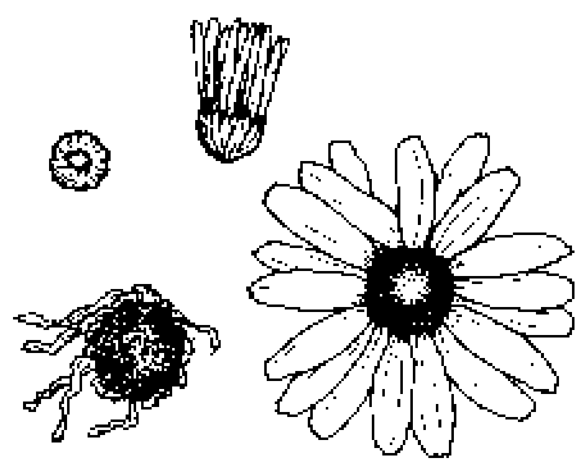

Figure 2-1. Stages of the pyrethrum daisy, the source of natural pyrethrins.

TOXICITY OF INSECTICIDES

Although many household and industrial products—including cleaning and polishing agents, degreasers, paints, and solvents—are toxic, insecticides are among only a few compounds used intentionally as poisons. The nature of insecticide toxicity and the manner in which insecticides are applied can make these compounds particularly hazardous. Because of this, it is important that insecticide users understand the basics of insecticide toxicology.

Insecticides are, by definition, compounds intended to kill insects. Most insecticides attack basic physiological processes such as nerve transmission or cellular respiration, processes that are common to insects, humans, and other animals. Whether natural or synthetic in origin, most insecticides can poison many forms of animal life. The risk of accidental poisoning may be heightened if a pesticide user perceives an insecticide to be harmless and consequently overapplies or misuses it. Such a problem can result from the widely held misconception that naturally derived insecticides are basically nontoxic to humans and other animals and are therefore “safe” to use in a careless manner. While most botanicals pose fewer hazards than many synthetic insecticides, their toxicity is still a factor to be considered.

Insecticide Toxicity

The toxicity of any chemical is usually evaluated in terms of both acute and chronic effects. Acute toxicity refers to the effects of a single dosage or exposure. Chronic toxicity refers to the effects of repeated doses or exposures over time.

The acute toxicity of an insecticide is generally described in terms of an LD_{50}, the dose required to kill 50 percent of the animals in a test. An LD_{50} is therefore a “median lethal dose.” LD_{50} values are usually expressed as milligrams of toxicant per kilogram of body weight of a test animal (mg/kg). Consequently, *a lower LD_{50} indicates a more toxic compound*. For example, an insecticide with an LD_{50} of 60 mg/kg is much more toxic than one with an LD_{50} of 5,000 mg/kg.

The most common measures of an insecticide’s toxicity to mammals are its oral and dermal LD_{50} values. Testing is generally performed on laboratory animals such as mice, rats, guinea pigs, or rabbits. Test animals are exposed to a range of single doses—a certain number of animals at each dose—to determine the insecticide’s acute oral or dermal toxic effects. Estimates of an insecticide’s acute human toxicity are derived from this type of animal testing.

Although LD_{50} values are useful indicators of toxicity, they do not provide a full picture of all of the risks associated with insecticide contact. For example, LD_{50} values fail to indicate toxic effects other than death. These effects may include eye injury, throat and lung irritation, chemical burns, neurological damage, and many other forms of injury. In addition, LD_{50} values generally indicate the acute toxicity of pure, unformulated insecticidal compounds rather than the diluted, formulated products actually used by consumers. Formulation (the process of turning a pure active ingredient into a finished insecticidal product) usually reduces poisoning risks because it involves diluting the active compounds with various carriers and additives. In some instances, however, formulation may increase poisoning risks; this occurs when carriers or other ingredients include toxic solvents or solvents that speed the entry of the active compounds into the body.

In comparison with questions about acute toxicity, questions about the chronic effects of repeated exposures to lower doses of pesticides are much more difficult to answer clearly. To investigate chronic effects, a compound is administered to laboratory animals at a range of doses (usually including the maximum dose that the animal can survive) for an extended period of time. The most common means of administering compounds is in combination with the animal's food, but compounds are sometimes administered dermally or by injection or inhalation. Following chronic exposures over a normal life span, the test animals are killed and examined for tumor production and other changes in major tissues and organs. A key purpose for chronic toxicity testing is to identify probable carcinogens (cancer-causing agents). Investigations of reproductive effects (birth rate, birth weight, incidence of birth defects) might also be conducted during each study.

Acute and chronic toxicity tests give indications of the immediate and long-term effects of human exposure to pesticides, but such tests provide only limited information. For instance, because different species react to insecticides in different ways, tests that measure rodent responses may not always accurately predict human responses. In addition, single-compound tests do not measure the effects of real-life human exposures to multiple compounds. Chronic, high-dose tests used to identify possible carcinogens may or may not yield results that are relevant for the prediction of cancer risks associated with the infrequent, low-level exposures that most humans are expected to encounter. Yet, despite these limitations, toxicological testing has produced results that help to describe the risks associated with pesticide exposure and that allow some meaningful comparisons of synthetic and botanical insecticides.

Botanicals Versus Synthetics

Natural compounds are not inherently less toxic to humans than synthetic ones. Some of the most deadly, fast-acting toxins and some potent carcinogens occur naturally. *Despite the claims presented in some advertising materials, "natural" does not necessarily mean safe or nontoxic, and it certainly does not mean nonchemical.*

The LD_{50} values presented in Table 2-1 illustrate the fact that botanical insecticides range from practically nontoxic (such as neem or insecticidal soap) to very toxic (such as nicotine). Most are only slightly to moderately toxic. LD_{50} values for some common organophosphate, carbamate, and pyrethroid insecticides are also listed in Table 2-1 for comparison.

In evaluating the toxicities listed in Table 2-1, it is important to consider the situations that might lead to pesticide exposures and poisoning. Human exposure to pesticides usually results from careless contact during application or from contacting or eating residues that remain on treated materials or foods. Because botanical insecticides and insecticidal soaps break down rapidly in the environment, they rarely pose any risk to consumers. Many synthetic insecticides are much more stable, and problems associated with persistent residues present a more realistic concern. As a result, where a short-lived insecticide (a botanical, a soap, or certain synthetics such as resmethrin) and a more persistent insecticide (certain synthetics such as permethrin or chlorpyrifos) are characterized by similar LD_{50} values, the persistent product is much more likely to pose some risk to persons other than the applicator.

For applicators, however, certain botanical insecticides and synthetic insecticides can pose similar risks. Rotenone and ryania, for example, are similar to carbaryl and malathion in acute toxicity; applicators may be poisoned by careless exposure to any of these products. The important concept to remember is that although the environmental safety of all botanical insecticides is enhanced by their rapid degradation, several botanical insecticides can readily poison the careless applicator. Users should always wear protective clothing and avoid insecticide exposure.

Table 2-1. Estimates of Acute Toxicity of Botanical Insecticides, Insecticidal Soap, and Selected Synthetic Insecticides

Generic name (trade name)	Class	Oral LD_{50}	Dermal LD_{50}	Signal word[a]
Insecticidal soap (Safer)	Soap	16,500	—	Caution
Neem	Botanical	13,000	—	N/A
Piperonyl butoxide (PBO)	Synergist	>7,500	7,500	Caution
d-Limonene (VIP)	Botanical	>5,000	—	Caution
Sabadilla (Red Devil)	Botanical	4,000	—	Caution
MGK 264	Synergist	2,800	—	Caution
Resmethrin	Pyrethroid	>2,500	3,000	Caution
Linalool (Demize)	Botanical	2,440 to 3,180	3,578 to 8,374	Caution
Pyrethrins	Botanical	1,200 to 1,500	>1,800	Caution
Malathion	Organophosphate	885 to 2,800	4,100	Caution
Carbaryl (Sevin)	Carbamate	850	>4,000	Warning/caution
Ryania (Ryan 50)	Botanical	750 to 1,200	4,000	Caution
Permethrin (Pounce, Ambush)	Pyrethroid	430 to 4,000[b]	>2,000	Danger/warning
Chlorpyrifos (Lorsban)	Organophosphate	135 to 163	2,000	Warning/caution
Rotenone	Botanical	60 to 1,500[b]	940 to 3,000	Caution
Nicotine (Black-Leaf 40)	Botanical	50 to 60	50	Danger
Carbofuran (Furadan)	Carbamate	8 to 14	>2,500	Danger/warning
Terbufos (Counter)	Organophosphate	2 to 5	7	Danger

[a] See Table 2-2 for explanation of signal words.
[b] Toxicity varies greatly depending on type of solvent used as a carrier.

covering from poisoning, most products containing pyrethrins also contain the synergist PBO. Without PBO the effectiveness of pyrethrins is greatly reduced.

Mammalian Toxicity. Pyrethrins are low in mammalian toxicity (see Table 2-1), and few cases of human poisonings have ever been reported. Cats, however, are highly susceptible to poisoning by pyrethrins, and care must be taken to follow label directions closely when using products containing pyrethrins to treat cats for fleas.

When ingested, pyrethrins are not readily absorbed from the digestive tract, and they are rapidly hydrolyzed under the acid conditions of the gut and the alkaline conditions of the liver. Pyrethrins are more toxic to mammals by inhalation than by ingestion because inhalation provides a more direct route to the bloodstream. Exposure to high doses may cause nausea, vomiting, diarrhea, headaches, and other nervous disturbances. Repeated contact with crude pyrethrum dusts may cause skin irritation or allergic reactions. The allergens that cause these reactions are not present in products containing refined pyrethrins. Tests indicate that chronic exposure to pyrethrins does not cause genetic mutations or birth defects (see Casida 1973 and Hayes 1982).

There is no single antidote for acute pyrethrin poisoning. Treatment of poisoning is symptomatic, that is, the various symptoms of poisoning are treated individually as they occur because there is no way to counteract the source of the poisoning directly.

Uses. Pyrethrins are contact poisons that have almost no residual activity in most applications. They break down very rapidly in sunlight, air, and moisture. Degradation is accelerated under acid or alkaline conditions, and for this reason pyrethrins should not be mixed with lime or soap solutions for application. Formulated products containing pyrethrins are stable in storage for long periods if not diluted, but powders made directly from ground pyrethrum flowers may lose up to 20 percent of their potency in a single year. Synergism by PBO or MGK 264 is essential for obtaining full effectiveness from pyrethrins.

Pyrethrins are used against a broad range of pests. Products containing synergized pyrethrins (pyrethrins plus PBO) are registered for use on pets and livestock to control fleas, flies, and mosquitoes. They are also registered as indoor household sprays, aerosols, and “bombs” for the control of various flying insects, fleas, and (less effectively) ants and roaches. Formulations containing microencapsulated pyrethrins may provide some residual activity for indoor use. Synergized pyrethrins are used in food-processing plants and food warehouses to control stored-product pests (flour beetles, Indianmeal moth, and others). Pyrethrins are also formulated with rotenone and ryania or copper for general use in gardens; rotenone and ryania are slower acting compounds to which pyrethrins are added for their rapid knockdown effect.

Pyrethroid Insecticides. Pyrethroids are not botanical insecticides. They are synthetic compounds that are based on the chemical structure and physiological action of the natural pyrethrins, but they are more toxic to insects and generally more persistent in the environment. A few pyrethroids, such as resmethrin (used for household insect control), are very low in mammalian toxicity and degrade quickly. Others, such as cypermethrin (used on cotton, vegetables, and fruits), are moderately toxic and more persistent. For many of the pyrethroids, acute toxicity and hazard vary greatly depending on the kind of solvent that is used as a carrier for the formulated product. Pyrethroids are generally effective at very low concentrations and are used at much lower application rates than most other synthetic insecticides.

Rotenone

Source. Rotenone is an insecticidal compound found in the roots of *Lonchocarpus* species in South America, *Derris* species in Asia, and several other related tropical legumes. Commercial rotenone was once produced from Malaysian *Derris*. Currently the main commercial rotenone source is Peruvian *Lonchocarpus*, often referred to as cubé root.

Rotenone is extracted from cubé roots in acetone or ether. Extraction produces a 2 to 40 percent rotenone resin, which contains several related but less insecticidal compounds known as rotenoids. The resin is used to make liquid concentrates or to impregnate inert dusts or other carriers. Most rotenone products are made from the complex resin rather than from purified rotenone itself. Alternatively, cubé roots may be dried, powdered, and mixed directly with an inert carrier to form an insecticidal dust.

Mode of Action. Rotenone is a powerful inhibitor of cellular respiration, the process that converts nutrient compounds into energy at the cellular level. In insects rotenone exerts its toxic effects primarily on nerve and muscle cells, causing rapid cessation of feeding. Death occurs several hours to a few days after exposure. Rotenone is extremely toxic to fish, and is often used as a fish poison (piscicide) in water management programs. It is effectively synergized by PBO or MGK 264.

Mammalian Toxicity. Although rotenone is a potent cell toxin, mammals detoxify ingested rotenone efficiently via liver enzymes. As with pyrethrins, rotenone is more toxic by inhalation than by ingestion. Exposure to high doses may cause nausea, vomiting, muscle tremors, and rapid breathing. Very high doses may cause convulsions followed by death from respiratory paralysis and circulatory collapse. Direct contact with rotenone may be irritating to skin and mucous membranes. Treatment of poisoning is symptomatic.

Chronic exposure to rotenone may lead to liver and kidney damage. Although some rodent testing has shown that chronic dietary exposure to rotenone may induce tumor formation, the most recent U.S. EPA registration standard considers rotenone to be noncarcinogenic (see Hayes 1982 and U.S. EPA report 1989).

Rotenone is one of the more acutely toxic botanicals. As a matter of comparison, pure, unformulated rotenone is more toxic than pure carbaryl (Sevin) or malathion, two commonly used synthetic insecticides (see Table 2-1). In the form of a 1 percent dust, rotenone poses roughly the same acute hazard as the commonly available 5 percent Sevin dust.

Uses. Rotenone is a broad-spectrum contact and stomach poison that is particularly effective against leaf-feeding beetles and certain caterpillar pests. On a commercial level, rotenone has been used widely in the northeastern United States to control populations of the Colorado potato beetle that have become resistant to most other registered insecticides (Figure 2-2). Rotenone is also used extensively in fish management programs.

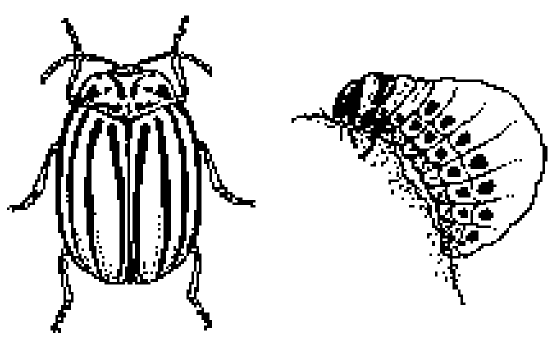

Figure 2-2. Colorado potato beetle, adult and larva. Rotenone is used on a commercial scale to control this major pest. In some areas of the United States, the Colorado potato beetle has become resistant to most classes of synthetic chemical insecticides.

Several products containing rotenone in combination with pyrethrins, ryania, copper, and / or sulfur are registered for general garden and orchard insect and disease control. Rotenone is commonly sold as a 1 percent dust or a 5 percent powder (for spraying).

Rotenone degrades (oxidizes) quickly in air and sunlight; under warm, sunny conditions, dust or spray residues on exposed plant surfaces provide some degree of protection for approximately 1 week. Degradation is greatly accelerated by mixing rotenone with alkaline materials such as soaps or lime.

Sabadilla

Source. Sabadilla is derived from the ripe seeds of *Schoenocaulon officinale*, a tropical lily plant which grows in Central and South America. Sabadilla is also known as cevadilla or caustic barley.

When sabadilla seeds are aged, heated, or treated with alkali, several insecticidal alkaloids are formed or activated. Alkaloids are physiologically active compounds that occur naturally in many plants. In chemical terms they are a heterogeneous class of cyclic compounds that contain nitrogen in their ring structures. Caffeine, nicotine, cocaine, quinine, and strychnine are some of the more familiar alkaloids. The alkaloids in sabadilla are known collectively as veratrine or as the veratrine alkaloids. They constitute 3 to 6 percent of the weight of aged, ripe sabadilla seeds. Of these alkaloids, cevadine and veratridine are the most active insecticidally.

European white hellebore (*Veratrum album*) also contains veratridine in its roots. Hellebore was once commonly used in Europe and the United States for insect control but is now unavailable commercially and is not registered by the U.S. EPA.

Mode of Action. In insects, sabadilla’s toxic alkaloids affect nerve cell membrane action, causing loss of nerve function, paralysis, and death. Sabadilla kills insects of some species immediately, whereas others may survive in a state of paralysis for several days before dying. Sabadilla is effectively synergized by PBO or MGK 264.

Mammalian Toxicity. Sabadilla, in the form of dusts made from ground seeds, is the least toxic of the registered botanicals (see Table 2-1). Purified veratrine alkaloids are quite toxic, however, and are considered on a par with the most toxic synthetic insecticides. Sabadilla can be severely irritating to skin and mucous membranes, and has a powerful sneeze-inducing effect when inhaled. Ingestion of small amounts may cause headaches, severe nausea, vomiting, diarrhea, cramps, and reduced circulation. Ingestion of very high doses may cause convulsions, cardiac paralysis, and respiratory failure. Sabadilla alkaloids can be absorbed through the skin or mucous membranes.

Uses. Sabadilla is mainly a broad-spectrum contact poison, but it also has some activity as a stomach poison. It is effective against certain “true bug” pests (order Hemiptera) such as harlequin bugs and squash bugs that are difficult to control with most other insecticides. Sabadilla is also highly toxic to honey bees, and care must be taken to avoid applying it when bees are present. The active alkaloids degrade rapidly in air and sunlight, and have little residual toxicity.

Sabadilla is registered by the U.S. EPA for use on squash, beans, cucumbers, melons, potatoes, turnips, mustard, collards, cabbage, broccoli, citrus, and peanuts. In citrus, sabadilla is applied with sugar as an insecticidal bait (stomach poison) for citrus thrips. For vegetable insect control, sabadilla is commonly applied as a contact insecticide in the form of a 20 percent dust or spray. *Several sabadilla products available for mail-order purchase are not registered for sale in specific states. See “Registration of Botanical Insecticides” for information on this problem.*

Ryania

Source. Ryania comes from the woody stems of *Ryania speciosa*, a South American shrub. Powdered *Ryania* stem wood is combined with carriers to produce a dust or is extracted to produce a liquid concentrate. The most active compound in ryania is the alkaloid ryanodine, which constitutes approximately 0.2 percent of the dry weight of stem wood.

Mode of Action. Ryania is a slow-acting stomach poison. Although it does not produce rapid knockdown paralysis, it does cause insects to stop feeding soon after ingesting it. Little has been published concerning its exact mode of action in insect systems. Ryania is effectively synergized by PBO and is reported to be most effective in hot weather.

Mammalian Toxicity. Ryania is moderately toxic to mammals by ingestion and only slightly toxic by dermal exposure. Ingestion of large doses causes weakness, deep and slow respiration, vomiting, diarrhea, and tremors, sometimes followed by convulsions, coma, and death. Purified ryanodine is approximately 700 times more toxic than the crude ground or powdered wood and causes poisoning symptoms similar to those of synthetic organophosphate insecticides. (Depending on exposure, organophosphate poisoning symptoms may include sweating, headache, twitching, muscle cramps, mental confusion, tightness in chest, blurred vision, vomiting, evacuation of bowels and bladder, convulsions, respiratory collapse, coma, and death.)

Uses. Ryania currently is registered by the U.S. EPA for use on citrus, corn, walnuts, apples, and pears for the control of citrus thrips, European corn borer, and codling moth. Ryania has longer residual activity than most other botanicals and is therefore useful where the more quickly degrading compounds are ineffective. Ryania is also sold in mixtures containing rotenone and pyrethrins for use on a variety of vegetables and fruits. *Several products containing ryania and distributed through mail-order catalogs are not registered for sale in specific states. See “Registration of Botanical Insecticides.”*

Nicotine

Source. Nicotine is a simple alkaloid derived from tobacco, *Nicotiana tabacum*, and other *Nicotiana* species. Nicotine contitutes 2 to 8 percent of dried tobacco leaves. Insecticidal formulations generally contain nicotine in the form of 40 percent nicotine sulfate, and most are currently imported in small quantities from India.

Mode of Action. In both insects and mammals, nicotine is an extremely fast-acting nerve toxin. It competes with acetylcholine, the major neurotransmitter, by bonding to acetylcholine receptors at nerve synapses and causing uncontrolled nerve firing. This disruption of normal nerve impulse activity results in rapid failure of those body systems that depend on nervous input for proper functioning. In insects, the action of nicotine is fairly selective, and only certain types of insects are affected.

Mammalian Toxicity. Despite the fact that smokers regularly inhale small quantities of nicotine in tobacco smoke, nicotine in pure form is extremely toxic to mammals and is considered a Class I (most dangerous) poison (Figure 2-3). Nicotine is particularly hazardous because it penetrates skin, eyes, and mucous membranes readily; both inhalation and dermal contact may result in death. Ingestion is slightly less hazardous due to the effective detoxifying action of the liver.

Symptoms of nicotine poisoning are extreme nausea, vomiting, excess salivation, evacuation of bowels and bladder, mental confusion, tremors, convulsions, and finally death by respiratory failure and circulatory collapse. Poisoning occurs very rapidly and is often fatal. Treatment for nicotine poisoning is symptomatic, and only immediate treatment, including prolonged artificial respiration, may save a victim of nicotine poisoning.

Nicotine has been responsible for numerous serious poisonings and accidental deaths because of its rapid penetration of both skin and mucous membranes and because of the concentrated form in which it is used.

Uses. Nicotine is used in greenhouses and gardens as a fumigant and contact poison to control soft-bodied sucking pests such as aphids, thrips, and mites. When nicotine sulfate is diluted with alkaline water or soap solutions, free nicotine alkaloid is liberated. Free nicotine is much more active than the sulfate form; it is fast-acting and degrades completely within 24 hours, leaving no toxic residues. Nonalkaline nicotine sulfate sprays liberate the free alkaloid more slowly (over 24 to 48 hours) and have limited use as stomach poisons for control of some leaf-eating pests. Certain roses and other ornamentals may be injured by nicotine sprays.

Tobacco teas are sometimes prepared by home gardeners for control of garden pests or for pests of houseplants. Although these teas are not as toxic as nicotine sulfate sprays, any nicotine solution that is toxic enough to kill insects is also toxic enough to be harmful to humans.

Citrus Oil Extracts: Limonene and Linalool

Source. Crude citrus oils and the refined compounds d-limonene (hereafter referred to simply as limonene) and linalool are extracted from orange and other citrus fruit peels. Limonene, a terpene, constitutes about 90 percent of crude citrus oil, and is purified from the oil by steam distillation. Linalool, a terpene alcohol, is found in small quantities in citrus peel and in more than 200 other herbs, flowers, fruits, and woods.

Terpenes and terpene alcohols are among the major components of many plant volatiles or essential oils. Other components of essential oils are ketones, aldehydes, esters, and various alcohols. Essential oils are the volatile compounds responsible for most of the tastes and scents of plants. Many essential oils also have some physiological activity.

Mode of Action. The modes of action of limonene and linalool in insects are not fully understood. Limonene is thought to cause an increase in the spontaneous activity of sensory nerves. This heightened activity sends spurious information to motor nerves and results in twitching, lack of coordination, and convulsions. The central nervous system may also be affected, resulting in additional stimulation of motor nerves. Massive overstimulation of motor nerves leads to rapid knockdown paralysis. Adult fleas and other insects may recover from knockdown, however, unless limonene is synergized by PBO. Linalool is also synergized by PBO. Little has been published regarding the mode of action of linalool in insects.

Mammalian Toxicity. Both limonene and linalool were granted GRAS ("generally regarded as safe"—see the "Terms to Understand" section in the summary to this chapter) status by the U.S. Food and Drug Administration in 1965, and are used extensively as flavorings and scents in foods, cosmetics, soaps, and perfumes. Both compounds are considered safe when used for these purposes because they have low oral and dermal toxicities (see Table 2-1). At higher concentrations, however, limonene and linalool are physiologically active and may be irritating or toxic to mammals.

When applied topically, limonene is irritating to skin, eyes, and mucous membranes. Both limonene and

Figure 2-3. Nicotine is a Class I (extremely toxic) poison. By law the label on nicotine sulfate insecticides must display the signal words "DANGER POISON" along with the skull and crossbones symbol.

linalool may be allergenic. Limonene acts as a topical vasodilator and a skin sensitizer; it was also shown to promote tumor formation in mouse skin that had been previously sensitized to tumor initiation (see Roe and Field 1965). Linalool is more active as a systemic toxin than as a skin irritant.

Both compounds affect the central nervous system, and moderate to high doses applied topically to cats and other laboratory animals cause tremors, excess salivation, lack of coordination, and muscle weakness. Even at the higher doses, however, these symptoms are temporary (lasting several hours to several days), and animals appear to recover fully. Some cats may experience minor tremors and excess salivation for up to 1 hour after applications of limonene or linalool at recommended rates.

Crude citrus peel oils and products prepared with the crude oils may be more toxic to animals than products containing purified limonene or linalool. Adequate research on the toxicity of crude citrus oils has not been conducted, and they are not recommended for use on animals.

Uses. Limonene and linalool are contact poisons and may also have some fumigant action against fleas. Both compounds are formulated as flea dips and shampoos (Figure 2-4). They also are included in some pet shampoos that do not directly claim to have insecticidal properties. These products are relatively new, and though showing promise, some questions persist concerning their toxicity. Citrus oil extracts have also been combined with insecticidal soap for use as contact poisons against aphids and mites; published evaluations of the effectiveness of these combinations are lacking. Linalool and limonene evaporate readily from treated surfaces and provide no residual control. Both compounds are most effective when synergized with PBO.

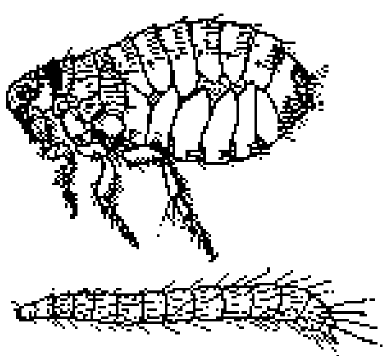

Figure 2-4. The cat flea, adult and larva. The citrus oil derivatives limonene and linalool are registered for use in controlling adult fleas on cats and dogs. Linalool also is registered for use in controlling all stages of fleas throughout the home.

Other Essential Plant Oils: "Herbal" Repellents and Insecticides

Essential oils are volatile, odorous oils derived from plant sources. Although they are used mainly as flavorings and fragrances in foods, cosmetics, soaps, and perfumes, some of them also have insect repellent or insecticidal properties. Many essential oils have GRAS status; how-ever, when applied topically at high concentrations they tend to be irritating to skin and mucous membranes. They are sometimes used as topical counterirritants to relieve or mask pain. Many of the essential oils that have low dermal toxicity may be toxic by ingestion.

The most common essential oils used as repellents are the oils of cedar, lavender, eucalyptus, pennyroyal, and citronella. They are used mostly on pets and humans to repel fleas and mosquitoes. With the exception of pennyroyal, these essential oils are thought to pose little risk to people or pets, though they should not be used above recommended rates. Some herbal pet products that contain essential oils recommend use daily or "as often as needed." These products should be used moderately and with careful observation of the pet to spot early signs of skin irritation or possible toxic effects.

Oil of pennyroyal contains pulegone, a potent toxin that can cause death in humans at doses as low as one tablespoon when ingested. At lower internal doses, it may cause abortion, liver damage, and renal failure. Although the dermal toxicity of pennyroyal is fairly low, some cats are susceptible to poisoning by topical application of oil of pennyroyal, possibly because they ingest it during grooming.

Citronella is sold mainly in the form of candles to be burned outdoors to repel mosquitoes from backyards or other small areas. It is also contained in some "natural" mosquito repellent lotions. Before the development of synthetic repellents, citronella was the most effective mosquito repellent available. Despite its wide usage, there is little scientific information available regarding its efficacy or mammalian toxicity.

Neem

Source. Neem products are derived from the neem tree, *Azadirachta indica*, which grows in arid tropical and subtropical regions on several continents. The principal active compound in neem is azadirachtin, a bitter, com-

REGISTRATION OF BOTANICAL INSECTICIDES

Laws governing pesticide sale and use require that any product sold to control pests must be registered (approved) by the U.S. Environmental Protection Agency (U.S. EPA). In order to gain registration, the product must pass through several levels of testing for toxicity, carcinogenicity, mutagenicity, teratogenicity, environmental fate, and so forth. It also must be tested for safety to nontarget organisms. Natural as well as synthetic insecticides must be registered by the U.S. EPA before they may be sold and applied legally.

Under federal pesticide laws, state agencies are required to enforce the regulations that cover the safe use of U.S. EPA–registered pesticides. As a result, many states also require state registration before a pesticide may be sold and applied legally in that state. Registration at the state level provides both the records and the funding needed to carry out federally mandated registration enforcement. To register a pesticide at the state level, the manufacturer usually pays an annual fee for the company, plus an annual fee for each individual product that is registered. Although some states (most notably California) require additional testing, paying fees and supplying a minimal amount of background information meet the requirements of most state registration programs.

Several products containing botanical insecticides are not registered in state programs. This may result from the fact that many of the manufacturers of botanical insecticides are small companies that have limited sales. These companies have chosen not to afford the cost of registering their products with each state that requires such a step. Consequently, these unregistered botanical products cannot (or at least should not) be found on store shelves. Instead, they are available only by mail order from various distributors of natural or alternative pest management supplies in other states.

Although it is the responsibility of the manufacturers to register their products, it appears to be the responsibility of the mail-order distributors to alert customers to the fact that certain products are not registered in the customers' home states. Ideally, mail-order suppliers should refuse to ship unregistered products into those states. Unfortunately, many mail-order distributors and manufacturers are not aware of or do not acknowledge these responsibilities. They often will ship products illegally without alerting customers to the registration laws.

Where does this leave the consumer who wishes to purchase a botanical insecticide that is not registered in his or her state? Although it may seem that shipping alternative, "natural" pesticides is a harmless practice, adequate regulation of all pesticides depends on the existence of complete records of sales and use at both the state and federal levels. Requiring registration is the only means by which a state can monitor pesticides properly. Producers of all pesticides—whether synthetic or botanical—must support state registration programs.

Perhaps the most responsible approach is for consumers to write to their state regulatory agencies (often the state Department of Agriculture or state Environmental Protection Agency) and to the manufacturer or distributor of the specific insecticide, stating a desire to see the product registered for sale and use in their state. By doing so, and by refusing to order the product until it is registered, consumers can encourage the proper regulation and sale of effective, environmentally sound insecticides.

plex chemical that is both a feeding deterrent and a growth regulator. Meliantriol, salannin, and many other minor components of neem are also active in various ways. Neem products include teas and dusts made from leaves and bark; extracts from whole fruits, seeds, or seed kernels; and an oil expressed from the seed kernel.

Mode of Action. Neem is a complex mixture of biologically active materials, and it is difficult to pinpoint the exact modes of action of various extracts or preparations. In insects, neem is most active as a feeding deterrent, but in various forms it also serves as a repellent, growth regulator, oviposition (egg deposition) suppressant, sterilant, or toxin.

As a repellent, neem prevents insects from initiating feeding. As a feeding deterrent, it causes insects to stop feeding, either immediately after the first "taste" (due to the presence of deterrent taste factors), or at some point soon after ingesting the food (due to secondary hormonal or physiological effects of the deterrent substance). As a growth regulator, neem is thought to disrupt normal development by interfering with insect hormone production or reception, thereby preventing insects from reaching reproductive maturity. Susceptibility to the various effects of neem differs by species.

Mammalian Toxicity. Neem has extremely low mammalian toxicity (see Table 2-1), and in most forms is nonirritating to skin and mucous membranes. The seed dust, however, may be extremely irritating to some people. In humans, neem has various pharmacological effects. Some of these effects are beneficial, such as lowering blood pressure and reducing inflammation and fever. Neem is also an antifungal agent. In addition, neem has antiulcer and strong spermicidal properties, depending on the type of extract. Neem is not mutagenic according to the Ames Test. It has been used in India and Asia for centuries for a multitude of practical and medicinal purposes.

Uses. Margosan-O, a neem seed extract, was registered briefly in the mid-1980s for outdoor control of gypsy moths and leafminers on trees and ornamental plants. A new, more stable formulation of Margosan-O received expanded U.S. EPA registration in 1989. The registration and availability of this and other neem products are expected to differ among individual states for at least a few years. Initial registration will allow use on ornamental (nonfood) plants.

Margosan-O controls whiteflies, thrips, mealybugs, and various caterpillar pests of ornamental plants, trees, and shrubs. It is formulated for use as a foliar spray or soil drench and acts as a feeding deterrent, growth regulator, or stomach poison, depending on the pest species.

INSECTICIDAL SOAPS

Source. Insecticidal soaps generally are not considered to be botanical insecticides, though the oils from which they are produced may be of plant origin. In chemical terms, insecticidal soaps (and all soaps in general) are made from the salts of fatty acids. Fatty acids are the principal components of the fats and oils found in animals and plants.

Numerous studies have been conducted to correlate insecticidal activity with the physical structure of fatty acids, and certain acids have been determined to be most insecticidal. Oleic acid, present in high quantities in olive oil and in lesser amounts in other vegetable oils, is especially effective. The common insecticidal soaps now available commercially contain potassium oleate (the potassium salt of oleic acid) as the active ingredient.

In this publication, the term insecticidal soap refers only to those products whose active insecticidal ingredient is the soap itself. Some insecticidal products contain soaps or shampoos in combination with organophosphates (for control of lice) or other kinds of insecticides (for control of fleas on pets). Such *insecticide-containing* soaps are not included in this discussion of *insecticidal* soaps.

Mode of Action. Despite many years of use, the manner in which insecticidal soaps work still remains somewhat unclear. Although the action of soaps involves some physical disruption of the insect cuticle (the outer body covering), additional toxic action is suspected. Some evidence indicates that soaps enter the insect's respiratory system and cause internal cell damage by breaking down cell membranes or disrupting cell metabolism. Soaps also exert some nonlethal developmental effects on immature insects.

Mammalian Toxicity. The mammalian toxicity of insecticidal soaps is basically the same as that of any soap or detergent. Ingestion causes vomiting and general gastric upset, but appears to have no serious systemic consequences. Insectidal soap concentrates may contain ethanol (up to 30 percent), which causes intoxication at doses above several ounces; however, vomiting is likely to clear most of the alcohol from the system before it is absorbed into the bloodstream. Externally, soaps are irritating to eyes and mucous membranes and have drying effects on skin.

Some insecticidal soap products contain additional insecticidal compounds such as pyrethrins or citrus oil derivatives. These combination products have a higher toxicity than products containing only soap, and their additional toxic effects depend on the kinds of insecticides added.

Uses. Soaps are used as contact insecticides to control soft-bodied pests such as aphids, thrips, scales (crawler stage only), whiteflies, leafhopper nymphs, and mites. Soaps are effective only against those insects that come into direct contact with the spray before it has dried. Dried residues on plant surfaces are not insecticidal, and they degrade rapidly.

Soaps are not very effective against insects with heavier cuticles, such as adult beetles, bees, wasps, flies, or grasshoppers. In addition, highly mobile insects may escape soap spray applications by flying away. Mobility and a hardened cuticle protect the adult forms of most beneficial insects such as lady beetles, lacewings, or syrphid flies from the toxic action of soaps. The immature forms of these insects are flightless and soft-bodied, however, and may be more susceptible to injury from soaps.

Soaps are particularly useful for controlling pests of ornamental plants and houseplants, though they may be phytotoxic to some plant species. Plants that have pubescent (hairy) leaves may be more susceptible to soap injury than smooth-leafed plants because the hairs tend to hold the soap solution on the leaf surface where a lens effect may cause burning.

In addition to commercial insecticidal soaps, many common household soaps and detergents are insecticidal when applied to plants as a 1 to 2 percent aqueous solution. Dishwashing liquids and laundry detergents are designed to dissolve grease, however, and they may cause plant injury by dissolving the waxy cuticle on leaf surfaces. Also, detergents differ from soaps chemically and are sometimes more phytotoxic. Plant injury may possibly be avoided if the soap or detergent is rinsed from plant surfaces shortly after application. Commercial insecticidal soaps are less likely to dissolve plant waxes than household cleaning products.

CAUTION: Although homemade soap sprays may be fairly harmless, creating homemade poisons for pest control can be a dangerous practice. Some “recipes” for pesticides call for cleaning agents, fuel oils, polishes, solvents, and other materials that are toxic to plants and many animals (including humans). The fact that these chemicals are not generally considered to be pesticides does not mean that they are not toxic. Many of them are very toxic! *Readers are strongly urged not to prepare homemade pesticides from household chemicals.*

SUMMARY

Botanical insecticides and insecticidal soaps share a number of advantages. Foremost among these are their rapid degradation in the environment and their rapid action in insects. Rapid degradation is beneficial because it minimizes the risks posed by unwanted insecticide residues in food, water, and the environment in general. Rapid action in insects is advantageous because it serves to minimize the extent of feeding damage. On the other hand, rapid degradation imposes certain limitations on the use of botanicals. Where persistent residues are needed for continuous control, botanicals and soaps do not provide adequate protection.

The safety of botanical insecticides and insecticidal soaps in general is a topic that deserves careful consideration. Many of the insecticides discussed in this publication are attractive alternatives to synthetics because, in addition to their rapid degradation, they have low mammalian toxicities (high LD_{50} values). Pyrethrins, sabadilla, limonene, linalool, and the insecticidal soaps fall into this category.

It is very important, nevertheless, to note that all botanical insecticides are *not* safer than all synthetic insecticides simply because they are “natural.” Ryania and rotenone are comparable in acute toxicity to commonly used synthetic insecticides such as malathion, carbaryl, diazinon, and permethrin. Nicotine is extremely toxic to mammals by both inhalation and dermal exposure. In addition, the chronic effects of repeated exposures to any insecticide—whether natural or synthetic—are not fully understood and are difficult to test realistically. Users are reminded to always read and follow pesticide label directions exactly and to wear proper protective clothing (long sleeves and long pants, shoes and socks, rubber or neoprene gloves, protective eye wear, and a respirator or dust mask) when applying any pesticide, natural or synthetic (Figure 2-5).

Finally, readers are encouraged to employ effective nonchemical control measures whenever possible. These may include crop rotation, sanitation, or other cultural controls; the release or conservation of beneficial insects; or the use of resistant crop varieties.

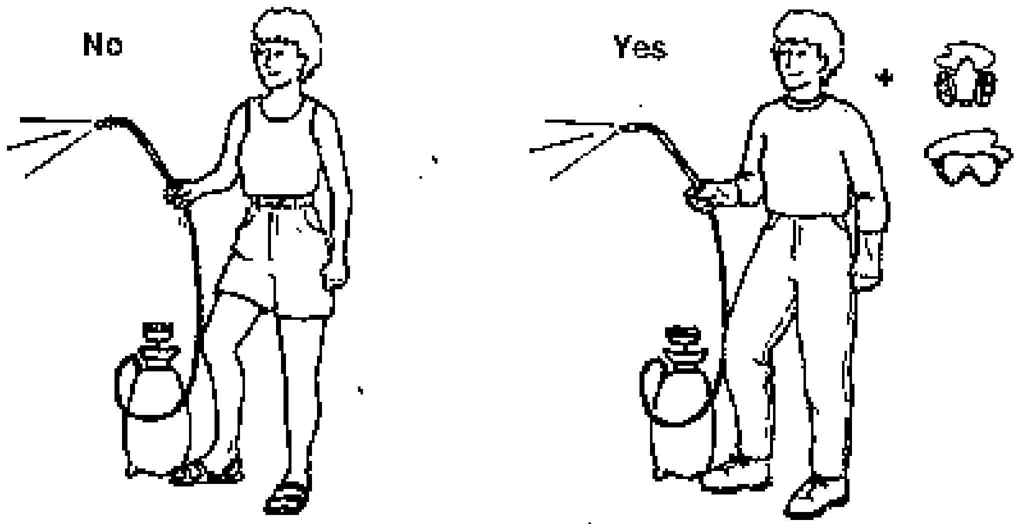

Figure 2-5. Applying pesticides of any sort is serious business requiring some degree of protection. Even though the active ingredients in most naturally occurring insecticides are relatively low in toxicity, they are often allergenic or irritating. The inert ingredients (solvents, carriers, and other additives) in formulated products also may be irritating to eyes, lungs, and skin.

Proper protective clothing should be worn whenever mixing concentrates or applying sprays or dusts. Essential protection includes a loose-fitting, long-sleeved shirt and long pants; rubber boots or sturdy; closed shoes, and rubber gloves (not cloth or leather, as they can absorb toxins). Safety goggles and a cartridge respirator are recommended when mixing concentrates or when applying sprays or dusts in greenhouses or other enclosed areas where contact with fumes or airborne particles is likely.

TERMS TO UNDERSTAND

Carcinogen: a substance or agent that produces or incites cancer (malignant tumors) in experimental animals or in humans.

Contact poison: a toxin that kills insects by contact; it does not have to be ingested to be effective. A contact poison either kills insects immediately (as they are touched by the wet spray) and then degrades quickly—as with pyrethrins or soaps—or has some residual action and kills insects over time (as they come into contact with the poison on plant surfaces)—as with the botanical insecticide sabadilla and the synthetic compounds carbaryl (Sevin) and permethrin, as well as many others.

GRAS: "Generally Regarded as Safe," a classification assigned by the Food and Drug Administration to certain compounds that have been used traditionally without apparent toxicity or are believed to be low enough in mammalian toxicity that certain testing requirements are waived during the pesticide registration process.

Hazard: the risk associated with the use of a formulated pesticide. Hazard depends on several factors, including the inherent toxicity of the active ingredients, the formulation (the form in which the product is used, such as liquid concentrate, wettable powder, ready-to-use spray), and the degree of exposure. Hazard, or risk, is sometimes defined as "toxicity times exposure."

LD_{50}: the abbreviation for "median lethal dose," the dose that kills 50 percent of the population of test animals. When dealing with pesticides, the LD_{50} values most commonly encountered are the mammalian oral and dermal LD_{50} values (measured in rats, mice, rabbits, etc.). These measurements provide an estimate of how toxic a substance might be to humans. LD_{50} values are usually reported in terms of milligrams of toxicant per kilogram of body weight of the test animal (mg/kg), so a lower LD_{50} indicates a more toxic substance.

Repellent: a volatile substance that keeps insects from alighting or feeding. Repellents are usually used to fend off mosquitoes, flies, fleas, ticks, and gnats (biting pests of humans and other animals).

Signal words: the words on a pesticide label that indicate the toxicity of the active ingredients. Although based on toxicity alone, signal words give an indication of potential hazard (see Table 2-2).

Stomach Poison: a toxin that must be ingested to be effective. A stomach poison usually has some residual activity, so it remains active until insects have a chance to feed on it. Most stomach poisons are used against plant-feeding insects or insects that will feed on baits. They are generally not effective against insects that suck plant sap. Rotenone and ryania are active as stomach poisons.

Synergist: in terms of pesticides, a material that is itself low in toxicity but increases the toxicity of the pesticide with which it is combined. Most synergists act by inhibiting the detoxification enzymes of the target pest, so that the pesticide has longer to act before being degraded in the insect's system.

Tolerance: the amount of pesticide residue permitted by the U.S. Environmental Protection Agency or the Food and Drug Administration to be present in or on raw agricultural commodities, processed or semi-processed food, or feed products.

Toxicity: the degree to which a substance is inherently poisonous (able to cause injury or death). The toxicity of pesticides is often expressed as an LD_{50} for the technical material (the pure active ingredient) in laboratory animals.

Table 2-2. Signal Words

Signal word	Toxicity category	Toxicity rating	Oral LD_{50}
DANGER or DANGER–POISON	I	Extremely toxic	0 to 50
WARNING	II	Very toxic	50 to 500
CAUTION	III	Moderately toxic	500 to 5000
CAUTION	IV	Slightly toxic or Practically nontoxic	>5000

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CHAPTER 3
Insect Attractants and Traps

Many chemical and visual lures attract insects and can be used to monitor or directly reduce insect populations. Because these attractants can be used in ways that do not injure other animals or humans or result in residues on foods or feeds, they are well suited to environmentally sound pest management programs.

The effective use of attractants and traps requires knowledge of basic biological principles and the pest- or crop-specific details involved in individual applications. This publication presents background information and specific guidance on the use of attractants and traps for monitoring and directly controlling insect pests. Its purpose is to aid farmers, homeowners, and others in understanding and making appropriate use of available technology. It covers chemical attractants, visual lures (such as light), and attractant-baited and unbaited traps.

CHEMICAL ATTRACTANTS

Insects use many different *semiochemicals*, chemicals that convey messages between organisms. (The Greek word *semeio* means sign.) Although semiochemicals may seem much like tastes or smells perceived by humans, the use of such compounds by insects is characterized by a high degree of sensitivity and specificity. Receptor systems that ignore or screen out countless irrelevant chemical messages are nonetheless able to detect messenger compounds at extremely low concentrations. Detection of a chemical message triggers very specific unlearned behaviors or developmental processes.

Chemicals that act as attractants or carry other messages across distances are volatile (quick to evaporate) compounds. When released into the air, they can be detected by certain insects (those receptive to a specific compound) a few inches to hundreds of yards away. Chemicals that carry messages over considerable distances are most often used in pest management.

Although this publication does not rely on special terminology, a few terms provide useful background. First, semiochemicals may carry messages either within or between species. *Pheromones* are semiochemicals that are produced and received by members of the same species. A range of behaviors and biological processes are influenced by pheromones, but pest management programs most often use compounds that attract a mate (sex pheromones) or call others to a suitable food or nesting site (aggregation pheromones). Other pheromones regulate caste or reproductive development in social insects (honey bees and termites, for example), signal alarm (in honey bees, ants, and aphids), mark trails (ants), and serve other functions.

Allelochemicals are semiochemicals that affect one or more species other than the producer. Of known allelochemicals, volatile compounds similar to those given off by food sources (plants or animals) are important in pest management. Feeding attractants are examples of *kairomones*, allelochemicals produced by one species but used to advantage by another species. For example, carbon dioxide given off by humans and other animals is used as a kairomone by female mosquitoes seeking a blood meal. In contrast, *allomones* are allelochemicals that favor the producer. For example, secretions that deter predators are allomones.

Although terms such as pheromone or kairomone help describe the functions of message-carrying chemicals, these words often oversimplify the complexity of chemical communication. A single chemical signal may act as both a pheromone and a kairomone; for example, the compounds emitted by a bark beetle colonizing a host tree attract other bark beetles (functioning as an aggregation pheromone), but the same compounds also attract certain predators and parasites that attack these bark beetles (functioning as a feeding attractant or kairomone).

Practical use of pheromones or feeding attractants for pest management usually requires that specific active chemicals be isolated, identified, and produced synthetically. The synthetic attractants—usually copies of sex or aggregation pheromones or feeding attractants—are used in one of four ways: (1) as a lure in traps used to monitor pest populations; (2) as a lure in traps designed to "trap out" a pest population; (3) as a broadcast signal intended to disrupt insect mating; or (4) as an attractant in a bait containing an insecticide.

Using Attractant-Baited Traps to Monitor Pest Populations

The most common use of chemical attractants is in traps to monitor insect populations. Although not all of the compounds used in this manner are pheromones, many publications refer to all attractant-baited traps as pheromone traps. For use in monitoring, chemical attractants usually are impregnated or encased in a rubber or plastic lure (Figure 3-1) that slowly releases the active component(s) over a period of several days or weeks. Traps containing these lures are constructed of paper, plastic, or other materials (Figure 3-2). Most traps use an adhesive-coated surface or a funnel-shaped entrance to capture the target insect. Traps for some pests (such as the apple maggot) are coated with an adhesive that also contains the chemical attractant.

Attractant-baited traps are used instead of (or in addition to) other sampling methods for two major reasons. First, these traps are very sensitive and may capture pest insects that are present at densities too low to detect with a reasonable amount of effort using other inspection methods. This attribute can be extremely important when the goal of a sampling program is to detect foreign or "exotic" pests as soon as they enter an area so that control measures can be initiated immediately. Second, traps baited with chemical attractants capture only one species or a narrow range of species. This specificity simplifies the identification and counting of target pests. Sensitivity and specificity make attractant-baited traps efficient, labor-saving tools.

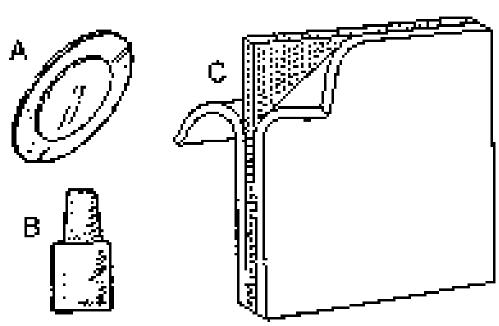

Figure 3-1. Insect attractants are often impregnated or encased in lures such as (A) Biolure's membrane-covered disk; (B) Trece's rubber septum; and (C) Hercon's plastic laminate lure.

Attractant-baited traps are used in monitoring programs for at least three purposes: (1) to detect the presence of an exotic pest (an immigrant pest not previously known to inhabit a state or region); (2) to estimate the relative density of a pest population at a given site; and (3) to indicate the first emergence or peak flight activity of a pest species in a given area, often to time an insecticide application or to signal the need for additional scouting. The use of traps to detect exotic pests has been demonstrated in widely publicized efforts to detect and eradicate pests such as the gypsy moth and the Mediterranean fruit fly whenever infestations are detected in new areas.

Although attractant-baited traps give an indication of pest density, several factors make the interpretation of density estimates complex and difficult. First, environmental factors affect trap catches. Temperature, rainfall, and wind speed and direction influence attractant release (from lures) and insect flight. Many insects fly and respond to semiochemicals only at certain times (dawn, midday, dusk, night, etc.), and then only if temperatures at that time exceed a minimum level (often 50° to 60°F). Wind speed and direction determine the extent of insect movement from surrounding areas to traps within a field or orchard.

Further complication can result from the fact that almost all attractant-baited traps are used to capture adult insects. Damage to crops, however, is caused not by the adult male moths attracted to the traps but by the subsequent generation of caterpillars that female moths produce. Because variable environmental conditions and variable densities of natural enemies greatly influence pest survival between the time trapping data are collected and the time pest damage occurs, establishing a precise economic threshold (the pest population level that warrants control) based on trap counts is difficult. Where counts from traps are used to estimate pest density and determine control needs, guidelines are usually conservative or somewhat vague.

Attractant-baited traps can be used to signal the need for additional sampling efforts or to time insecticide applications and eliminate unnecessary spraying. One example of the use of pheromone traps to trigger further sampling involves the black cutworm, a common but sporadic pest of seedling corn in the Midwest. Pheromone traps baited with a specific sex attractant are used in Illinois in a statewide sampling program to monitor the annual spring migration of black cutworm moths

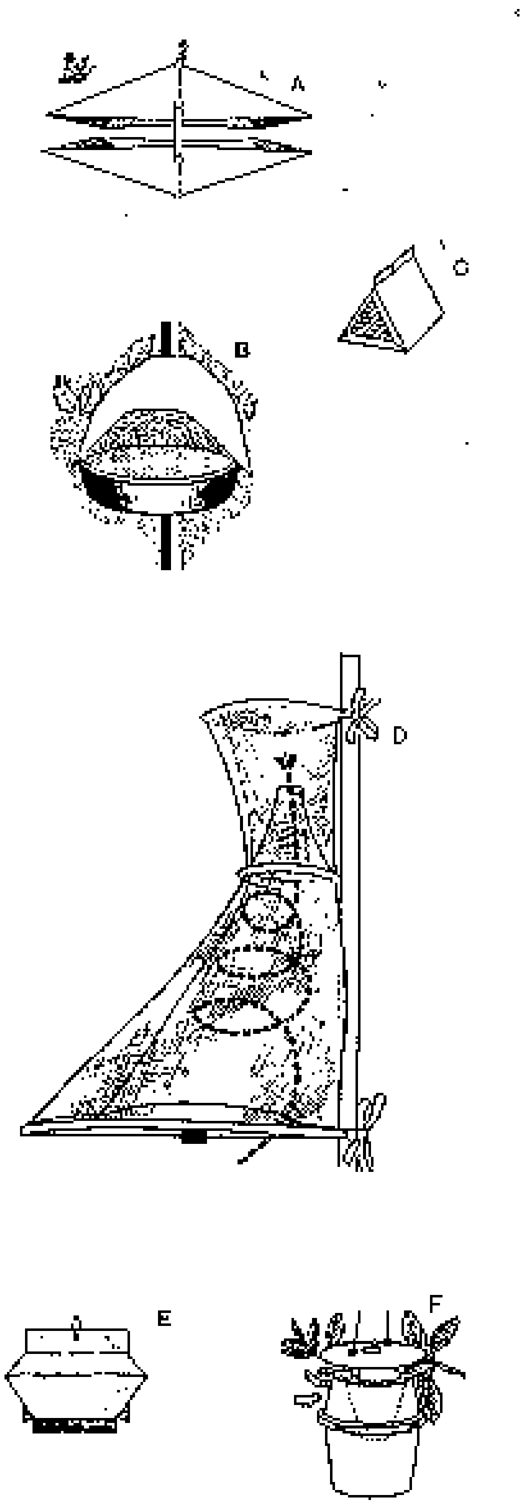

Figure 3-2. Commercially available traps used for monitoring insect populations include (A) the "wing" trap; (B) the water pan trap; (C) the Delta trap; (D) the Heliothis trap; (E) the Pherocon II trap; and (F) the funnel trap. Several other trap designs also are available.

from southern states. In areas where counts of male moths in traps indicate the potential for damaging infestations of cutworm larvae, producers are urged to check for cutworm density and crop damage in fields of seedling corn (see Table 3-1). For pests that cause unacceptable levels of damage even at low population densities, such as the codling moth or apple maggot in commercial apple orchards, traps can be used as the only sampling method for determining the dates to begin and end insecticide application programs.

For all programs that use traps of any type, trap design and trap placement are important factors. For example, common paper sticky traps are ineffective for monitoring corn earworm moths. Male corn earworm moths that are attracted to a chemical lure seldom enter these box- or tentlike traps. Instead, a much larger, cone-shaped trap must be used to capture this insect (Figure 3-2). Similarly, placing traps at the correct height and in the correct portion of a field (edge or center) or building is sometimes the key to detection or interpretation. Recommendations on trap selection and trap placement for specific insects are included in Table 3-1.

Using Attractant-Baited Traps to "Trap Out" Pest Populations

Because pheromone traps are so effective for catching certain insects, numerous traps placed throughout a pest's environment can sometimes remove enough insects to substantially reduce the local population and limit the damage it causes. Efforts to "trap out" insect pests (a process also termed *removal trapping* or *mass trapping*) have utilized species-specific aggregation pheromones that attract both male and female beetles or species-specific sex pheromones that attract male moths. When aggregation pheromones are used to attract adult beetles of both sexes, traps may reduce the feeding damage caused by the adult insects and reduce reproduction by capturing adults before they lay eggs. When sex pheromones are used to capture moths, success depends upon capturing males before mating occurs.

Although mass trapping programs using chemical attractants have targeted such important pests as bark beetles, codling moth, apple maggot, Japanese beetle, and Indianmeal moth, field-scale successes have been limited. For mass trapping to adequately reduce pest populations, a large number of very efficient traps are usually needed. Efficient traps capture a high percentage (and often a very large volume) of the target insects that are drawn to the area by the attractant. For many insects, the efficiency of commonly used traps is not known; however, low efficiency seems to be a limiting problem in some instances. Removal trapping is also most likely to succeed when the density of the target pest is low and immigration into the trapped area is minimal.

The recommendations presented in Table 3-1 include information on mass trapping for pests that might be managed by such an approach. In addition, the following examples illustrate conditions that favor or limit the potential use of mass trapping.

Codling Moth. Larvae of the codling moth tunnel into apples and pears, leaving the fruit scarred, contaminated, and unsuitable for most commercial markets. Although pheromone traps are used to monitor the seasonal timing and sometimes the density of codling moth populations in commercial orchards, mass trapping has not been widely adopted. In experimental programs, high numbers of pheromone traps (14 and 72 traps per acre) in some trials provided less control of subsequent larval damage than did fewer traps (4 per acre) in other trials. These seemingly contradictory results appear to have resulted from different conditions in and surrounding the test orchards. Available data indicate that mass trapping for codling moth control is likely to be successful only in reasonably isolated orchards (at least 100 yards, preferably farther, from the nearest source of moths) where codling moth populations are already low. Where nearby fruit trees harbor codling moth infestations, mated female moths can disperse into the trapped orchard and lay eggs even if the local males have been trapped. (Immigration also limits the successful use of mass trapping to protect fruit on one or two backyard trees in most urban situations.) Where initial moth populations are high, some males will locate and mate with a nearby female even if a great number of traps have been used; in these orchards the mated females produce enough fertile eggs to damage a measurable portion of the fruit. Despite these limitations, mass trapping can reduce codling moth damage in backyard trees and some orchards (see Olsen et al. 1990). Although damage may not be limited to the extremely low levels required by most commercial markets, producers who sell to "organic" markets might use mass trapping along with other steps (such as removal of dropped fruit and banding of trunks) to substantially limit codling moth damage. Because the number of traps needed for mass trapping of codling moths has not been determined, the economic feasibility of mass trapping is unclear.

Japanese Beetle. Adult Japanese beetles eat the leaves of many different ornamental plants (both trees and shrubs), and the larvae (grubs) of this species feed on the roots of grasses. Can- or baglike traps for Japanese beetles contain a feeding attractant alone or in combination with a sex attractant. These traps are sold under claims that they will reduce beetle numbers and protect nearby plants from feeding damage. Although their lures are indeed very attractive to adult Japanese beetles, the use of these traps in areas where the Japanese beetle is prevalent has been shown to increase beetle numbers and damage to host plants in the area around the trap. This outcome apparently results from the fact that many beetles are attracted by the lure but not captured by the trap. In areas where the Japanese beetle is a serious pest, only very widespread use of many traps (several traps per homeowner by a majority of homeowners in an area) is likely to reduce damage to plant foliage. In contrast, in areas where Japanese beetle densities are low, traps placed several yards away from valuable plants can reduce the damage caused by adult beetles feeding on foliage or flowers. Additionally, these traps have been used at densities of one or two per acre to remove adult beetles from golf courses and to reduce turf damage caused by the subsequent generation of grubs.

Using Attractants to Disrupt Insect Mating

To disrupt insect mating, a species-specific sex attractant is broadcast throughout an area. In an environment permeated with artificially applied sex pheromone molecules, male insects that rely on pheromones to locate females are unable to do so. Either they follow an artificial signal to a frustrating destination or their sensory receptors become overloaded by constant exposure to pheromone molecules, leaving the insect temporarily unable to detect additional pheromone messages. The way in which artificial attractants might "out-compete" female moths and prevent their success in attracting a mate is illustrated in Figure 3-3.

In field applications of mating disruption techniques, attractants have been applied to fields or forests in hollow plastic fibers, capsulelike pellets, and attractant-impregnated plastic strings or ties. Although mating disruption programs are not widely used, trials have been successful against the oriental fruit moth, pink bollworm in cotton, grape berry worm, tomato pinworm, and several pests of forest conifers. The trial use of pheromones to disrupt mating for codling moth control in apples has produced mixed results. Mating disruption programs are most successful where large areas are treated, where the treated area is isolated from sources of pests that might immigrate, and where the pest population is low. When pest densities are low, artificial attractants are more likely to out-compete a high percentage of female insects in attracting males. For insect attractants to be broadcast into the environment for direct control, the attractants (regulated as pesticides) must be evaluated and approved by the U.S. Environmental Protection Agency. The sex attractants of the oriental fruit moth and the codling moth have been approved for such use in plastic “ropes” to be tied onto the limbs of fruit trees.

Using Attractants in Poison Baits

Combining insect attractants with poisons (insecticides) is a practice that has been used in pest management for many years. In the early 1900s, for example, poisoned bran baits were used for grasshopper control; hoppers that were attracted to the treated bran and fed on it were killed by an insecticide that could not be applied safely, economically, or effectively in any other manner.

Because pests are lured to toxic compounds that are combined with attractants, poisoned baits can sometimes be used effectively at low rates and often in a manner that does not leave residues on plants or animals. Insecticidal baits are currently used in the control of several pests, including the house fly, slugs, certain ants, cockroaches, and yellowjackets. Research in progress is investigating the use of feeding attractants and feeding arrestants (cucurbitacins) derived from wild squash in combination with an insecticide to control adult corn rootworm beetles. Table 3-1 lists baits that allow unique, low-rate applications of insecticides.

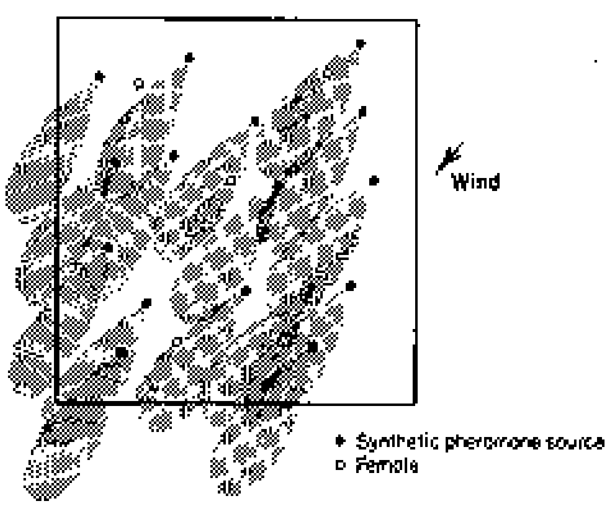

Figure 3-3. Synthetic attractants used in mating disruption programs produce “odor” plumes that obscure the locations of females. Males attempting to follow a plume upwind and locate a female will most often reach a synthetic lure, and many females will fail to attract a mate. (Illustration from Birch and Haynes 1982.)

VISUAL LURES

That light attracts many insects is common knowledge, but making use of light and its component colors in visual lures requires considerably more detailed understanding. Visual lures used in insect management fall into three general categories: (1) lights (incandescent, fluorescent, and ultraviolet) that attract insects from dark or dimly lit surroundings; (2) colored objects that are attractive because of their specific reflectance; and (3) shapes or silhouettes that stand out against a contrasting background.

Using Lights to Attract Insects

A great number of insect species are attracted to light of various wavelengths. Although different species respond uniquely to specific portions of the visible and nonvisible spectrum (as perceived by humans), most traps or other devices that rely on light to attract insects use fluorescent bulbs or bulbs that emit ultraviolet wavelengths (black lights). Hundreds of species of moths, beetles, flies, and other insects, most of which are not pests, are attracted to artificial light. They may fly to lights throughout the night or only during certain hours. Key pests that are attracted to light include the European corn borer, codling moth, cabbage looper, many cutworms and armyworms, diamondback moth, sod webworm moths, peach twig borer, several leaf roller moths, potato leafhopper, bark beetles, carpet beetles, adults of annual white grubs *(Cyclocephala)*, house fly, stable fly, and several mosquitoes. (The mosquitoes *Aedes triseriatus*, *Aedes hendersoni*, and *Aedes albopictus* are not attracted to light, however.) Lights and light traps are used with varying degrees of success in monitoring populations and in mass trapping.

Light traps similar to the one pictured in Figure 3-4 have been used for several decades to monitor the presence of insects and to determine seasonal patterns of pest density. But because pheromone traps are much more specific (they catch only one or a few pest species instead of many) and more convenient, light traps are no longer as widely used. Nonetheless, light traps provide useful information about the timing, relative abundance, or species composition of flights of European corn borer, white grubs, sod webworms, and a few other pests.

Although numerous companies market devices that use light as a lure for mass trapping or removal trapping, using light to trap out insect infestations is effective in only a few specific situations. One widely used but very ineffective application of light for insect control is the placement of electrocutors or “bug zappers” on lawns or patios. Such uses are ineffective for at least two reasons. First, many insects that are attracted to the area around the light traps (sometimes from considerable distances) do not actually fly into the trap. Instead, they remain nearby, actually increasing the total number of insects in the immediate area. Second, these lighted electrocutors attract and kill a wide variety of insects, the overwhelming majority of which are not pests. The nonpest species killed by such devices include such beneficial insects as the green lacewing, a predator that attacks a variety of plant pests.

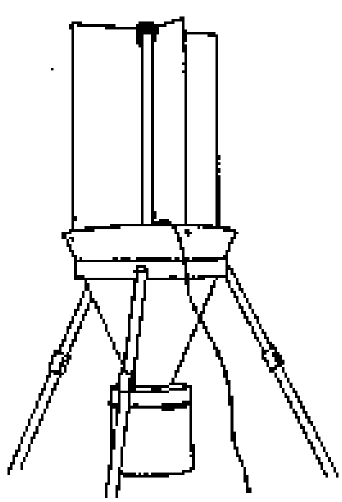

Figure 3-4. A light trap used to survey night-flying insects. Most light traps use ultraviolet lamps and capture a wide range of moths, beetles, and other insects.

Insect electrocutors can be effective in certain indoor situations, especially in food warehouses, processing plants, and restaurants. In these facilities, electrocutors are placed in otherwise dimly lit areas where their light is not visible from outdoors. In such locations the trap does not lure insects into the building, yet it does attract and kill certain flies, moths, and beetles that are pests of stored products or nuisances in food production areas (see Gilbert 1984). These traps can also be used somewhat effectively in barns and stables to reduce some fly and mosquito infestations. The efficiency of electrocutors in such situations appears to be low, however, and they must be positioned so that they do not attract insects into a building from outdoors.

Although using electrocutor light traps outdoors is not efficient, the placement of outdoor lights can be important. Positioning outdoor lights away from entrances, windows, or other openings reduces problems associated with insect activity around the lights. Floodlights directed at loading docks, for instance, do not lure insects into food warehouses as do overhead lights mounted just inside the loading dock door. Placing outdoor lights several feet away from doors of homes and apartments also concentrates insect activity away from the sites where they cause the most annoyance. In addition, yellow light bulbs attract fewer insects than white incandescent lights or fluorescent bulbs.

Using Colored Objects to Attract Insects

Specific colors are attractive to some day-flying insects. For example, yellow objects attract many insects and are often used in traps designed to capture winged aphids and adult whiteflies. Red spheres and yellow cards attract apple maggot flies. Like other attractants, colored objects can be used in traps for monitoring or mass trapping. Yellow plastic tubs filled with water, for example, are used to monitor the flights of aphids in crops where these insects are important vectors of plant viruses. Aphids attracted to the yellow tub land on the water and are unable to escape. Yellow, sticky-coated cards or plastic cups are widely used in mass trapping programs to help control whiteflies in greenhouses. Although recommended trap densities in greenhouses are based on studies involving only a few crops, recommendations of one trap per 5 square yards or one trap every 3 to 4 feet along benches are common. Yellow sticky traps capture adult whiteflies, not wingless nymphs.

Both yellow cards and red spheres (and red hemispheres attached to yellow cards) coated with adhesives are used to attract and capture apple maggot flies in orchards. A chemical attractant may be incorporated in the adhesive applied to commercially available yellow cards or dispensed from a separate vial. Apple maggot traps are most often used to detect the movement of adult flies into orchards from nearby overwintering sites. To do so, place traps in trees along the perimeter of the orchard, with no more than 150 feet between traps. Timing of insecticide applications can be based on results of such a trapping program.

Research indicates that red sphere traps and chemical attractants can be used to "trap out" apple maggot flies and limit damage to fruit. For mass trapping programs to work, traps must be in place before flies begin to move into orchards (in early June), and a great number of traps must be used (one every 15 feet in the trees at the perimeter of the orchard). Mass trapping for apple maggot control is still an experimental approach, and commercial producers should not adopt a mass trapping program if complete control of apple maggot damage is necessary. See Table 3-1 for further details on using traps for apple maggot.

Traps used to capture stable flies around livestock and outdoor recreation facilities are constructed of alsynite, a translucent building material similar to fiberglass. It is attractive to stable flies apparently because of its specific reflectance. Alsynite panels coated with adhesive are used to determine stable fly abundance, and their effectiveness in mass trapping is under investigation. Although they can provide some control of flies in isolated sites, their value in feedlot and dairy situations has not been established. If alsynite traps are to be effective, producers will need to use many traps (perhaps one for every five to ten animals, but an adequate number has not been determined).

Other Traps

Several unique types of traps are used for the control of various species of flies. House fly traps containing foods or chemical attractants lure house flies to a reservoir from which they cannot escape. These traps capture thousands of house flies around livestock facilities, but the overall population in such areas is usually not reduced by a meaningful level unless a great number of traps are used. The effectiveness of such traps must be judged not by the number of flies in the traps but by the number of flies still present in the area. (These traps do not capture stable flies, the biting flies that are most annoying to livestock.)

Because house flies commonly land and rest on narrow, vertical objects, hanging sticky "fly strips" is somewhat effective in small, closed areas where fly populations are low. Although these strips quickly become coated with flies where flies are numerous, they can be useful on a closed porch or similar indoor area. Because flies often land near other flies, strips that have captured a few flies and strips that bear pictures of flies may be more effective than clean strips. (Strips should be hung so that people do not inadvertently contact them; the adhesive combined with dead flies is an unpleasant addition to hair or clothing.)

Other traps designed to control certain pasture flies can be constructed from commonly available materials. Walk-through traps for horn fly control can reduce horn fly infestations on cattle by 50 to 70 percent. Box or canopy traps rely on the horse fly's attraction to dark silhouettes. Although horse fly traps are impractical where horses or cattle graze in large pastures or extensive rangelands, they can reduce horse fly numbers in small pastures. See Table 3-1 for additional information on traps designed for fly control.

One other type of trap useful to gardeners and farmers is the pitfall trap. Perhaps its best known use is in slug control. Bowls, cups, or other containers are set into the soil so that the lip is level with the soil surface. Beer or a fermented mixture of flour, sugar, yeast, and water is added to the container to attract slugs; slugs that enter the container are unable to escape and "drown" in the liquid. Similar pitfall traps containing a preservative (not an attractant) are sometimes used in research to sample populations of insects active at the soil surface. Relatively new pitfall traps are now available for detecting beetle infestations in stored grains (Figure 3-5). These traps can be used with or without an attractant to provide a sensitive measure of insect presence in warm grain. Table 3-1 contains additional information on traps for stored-grain insects.

Tables 3-1 and 3-2 provide specific details about the purchase and use of attractants and traps. Table 3-1 lists recommendations for specific pests; Table 3-2 lists several manufacturers and distributors of attractants and trap supplies.

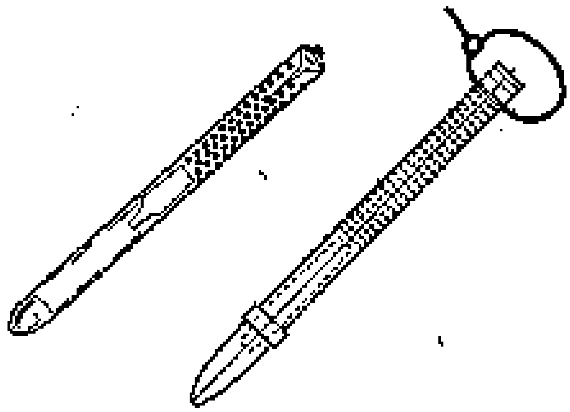

Figure 3-5. Perforated pitfall traps are used to detect or monitor populations of insects in stored grains. Such traps are sold under the names Storgard Grain Probe, Grain Guard, and Storgard WB Probe II.

SUMMARY

Insect attractants and traps are useful tools for monitoring insect populations to determine the need for control or the timing of control practices. In some instances, attractants and traps also can be used to control insect populations directly by mass trapping or mating disruption. Using attractants and traps to monitor and control insect populations can improve the effectiveness of insecticide applications and sometimes reduce the use of broad-spectrum, more toxic compounds.

Pest	Trapping period	Instructions, interpretation, comments
Field crop pests		
Black cutworm, *Agrotis ipsilon*	March to May	Use wing traps baited with specific sex attractant; place 3 to 4 feet high on stakes in fields or along field edges. Check daily. Results do not predict field-specific risks at the trap site. In Illinois, a statewide trapping program operated by the Cooperative Extension Service determines timing and intensity of spring moth flight. Further sampling is especially important in regions where moth captures exceed 9 per trap per night (“intense” flight). Begin sampling for larvae and damage 300 degree days (base 50°F) after intense flight. Control decisions are based on larval density, plant damage, and growth stage of cutworms and plants. See Curran et al. (1989).
European corn borer, *Ostrinia nubilalis*	Late May to late August	Use water pan traps with specific sex attractant; place traps 4 to 5 ft high on stakes in grassy areas near field edges. Counts indicate peak flight periods and timing for further sampling; they do not allow prediction of damage or control needs for individual fields. See Showers et al. (1989) for further details on decision making for corn borer control. Light traps are also effective for determining the flight period of European corn borer.
Northern and western corn rootworms, *Diabrotica* spp.	August 10 to 30 (See comments.)	Dates for monitoring vary according to weather and planting date; begin trapping when corn is silking. Use unbaited yellow sticky traps such as the Pherocon AM (Trece, Inc.). Use 8 to 12 traps evenly spaced throughout each field, positioned near corn ears. Check twice weekly. Maintain for at least 7 days. Captures of more than 6 beetles per trap per day indicate potentially damaging populations (populations that will produce enough eggs/larvae to result in economic damage to the roots of corn planted in the same field the next year). Toxic baits containing a combination of attractants are under investigation, and preliminary results are promising.
Corn earworm, *Heliothis zea*	At early stages of silking in seed corn	Use large cone-shaped traps constructed of wire or plastic mesh (Heliothis traps) and baited with specific sex attractant. Position on stake so that bottom of trap is 4 to 6 feet above soil. Place near fields where corn is beginning to silk. Preliminary estimates of a treatment threshold for seed corn range from 10 to 30 moths per trap per day during silking.

Table 3-1. (continued)

Pest	Trapping period	Instructions, interpretation, comments
Armyworm, *Pseudaletia unipuncta,* and Fall armyworm, *Spodoptera frugiperda*	May 1 to autumn	Wing traps and specific attractants for armyworm and fall armyworm are available, but their use in field crops provides little benefit. Although they indicate the presence and timing of moth flights, control decisions must be made later when partially mature larvae are present.
Orchard pests		
Codling moth, *Cydia pomonella*	Bloom through harvest	Begin trapping in April in southern portions of the Midwest, May in central and northern areas. For monitoring, use specific sex attractant in IOBC cartons or modified wing traps such as the Pherocon 1CP (from Trece, Inc.) placed 6 ft high or 1/3 up the vertical canopy. Place in south or east quadrant of tree within 2 ft of outer edge of canopy. Use at least 1 trap per 10 acres and a minimum of 3 traps in small orchards. Count and remove moths twice weekly. Counts indicate timing of moth flights and need for cover sprays. Threshold estimated at 5 moths per trap per week. Mating disruptant formulations are available (Check-Mate CM), but the success of mass trapping or mating disruption is limited if mated females enter orchards from nearby wooded areas. For information on mating disruption and mass trapping, see Reidl et al. (1986) and Olsen et al. (1990). (Wrapping trunks with burlap to capture larvae as they move down trunks to overwintering sites and then destroying the collected larvae can reduce numbers wintering in orchards; wrapping will not eliminate the next season's damage.)
Apple maggot, *Rhagoletis pomonella*	June 1 to October 15	Use red spheres or yellow sticky traps baited with feeding or egg-laying attractants. To monitor flights, place at 150-ft intervals around orchard borders. Traps at borders near woods or abandoned orchards are most important. Place 6 ft high on limb at outside edge of canopy (no foliage within 1 ft) on south side of tree. Check twice weekly. Treat when cumulative counts reach 15 per trap. Restart count at zero and retreat each time cumulative count reaches 15 per trap. For mass trapping, use 1 trap every 15 ft along orchard perimeter (see Olsen et al. 1990). Mass trapping can be effective in small orchards (perhaps 5 to 15 acres) but is less likely to work well in large orchards. Apple maggot is more common in northern portions of the Midwest.
Peachtree borer, *Synanthedon exitiosa,* and Lesser peachtree borer, *S. pictipes*	May to September	Most important monitoring period for peachtree borers corresponds with timing of local apple blossoms. Use wing traps baited with sex attractant and hang 3 ft high on or adjacent to trunks. Use 1 trap per 2 1/2 acres; at least 2 traps per orchard. Check twice weekly. Time trunk sprays a few days after first captures. Pheromone products for use in mating disruption are under development.

Pest	Trapping period	Instructions, interpretation, comments
Peach twig borer, *Anarsia linetella*	May to September	Rarely a pest in fruit orchards. See **Pests of woody ornamentals and shade trees**.
San Jose scale, *Quadraspitiotus perniciosus*	At "pink" stage of bloom	Use tent traps (from Trece, Inc.) with sex attractant, at least 4 per orchard, or in or near infested trees (identified from previous season's fruit damage). Place 6 ft high on limb near edge of canopy, or place in upper half of canopy to increase detection sensitivity. Check twice weekly. Traps indicate success of oil sprays applied at half-inch green and at tight cluster; crawler activity begins 2 to 4 weeks after males are captured in traps. Crawler activity also can be measured using sticky tapes (such as black electrical tape) on twigs and branches.
Spotted tentiform leafminer, *Phyllonorycter* spp.	"Delayed dormant" bud stage through end of season	Use wing trap or dark red sticky board baited with sex attractant. Use at least 2 traps per orchard; place 6 ft high on limb near edge of canopy. Check twice weekly; heavy flights often occur where leafminers were a problem the previous year. Traps indicate timing; correlation between trap catches and larval damage is low. Follow trapping by checking foliage. Economic threshold is estimated at 1 to 3 miners per leaf.
Redbanded leafroller, *Argyrotaenia velutinana*	July 1 to harvest	Use wing traps with sex attractant. One trap per 5 acres; minimum of 2 traps per orchard. Hang 6 ft high on limb at outer edge of canopy; check twice weekly. Redbanded leafroller is a minor pest of apples in much of the Midwest; the third generation is most damaging and occurs near harvest. Traps indicate presence and timing of this generation.
Oriental fruit moth, *Grapholitha molesta*	Fruit-set to harvest (peaches)	To monitor, use wing traps with specific sex attractant; 1 trap per 5 acres, minimum of 2 traps per orchard. Hang 6 ft high on limb in northeast quadrant of tree, 1 to 2 ft from edge of canopy. Monitor twice weekly. Traps indicate presence and timing of second and third generations of moths (subsequent larvae bore into fruit). Apply cover spray at peak flight (about 2 weeks after first capture). Mating disruption can be used in orchards where first generation damage (tunneling into terminals) indicates pest presence. Use attractant-impregnated plastic ties (Isomate M from Biocontrols, Inc., or Checkmate OFM from Consep Membranes) according to manufacturer's directions.
Fruittree leafroller, *Archips argyrospila*	June to July	Use wing traps with specific sex attractant. One trap per 5 acres; minimum of 2 traps per orchard. Hang 6 ft high on limb at outer edge of canopy; check twice weekly. Trap indicates presence of moths, but eggs deposited in June or July do not hatch until the following spring. Counts of moths in traps are not good predictors of subsequent larval density; sample for larvae and damage in foliage in spring to determine control needs.

Table 3-1. (continued)

Pest	Trapping period	Instructions, interpretation, comments
Tarnished plant bug, *Lygus lineolaris*	At “pink” stage of bloom	Use non–UV-reflecting white sticky trap. For mass trapping, use 1 trap per dwarf tree, 2 to 3 traps per large tree. Hang 5 to 6 ft high at the south edge of the canopy; remove foliage from within 1 ft of trap. (See Olsen et al. 1990.)
Lesser appleworm, *Grapholitha prunivora*	Bloom to harvest	Use wing traps baited with specific sex attractant; hang 6 ft high on limb at outer edge of canopy. 1 trap per 5 acres, minimum of 2 traps per orchard. Check twice weekly. Traps indicate moth presence and timing. The late-summer generation is most damaging. Apply cover spray at peak flight in orchards where moths are captured.
Dogwood borer, *Synanthedon scitula*	May to September	Use wing trap baited with sex attractant. Optimum trap density and placement not yet defined; use in manner similar to traps for peachtree borer. Traps indicate presence and timing of moth flight. Dogwood borer attacks graft unions on dwarf and semidwarf trees. Flights are usually greatest May to July.
Vegetable pests		
Diamondback moth, *Plutella xylsotella*	Early head formation to harvest in crucifers	Use wing traps baited with specific sex attractant. Hang from stake at level even with top of crop. Use 1 trap per 5 acres and a minimum of 2 traps per field. Sample for eggs, larvae, and defoliation beginning 1 week after first moths are trapped.
Cabbage looper, *Trichoplusia ni*	Early head formation to harvest in crucifers	Use wing traps baited with specific sex attractant. Hang from stake at level even with top of crop. Use 1 trap per 5 acres and a minimum of 2 traps per field. Sample for eggs as soon as moths are captured or sample for larvae and defoliation 1 week later. Pheromone traps also can be used to detect this insect in other vegetables such as tomato, potato, greens, and lettuce. Place traps in these crops May through September or when harvestable tissues (fruits, edible leaves, etc.) are present.
European corn borer, *Ostrinia nubilalis*	During silking and kernel fill in sweet corn, during fruit formation in peppers, and during pod set in snap beans	No thresholds have been established for the use of sex attractants in water pan traps. Ultraviolet light traps operated in the vicinity of vegetable fields indicate treatment needs according to the following guidelines: peppers—treat when counts exceed 10 moths per light trap per night; sweet corn (for processing)—treat when counts exceed 50 moths per light trap per night; snap beans—treat when counts exceed 25 to 50 moths per light trap per night and more than 300 heat units (10 to 14 days) remain before harvest. Consult individual processors for specific guidelines

Pest	Trapping period	Instructions, interpretation, comments
Corn earworm, *Heliothis zea*	Before and during silking in sweet corn	Use large cone-shaped traps constructed of wire or plastic mesh (Heliothis traps). Position on stake so that bottom of trap is 4 to 6 ft above soil. Place near corn fields that are just beginning to silk. Threshold for treatment of fresh market corn estimated at 5 moths per trap per day; threshold for treatment of processing corn estimated at 10 moths per trap per day.
Variegated cutworm, *Peridroma saucia*	When fruit is forming in tomatoes	Use wing trap baited with specific sex attractant; hang from stake at level even with top of crop. Use 1 trap per 5 acres; minimum of 2 traps per field. Check twice weekly. Traps indicate moth presence and timing for additional sampling for larvae and damage. No threshold based on moth counts in traps has been established.
Squash bug, *Anasa tristis*	When squash is producing runners	In home gardens, place boards on soil near squash plants. Squash bugs gather under the boards during the night and can be killed the next day. (Remove dead leaves and mulches around squash plants to reduce other shelter.)
Slugs, *Agriolimax reticulatus* and others	Throughout the growing season	For home gardens and similar plantings, shallow dishes (pitfall traps) of beer or a fermented mixture of water, sugar, flour, and yeast attract and kill slugs. Set dishes into soil in areas where slug damage is evident; dispose of slugs and freshen bait daily. Commercial baits for slugs contain a feeding attractant and toxicant.
Lawn and turf pests		
Sod webworms, *Crambus* spp. and others	June to September	Use ultraviolet or fluorescent light traps to determine presence and timing of moth flights. Check daily. Control decisions are based on subsequent sampling of turf; threshold estimated at 2 to 4 larvae per square foot of turf.
Cranberry girdler, *Chrysoteuchia topiaria*	June to September	Use wing traps with specific sex attractant; hang 1 to 3 ft high on stake in lawns or turf. Use in areas where this pest has caused damage in previous years. Traps indicate presence and timing of moth flights and indicate need to sample turf for larvae and damage.
Bluegrass billbug, *Sphenophorus parvulus*	April to June	Use pitfall traps (2- to 3-inch diameter cups set into the soil so that the lip is level with the soil surface) containing a small amount of mineral oil or vegetable oil. Place 2 to 4 traps in lawns with histories of billbug damage to determine overwintering survival and likelihood of turf damage. No thresholds have been established.

Table 3-1. (continued)

Pest	Trapping period	Instructions, interpretation, comments
Japanese beetle, *Popillia japonica*	June to September	Can- or baglike traps baited with a mixture of sex and feeding attractants can be used to indicate beetle presence or for mass trapping. Hang traps 3 to 5 ft high on stakes; do not place traps adjacent to adult beetles' host plants because increased feeding damage may result. For mass trapping, use 1 to 2 traps per acre on golf courses to reduce beetle numbers and egg laying (to reduce subsequent damage to turf caused by larvae). Where beetles are numerous, mass trapping is not likely to provide adequate control of adult feeding on foliage. Where populations are low, traps placed several yards away from host plants can remove enough beetles to substantially reduce feeding on foliage or flowers.
Pests of woody ornamentals and shade trees		
Japanese beetle, *Popillia japonica*	June to September	See **Lawn and Turf Pests**.
Lilac borer (ash borer), *Podosesia syringae*	Mid-May to mid-June	Use wing traps with specific sex attractant; hang from branch of host tree (lilac or ash). Check twice weekly. Traps indicate dates of moth flight and allow accurate timing of insecticide applications to ash. Control in lilac is accomplished by pruning.
Peachtree borer, *Synanthedon exitiosa*	May to September	Most important monitoring period is from mid-May through June. Use wing traps with specific sex attractant; hang 3 ft high on trunks of host trees (purpleleaf plum and flowering cherry). Traps indicate dates of moth flight and allow accurate timing of insecticide application (trunk sprays).
Viburnum borers, *Synanthedon viburni* and *S. fatifera*	Early May to late June	Use wing traps with specific sex attractant; hang traps from branches of viburnum. Check twice weekly. Traps indicate dates of moth flight and allow accurate timing of insecticide sprays.
European pine shoot moth, *Rhyacionia buoliana*	Mid-May to mid-July	Use wing traps with specific sex attractant; hang traps from branches of host trees (several pines). Check twice weekly. Traps indicate dates of moth flight and allow accurate timing of insecticide sprays.
San Jose scale, *Quadraspitiotus perniciosus*	May 1 to September	Use tent traps (from Trece, Inc.) with specific sex attractant; hang on limbs of host plants. Check twice weekly. Traps indicate dates of male flights; crawler activity begins 2 to 4 weeks later. Where pheromone traps capture adult male scales, use bands of black electrical tape around twigs and branches to detect scale crawlers (immatures). Insecticide applications should be applied when crawlers are active (often 2 to 4 weeks after males were first captured in pheromone traps).

Pest	Trapping period	Instructions, interpretation, comments
Fall cankerworm, *Alsophila pometaria*, and Spring cankerworm, *Paleacrita vernata*	October for fall species; late February for spring species	Apply tanglefoot or similar sticky material to paper bands wrapped tightly around tree trunks to trap and kill ascending cankerworm moths (females are wingless). Leave traps in place for 6 weeks after the starting dates indicated.
Slugs, various species	Throughout the growing season	See **Vegetable pests**.
Gypsy moth, *Lymantria dispar*	July to August	Delta (triangular) traps with specific sex attractant are hung from branches of trees and shrubs. Trapping is done by government agencies to detect the spread of this pest. Larval control programs or mass trapping programs are conducted the year following initial detections in an area. Individual operation of traps for gypsy moth usually is discouraged.
Smaller European elm bark beetle, *Scolytus multistriatus*	April 1 to August 20	For mass trapping, use aggregation pheromones on large panels attached to telephone poles around the perimeter of a protected area in which bark beetles and dutch elm disease are controlled by sanitation. Traps used in this manner are intended to attract beetles away from American elm. Beetle flights are greatest in spring.
Greenhouse pests		
Greenhouse whitefly, *Trialeurodes vaporariorum*	Continuous	For monitoring or mass trapping, use yellow sticky panels; place on benches or beds at the same height as foliage. Use 2 to 4 traps per range to detect whitefly infestations; use 1 trap for every 3 to 4 linear feet of bench or bed for mass trapping.
Leafminers, several species, and fungus gnats, several species	Continuous	Yellow sticky panels used against whiteflies also capture leafminer adults and fungus gnats. Yellow panels indicate the presence of these pests but are not recommended for mass trapping.
California red scale, *Aonidiella aurantii*	Continuous	Use tent traps (from Trece, Inc.) with specific sex attractant; place near foliage of susceptible plants (for example, hibiscus, many woody plants). Traps indicate presence of scale infestation but do not indicate density or aid significantly in timing insecticide application.

Table 3-1. (continued)

Pest	Trapping period	Instructions, interpretation, comments
Stored-product pests		
Indianmeal moth, *Plodia interpunctella,* and related species (Mediterranean flour moth, raisin moth, almond moth, and meal moth)	Continuous in heated warehouses and food-processing plants; April to October in grain bins	Use pull-down traps such as the Pherocon II with sex attractant; a single attractant is effective for all species listed. Hang traps in bin headspace or from shelves, walls, or ceilings of warehouses and processing plants. Traps indicate pest presence; spring trapping in grain bins signals the start of seasonal activity and invasion of the bin. No thresholds have been established for control decisions; however, raw grain that will remain in storage for more than 4 to 6 weeks after moths are detected in the spring should be "topdressed" with an insecticide to prevent infestation.
Angoumois grain moth, *Sitotroga cerealella,* warehouse beetle and Khapra beetle, *Trogoderma* spp., red and confused flour beetles, *Tribolium* spp., cigarette beetle, *Lasioderma serricorne,* and lesser grain borer, *Rhyzopertha dominica*	Continuous in heated warehouses and food-processing plants; April to October in grain bins	Use wing traps or pull-down traps (such as the Pherocon II) for flying insects; use flat, corrugated paper traps (Storgard traps, Trece, Inc.) or cylindrical pitfall (probe) traps to detect insects on or in grain or other commodities. Specific traps are available for cigarette beetle, *Tribolium* spp., and *Trogoderma* spp. Specific attractants are available for the species listed. Traps indicate pest presence; no widely applicable thresholds for control decisions based on trap captures have been established.
Several species of stored-product beetles	Continuous in heated warehouses and food-processing plants; April to October in grain bins	Use flat, corrugated paper traps (Storgard) baited with feeding attractants (oat and wheat germ oils) on grain surfaces, shelves, floors etc. to detect stored-product beetles. Use unbaited cylindrical pitfall traps (probe traps) in warm grain to detect infestations of most beetle pests. Use at least 3 traps per bin, with one or two placed in spout lines; leave traps in place 3 to 4 days before removing to inspect.
Stored-product pests that are attracted to light	Continuous in heated warehouses and food-processing plants	For mass trapping, use electrocuting light traps with ultraviolet bulbs. Place traps in dimly lit areas not visible from outdoors (to avoid drawing in additional pests). See Gilbert (1984) for details on placement. Light traps with collection pans (not electrocutors) can be used in similar locations to monitor pest presence. Stored-product pests attracted to lights include Angoumois grain moth, black carpet beetle, cigarette beetle, drugstore beetle, Indianmeal moth, merchant (not sawtoothed) grain beetle, red (not confused) flour beetle, and warehouse beetle.

Pest	Trapping period	Instructions, interpretation, comments
Livestock pests		
House fly, *Musca domestica*	Throughout the summer	For mass trapping, juglike traps baited with raw meat ("stinky traps") or with a specific attractant capture many flies but often do not substantially reduce local populations. Insecticidal baits containing sugary attractants help control fly populations in and around livestock facilities; place these poison baits only where livestock, pets, and children do not have access. Sticky fly strips can reduce fly numbers in small closed areas such as milking rooms and farm offices. If a trap is to reduce house fly populations outdoors, many traps must be used (specific numbers undetermined). For all baits and traps, effectiveness should be judged by the remaining fly population, not the number of flies killed.
Stable fly, *Stomoxys calcitrans*	Throughout the summer	For monitoring or mass trapping, use alsynite panels (Olson Products) coated with adhesive. Place traps 2 to 4 ft high on stakes. Use 3 or 4 traps per feedlot for monitoring; trap density for effective mass trapping has not been determined. The effectiveness of these traps for substantially reducing stable fly populations in and around feedlots is not well established.
Horn fly, *Haematobia irritans*	May 1 to September 30	For mass trapping, use walk-through traps constructed of lumber, screen, and canvas; see Hall et al. (1987a) and Meyer et al. (1988) for plans for the construction of this trap. Place traps in a gate that cattle must pass through daily. The walk-through fly trap provides 50 to 70 percent reductions in horn fly infestations on pastured cattle.
Horse flies, *Tabanus* spp. and others	June to September	For mass trapping, use canopy traps or box traps; see Hall et al. (1987b) for information on construction. Horse flies are attracted to the dark silhouettes of these traps. Trap density for effective mass trapping has not been determined; use several traps in loafing areas. Although the overall effectiveness of canopy or box traps for substantially reducing horse fly numbers has not been well established, no other effective controls have been identified.
Household pests and nuisance pests		
Cockroaches, several species	When infestations develop	Use sticky board traps along baseboards in protected areas to detect roach infestations. Foods or dead cockroaches on the traps may make them more attractive. Small jars or cans with a 1-inch wide ring of petroleum jelly around the inside of the rim also can be used as traps; place upright along baseboards. Use baits such as beer-soaked bread, banana slices, raisins, or a mixture of dehydrated potatoes, sugar, and water to attract German cockroaches. Sticky boards and jar traps provide some control of roach populations but are intended primarily for monitoring. "Traps" containing hydramethylnon (Maxforce and Combat) are actually bait stations for use against German cockroach; these bait stations are attractive to roaches and very effective for control.

Table 3-1. (continued)

Pest	Trapping period	Instructions, interpretation, comments
Ants, several species	When infestations develop	Commercial ant traps or bait stations lure ants to an insecticide. Sweet baits are attractive to carpenter ants and pavement ants; pharaoh ants are attracted to mint jelly and other sweet and grease baits. Place traps or bait stations on ant trails but out of reach of children and pets.
Earwigs, including *Forficula auricularia* and other species	When infestations develop	Use 1-ft lengths of garden hose or rolled newspaper placed in areas where earwigs have been seen. Earwigs enter these shelters at night and can be collected and killed the next day. These traps can be used to monitor earwig infestations (to determine the effectiveness of an insecticide treatment, for example) or to provide some degree of direct control.
Yellowjackets, *Vespula* spp. and others	Summer and early autumn	Commercial traps sold for mass trapping contain N-methyl-valerate as an attractant. Homemade traps can be made by suspending a dead fish or fish-flavored cat food over a dishpan of water containing several drops of vegetable oil, mineral oil, or detergent. Wasps that take the bait become overweighted, drop into the water, and drown. Place traps several yards from main recreation areas. Although these traps kill many wasps, their effectiveness in reducing local populations is variable. Minimize yellowjacket annoyance by tightly covering garbage containers and keeping food and drink containers closed as much as possible during outdoor activities such as picnics.
Stable fly, *Stomoxys calcitrans*	Summer	See **Livestock pests**. For mass trapping, use alsynite panels (Olson Products) coated with adhesive. The effectiveness of these traps in reducing stable fly numbers is variable. For picnic areas, campgrounds, and beaches where stable flies breed in shoreline debris, use several traps (specific numbers undetermined) placed 3 to 4 ft high on stakes.
House fly, *Musca domestica*	Summer	See **Livestock pests**. For mass trapping, use sticky fly strips indoors. Strips that have already captured a few flies and strips that contain pictures of flies are most attractive. Outdoor juglike traps such as those baited with raw meat (“stinky traps”) or a specific house fly attractant usually capture many flies but often do not reduce local house fly numbers substantially.
Various insects attracted to light	Summer	Electrocuting light traps and similar devices that attract insects to ultraviolet or fluorescent light kill many night-flying insects (pests and nonpests) but usually do not reduce pest densities in outdoor (lawn) uses. See **Stored-product pests** for information about the use of these traps in warehouses and food-processing facilities. Placing outdoor lighting away from entrances and windows minimizes insect concentrations around these locations and reduces insect entry into buildings.

Additional companies produce attractants and traps; no endorsement or discrimination is intended by the listing presented here.

Companies specializing in pheromone identification and formulation

Bedoukian Research, Inc.
Finance Drive
Danbury, CT 06810

Bend Research, Inc.
64550 Research Road
Bend, OR 97701

Frank Enterprises, Inc.
700 Rose Avenue
Columbus, OH 43219

Provesta Corporation
14 C4 Phillips Building
Bartlesville, OK 74004

Distributors (retailers) of attractants, traps, and supplies

Dewill, Inc.
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Riverside, IL 60546

Great Lakes IPM
10220 Church Road, NE
Vestaburg, MI 48891

Insects Limited, Inc.
P.O. Box 40641
Indianapolis, IN 46280

Iselin and Associates
4520 S. Juniper
Tempe, AZ 85282

Pest Management Supply Co.
P.O. Box 938
Amherst, MA 01004

Manufacturers of attractants and traps

AgriSense
4230 West Swift, Suite 106
Fresno, CA 93722

Biocontrol Ltd.
538 I Street
Davis, CA 95616

Consep Membranes, Inc.
P.O. Box 6059
Bend, OR 97708

Grain Guard
205 Legion Street
Verona, WI 53593

Heron Environmental Company
Aberdeen Road
Emigsville, PA 17318

Ladd Research Industries
P.O. Box 1005
Burlington, VT 05402

Olson Products
P.O. Box 1043
Medina, OH 44258

Pherotech, Inc.
1140 Clark Drive
Vancouver, British Columbia
Canada V5L 3K3

Reuter Laboratories
8450 Natural Way
Manassas Park, VA 22111

Scentry, Inc.
P.O. Box 426
Buckeye, AZ 85326

Trece, Inc.
635 S. Sanborn Road, Suite 17
Salinas, CA 93901

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CHAPTER 4
Beneficial Insects and Mites

Many insects and related arthropods perform functions that are directly or indirectly beneficial to humans. They pollinate plants, contribute to the decay of organic matter and the cycling of soil nutrients, and attack other insects and mites that are considered to be pests. Only a very small percentage of over one million known species of insects are pests. Although all the remaining nonpest species might be considered beneficial because they play important roles in the environment, the beneficial insects and mites used in pest management are natural enemies of pest species. A natural enemy may be a predator, a parasitoid, or a competitor.

NATURAL ENEMIES OF PEST SPECIES

Predators

Predaceous insects and mites function much like other predaceous animals. They consume several to many prey over the course of their development, they are free living, and they are usually as big as or bigger than their prey. Some predators, including certain syrphid flies and the common green lacewing, are predaceous only as larvae; other lacewing species, lady beetles, ground beetles, and mantids are predaceous as immatures and adults. Predators may be generalists, feeding on a wide variety of prey, or specialists, feeding on only one or a few related species. Common predators include lady beetles, rove beetles, many ground beetles, lacewings, true bugs such as *Podisus* and *Orius*, syrphid fly larvae, mantids, spiders, and mites such as *Phytoseiulus* and *Amblyseius*.

Parasitoids

Parasitoid means parasitelike. Although parasitoids are similar to true parasites, they differ in important ways. True parasites are generally much smaller than their hosts. As they develop, parasites usually weaken but rarely kill their hosts.

In contrast, many parasitoids are almost the same size as their hosts, and their development always kills the host insect. Although parasitoids are sometimes called parasites or parasitic insects, these terms are not completely accurate. In contrast to predators, parasitoids develop on or within a single host during the course of their development.

The life cycles of parasitoids are quite unusual. In general, an adult parasitoid deposits one or more eggs into or onto the body of a host insect or somewhere in the host's habitat. The larva that hatches from each egg feeds internally or externally on the host's tissues and body fluids, consuming it slowly; the host remains alive during the early stages of the parasitoid's development. Late in development, the host dies and the parasitoid pupates inside or outside of the host's body. The adult parasitoid later emerges from the dead host or from a cocoon nearby. (See Figure 4-1.)

Most parasitoids are highly host-specific, laying their eggs on or into a single developmental stage of only one or a few closely related host species. They are often described in terms of the host stage(s) within which they develop. For example, there are egg parasitoids, larval parasitoids, larval-pupal parasitoids (eggs are placed on or into the larval stage of the host, and the host pupates before it dies), pupal parasitoids, and a few species that parasitize adult insects.

The vast majority of parasitoids are small to minute wasps that do not sting humans or other animals. Certain species of flies and beetles also are parasitoids. *Bathyplectes*, *Trichogramma*, *Encarsia*, *Muscidifurax*, *Spalangia*, and *Bracon* are some of the more important parasitoids studied or used in agricultural systems.

Competitors

Competitors are often overlooked in discussions of natural enemies, perhaps because many competitors of common crop pests also are pests themselves. Competitors can be beneficial, however, in instances where they compete with a nondamaging stage of a pest species. For example, dung beetles in the genera *Onthophagus* and *Aphodius* break up cow pats in pastures as they prepare dung to feed their larvae. This action speeds the drying of dung and makes it less suitable for the development of the larval stages of horn flies, face flies, and other pest flies. Some nonpest flies also develop in pasture dung and compete with pest species for the resources it provides. Despite these and a few other examples, the use of competitors in pest management is not common.

TYPES OF BIOLOGICAL CONTROL

Biological control, sometimes referred to as biocontrol, is the use of predators, parasitoids, competitors, and pathogens to control pests. In biological control, natural enemies are released, managed, or manipulated by humans. Without human intervention, however, natural enemies exert some degree of control on most pest populations. This ongoing, naturally occurring process is termed biotic natural control. Applied biological control produces only a small portion of the total benefits provided by the many natural enemies of pests.

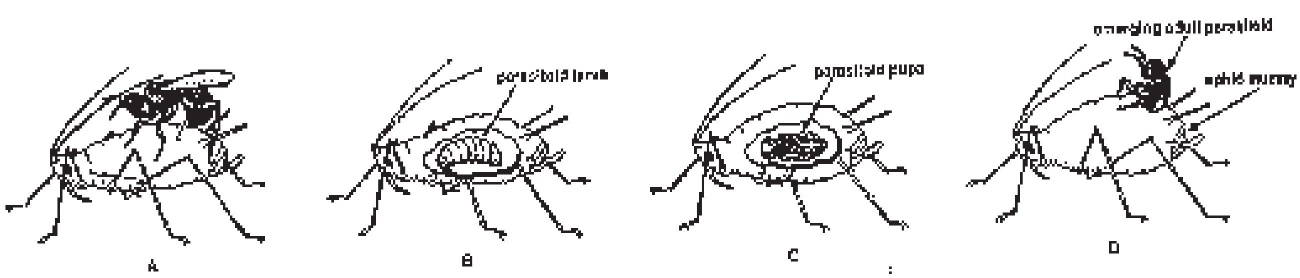
There are three basic approaches to the use of predators, parasitoids, and competitors in insect management. These approaches are (1) classical biological control—the importation and establishment of foreign natural enemies; (2) conservation—the preservation of naturally occurring beneficials; and (3) augmentation—the inundative or inoculative release of natural enemies to increase their existing population levels. Broad definitions of biological control sometimes include the use of *products* of living organisms (such as purified microbial toxins, plant-derived chemicals, pheromones, etc.) for pest management. Although these products are biological in origin, their use differs considerably from that of traditional biological control agents.

Classical Biological Control

Importing natural enemies from abroad is an important step in pest management in part because many pest insects in the United States and elsewhere were originally introduced from other countries. Accidental introductions of foreign pests have occurred throughout the world as a result of centuries of immigration and trade. Although the foreign origins of a few recently introduced pests such as the Asian tiger mosquito, Russian wheat aphid, and Mediterranean fruit fly are often noted in news stories, many insects long considered to be serious pests in this country are also foreign in origin. Examples of such pests include the gypsy moth, European corn borer, Japanese beetle, several scale insects and aphids, horn fly, face fly, and many stored-product beetles. In their native habitats, some of these pests cause little damage because their natural enemies keep them in check. In their new habitats, however, the same set of natural enemies does not exist, and the pests pose more serious problems. Importing and establishing their native natural enemies can help to suppress populations of these pests.

Importation typically begins with the exploration of a pest's native habitat and the collection of one or several species of its natural enemies. These foreign beneficials are held in quarantine and tested to ensure that they themselves will not become pests. They are then reared in laboratory facilities and released in the pest's habitat until one or more species become established. Successfully established beneficials may moderate pest populations permanently and at no additional cost if they are not eliminated by pesticides or by disruption of essential habitats.

Figure 4-1. Generalized life cycle of an aphid parasitoid. (A) Adult parasitoid wasp injects an egg into a live aphid. (B) The parasitoid larva feeds within the aphid; late in the parasitoid's development the aphid dies. (C) The parasitoid pupates within the enlarged, dry shell of the dead aphid. (D) The new adult parasitoid cuts an exit hole in the back of the aphid and flies away, leaving behind the empty "aphid mummy."



Importation of natural enemies has produced many successes. An early success was the introduction of the Vedalia beetle, *Rodolia cardinalis,* into California in 1889 for the control of cottony cushion scale on citrus. For over 100 years this predaceous lady beetle from Australia has remained an important natural enemy in California citrus groves. In Illinois, populations of *Coccinella septempunctata*, an introduced lady beetle, have become increasingly widespread in recent years. This beetle feeds on a variety of aphids, including such pests as the green peach aphid and the pea aphid. *Bathyplectes curculionis* and *Bathyplectes anurus* are introduced parasitoids that help to regulate alfalfa weevil populations in many regions. Efforts to introduce and establish natural enemies of several important Midwestern pests are ongoing.

Although the importation of new natural enemies is important to farmers, gardeners, and others who practice pest management, the scope of successful introduction projects (involving considerable expertise, foreign exploration, quarantine, mass rearing, and persistence through many failures) is so great that only government agencies commonly conduct such efforts. Introducing foreign species is not a project for the commercial farmer or home gardener.

Conservation

Conserving natural enemies is often the most important factor in increasing the impact of biological control on pest populations. Conserving or encouraging natural enemies is important because a great number of beneficial species exist naturally and help to regulate pest densities. Among the practices that conserve and favor increases in populations of natural enemies are the following:

Recognizing beneficial insects. Learning to distinguish between pests and beneficial insects and mites is the first step in determining whether or not control is necessary. This circular provides general illustrations of several predators and parasitoids. Picture sheets that feature common pests of many crops and sites can be obtained by writing Extension entomologists or county Extension offices in most states. Insect field guides are also useful for general identification of common species (see Borror and White 1970).

Minimizing insecticide applications. Most insecticides kill predators and parasitoids along with pests. In many instances natural enemies are more susceptible than pests to commonly used insecticides. Treating gardens or crops only when pest populations are great enough to cause appreciable damage or when levels exceed established economic thresholds minimizes unnecessary reductions in populations of beneficial insects.

Using selective insecticides or using insecticides in a selective manner. Several insecticides are toxic only to specific pests and are not directly harmful to beneficials. For example, microbial insecticides containing different strains of the bacterium *Bacillus thuringiensis (Bt)* are toxic only to caterpillars, certain beetles, or certain mosquito and black fly larvae. Other microbial insecticides offer varying degrees of selectivity. (See Chapter 1 in this publication for more information on microbial insecticides.)

Other insecticides that function as stomach poisons, such as the plant-derived compound ryania, do not directly harm predators or parasitoids because these compounds are toxic only when ingested along with treated foliage. Insecticides that must be applied directly to the target insect or that break down quickly on treated surfaces (such as natural pyrethrins or insecticidal soaps) also kill fewer beneficials. Leaving certain areas unsprayed or altering application methods can also favor survival of beneficials. For example, spraying alternate middles of orchard rows, followed by treating the opposite sides of the trees a few days later, allows survival and dispersal of predatory mites and other natural enemies and helps to maintain their impact on pest populations.

Maintaining ground covers, standing crops, and crop residues. Many natural enemies require the protection offered by vegetation to overwinter and survive. Ground covers supply prey, pollen, and nectar (important foods for certain adult predators and parasitoids), and some degree of protection from weather. Most studies show greater numbers of natural enemies in no-till and reduced tillage cropping systems. In addition, some natural enemies migrate from woodlots, fencerows, and other noncrop areas to cultivated fields each spring. Preserving such uncultivated areas contributes to natural biological control.

Maintaining standing crops also favors the survival of natural enemies. Where entire fields of alfalfa are cut, natural enemies must emigrate or perish. Alternate strip cutting (with time for regrowth between the alternate cutting dates) allows dispersal between strips, so natural enemies remain in the field and help to limit outbreaks of pests.

Understanding biological control requires a general knowledge of insect biology. One of the key features of insect growth and development is the process of metamorphosis.

The insect cuticle (skin) is a rigid or semirigid body covering that provides protection and support but limits growth. In order to increase in size or change form, an insect must shed its old skin and replace it with a new one through a process known as molting. Immature insects undergo two to several molts (the number differs among species) that mainly result in increases in size. Once an immature insect is fully grown, it undergoes one or two final molts to become an adult possessing wings and mature reproductive organs. The process of development from immature to adult is known as metamorphosis (meaning change in form).

There are two main types of insect metamorphosis—complete and gradual. In complete metamorphosis, the change in form from the immature stage (known as a larva) to the adult is extreme and occurs abruptly. In most cases, larvae differ greatly from adults in both physical form and life style. Because the massive changes involved in complete metamorphosis cannot be accomplished in a single molt, the fully grown larva molts first to an intermediate stage known as a pupa. Wings, reproductive structures, and other adult features begin to develop during the pupal stage. When development is complete and environmental conditions are appropriate, the pupa molts and emerges as an adult. Beetles, flies, lacewings, ants, bees, wasps, butterflies, and moths undergo complete metamorphosis. (See Figure 4-2a.)

In gradual metamorphosis, the change from immature form (in most cases known as a nymph) to adult occurs gradually from molt to molt. Nymphs differ from adults mainly in their smaller size and lack of wings and reproductive maturity. Little rearrangement of tissues is required during the last molt from nymph to adult, and there is no pupal stage. Grasshoppers, cockroaches, mantids, true bugs, and aphids are among the insects that undergo gradual metamorphosis. (See Figure 4-2b.)

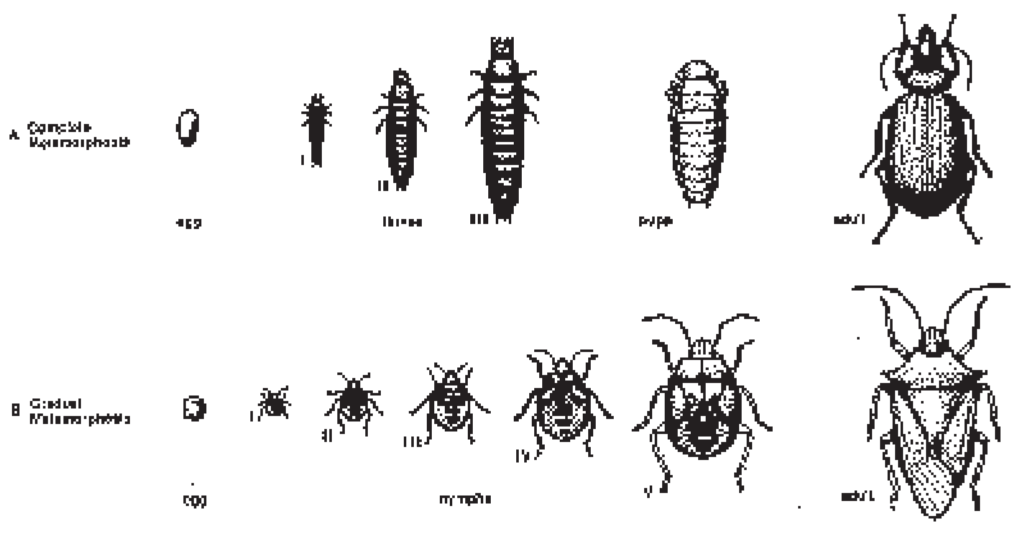


Figure 4-2. Insect metamorphosis. (A) Complete metamorphosis. The ground beetle,* Calosoma scrutator, *passes through four life stages (egg, larva, pupa, and adult) in the course of its development. Larvae are wingless and reproductively immature; in addition, their legs, mouthparts, antennae, eyes, and general body form differ from those of the adult. (B) Gradual metamorphosis. The spined soldier bug,* Podisus maculiventris, *passes through three life stages (egg, nymph, and adult). Nymphs have the same form as adults in most respects, differing mainly in their smaller size, winglessness, and reproductive immaturity.

Providing pollen and nectar sources or other supplemental foods. Adults of certain parasitic wasps and predators feed on pollen and nectar. Plants with very small flowers (such as some clovers, Queen Anne's lace, and other plants in the family Umbelliferae) are the best nectar sources for small parasitoids and are also suitable for larger predators. Seed mixes of flowering plants intended to attract and nourish beneficial insects are sold at garden centers and through mail-order catalogs. Although no published data document the effectiveness of particular commercial mixes, these flower blends probably encourage a variety of natural enemies. The presence of flowering weeds in and around fields may also favor natural enemies.

Artificial food supplements containing yeast, whey proteins, and sugars may attract or concentrate adult lacewings, lady beetles, and syrphid flies. As adults these insects normally feed on pollen, nectar, and honeydew (the sugary, amino acid–rich secretions from aphids or scale insects), and they may require these foods for egg production. Lady beetles are predaceous as adults, but some species eat pollen and nectar when aphids or other suitable prey are unavailable. The proteins and sugars in artificial foods provide enough nutrients for some species to produce eggs in the absence of abundant prey. Wheast, BugPro, Bug Chow, and PredFeed are a few of the artificial foods available from suppliers of natural enemies.

The practices listed above must be judged according to their impacts on pest populations as well as their effects on natural enemies. Practices that favor natural enemies may or may not lessen overall pest loads or result in acceptable yields. For example, reduced tillage favors beneficials but also contributes to infestations of such pests as the common stalk borer and European corn borer in corn. Moreover, tillage decisions may be influenced more by soil erosion and crop performance concerns than by impacts on pests or natural enemies. Flower blends and flowering weeds can serve as nectar sources for moths (the adult forms of cutworms, armyworms, and other caterpillar pests) as well as beneficials. The ultimate goal of conserving natural enemies is to limit pest problems and damage to crops, rather than simply to increase numbers of predators or parasitoids. Pest densities and crop performance are factors that must be included in any evaluation of the effectiveness of natural enemy conservation efforts.

Augmentation

Augmentation involves releasing natural enemies into areas where they are absent or exist at densities too low to provide effective levels of biological control. The beneficial insects or mites used in such releases are usually purchased from a commercial insectary (insect-rearing facility) and shipped in an inactive stage (eggs, pupae, or chilled adults) ready for placement into the habitat of the target pest. Augmentation is broadly divided into two categories—inoculative releases and inundative releases.

Inoculative releases involve relatively low numbers of natural enemies and are intended to inoculate or "seed" an area with beneficial insects that will reproduce. As the natural enemies increase in number, they suppress pest populations for an extended period. They may limit pest populations over an entire season (or longer) or until climatic conditions or a lack of prey results in population collapse. Generally only one or two inoculative releases are made in a single season.

In contrast, inundative releases involve large numbers of natural enemies that are intended to overwhelm and rapidly reduce pest populations. Such releases may or may not result in season-long establishment of natural enemies in the release area. Inundative releases that do not result in season-long establishment are the most expensive way to employ natural enemies because the costs of rearing and transporting large numbers of insects produce only short-term benefits. Such releases are usually most appropriate against pests that undergo only one or two generations per year.

The distinction between inoculative and inundative releases is not absolute. Many programs attempt to blend long-term establishment with short-term results. In addition, conservation and augmentation may be used together in a variety of ways to produce the best results.

INSECTS AND MITES AVAILABLE FOR PURCHASE AND RELEASE: A SELECTED LIST

The beneficial insects and mites discussed below may be purchased from insectaries or gardening and farming supply outlets. *Suppliers of Beneficial Organisms in North America,* a booklet available from the California Department of Food and Agriculture (see "Selected References"), contains a list of suppliers.

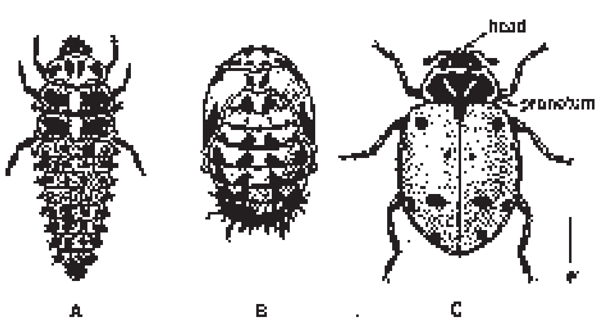
The Convergent Ladybeetle, *Hippodamia Convergens*. The convergent lady beetle is one of the best known of all insect natural enemies. The adult beetle has orange wing covers, usually with six small black spots on each side. The beetle's pronotum (the shieldlike plate often mistaken for the head) is black with white margins and two diagonal white dashes. These "convergent" dashes give this lady beetle its common name. The immature convergent lady beetle is a soft-bodied, alligator-shaped larva. It is grey and orange and is covered with rows of raised black spots (Figure 4-3).

Larval and adult convergent lady beetles feed primarily on aphids. Where aphids are not available, they may feed on scale insects; other small, soft-bodied insect larvae; insect eggs; and mites. Adults also feed occasionally on nectar, pollen, and honeydew (the sugary secretions of aphids, scales, and other sucking insects). Development from egg to adult takes 2 to 3 weeks, and adults live for several weeks to several months, depending on location and time of year.

The convergent lady beetle occurs naturally throughout much of North America. In the Midwest, adult beetles overwinter in small groups beneath bark or in other protected sites. In California, adult beetles overwinter in huge aggregations in the foothills of the central and southern mountain ranges. These California beetles are harvested from their overwintering sites, stored at cool temperatures to maintain their dormant state, and shipped to customers in the spring and summer for release in gardens or crops.

A common problem that limits the usefulness of convergent lady beetles is that they fly away soon after being released. In California, when convergent lady beetles emerge from their overwintering sites in the foothills, they disperse, seeking feeding and reproduction sites where aphids or some other suitable prey are abundant. Convergent lady beetles harvested in California and released in Midwest gardens retain this natural tendency to disperse, making them poorly suited for small-scale releases. Field-scale or communitywide releases of convergent lady beetles for control of heavy aphid outbreaks are likely to be more useful than backyard garden releases for control of minor pest problems.

Figure 4-3. The convergent lady beetle, **Hippodamia convergens.** *(A) Larva. (B) Pupa. (C) Adult.*
**Bar indicates actual length of insect.*



Convergent lady beetles provide long-term, adequate aphid control in a release area only if they reproduce. Several factors influence reproduction. Adult female beetles harvested from overwintering sites cannot produce eggs until they have fed on prey. In addition, they lay their eggs only where prey are abundant enough to sustain the resulting larvae. Because adults are able to fly, they tend to disperse in search of more abundant prey when aphid populations fall below a critical threshold. If they disperse without laying eggs, the aphids that are left behind may build up to damaging levels. If the lady beetles lay eggs before dispersing, the resulting larvae continue to control aphids when the adults are gone. Larvae provide better aphid control than adults because they cannot fly away when aphid populations are low.

Despite problems with dispersal, the convergent lady beetle is widely advertised in gardening supply catalogs for small-scale releases. Suppliers recommend release rates ranging from 1 pint to 1 quart of beetles per home garden, and from 1 gallon of beetles per acre to 1 gallon per 15 acres for field-scale releases. The basis for these release rates is unclear.

Making releases at dusk (lady beetles do not fly at night) and watering the release site so that plenty of moisture is available may increase the chances that the lady beetles will remain in the area. Some distributors recommend spraying the beetles with a dilute soft drink solution to glue their wing covers down temporarily (to prevent flying), or providing the beetles with artificial foods such as Bug Chow, BugPro, or Wheast. Whether or not these approaches help to keep lady beetles near the site of release is not clear.

The Mealybug Destroyer, *Cryptolaemus Montrouzieri*. The mealybug destroyer is an Australian lady beetle. The adult is a small (about 4 mm), round, black beetle with an orange pronotum and orange wing tips. The larva is covered with a shaggy, white, waxy material, and resembles its mealybug hosts when small (Figure 4-4). As its common name implies, the mealybug destroyer feeds on all species of aboveground mealybugs including the citrus mealybug (*Planococcus citri*), which is a serious pest of ornamental plants in greenhouses and interior plant-

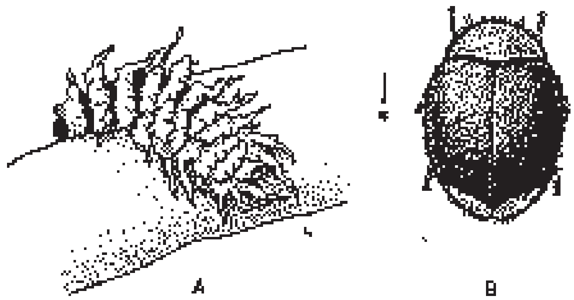


Figure 4-4. The mealybug destroyer, **Cryptolaemus montrouzieri.** ***(A) Larva. (B) Adult.   * Actual length.***

scapes. If mealybugs are not available, the mealybug destroyer may feed on aphids and immature scale insects. Both larvae and adults are predaceous.

Adult mealybug destroyers lay hundreds of eggs, depositing them singly in mealybug egg masses. Each beetle larva may consume more than 250 immature mealybugs in the course of its development. The mealybug destroyer requires high mealybug populations and optimum environmental conditions in order to reproduce and is most effective for quick reductions of heavy mealybug infestations.

Development and reproduction of the mealybug destroyer occur most rapidly at temperatures between 22º and 25ºC (72º and 77ºF), and relative humidities of 70 to 80 percent. Temperatures below 20ºC (68ºF) and short days slow the reproductive rate of this predator but do not have as much effect on mealybug reproductive rates. As a result, the mealybug destroyer is often unable to control mealybug infestations during winter months in greenhouses or other facilities where temperature and day length are reduced. Suppliers recommend releases of one beetle per 2 square feet of planted area or two to five beetles per infested plant. Mealybug populations should not be reduced by insecticidal sprays prior to beetle releases. Although the mealybug destroyer is widely advertised, supplies are often limited due to difficulties in maintaining colonies.

The Green Lacewings, *Chrysoperla* (Formerly *Chrysopa*) *Carnea* and *Chrysoperla Rufilabris.* Green lacewings occur naturally throughout North America and are widely available for purchase and release. Adult green lacewings have delicate, light green bodies; large, clear wings; and bright golden or copper-colored eyes. The larvae are small, grayish brown, and elongate and have pincerlike mandibles. Green lacewing eggs are found on plant stems and foliage. They are laid singly or in small groups on top of fine, silken stalks which reduce predation and parasitism by keeping the eggs out of reach (Figure 4-5).

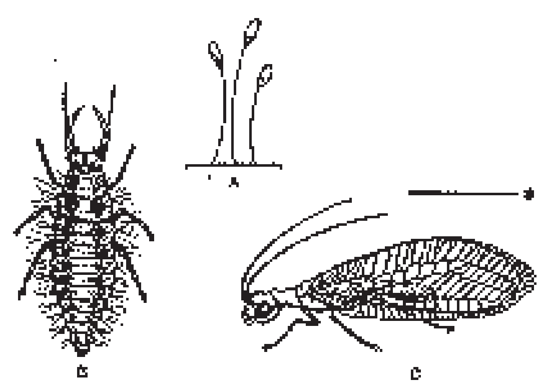
Green lacewing larvae are generalist predators of soft-bodied insects, mites, and insect eggs, but they feed primarily on aphids and are commonly known as “aphid lions.” Lacewing larvae are also cannibalistic, feeding readily on other lacewing eggs and larvae if prey populations are low. Larvae feed for about 3 weeks before pupating inside silken cocoons that are usually attached to the undersides of leaves.

Although adults of some lacewing species are predaceous, *Chrysoperla carnea* adults feed only on nectar, pollen, and aphid honeydew. *Chrysoperla carnea* females cannot produce eggs if these foods are not available. Green lace-wing adults make long dispersal flights soon after emerging from the pupal stage; this dispersal takes place regardless of the availability of food when the adults emerge. Lacewings are night fliers and may travel many miles before mating and starting to produce eggs. Females are mobile throughout their egg-laying period, although they concentrate where nectar and honeydew are abundant. They tend to lay eggs wherever they land to feed or rest.

Artificial foods such as Bug Chow, BugPro, Wheast, or PredFeed can be used in place of natural foods (nectar and honeydew) to attract and concentrate adult lacewings. The presence of artificial foods does not keep newly emerged adults from dispersing, but such foods may attract older adults that are in the area. Food sprays are useful only when a substantial population of lacewings is present in the area.

Lacewings are usually purchased as eggs. They are shipped in a mixture of rice hulls and frozen (killed)

Figure 4-5. The common green lacewing, **Chrysoperla carnea.** ***(A) Eggs. (B) Larva, commonly known as an “aphid lion.” (C) Adult.   * Actual length.***



SOME BASIC PRINCIPLES OF BIOLOGICAL CONTROL

The actions of natural enemies can be manipulated by the timing and magnitude of releases and by habitat management. Unlike insecticides, however, natural enemies are living organisms with biological needs and behavioral traits that may conflict with the goals or constraints of pest management programs. Success with natural enemies depends on understanding and accommodating their biological and evolutionary limitations.

Natural Enemies Survive Better in Stable Environments

Many pests colonize annual crops or temporary habitats rapidly. In contrast, most natural enemies colonize such habitats slowly. Where crop residues are frequently removed and soil is disturbed by tillage, or where insects are nearly eliminated by the use of insecticides, the rebuilding of natural enemy populations tends to lag behind the regrowth of pest populations. Consequently, naturally occurring predators and parasitoids are more prevalent and more easily maintained in perennial crops (such as alfalfa, pasture grasses, and orchard crops) than annual crops. Providing a more stable environment by using reduced tillage, ground covers, or strip harvesting contributes to the survival of a range of natural enemies, both naturally occurring and introduced. These practices may also favor certain pests, however, and each must be evaluated according to its overall benefits and drawbacks.

Natural Enemies Usually Leave a Moderate Pest Residue

As natural enemies reduce pest population densities, it becomes increasingly difficult for them to locate and attack the few surviving pests. When pest population densities become too low, natural enemies often leave the pest residue (the remaining pest population) and disperse in search of more abundant hosts or prey. In the absence of predators or parasitoids, the remaining pest population rebuilds, providing hosts or prey for subsequent generations of natural enemies. This cycling of populations allows the natural enemies and their hosts to avoid extinction. Exceptions to this rule occur in greenhouses, for example, where natural enemies are confined with their hosts or prey and cannot disperse when pest population densities fall.

The occurrence of moderate pest residues may or may not limit the use of biological control. Where nearly 100 percent control is necessary, natural enemies alone usually do not provide sufficient control. This is the case with certain pests of commercial fruits and vegetables, cut flowers, ornamentals, and other commodities for which current cosmetic or grade standards are very strict. In many situations, however, moderate levels of pest infestation are acceptable. This is true for most pests of gardens, lawns, and field crops. In these settings natural enemies may provide acceptable levels of control.

Control by Natural Enemies Takes Time

Unlike insecticides, which are uniformly applied and have nearly immediate effects on pest populations, natural enemies require time to disperse from release sites, search for hosts or prey, and handle (consume or lay eggs into) each host or prey individually. In some cases, the natural enemies that are released must reproduce before a significant degree of control occurs. Consequently, where commodities must be rapidly disinfested or protected from a pest that is already causing serious losses, predators and parasitoids do not (or only rarely) provide sufficiently rapid control.

Determining the correct timing for releases is one of the most important steps in the implementation of biological control. Because natural enemies do not provide immediate control, they usually must be released before severe damage is imminent. Preventive releases, however, are almost never appropriate or effective because natural enemies die or disperse in the absence of hosts or prey. In general, releases should begin when pest populations are substantial enough to sustain the natural enemy but low enough to allow the natural enemy time to catch up and provide an adequate degree of control. Knowledge of pest development and careful monitoring of pest populations are key factors in determining when to make releases.

Natural Enemies Are Products of Evolution, Not Manufacturing

In evolutionary terms, the success of a natural enemy is defined by its ability to survive as a species. This survival depends on the continued availability of the natural enemy's host or prey. In pest management terms, however, the success of a natural enemy is defined by the degree to which it controls its host or prey. Where high levels of control are required, naturally selected behaviors that result in moderate pest residues and guarantee species survival may prevent predators and parasitoids from "succeeding" in pest management terms. Rearing and releasing greater numbers of natural enemies does not always overcome these limitations.

Traits such as host or prey preferences, host-finding behaviors, dispersal thresholds, climatic dependencies, habitat preferences, and sensitivity to insecticides are genetically determined. Some of these traits—climatic tolerances and insecticide resistance, in particular—can be manipulated through selective breeding. In addition, some trait selection may occur unintentionally during mass rearing. Continuous rearing of natural enemies in insectaries can select for undesirable traits such as a preference for hosts other than the target pests or a lack of vigor under field conditions. Many traits, however, are difficult to alter and must be accommodated when developing biological control programs.

Rearing and releasing natural enemies is much more complicated than spraying an insecticide. Consequently, attempts to use natural enemies without understanding their behavior often result in failure and disappointment. However, when natural enemies are used in ways that accommodate their strengths and weaknesses, they can become effective components of integrated pest management programs.

caterpillar eggs. The caterpillar eggs provide food for the larvae that hatch during shipment, and the rice hulls keep the larvae separated to minimize cannibalism. Lacewings shipped in this manner are meant to be released as soon as hatching begins. Some insectaries offer lacewing eggs in sufficient quantities for aerial application to fields or orchards.

For small-scale gardens, suppliers recommend release rates of one to five lacewing eggs per square foot of garden space. For field crop or orchard releases, recommendations range from 50,000 to 200,000 lacewing eggs per acre. Releases are made singly or sequentially at 2-week intervals, depending on the pest to be controlled. In field trials for control of various caterpillar and aphid pests in cotton, corn, and apples, lacewing releases at these rates have provided high levels of control and significant protection of yields in some cases. However, the costs of purchasing and releasing high numbers of lacewing eggs may be prohibitive for commercial use.

Lacewing larvae are naturally tolerant of low rates of several insecticides, including azinphos-methyl (Guthion), dimethoate (Cygon), trichlorfon (Dylox), carbaryl (Sevin), permethrin, pyrethrin, rotenone, and ryania. Larvae are highly susceptible to many other insecticides, however, and adults tend to be more susceptible than larvae in all cases.

Chrysoperla carnea, the common green lacewing, is the most widely available lacewing species. It is sold for general field and garden releases. *Chrysoperla rufilabris* is an eastern lacewing species that is better adapted for use in tree crops. *Chrysoperla rufilabris* adults are predaceous to a limited extent.

The Spined Soldier Bug, *Podisus Maculiventris.* The spined soldier bug is the only predaceous "true bug" (order Hemiptera) available for purchase. It occurs naturally throughout the Midwest and is one of the most common predatory stink bugs throughout much of the country.

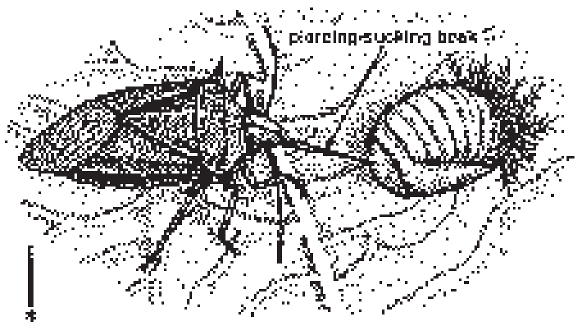


Figure 4-6. An adult spined soldier bug, **Podisus maculiventris,** ***feeding on a Mexican bean beetle pupa. * Actual length.***

Figure 4-7. The Chinese praying mantid, **Tenodera aridifolia sinensis.** ***(A) Egg case with newly hatched nymphs. (B) Adult.***

The adult spined soldier bug is grayish brown with sharply pointed "corners" on its pronotum. Nymphal soldier bugs are various shades of orange with black markings. They are round bodied and wingless. Nymphs and adults stab their prey with long, pointed "beaks" that are held folded under their bodies while not feeding. (See Figures 4-1 and 4-6.)

Although the spined soldier bug is sold mainly as a predator of Mexican bean beetle (*Epilachna varivestis*) larvae, it is a generalist that feeds readily on many soft-bodied insects and larvae. Spined soldier bug nymphs and adults feed on the same kinds of prey, and if ample prey is available these predators may provide some degree of control for several weeks after the initial release (they are sold as nymphs). At this time there are no adequate guidelines for release rates.

Praying Mantids. Although several mantid species occur naturally in the southern U.S., many of the species found commonly in the Midwest were originally introduced from the tropics. In the fall, adult female mantids produce egg cases that may contain up to two hundred eggs. These eggs remain dormant until early summer when tiny mantid nymphs hatch and begin to search for prey. Only one generation of mantids develops each year.

Mantid nymphs and adults are indiscriminate generalist predators that feed readily on a wide variety of insects, including many beneficial insects and other mantids. Older mantids feed on medium-sized insects such as flies, honey bees, crickets, and moths. They are not effective predators on aphids, mites, or most caterpillars. Most of the mantids that hatch from an egg case die as young nymphs as a result of starvation, predation, or cannibalism. In addition, mantids are territorial, and by the end of the summer often only one adult is left in the vicinity of the original egg case.

Although mantids are fascinating to watch in action, they are nearly useless for pest control in home gardens because of their indiscriminate appetites and poor survival rate. Nevertheless, they are widely advertised for sale to home gardeners. Mantids are sold as egg cases, and prices vary greatly from one supplier to the next. The Chinese praying mantid, *Tenodera aridifolia sinensis*, is the species that is most commonly available for purchase. (See Figure 4-7.)

Predators of Spider Mites. Mites in the genera *Phytoseiulus* and *Amblyseius* are fast-moving, pear-shaped predators with short life cycles (from 7 to 17 days, depending on temperature and humidity) and high reproductive capacities. They are pale to reddish in color and can be distinguished from twospotted spider mites by their long legs, lack of spots, and rapid movement when disturbed. The eggs of predatory mites are elliptical and larger than the spherical eggs of spider mites (see Figure 4-8). Predatory mite nymphs feed on spider mite eggs, larvae, and nymphs. Adult predators feed on all developmental stages of spider mites.

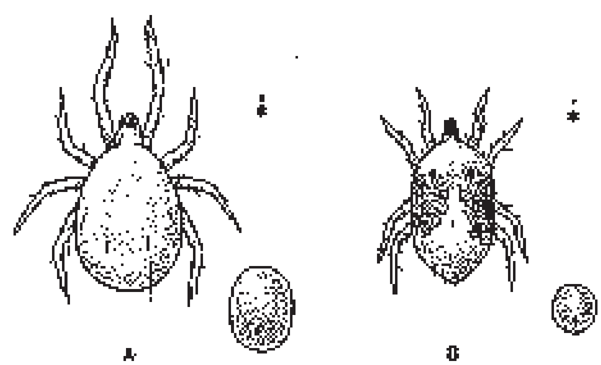


Figure 4-8. (A) A predatory mite, **Phytoseiulus persimilis,** ***adult and egg. (B) The twospotted spider mite,*** **Tetranychus urticae,** ***adult and egg. * Actual size.***

Several species of predatory mites are sold by U.S. distributors, but the only species that has been studied extensively for use on a commercial scale is *Phytoseiulus persimilis*. This mite develops, reproduces, and preys on spider mites most effectively in a temperature range of 21° to 27°C (70 to 80°F), with relative humidities of 60 to 90 percent. Above and below these ranges, *Phytoseiulus persimilis* is less able to bring twospotted spider mite populations under control.

Most of the scientific literature on the use of *Phytoseiulus persimilis* in greenhouses deals with commercial production of tomatoes and cucumbers in Great Britain and the Netherlands. Evaluating European research results and biological control programs for use in U.S. greenhouses is difficult. In the U.S., many greenhouses are used to produce flowers or ornamental plants rather than vegetables. The degree of spider mite control needed for ornamentals is generally much higher than it is for vegetables. In addition, production practices in U.S. greenhouses differ from those in Europe. (See Osborne et al. 1985).

In the U.S., insectaries generally recommend releasing *Phytoseiulus persimilis* when there are one or fewer spider mites per leaf throughout a greenhouse. If spider mite populations exceed that level, application of an insecticidal soap or other nonresidual insecticide is recommended to reduce the infestation before the predatory mites are released. Some insectaries recommend spot introductions to control patchy spider mite infestations, while others recommend systematic uniform introductions. The best method probably depends on the distribution of the twospotted spider mite. Release rate recommendations range from 2 to 30 *Phytoseiulus persimilis* per plant, depending on the stage and susceptibility of the crop. Some experimentation may be necessary to determine the appropriate release rate and method for specific situations. (See Table 4-1 for further information.)

In Europe, twospotted spider mites are sometimes introduced intentionally to greenhouse crops at a low, even rate soon after planting; this is followed some days later by a uniform release of *Phytoseiulus persimilis*. This "pest-in-first" method allows the predatory mites to become established throughout the greenhouse before natural spider mite outbreaks occur in isolated spots. Another alternative is to introduce spider mites and *Phytoseiulus persimilis* simultaneously at the start of the growing season. These techniques have been more consistently successful than attempts to introduce the predatory mite only after natural infestations have been detected.

Phytoseiulus longipes and *Amblyseius californicus* are also sold in the U.S. for control of twospotted spider mites. *Phytoseiulus longipes*, an African species, tolerates temperatures up to 38°C (100°F) if humidity is high; it can tolerate low relative humidities (down to 40 percent) at 21°C (70°F). *Amblyseius californicus* occurs naturally in California, the Mediterranean, and several other regions of the world. It is an important predator of pest mites in California strawberry fields and is used extensively for greenhouse releases. *Amblyseius californicus* also tolerates higher temperatures (up to 32°C/90°F). It consumes mites at a slower rate than *Phytoseiulus* species, but is able to tolerate short periods of starvation when spider mite densities are low. Mixed releases of *Phytoseiulus persimilis* and *Amblyseius californicus* function well in greenhouses where conditions and pest mite population densities are variable.

Thrips Predators. In addition to spider mite predators, two species of predatory mites feed primarily on thrips. *Amblyseius cucumeris* and *Amblyseius mckenziei* (also known as *Amblyseius barkeri*) feed on the western flower thrips (*Frankliniella occidentalis*) and the onion thrips (*Thrips tabaci*), both of which may be serious pests in greenhouses. If introduced early in an infestation, these mites can eliminate thrips populations in greenhouses.

Amblyseius cucumeris and *Amblyseius mckenziei* can subsist for short periods on pollen, fungi, or spider mite eggs when thrips are not available. These mites require high relative humidities and are not tolerant of insecticides. Short days inhibit egg production by predatory mites, making thrips control difficult during winter months.

U.S. suppliers recommend high release rates of *Amblyseius cucumeris* and *Amblyseius mckenziei* for control of thrips. For control of *Thrips tabaci* on sweet peppers, suppliers recommend releasing 10 predatory mites per plant plus an extra 25 mites per infested leaf throughout the greenhouse. For cucumbers, the recommended rate is 50 predatory mites per plant plus an extra 100 per infested leaf. For both crops, distributors recommend that introductions be made weekly until there is one predatory mite for every two thrips. The efficacy of these release rates is difficult to evaluate because very little published research on *Amblyseius cucumeris* or *Amblyseius mckenziei* exists. Literature from Europe indicates that control may be possible with lower release rates.

Parasitoids

***Encarsia Formosa*, a Parasitoid of the Greenhouse Whitefly.** *Encarsia formosa*, a tiny parasitic wasp, has been used to control greenhouse whiteflies on tomatoes and cucumbers in Europe for over 50 years. *Encarsia* adults lay their eggs into the scalelike third and fourth nymphal stages of whiteflies (see Figure 4-9a). Parasitized whitefly nymphs blacken and die as the parasitoid larva develops inside. Adult wasps provide additional whitefly control by feeding directly on early and late nymphal stages.

Encarsia performs best when greenhouse temperatures are maintained between 21° and 26°C (70° and 80°F), with relative humidities of 50 to 70 percent. In these conditions, *Encarsia* reproduces much faster than the whitefly. At lower temperatures the whitefly reproduces more rapidly than the parasitoid, and *Encarsia* may not provide adequate control. In addition, *Encarsia* requires bright light for optimum reproduction and development. This dependence on light intensity further limits the parasitoid's effectiveness during winter months when day length is shorter and light intensities are lower.

Numerous release schedules have been developed for *Encarsia*. As with predatory mites, most of the research and practical information on *Encarsia* has come from Great Britain and the Netherlands and involves commercial tomato and cucumber production. In these countries the "pest-in-first" method (introducing the pest at low levels before releasing the natural enemy) is commonly used for whitefly control. Where this approach is not used, *Encarsia* must be released at the very first sign of whitefly infestation. As with releases of predatory mites for spider mite control, the degree of whitefly control provided by *Encarsia* is not likely to be sufficient for production of commercial ornamentals.

Most U.S. *Encarsia* suppliers recommend that releases be made when there is an average of less than one adult whitefly per upper leaf (regardless of plant species) on all plants throughout the greenhouse. Introductions should be made sequentially (usually at 2-week intervals) for several weeks in order to control immature whiteflies as they hatch. Release rates range from one to five wasps per square foot or from one to eight per plant, depending on plant species and the severity of the infestation. Evidence of parasitism by *Encarsia* (presence of blackened whitefly scales) becomes apparent 2 to 3 weeks after the initial release, and whitefly populations are usually reduced to low levels within 2 to 3 months. After *Encarsia* has become established in a greenhouse, it continues to reproduce and control whitefly populations as long as conditions are favorable and the whitefly is present. (See Table 4-1 for further information.)

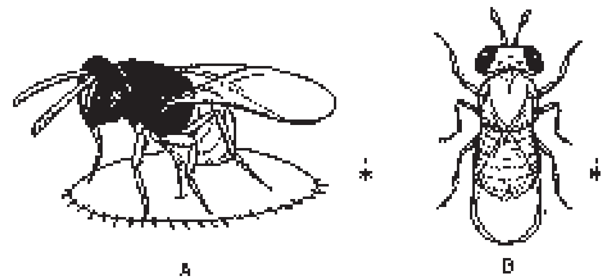


Figure 4-9. (A) An adult female* Encarsia formosa *depositing an egg into the scalelike fourth nymphal stage of the greenhouse whitefly. (B) An adult* Trichogramma *wasp. * Actual length.

***Trichogramma* Wasps, Egg Parastioids.** The *Trichogramma* wasps are the most commonly used parasitoids worldwide. They are released extensively in Europe and Asia for the control of many species of caterpillar pests in various crops. *Trichogramma* wasps are very small, averaging about 0.7 mm long as adults (the size of the period at the end of this sentence; see Figure 4-9b).

Most *Trichogramma* species lay their eggs into the eggs of moths and butterflies. A few species parasitize eggs of other kinds of insects. *Trichogramma* larvae develop within host eggs, killing the host embryos in the process. Instead of a caterpillar hatching from a parasitized egg, one or more adult *Trichogramma* wasps emerge. Because the caterpillar pests are killed in the egg stage, no feeding damage occurs. This makes *Trichogramma* an especially important natural enemy for control of pests such as codling moth larvae, European corn borers, and corn earworms, all of which bore into plant tissues and cause economic damage soon after hatching.

There are many species of *Trichogramma*, and each prefers different hosts. Although several *Trichogramma* species are generalist parasitoids, many parasitize only one or a few related species. Three species are commonly available for purchase and release in the U.S. *Trichogramma pretiosum*, sold for control of caterpillar pests in field crops, vegetables, and stored grain, is capable of parasitizing more than 200 species of caterpillar eggs (although it is not equally effective against all of those species). *Trichogramma minutum* is sold for control of orchard and forest caterpillars. The third species, *Trichogramma platerni*, parasitizes a caterpillar pest of avocadoes and is not useful in the Midwest. *Trichogramma nubilale*, a species currently under research, shows promise as an effective parasitoid of the European corn borer; it is not yet available for purchase.

Success with *Trichogramma* is extremely variable. In research trials, it has been used in single or sequential releases at rates of 50,000 to 300,000 wasps per acre per release. *Trichogramma* wasps are usually released as mature pupae inside host eggs. Adult wasps emerge within 1 to 3 days of release and are active for about 9 days. If a mixture of larval-stage and pupal-stage parasitoids is released, activity is extended by several days. Releases are usually timed to correspond with the start of egg laying by the pest, as determined by pheromone trapping or other monitoring methods. (See Table 4-1.)

The size and host-finding ability of *Trichogramma* wasps are partially dependent on the species of host egg within which the wasps are reared. Most insectaries rear *Trichogramma* in the eggs of the Angoumois grain moth, *Sitotroga cerealella*, because this moth is easy to rear inexpensively in large numbers. Angoumois grain moth eggs are very small, however, and the resulting parasitoids may also be small and not well suited to locating and parasitizing eggs of other target pest species when released in the field. Locally collected species or strains of *Trichogramma* reared on the intended target host are more likely to be successful for field releases than exotic species; however, rearing facilities do not provide customized regional production.

Filth Fly Parasitoids, *Muscidifurax* and *Spalangia* Species. Most parasitoids sold for use in the biological control of filth flies around livestock and poultry are wasps in the genera *Muscidifurax* and *Spalangia*.

Adult wasps in these genera are less than 2.5 mm long. They deposit their eggs in or on fly pupae located in manure or other breeding sites. These wasps parasitize both house fly and stable fly pupae, but different species exhibit different host or habitat preferences.

Studies of the effectiveness of releasing parasitoids for fly control have produced mixed results, and the use of parasitoids for the control of filth flies must be considered somewhat experimental. Nonetheless, several key findings can serve as guidelines for release programs.

The parasitoid species most likely to contribute to the control of house flies in cattle feedlots are *Muscidifurax raptor* and *Muscidifurax zaraptor*. For the control of stable flies in feedlots, *Spalangia nigroaenea* and *Spalangia cameroni* are most likely to provide benefits. (These two *Spalangia* species also parasitize house flies, but not as frequently as the *Muscidifurax* species.) Two commonly sold parasitoids are very unlikely to provide any benefit in feedlots; neither *Nasonia vitripennis* nor *Spalangia endius* parasitized a significant percentage of house flies or stable flies when released in large numbers in studies conducted in Midwest (Kansas and Nebraska) feedlots. Because these two parasitoids are distributed by several companies but are unlikely to provide any significant fly control in feedlots, cattle producers are cautioned not to purchase "generic" fly parasitoids that are not identified by species.

Significant control of stable flies requires releases of 50 to 100 *Spalangia nigroaenea* or *Spalangia cameroni* per animal per week. Simultaneous weekly releases of 50 to 100 *Muscidifurax raptor* or *Muscidifurax zaraptor* per animal are necessary for house fly control. Although these release rates exceed most suppliers' recommendations, they still can be economically feasible.

Parasitoids can be used effectively for house fly control in poultry facilities, especially those with concrete floors. *Muscidifurax raptor*, *Muscidifurax zaraptor*, *Spalangia cameroni*, *Spalangia nigroaenea*, and *Spalangia endius* parasitize house fly pupae in poultry buildings. *Pachycrepoideus vindemiae*, also useful in poultry buildings, is available from some insectaries. Release rates for the use of these parasitoids in poultry depend upon house construction and manure management, but a general recommendation is the weekly release of one parasitoid per two birds. Practices that minimize moisture problems (fixing leaks and improving drainage) help to lower the moisture content of manure accumulations and contribute to parasitoid buildup and fly control. Removing only a portion of the manure (for example, under alternate rows of cages) at any one time also favors parasitoid success.

SOME COMMON INTRODUCED OR NATURALLY OCCURRING BENEFICIAL INSECTS AND MITES

Few guidelines exist for monitoring populations of natural enemies and determining their likely impacts on pest infestations. Nonetheless, recognizing the beneficials that are present in any situation and understanding their roles are useful steps in deciding on appropriate pest management practices. Some common, naturally occurring species are described below.

Predators

Lady Beetles (Family Coccinellidae). Beetles in the family Coccinellidae are known as lady beetles, though they are commonly referred to as "ladybugs." There are more than 400 species of lady beetles in North America, ranging in color from the familiar orange with black spots to various shades of red and yellow to jet black. The vast majority of lady beetles are beneficial predators of soft-bodied insects (aphids and scale insects in particular), mites, and insect eggs. In each species, adults and larvae consume similar prey and generally can be found together where their prey is abundant. Most species of lady beetles are not available for purchase and release, but many of them provide significant levels of pest control if they are not eliminated by insecticides, tillage, or other land-use practices.

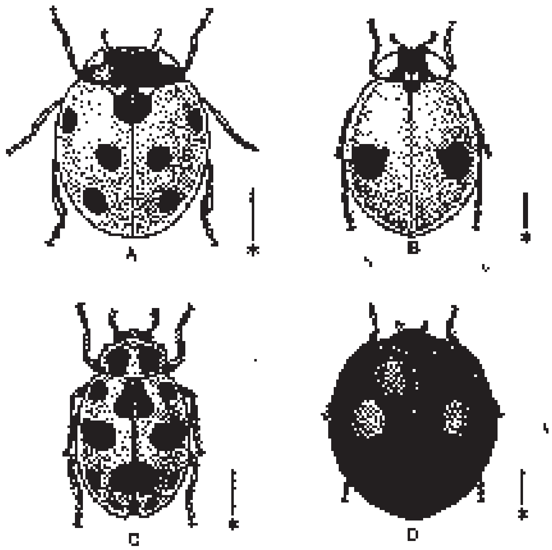


Figure 4-10. Some important Illinois lady beetles. (A) C-7, **Coccinella septempunctata.** *(B) The twospotted lady beetle,* **Adalia bipunctata.** *(C) The spotted lady beetle,* **Coleomegilla maculata.** *(D) The twice-stabbed lady beetle,* **Chilocorus stigma.** ** Actual length.*

Coccinella septempunctata, referred to as "C-7" for its seven spots, is a Eurasian lady beetle that was introduced into the U.S. several times in the 1970s and 1980s. Now common in several Midwest states, it is a significant natural enemy of several important aphid species, including the pea aphid and the green peach aphid. (See Figure 4-10a.)

Other common aphid-feeding lady beetles found in the north-central states include the convergent lady beetle (*Hippodamia convergens,* Figure 4-3), the twospotted lady beetle (*Adalia bipunctata*, Figure 4-10b), and the spotted lady beetle (*Coleomegilla maculata,* Figure 4-10c). *Coleomegilla maculata* may play a key role in limiting European corn borer populations by feeding on corn borer egg masses. The twice-stabbed lady beetle (*Chilocorus stigma,* Figure 4-10d) is a predator of many species of scale insects.

Stethorus punctum—an important predator of spider mites in apple orchards throughout Michigan, Pennsylvania, and western New York—is found sporadically in Illinois. Adults are tiny (3 mm), round, shiny, black beetles. Both adults and larvae feed on mites, and they are most often found where spider mite populations are high (15 or more mites per leaf). Adults overwinter in debris at the base of apple trees or in fields or wooded areas near orchards. Although *Stethorus punctum* is susceptible to standard rates of most orchard insecticides and miticides, adults are mobile and can fly into orchards after spray residues have declined.

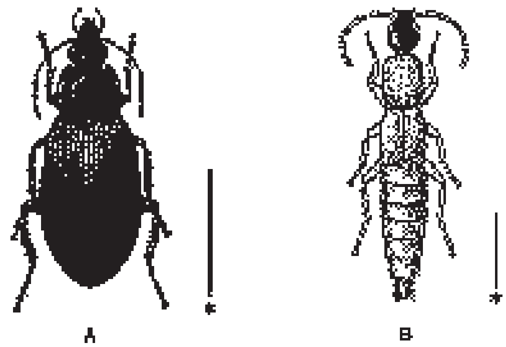


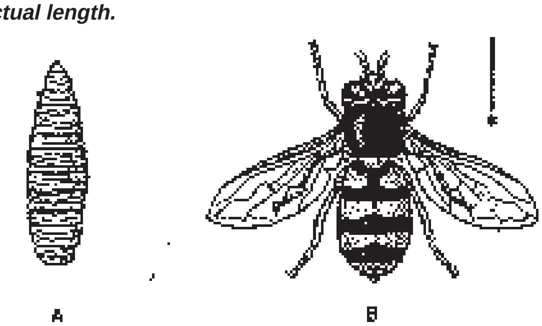
*Figure 4-11. (A) A ground beetle, Family Carabidae. (B) A rove beetle, Family Staphylinidae. * Actual length.*

Ground Beetles (Family Carabidae) and Rove Beetles (Family Staphylinidae). Adult and larval ground beetles and rove beetles prey on a wide range of insects and are especially important as predators of caterpillars and other soft-bodied insects in field crops, forests, and many other habitats. Together these two families of beetles include nearly 5,000 species that are widely distributed throughout North America. (See Figure 4-11.)

Both ground beetles and rove beetles are commonly found under plant debris and beneath the soil surface. Many species are nocturnal (active at night) and as a result are not as apparent as other natural enemies. Some of the larger species of ground beetles can be found in trees, where they prey on various caterpillar pests, including tent caterpillars, tussock moth larvae, and gypsy moth larvae. Ground beetles and rove beetles, along with spiders, are the most common predators found in many field crops.

Syrphid, Flower, or Hover Flies (Family Syrphidae). Syrphid flies are common in many habitats. The small, wormlike larvae of many species are found on foliage, where they prey on aphids. Adult syrphid flies feed on pollen and nectar. The adults of many species closely resemble bees or wasps but do not sting or bite. (See Figure 4-12.)

*Figure 4-12. A syrphid fly. (A) Larva. (B) Adult. * Actual length.*



True Bugs (Order Hemiptera) Many species of true bugs are predaceous, and several play important roles in the control of agronomic pests. The minute pirate bug (*Orius insidiosus*, Figure 4-13a) feeds on the eggs of caterpillar pests in corn and other crops; it also feeds on many other small soft-bodied insects. The big-eyed bugs (*Geocoris* species, Figure 4-13b) also prey on caterpillar eggs and other small insects. Damsel bugs (*Nabis* species, Figure 4-13c) are common in gardens and crops, where they feed on aphids and other pests.

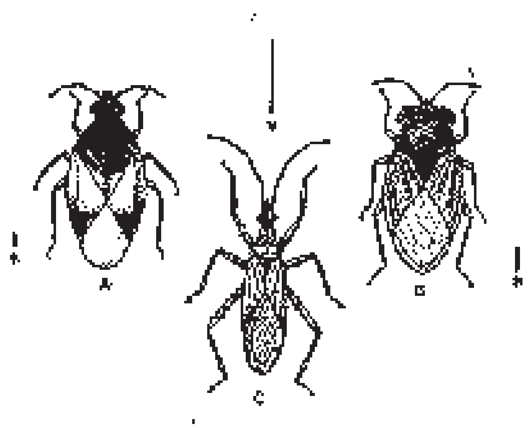


Figure 4-13. Some important Illinois predaceous bugs. (A) The minute pirate bug,* Orius insidiosus. *(B) A big-eyed bug,* Geocoris *species. (C) The common damsel bug,* Nabis americoferus. ** Actual length.

Predatory Mites (Family Phytoseiidae) Several important predatory mites prey on pest mites in apple orchards. In some areas, integrated mite management programs have been developed to take advantage of these naturally occurring predators.

Amblyseius fallacis, sometimes called the "fallacis mite," is the most important predatory mite in Illinois apple orchards. It overwinters along with twospotted spider mites in ground cover and debris beneath apple trees. In early summer *Amblyseius fallacis* follows the movement of the twospotted spider mite up into the apple tree canopy. Once in the canopy, *Amblyseius fallacis* feeds on all species of pest mites (the European red mite and the apple rust mite, as well as the twospotted spider mite).

Mite management programs call for early season oil sprays to control the European red mite (as well as San Jose scale and apple aphids) when necessary. Then oil sprays should be discontinued during summer months after *Amblyseius fallacis* and the twospotted spider mite have moved up into the canopy. These programs include guidelines for sampling pest and predatory mite populations to determine whether populations of *Amblyseius fallacis* are sufficient to control pest mites adequately. (See Croft 1975 and van Driesche et al. 1989.) Some populations of *Amblyseius fallacis* have developed resistance to low levels of azinphos-methyl (Guthion) and phosmet (Imidan), two organophosphate insecticides commonly used in apple orchards for control of the codling moth.

Parasitoids

Parasitoids are very common as naturally occurring biological control agents, with more than 8,500 species of parasitic wasps and flies occurring in North America. Despite their prevalence and importance, parasitoids go largely unnoticed because of their small size and inconspicuous behavior. A detailed discussion of individual, naturally occurring parasitoid species is beyond the scope of this chapter. For useful background information and specific details on selected parasitoids, see Askew (1971), Clausen (1940), and De Bach (1964).

SUMMARY

Biological control is a complex subject that can be presented only superficially in a publication of this length. Successful use of natural enemies in pest management requires detailed understanding of insect biology and pest management techniques. In addition, it requires realistic expectations. The possibilities are not endless; there are real limitations that result from biological constraints and from current agricultural production and marketing practices. Nonetheless, biological control utilizing beneficial insects and mites represents an effective alternative for insect management in some situations. In almost all settings, encouraging or conserving naturally occurring populations of beneficial insects and mites is possible. Conservation may be aided greatly by the development and use of more selective, rapidly degrading insecticides and by the use of insecticides in a more selective manner. The greatest promise for biological control may lie in such conservation efforts.

This table presents biological control guidelines adapted from scientific literature and suppliers' recommendations. These guidelines should be viewed only as suggestions rather than as established recommendations. Refer to the text for more detailed information.

Commodity/ site	Pest	Natural Enemy	Notes
General			
Various field and vegetable crops, gardens, orchards, ornamentals and shade trees	Aphids, caterpillars, mites, and many other small, soft-bodied pests	*Chrysoperla carnea* or *Chrysoperla rufilabris*	The larval stages of the green lacewings, *Chrysoperla carnea* and *Chrysoperla rufilabris,* are generalist predators of aphids, caterpillar eggs, mites, and small soft-bodied insects. Green lacewing larvae may contribute significantly to insect control when used with other tactics in integrated pest management programs. Specific release rates have not been determined for most crops; however, research indicates that 2 to 3 releases of 50,000 to 100,000 eggs per acre per release, made at intervals of 10 to 14 days, may provide significant control. Experimentation may be necessary to determine optimum release rates and timing for specific crops. *Chrysoperla carnea* is used in field and vegetable crops and gardens; *Chrysoperla rufilabris* is used in orchards and shade trees.
Field crops			
Field corn	European corn borer	*Trichogramma pretiosum*	*Trichogramma pretiosum* may be effective in controlling European corn borer when released at rates of 50,000 to 300,000 (total) per acre per generation. Three releases of 100,000 *Trichogramma* per acre per release should be made at 7- to 10-day intervals during corn borer egg laying. Releases should begin as soon as corn borer moths are captured in pheromone or light traps. Control of second-generation corn borers may require higher release rates or a longer release period because egg laying usually occurs over an extended period. *Trichogramma nubilale* may be more effective against corn borers than *Trichogramma pretiosum*, however, *T. nubilale* is not yet available commercially. *Bt* (*Bacillus thuringiensis,* a microbial insecticide approved by most organic certification programs) is easier to apply, more effective, and more economical than *Trichogramma* for control of European corn borer in corn.
Small grains and forage crops	Various pests	See "Notes"	Naturally occurring predators, parasitoids, and pathogens often contribute significantly to suppression of pests in small grains and forage crops. Natural enemy populations (species and numbers) should be monitored when scouting for pests; however, specific management decisions based on natural enemy populations have not been developed for most crops. Conservation practices may help increase natural populations of beneficial insects (see text), but purchase and release of natural enemies is not economically feasible for many of these crops.

Commodity/ site	Pest	Natural Enemy	Notes
Orchards			
Apples	Spider mites: European red mite, twospotted spider mite, and apple rust mite	*Amblyseius fallacis*	*Amblyseius fallacis* is a naturally occurring predatory mite. Populations can be encouraged and conserved by maintaining orchard ground covers and carefully timing oil sprays. Early oil sprays for control of European red mite and San Jose scale should be discontinued as soon as *Amblyseius fallacis* moves up onto apple foliage during June. Spraying “alternate middles” preserves natural enemies during the season.
	Codling moth	*Trichogramma minutum*	Success with *Trichogramma* species for control of codling moth in apple orchards has been variable. Release rates of 50,000 to 100,000 wasps per acre per release at weekly intervals during egg laying (as determined by pheromone trapping) may provide some control. Releases should be made evenly throughout the orchard rather than at a single site. *Trichogramma* is most effective in orchards during warm, sunny weather.
Peaches	Various pests	See “Notes”	Little information is available concerning biological control of peach pests. The major insect pests of peaches in the Midwest include the oriental fruit moth, plum curculio, green stink bug, and tarnished plant bug. Because the oriental fruit moth has 4 generations per year, it is very difficult to control with *Trichogramma* (constant releases of parasitoids would be needed to control overlapping generations). No natural enemies available commercially provide control of plum curculio, green stink bug, or tarnished plant bug in peaches.
Commercial vegetables (for fresh market or processing)			
Sweet corn	European corn borer	*Trichogramma pretiosum*	See "Field corn." Limited data indicate substantial control of corn borer in sweet corn at release rates of 40,000 to 50,000 *Trichogramma* per acre per release and 3 releases at 7- to 10-day intervals.
Tomatoes, cole crops, squash, peppers, and snap beans	Various pests	See “Notes”	Because of the high degree of insect control required for fresh market or processing vegetables, and because many vegetable crops are susceptible to damage by several key pests, there are few biological control alternatives that are economically feasible on a commercial scale. *Trichogramma* or *Chrysoperla* may provide some control of caterpillar pests, but timing and release rates have not been determined.

Table 4-1. (continued)

Commodity/ site	Pest	Natural Enemy	Notes
Commercial greenhouses			
Vegetables (tomatoes and cucumbers)	Greenhouse whitefly	*Encarsia formosa*	*Encarsia* should be released at the first sign of whitefly infestation. Releases should be made 4 times at 10- to 14-day intervals (or until black scales appear). Release rates and methods vary considerably depending on initial infestation and cropping system. For very low initial infestations (less than 1 whitefly adult per 50 to 100 plants), rates of 1 parasitoid per 4 to 7 square feet are recommended for each release. For higher initial infestations (still less than 1 whitefly adult per upper leaf), releases of 1 to 5 parasitoids per square foot should be made at 10- to 14-day intervals. If the initial whitefly population is higher than 1 adult per upper leaf, it should be reduced with a nonresidual insecticide, such as an insecticidal soap or natural pyrethrins (*not* pyrethroids; see Chapter 2, "Botanical Insecticides and Insecticidal Soaps"), before releasing *Encarsia*. Maintaining greenhouse temperatures at 23^o to 27^oC (75^o to 80^oF) and relative humidities at 50 to 70 percent and providing high light intensity favor the survival of *Encarsia*.
	Twospotted spider mites	*Phytoseiulus persimilis, Phytoseiulus longipes,* and/or *Amblyseius californicus*	Predatory mites should be released at the very first sign of spider mites. Release rates and methods vary, depending on crop and levels of infestation. If the infestation is low and uniform throughout the greenhouse, releasing 2 predatory mites per small plant is recommended. If the infestation is high or patchy, releases of 10 to 30 predatory mites per plant are recommended. Mites should be placed on individual leaves (predatory mites will not move from leaf to leaf if spider mite populations are high). See text for discussion of temperature and humidity requirements for each strain or species.
	Western flower thrips, onion thrips	*Amblyseius cucumeris* or *Amblyseius mckenziei (= barkeri)*	Repeated releases of high numbers of *Amblyseius cucumeris* are required for adequate protection of peppers or cucumbers. High release rates are economically feasible with this predatory mite, however, because it is very easy to rear in large quantities. For peppers, suppliers recommend releasing 10 predatory mites per plant plus an additional 25 per infested leaf. For cucumbers, releases of 50 predatory mites per plant plus an additional 100 per infested leaf are recommended. In both cases, releases should be made weekly until there is 1 predatory mite per 2 thrips.
	Serpentine leafminers	*Dacnusa sibirica* and/or *Diglyphus isaea*	*Dacnusa sibirica* and *Diglyphus isaea* are parasitoids of the serpentine leafminer (*Liriomyza trifolii*). Release rates for tomatoes are not well established. Research suggests the release of 1 parasitoid per every 10 *new* miners per week for the first 6 weeks of an infestation. Greater than 90 percent parasitism must occur for control to be sufficient. High cost and limited availability limit the usefulness of these parasitoids.

Commodity/ site	Pest	Natural Enemy	Notes
Commercial flowers and ornamentals	Various pests	See “Notes”	Commercially produced flowers and ornamental plants are sold on the basis of appearance, and little or no insect damage is tolerated. In general, biological control alone cannot maintain sufficiently low levels of insect damage and is usually not economical for commercial operations. One exception is the control of leafminers in chrysanthemums.
Chrysanthemums	Serpentine leafminers	*Dacnusa sibirica* and/or *Diglyphus isaea*	Experimental evidence indicates that the release of 3 *Dacnusa* adults per 1,000 plants early in the growing season can provide control of first-generation leafminers. *Diglyphus* may be more effective for controlling subsequent generations, especially if temperatures are high. An alternate approach involves the release of 500 *Dacnusa* adults per acre every 2 weeks, beginning when the first signs of adult leafminer feeding are detected.
Botanical gardens or conservatories	Whitefly	*Encarsia formosa*	Where many different plant species are maintained together in a permanent collection for public display or for research or educational purposes, biological control poses few risks and can provide adequate protection. Careful monitoring of populations of pest insects and natural enemies and the development of complex management programs may be necessary. Experimentation may be required to determine the best release rates and timing for each situation. Because the yield or marketability of conservatory plants is not a factor, tolerance for injury may be higher, and lower release rates than those that are recommended for commercial production may be adequate.
	Spider mites	*Phytoseiulus* and *Amblyseius* spp.	
	Mealybugs	*Cryptolaemus montrouzieri*	
	Aphids	*Aphidoletes aphidimyza* (predatory midge)	
	Soft scales	*Metaphycus helvolus* (parasitoid)	
	Armored scales	*Aphytis melinus* (parasitoid)	
Home, yard, and garden			
Vegetable gardens; flowers, shrubs, and trees; lawns	Various pests	See “Notes”	Problems of dispersal, timing of releases to coincide with the susceptible stage(s) of specific pests, and patchy or limited distribution of pests often reduce the effectiveness of natural enemies when released in home gardens. For the degree of control needed in home gardens, such readily available alternatives as insecticidal soaps, *Bt*, and various row covers are easier to use and more dependable than natural enemies. Conservation of naturally occurring beneficial insects and mites (by reduced use of broad-spectrum insecticides, providing nectar and pollen sources, use of artificial foods such as Wheast, etc.) may be more effective than purchasing and releasing predators and parasitoids. For home gardeners wishing to experiment with natural enemies, generalist predators such as green lacewings (*Chrysoperla carnea*) and spined soldier bugs (*Podisus maculiventris*) are probably the best choices. Lady beetles and praying mantids are seldom effective (see text).

Table 4-1. (continued)

Commodity/ site	Pest	Natural Enemy	Notes
Livestock and poultry			
Feedlot and dairy cattle	Stable flies	*Spalangia nigroaenea* and/or *Spalangia cameroni*	Releases of 50 to 100 *Spalangia* per animal per week may help limit fly populations. Suppliers' recommended rates are much lower and are not likely to reduce fly numbers substantially. Purchases of "generic" filth fly parasitoids should be avoided because these mixtures often do not include *Spalangia nigroaenea* or *Spalangia cameroni*, the two species shown to parasitize stable fly pupae effectively. These species also parasitize house fly pupae, but not as frequently. *Spalangia endius* and *Nasonia vitripennis* are sometimes sold, but neither species has been shown to be effective for the control of flies in Midwest feedlots.
	House flies	*Muscidifurax raptor* and/or *Muscidifurax zaraptor*	Releases of 50 to 100 *Muscidifurax* per animal per week may help limit fly populations. Some parasitism of house flies may also be achieved with *Spalangia nigroaenea* and *Spalangia cameroni*.
Poultry	House flies	*Muscidifurax* species, *Spalangia* species, and/or *Pachycrepoides vindemiae*	All of these parasitoids can be used for house fly control in poultry houses (especially those with concrete floors). Release rates depend on manure management and poultry-house construction. A general recommendation is to make weekly releases of 1 parasitoid per 2 birds. Fly control is improved where moisture problems are minimized.
Stored products			
Raw grains	Indianmeal moth	*Trichogramma pretiosum* and/or *Bracon hebetor*	*Trichogramma* and *Bracon* can provide moderate levels of control of Indianmeal moth eggs and larvae. This degree of control is not adequate in most cases, however, due to very stringent regulations on levels of insect infestation in grains. Dependable release rates have not been determined.
	Weevils and grain beetles	*Xylocorus flavipes* and *Anisopteromalus calandrae*	*Xylocorus* feeds on the eggs of grain weevils and the eggs and larval stages of grain beetles and the Indianmeal moth. *Anisopteromalus* is a parasitoid of weevil larvae. Both of these natural enemies provide some control of the immature stages of stored grain pests but do not attack adults. Because adult grain weevils and beetles may live and reproduce for 3 to 6 months or longer in stored grain, *Xylocorus* and *Anisopteromalus* are not able to reduce pest infestations to the low levels required by grain regulations. Release rates have not been determined.

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