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Biological control of insects and other pests of greenhouse crops

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acknowledgements

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preface

Why use biological control?

Since the late 1940s, much of the insect control in the United States has been based on the use of synthetic chemical insecticides. Insecticides are relatively easy to use and have generally provided effective pest control; it is likely that they will always be a component of pest management programs. Unfortunately, insecticides have some undesirable attributes. They usually present some degree of hazard to the applicator and other people who may come in contact with them; they can leave residues that some find unacceptable; they can contaminate soil and water and affect wildlife, aquatic life, and other nontarget organisms; they can interfere with beneficial organisms, such as pollinating insects and the natural enemies of pests; and insects can develop resistance to insecticides, effectively eliminating those materials as pest management options. For these reasons, there is growing interest among farmers, horticulturists, and gardeners to explore and adopt methods that reduce pesticide use.

Biological control represents one alternative to the use of insecticides. Biological control is the conscious use of living beneficial organisms, called natural enemies, for the control of pests. Virtually all pests have natural enemies, and many pests can be effectively controlled by managing these natural enemies. Although biological control will not control all pests, it can be the foundation of an approach called integrated pest management, which combines a variety of pest control methods in an ecologically safe system. Biological control can be effective, economical, and safe, and it should be used more widely than it is today.

Why this publication?

Biological control relies on living organisms that must have food and shelter and that interact, often in complex ways, with the pests, the crop, and other environmental factors. The pest manager (a grower or crop consultant) should be able to recognize important natural enemies, understand their needs, and know how to maximize their effectiveness. A good understanding of the relationships between pests, their natural enemies, and the environment is essential for the successful implementation of biological control. The need for this type of knowledge is the rationale for this publication.

Most insects that attack greenhouse crops are readily controlled by biological means. This publication provides information on important natural enemies and offers practical advice on how to use beneficial organisms for pest management in greenhouses. The publication emphasizes the use of biological control, but it also tells how best to use cultural and least-toxic chemical controls if it becomes necessary to supplement biological control. Therefore, the publication is truly a manual for biologically based integrated pest management.

Chemical insecticides are fairly straightforward to use—after identifying the pest problem, you can choose an appropriate material, read the label, and follow directions to achieve good control. Because biological controls are based upon living organisms that have specific needs and behaviors, it is not always easy to give a recipe to assure success. With commercially available natural enemies, there will be instructions as to release rates and timing. However, with other approaches to biological control, it may be necessary to conduct your own research, or to "tinker with the system" to get optimum results. Therefore, we provide background information on biological control in general, and on the specific pests and their natural enemies that occur in greenhouse crops to help you refine your pest management program. More than 1,000 research, technical, and popular publications have been carefully reviewed and summarized for this publication. I hope *Biological Control of Insects and Other Pests of Greenhouse Crops* helps you plan and conduct successful biological control.

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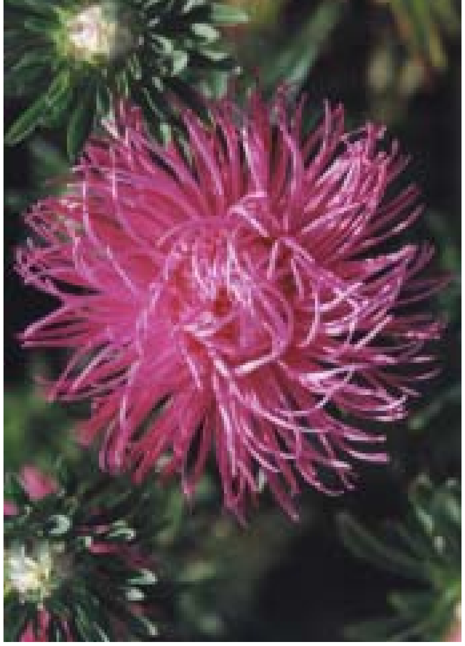
September 2001



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Disclaimer

The complex interactions between a pest, its host crop, its natural enemies, various environmental factors, and crop management practices make it difficult to provide exact recommendations for the use of natural enemies in biological control. Therefore, the suggestions in this publication for the release of natural enemies in augmentative biological control are guidelines rather than specific recommendations. Some experimentation on your part will be necessary to achieve optimal pest management using natural enemies and other control approaches.

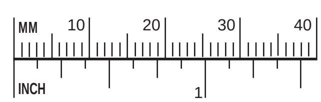
Some states have regulations regarding the shipment and release of commercial natural enemies, and permits are required in some cases. If you are uncertain about such regulations, contact your state's department of agriculture for more information.

In several cases we refer to experimental controls that have not been fully evaluated in the United States, have not been commercialized, or, in the case of pesticidal products, have not been registered with the Environmental Protection Agency.

These references do not constitute recommendations but are included to indicate potential future developments or to point to areas of possible experimentation by the grower. We have made every attempt to be accurate regarding the commercial availability of natural enemies and products at the time of publication. However, as more natural enemies are proven to be effective, they will likely become commercially available. Check with biological control distributors to determine the best available natural enemies for your needs.

References to products or companies in this publication are for your convenience and are not an endorsement over similar products or companies. You are responsible for using pesticides according to the manufacturer's current label directions and federal and state laws. Follow label directions exactly to protect the environment and people from pesticide exposure. Failure to do so violates the law.

Measurements
Many of the beneficial natural enemies described in this publication are very small. Because of its accuracy, we include metric measurements when giving the size of organisms. If you remember that 1 inch equals approximately 25 mm, you will be able to make rapid conversions. You can also use the accurate conversion scale below to get a sense of insect size.



A note about scientific names
Most beneficial natural enemies do not have common names. Therefore, we use scientific names throughout the publication. To gain an understanding of the nature and use of scientific names, read the section entitled "Insect Classification" on page 4.

SECTION

1

Understanding pests and their biological control

Biological control is the use of one or more types of beneficial organisms, usually called natural enemies, to reduce the numbers of another type of organism, the pest. Although this publication focuses on the biological control of pest insects, biological control has also been used to manage other types of pests, including weeds and microorganisms that cause plant diseases.

Biological control relies on the interactions of living organisms with the target pests and the environment. It is therefore more complex than certain traditional pest control practices, such as the use of chemical pesticides. This introductory section provides basic information on the biology of insects, the natural enemies of insects, and the methods used to implement biological control. There is also a discussion of the economics of pest control as it relates to biological control. Terms in **boldface** are in the glossary at the end of the publication.

Figure 1. All insects have three body regions: head, thorax, and abdomen.

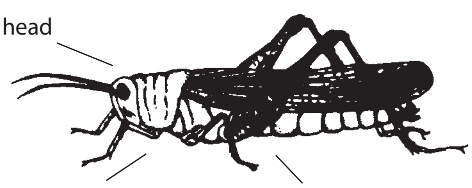
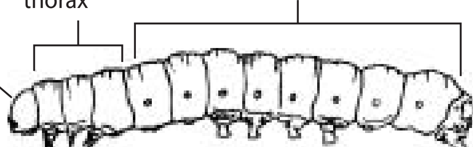


Figure 2. This caterpillar shows the basic body form of a larval insect. Certain groups of larvae, especially caterpillars and sawfly larvae, have auxiliary legs, called prolegs, on the abdomen.



The biology of insects

Biological control is most successful when the pest manager has a fundamental understanding of the biology of the pests and their **natural enemies**. This section explains some of the principles of insect biology and defines terms used throughout this publication.

Insect structure

The insect body is divided into three regions: the head, **thorax**, and abdomen (figure 1). The head contains the brain, the mouth and mouthparts, and important sensory organs such as the eyes and antennae. Behind the head is the thorax, to which the legs and wings are attached. Insects have three pairs of true legs, although some larval insects, especially caterpillars, possess fleshy auxiliary legs, called **prolegs**, that are attached to the abdomen (figure 2). There are usually two pairs of wings, except in true flies, which have only one pair. In some insects such as grasshoppers and beetles, the front pair of wings has become thickened to serve as a protective covering over the abdomen while the insect is not flying. The abdomen is located behind the thorax. It is usually distinctly segmented and as long as, or longer than, the head and thorax combined. Internally, the abdomen contains most of the digestive system, the reproductive system, and other important organs. It is usually more flexible than the head and thorax because it needs to stretch to accommodate food, water, air, fat reserves, and eggs.

Insect growth and development

Most insects start life in an egg stage. The act of egg laying is called **oviposition**. The reproductive adult females of many species lay their eggs specifically in the area where the offspring will feed. For example, greenhouse whiteflies lay their eggs on the foliage where the immatures will feed, and fungus gnats oviposit on the surface of the soil or growing medium where the larvae will develop. Insects have specialized organs called **ovipositors** for depositing the eggs in the appropriate location (figure 3). Some ovipositors are internal except during oviposition (as with most flies); others are external and very obvious (as with crickets and ichneumonid wasps). A few insects, such as aphids, give birth to live young.

The two major categories of growth and development are simple and complete metamorphosis. **Simple metamorphosis** (sometimes called incomplete metamorphosis) occurs in those insect species in which the young usually look very similar to the adults, except that wings are absent and they are not reproductively mature. In the immature stage, these insects are called **nymphs** (figure 4). Common insects that undergo simple metamorphosis include dragonflies, mayflies, grasshoppers, crickets, cockroaches, true bugs, and leafhoppers. Greenhouse pests with simple metamorphosis include aphids, whiteflies, thrips, mealybugs, and scales. (Whiteflies and thrips have an inactive nymphal stage that is commonly, but incorrectly, referred to as a pupa, even though these insects do not have a true pupal stage like insects which undergo complete metamorphosis—see below.) Mites, which are not insects, also develop by simple metamorphosis.

Most insects undergo a more complex form of juvenile development called **complete metamorphosis**. These insects are worm-like, maggot-like, or grub-like in the immature stage. These types of immature insects are called **larvae** (singular—**larva**). The major change in body shape between the larval and adult stages requires an intermediate stage of development, the pupal stage (figure 5). **Pupae** (singular—**pupa**) are nonfeeding and inactive. They usually change shape (metamorphose) in a protected location—such as within a **cocoon**, under tree bark, or in the soil—because they cannot fly, walk, or otherwise avoid natural enemies and environmental extremes. Insects with complete metamorphosis include all beetles, butterflies, moths, bees, wasps, ants, flies, and lacewings. Greenhouse pests with complete metamorphosis include leafminers, fungus gnats, shore flies, caterpillars, and weevils.

Figure 3. A cricket (left) and an insect-parasitic wasp (right), each with an obvious ovipositor. The cricket inserts its eggs in soil and the parasitic wasp "stings" its host insect, laying its egg inside the host.

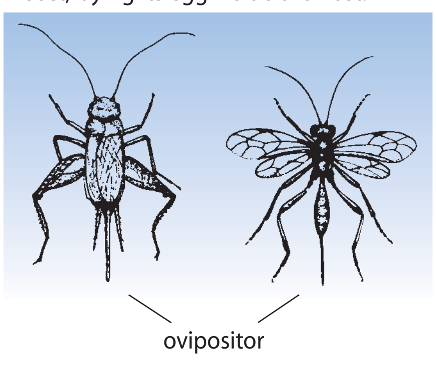
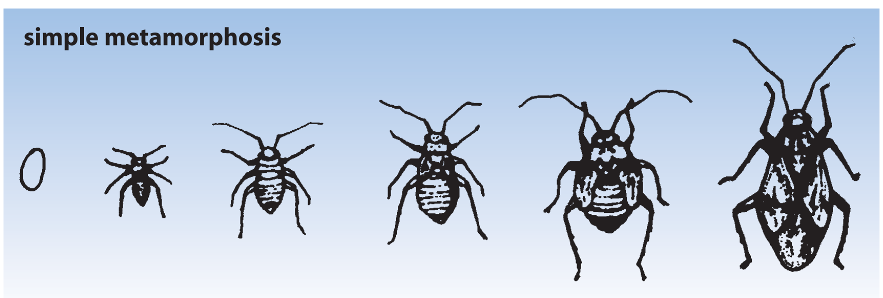


Figure 4. A plant bug is an example of an insect with simple metamorphosis. After hatching from the egg, the nymph grows, occasionally shedding its skin, until it reaches the adult winged and reproductive stage, after which it no longer grows.



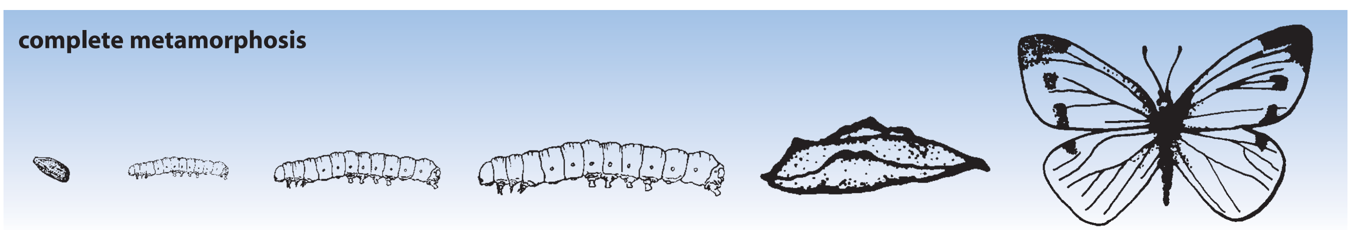


Figure 5. The imported cabbageworm is an example of an insect with complete metamorphosis. After hatching from the egg, the larva grows, occasionally shedding its skin, until it is fully grown. The larva then molts one more time and transforms into the pupa. The pupa in turn molts and transforms into the adult winged and reproductive stage, after which it no longer grows.

As both nymphs and larvae grow, they periodically have to shed their skins (the **exoskeleton**), through a process called **molting**. Most species of insects molt a set number of times before they become adults. The distinct immature stages between successive molts are called **instars**. For example, greenhouse whiteflies have four instars while vegetable leafminers have three instars. The first instar is that which hatches from the egg, the second instar is after the first molt, and so on. Many natural enemies, especially parasitic wasps, attack only certain instars of the target pest. This can be an important factor for effective biological control, especially when timing releases of natural enemies.

Adult insects are characterized by the presence of wings and by reproductive maturity. (With insects it seems that there are exceptions to every rule; most adult aphids and all fleas are wingless.) Once an insect reaches the adult stage, it doesn't grow any further and never molts again. Therefore, small beetles do not grow into large beetles; small flies do not grow into large flies; and so forth (figure 6).

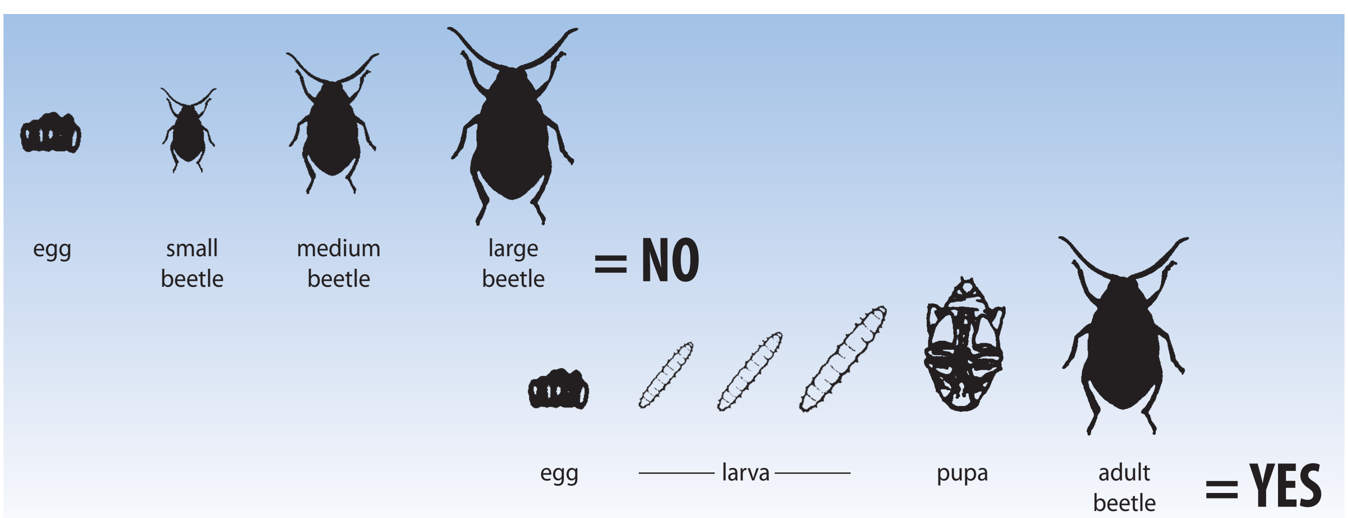
The rate of insect growth and development depends largely on environmental factors (e.g., temperature, humidity, and availability of food) and the genetic traits of the species. Within limits, the warmer the temperature, the more rapid the development and the shorter the generation time. The length of time required for an insect to complete one generation varies considerably with the type of insect, the availability of food, and, to some degree, the location and climate. Greenhouse environmental conditions usually promote more rapid growth of pest populations than would occur outdoors, although population development often slows down under cooler winter conditions.

Table 1. Common natural enemies with simple and complete metamorphosis.

Simple metamorphosis (immature stage—nymph)	**Complete metamorphosis** (immature stage—larva)
bigeyed bugs	ground beetles
damsel bugs	hover flies (syrphid flies)
minute pirate bugs	lacewings
predatory mites	lady beetles
stink bugs	parasitic wasps (such as ichneumonids, braconids, and chalcids)
	tachinid flies

In temperate climates with cold winters, insects either die or go into an overwintering protective state of arrested development called **diapause**. A given species diapauses in a specific stage of development. Outdoors, aphids overwinter in the egg stage, caterpillar pests such as the cabbage looper overwinter as pupae, and vine weevils or root weevils diapause as adults. In the greenhouse, many pests do not enter diapause; they develop year round. But certain natural enemies do diapause in the greenhouse. The predatory aphid midge *Aphidoletes aphidimyza*, for example, diapauses as pupae, and the predatory mite *Neoseiulus cucumeris* as adults, although there are nondiapausing strains of the mite.

Figure 6. The upper life cycle shows the common misconception that little insects are smaller versions of adult insects, while the lower life cycle illustrates the correct growth pattern of a beetle. When two similar adult insects are substantially different in size, they are likely different species with different habits.



Insect feeding

Insects with simple metamorphosis often feed as both nymphs and adults in the same location and on the same food. This is true of aphids, mites, mealybugs, scales, and thrips. The larvae of insects with complete metamorphosis often feed in a different location and on a different food than the adults. For example, black vine weevil larvae feed on roots, but the adults feed on foliage. Some insects, especially those with complete metamorphosis, feed primarily in the immature stages, and adult feeding may be insignificant. For example, leafminer maggots feed by chewing on plant tissue in their mines, while the adult flies feed by sucking plant juices from holes made in the leaves.

Insects may feed in two basic ways: by sucking fluids or by chewing. Mosquitoes, for example, suck blood, butterflies suck nectar from a flower, and aphids suck plant sap from leaves. On the other hand, grubs chew on roots of plants, and caterpillars or grasshoppers chew holes in leaves. Nymphs and adults of insects with simple metamorphosis usually have the same type of mouthparts. In all stages of development, aphids have sucking mouthparts and grasshoppers have chewing mouthparts. The adults of insects with complete metamorphosis do not necessarily have the same type of mouthparts as the larvae. Caterpillars have chewing mouthparts, whereas adult butterflies have sucking mouthparts.

Many beneficial natural enemies, such as lady beetles, praying mantids, and parasitic wasps, have chewing mouthparts. Other natural enemies, such as the larvae of lacewings and the nymphs and adults of the true bugs, have sucking mouthparts.

Insect classification

Classification is the process of categorizing organisms into related groups, based on a standard hierarchy of categories (see table 2). The most basic category in classification is the **species**, a grouping of animals that is functionally capable of reproducing and routinely does so, thereby perpetuating the species. The scientific name of a species consists of the genus name (capitalized) plus the species name (not capitalized), both italicized or underlined. For example, the scientific name of the species we call greenhouse whitefly is *Trialeurodes vaporariorum*. Using scientific names is preferable to using common or colloquial names because in different places the same common names sometimes refer to different species. Also, only very common, very showy, or very pestiferous species have common names. The majority of insects, including most beneficial natural enemies, are uncommon, small, or nondescript, and have never received common names. The Entomological Society of America publishes a list of approved common names that can be used for individual species. In this publication, we will use approved common names in conjunction with the scientific names.

We also describe insects using their family name. Thus, mirid bugs, *Deraeocoris brevis* and *Macrolophus costalis*, are both members of the family Miridae.

A note about mites

Mites are not insects but are classified with the insects and several other groups in the phylum Arthropoda. Arthropods are categorized by their hard exoskeleton, or skin, and by their jointed appendages. Mites are in the class Arachnida, which also includes spiders and scorpions, and the order Acari (sometimes called Acarida), which includes all mites. Mites have two body regions instead of three and usually have four pairs of legs. No species of mite has wings. They develop by simple metamorphosis, although in some cases the immatures are markedly different from the adults in structure and biology. Most mites are very small. Those important to agriculture are about 1/50 inch (1/2 mm) in size or less when fully grown. There are many mite pests of greenhouse crops, as well as several predatory mites, especially in the family Phytoseiidae, that are important natural enemies of small insect pests such as thrips and spider mites.

Table 2. Example of insect classification, based on the greenhouse whitefly, *Trialeurodes vaporariorum*.

Category	Classification of greenhouse whitefly	
Kingdom	Animalia	The animal kingdom
Phylum	Arthropoda	The arthropods
Class	Hexapoda	Insects and their relatives
Order	Homoptera	Aphids, cicadas, leafhoppers, mealybugs, planthoppers, scale insects, treehoppers, and whiteflies
Family	Aleyrodidae	Whiteflies
Genus	*Trialeurodes*	A group of several closely related whitefly species
Species	*vaporariorum*	Greenhouse whitefly

The natural enemies of insects

All insects and mites have natural enemies. Some pests have more—or more efficient—natural enemies than others. Biological control relies on effective natural enemies that can be managed by humans.

Types of natural enemies

Vertebrate natural enemies of insects include certain birds, such as flycatchers, woodpeckers, purple martins, starlings, and chickens; certain mammals, such as bats, moles, voles, skunks, and hogs; and toads, frogs, and lizards. With a few minor exceptions, these cannot be managed to reduce the populations of pests significantly, and they will not be considered further in this publication.

Insects and mites that feed on other insects or mites make up the most important group of natural enemies. This is an extremely large and diverse group. Unfortunately, because beneficial insects are often tiny and nondescript, they are frequently overlooked by even the most dedicated practitioners of biological control. Only the large, common, or brightly colored species, such as praying mantids and lady beetles, are commonly recognized.

Insects that eat other insects are either predatory or parasitic. Predatory insects, or **predators**, are usually much larger than their prey. They eat and kill many prey as they grow and reproduce. Many predators will feed on almost anything they can catch, but some specialize in consuming certain prey types. Most predators are fairly mobile and can search rapidly for prey. The adults of relatively nonmobile species, such as hover fly larvae, lay their eggs in the immediate vicinity of prey insects, such as aphids. Some types of predators undergo simple metamorphosis—the various families of predatory bugs are examples—whereas others undergo complete metamorphosis—examples include the lady beetles and lacewings (see table 1). Many important predators are predatory as both immatures and adults.

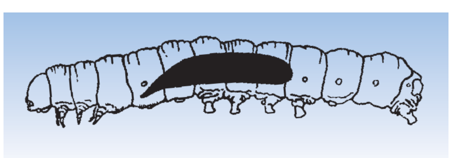
Table 3. Major groups (orders) of insects, listed in order of increasing evolutionary complexity.[1]

Order	Type of insect	Type of metamorphosis	Number of North American species[2]
Thysanura	silverfish	simple	18
Ephemeroptera	mayflies	simple	610
Odonata	dragonflies, damselflies	simple	400
Plecoptera	stoneflies	simple	465
Phasmatodea	walkingsticks	simple	30
Orthoptera	grasshoppers, crickets, katydids	simple	1,080
Dermaptera	earwigs	simple	20
Dictyoptera	mantids, cockroaches	simple	70
Isoptera	termites	simple	45
Psocoptera	booklice, barklice	simple	250
Phthiraptera	chewing and sucking lice	simple	1,000
Hemiptera	true bugs	simple	3,600
Homoptera	aphids, cicadas, leafhoppers, mealybugs, planthoppers, scale insects, treehoppers, and whiteflies	simple (some modified)	6,300
Thysanoptera	thrips	simple (but modified)	700
Neuroptera	dobsonflies, lacewings, and relatives	complete	350
Coleoptera	beetles (including weevils)	complete	23,700
Hymenoptera	sawflies, bees, wasps, ants, parasitic wasps	complete	17,800
Trichoptera	caddisflies	complete	1,260
Lepidoptera	moths, butterflies	complete	11,300
Diptera	flies	complete	16,900
Siphonaptera	fleas	complete	300
Approximate total insect species in the United States and Canada[3]			**86,300**

[1] *Additional orders include Grylloblattodea (rock crawlers), Zoraptera (angel insects), and Mecoptera (scorpionflies).*
[2] *An approximation of the number of species in this order found north of Mexico.*
[3] *Authorities estimate that 10–25% of all species are still unknown to science.*

The majority of **parasites** (also called **parasitoids)** are very small wasps in several families of the order Hymenoptera. Another important group is tachinid flies (order Diptera, family Tachinidae). Parasites are about the same size as their hosts, or smaller. All parasites undergo complete metamorphosis. In most cases, the adult female lays eggs on, within, or near a host insect of the appropriate stage. When the egg hatches, the parasite larva consumes its host. Each parasite larva can attack only one host. A parasite larva that feeds and develops within its host is called an **endoparasite** (figure 7), whereas one that feeds while attached to the outside of its host is called an **ectoparasite** (figure 8). Endoparasites are much more common than ectoparasites. When a single parasite develops within a single host, it is called a **solitary parasite**; when two or more individuals of the same species can develop within one host, the species is said to be a **gregarious parasite**.

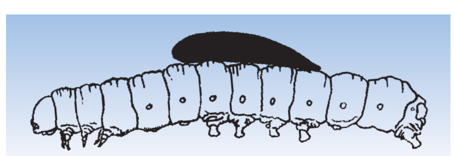
Figure 7. Endoparasites develop inside the body of the host insect.



Different parasites attack different stages of the host. There are egg parasites, nymphal parasites, larval parasites, pupal parasites, and adult parasites. Parasites are generally host specific, attacking only a single insect species or a group of closely related species. Most types of insects are attacked by one or more species of parasite. In fact, many parasites themselves are parasitized by other species, called **hyperparasites**.

Section 2 contains more details on specific predatory and parasitic insects. Many of these insects are covered in even greater detail in the companion publication *Biological Control of Insects and Mites* (NCR 481), which includes descriptions and color photographs of many types of natural enemies.

Figure 8. Ectoparasites feed externally, attached to the outside of the host.



Pathogens are microorganisms that cause diseases. The most common types of insect pathogens are bacteria, fungi, nematodes, viruses, and protozoans. Some insect diseases are highly lethal, killing a large portion of the insect population. Other diseases are less lethal but may retard insect development, shorten the insect's life, or prevent reproduction. Most insect pathogens are pathogenic only to insects, frequently to very small groups of closely related species. Microorganisms that are pathogenic to a specific pest are often harmless to other insects, including predators and parasites.

Often, specific conditions are necessary for an insect pathogen to reduce a pest population effectively. These conditions vary with the type of pathogen and the host. Most fungal pathogens are only effective during periods of relatively high humidity, because it is only under these conditions that the fungi will produce spores and the spores will germinate. Viral pathogens are often most effective when the host population is very high, which facilitates spread from individual to individual within the population. Bacterial pathogens must be ingested to be effective, and therefore do not usually kill sucking insects such as aphids and whiteflies. Nematodes require a thin film of moisture on which to move, so they are not effective under dry conditions.

Because of these characteristics, the degree of control exerted by naturally occurring pathogens is often unpredictable. However, pest managers should be aware of the symptoms of insect diseases and should be able to assess their impacts on pest populations.

A few insect pathogens are available commercially. You can spray these on the crop using conventional pesticide spray equipment. When used in this fashion, insect pathogens are called **microbial insecticides.** These can be very effective at the time of application, but they usually do not persist in the greenhouse environment. Their advantages include wide availability from commercial sources, safety to humans, and safety to nontarget organisms, including beneficial insects. However, microbial insecticides have some disadvantages: they may be more costly to use than traditional pesticides; multiple applications may be necessary because residual activity is short; and if other types of insect pests are present, you may still need to suppress these with other controls. Microbial insecticides containing the bacterium *Bacillus thuringiensis* are discussed in Section 2 of this publication. More information on insect pathogens and microbial control can be found in the companion publication *Biological Control of Insects and Mites* (NCR 481) and in *Alternatives in Insect Management* (NCR 401).

The general approaches to biological control

There are three broad approaches to the biological control of insects: **importation** and permanent establishment of new natural enemies; **augmentation** of existing natural enemies by releasing predators or parasites or by applying microbial insecticides; and **conservation** of natural enemies by changing aspects of the environment that threaten their survival or effectiveness.

Importation of natural enemies is based on the understanding that the most effective natural enemies may not occur in the region where the pest is causing damage. Many pests in the United States are native to other parts of the world, especially Europe, Australia and northern Asia, and were introduced accidentally into this area by such human activities as immigration and commerce. Although modern federal and state quarantine practices help exclude many serious foreign pests, occasionally new alien species are introduced and become established. For example, the southeast Asian thrips *Thrips palmi* is now a problem in Florida.

The most efficient natural enemies are those that evolved with the pest and are therefore adapted to the pest's life cycle, behavior, and other characteristics. Scientists search throughout the native range of the pest for natural enemies that have the potential for controlling the insect in its new area. Exotic natural enemies are carefully screened to be certain that they have no undesirable characteristics. Then they are introduced into the target region, with the goal that they become permanently established and provide ongoing biological control of the pest. This process is called foreign exploration for natural enemies.

International, federal, and state agencies, along with a few land-grant universities, import natural enemies. An agency undertaking this process requires stringently maintained quarantine facilities and highly trained personnel to assure that the introduction of exotic natural enemies does not result in the introduction of additional pest species. Researchers at several of these facilities are currently evaluating exotic natural enemies of whiteflies, thrips, and other pests for possible introduction in subtropical areas of the United States. Some of these may also be useful for controlling certain greenhouse pests if commercial suppliers of natural enemies produce them in the future.

Augmentation of natural enemies means increasing natural enemy numbers through human involvement. Natural enemies moving into greenhouses will rarely be abundant enough to maintain the pest population below damaging levels. Increasing the natural enemy population improves the chance of gaining economic control over the pests. This typically requires purchasing and releasing natural enemies from commercial vendors, many of which are insectaries. An **insectary** is a facility that grows insects, often mass-producing natural enemies for augmentation purposes. The three types of natural enemies commercially available for purchase and release in augmentation programs are generalist natural enemies, which are usually predatory insects; specialist natural enemies, usually parasites; and insect pathogens produced as microbial insecticides.

Generalist natural enemies feed on a variety of prey and may or may not be adapted to specific types of prey. For example, lacewings and certain lady beetles prefer to feed on aphids and similar insects, but will also consume small caterpillars, spider mites, insect eggs, and other types of prey. Some of the species of egg parasites in the genus *Trichogramma* attack the eggs of many types of moths. Praying mantids are generalists that are not recommended for augmentation because they are indiscriminate in prey choice; they will eat beneficial and innocuous insects as well as pests.

Specialist natural enemies attack only a specific type of pest or a group of closely related species. For example, the parasite *Encarsia formosa* attacks only whiteflies, and *Dacnusa sibirica* attacks only leafminers. Although most commercially available specialist natural enemies are parasites, some are predators. The mealybug destroyer, *Cryptolaemus montrouzieri*, and the spider mite destroyer, *Stethorus punctum*, are both specialized predatory lady beetles.

Microbial insecticides also tend to be fairly host specific, but their range of activity can vary. For example, *Bacillus thuringiensis* (Bt) can kill mosquitoes, beetles, and caterpillars, but the activity depends on the strain of bacterium. The caterpillar-active strains of Bt are fairly broad spectrum, affecting almost all caterpillars. On the other hand, most insect-pathogenic viruses are highly selective, often affecting only one or a very few species.

There are two general approaches to the augmentative release of natural enemies. **Inundation** is the mass release of large numbers of natural enemies to gain rapid control of a damaging or near-damaging pest population. This method only works when the natural enemy can kill the pest relatively rapidly. If the natural enemy acts slowly, then the pest population is likely to do considerable damage before it is brought under control.

Inoculation is the release of small numbers of natural enemies when the pest population is still at low levels. The strategy of inoculation is to encourage the released natural enemies to reproduce rapidly enough to counter the build-up of the pest. This is the more "natural" of the two approaches because it relies on the reproduction of the beneficial insect and takes advantage of its biological characteristics, such as the ability to seek out scattered prey. Inoculative releases are usually less expensive than inundation, but they require routine monitoring of pest and natural enemy populations to be certain that the pest is being controlled. Often, a sequence of inoculative releases at prescribed intervals is more effective and less expensive than an inundative release.

Conservation of natural enemies entails preserving those predators, parasites, and pathogens that occur naturally or that have been introduced through importation or augmentation programs. Natural enemies, like all living things, have specific requirements for life, growth, and reproduction. These requirements include sufficient food and water, and shelter which allows natural enemies to avoid environmental extremes such as high temperatures and flooding. Providing natural enemies with necessary resources and protecting them from major mortality factors, such as virulent diseases and toxic chemicals, are the two main approaches to natural enemy conservation.

Natural enemies benefit from living among a variety of food sources. In the absence of their preferred prey, generalist natural enemies can shift to other types of prey. For optimal reproduction, some adult natural enemies also require certain nutrients from such sources as plant exudates, flower nectar, or the honeydew excrement of sucking insects. A diverse environment is more likely to meet the natural enemies' needs and allow them to stay where you want them. A simple environment, characterized by few plant and insect species, often encourages natural enemies to leave. Once natural enemies leave to seek food or other necessities, they are unlikely to return. Unfortunately, it is often impractical to provide the diversity necessary for natural enemy reproduction in greenhouses. Thus, continued introductions into greenhouses are usually required to maintain the natural enemy population.

One of the major deterrents to effective natural enemy activity is the use of broad-spectrum pesticides, because natural enemies are just as susceptible to pesticides as are the target pests. Frequently one pest will be under good biological control, but another requires a pesticide to prevent economic damage from occurring. Pesticide applications may eliminate natural enemy populations, leading to a **secondary pest outbreak.** This is the term used when a species that was not causing damage becomes a problem because of major, usually rapid, changes in the pest's environment. A similar phenomenon, **pest resurgence**, occurs when the population of the pest that was the target for the pesticide application rebounds rapidly after the initial application, often because of the elimination of its own natural enemies. The use of chemical pesticides may provoke both phenomena.

No chemical insecticide is completely specific to one target pest species. Even so-called natural products such as pyrethrum, a plant extract, can be damaging to some natural enemies. The insecticide's residual activity may determine how harmful it is. While pyrethrum, rotenone, and many other plant-derived insecticides are highly toxic to natural enemies at the time of application, these products break down very rapidly in the environment. They generally will not harm natural enemies released after the insecticide application. However, many insecticides have a period of residual activity lasting several days to several weeks. These not only kill natural enemies at the time of application, but can also kill some individuals introduced later. Many insecticides fall into this category. Those materials safest to natural enemies include the microbial insecticides (e.g., Bt) and insecticidal soaps.

The economics of pest control

Releases of natural enemies can often provide adequate pest control and result in a relatively undamaged crop. However, the cost of purchasing, monitoring, and managing natural enemies may be greater than the cost of using insecticides.

The operational expenses of producing the crop, including pest management costs, must be made up by the revenue from marketing the crop, as determined by the quantity and quality of the crop and the marketing approach used. The costs of pest management must be weighed against the potential economic impact of each type of pest and related factors. These may include (1) the amount of physical damage that each pest can cause to the crop—that is, the loss in yield or quality, (2) the actual number of pests present, (3) the cost of managing the pests either individually or, more appropriately, as an entire pest complex, (4) the effectiveness of the control methods used, and (5) the end use and market value of the crop.

The damage caused by each pest

Some pests cause much more damage than others. Caterpillars feeding directly on the flowers of ornamentals cause more damage than fungus gnats breeding in the potting medium of the same plants. Sweetpotato whiteflies remove more sap and produce more honeydew than greenhouse whiteflies. Western flower thrips transmit tomato spotted wilt virus and impatiens necrosis virus to ornamental plants, reducing their marketability, whereas greenhouse thrips only create feeding scars on the leaves. Each particular pest problem requires its own specific solution.

The level of the pest population

It is impractical, and usually impossible, to make your greenhouse completely pest free; the costs of control would far exceed the benefit of controlling the last few insects. Therefore, growers must monitor carefully and routinely for pest activity to determine the relative abundance of each pest throughout the growing season. Growers should also keep weekly records of pest activity and relate these to actual insect damage. Because of the relatively constant greenhouse environment, most greenhouse pests can occur at any time. During warm months pests may enter the greenhouse from outside, and those that are established in the greenhouse may develop rapidly. In northern states with cold winters, pest activity usually declines when the days are shorter and the temperatures lower, and when there is no pest invasion from outside.

The costs of managing the pests

The product used for controlling a pest, any equipment required for application, and the labor required for the control process are the primary costs of pest management. The costs of pest monitoring also can be significant. These include the costs of traps and other monitoring equipment, as well as the salary or consultant fee of the individual responsible for monitoring.

When considering costs, it is important to consider the entire pest complex. Typically, a particular biological control method is effective against only a single type of pest or a narrow range of pests. For example, some parasitoids only attack certain aphid species. If numerous types of pests are present, several biological control agents may be necessary. This could be much more costly than using a broad-spectrum insecticide.

Effectiveness of control methods

Label directions for traditional chemical insecticides can usually tell you how to achieve maximum control. Such precise recommendations may not be possible for many biological controls. Complex environmental factors can make it difficult to predict the ultimate degree of control that releasing natural enemies will provide. Furthermore, some commercially available natural enemies are much more effective than others. Although there are general guidelines for the release of natural enemies, growers must gain some experience in their own greenhouses to determine the effectiveness of the chosen biological control agents, and then must decide if the level of effectiveness is acceptable.

The end use and market value of the crop

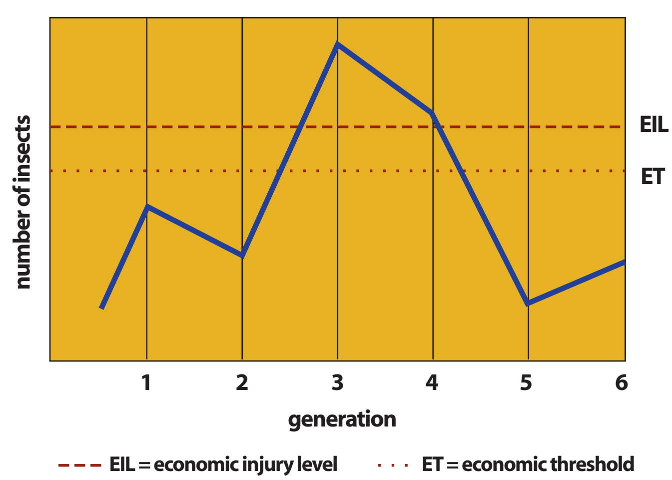
The best pest control method for your crop may depend on the end use and market value of the crop. Whether a grower is cultivating chrysanthemums for cut flowers or for potted plants, for example, may determine the amount of damage that can be tolerated. Fungus gnats are unacceptable on potted chrysanthemums nearing harvest but are of no importance on cut chrysanthemums. Market value is determined by many factors, such as available supply, competition, quality, cultivar, and consumer demand. Values vary from season to season and even within the season. When supply is high and prices low, quality must often be the highest in order to sell the product at all. Quality becomes more flexible when supply is low and prices are high. Unfortunately, this market information is not usually available at the time pest control decisions are made. However, your marketing strategies can also influence the gross value of the crop. Biological controls can be more expensive than traditional chemical approaches, but if the additional expense is offset by a new marketing strategy—by selling greenhouse tomatoes to the organic market, for example—then this may still be a smart approach.

One of the most frequently asked questions is, "How many bugs will it take to cause economic damage to my crop?" There is no simple answer. However, you can consider the five factors listed above to develop **action thresholds**. These are actual pest population levels at which you will apply controls to avoid economic injury. There are two types of action thresholds. The **economic injury level** (EIL) is that pest population that will cause economic injury, all other factors considered (figure 9). At this point, the cost of applying controls exactly offsets the economic loss caused by the pest. If controls are exerted at population levels below the EIL, then the control costs exceed the benefits. Conversely, if controls are not exerted until the pest population surpasses the EIL, some economic loss to the crop will have occurred. It is usually impractical to apply controls exactly as the pest population reaches the EIL and still keep the pest from causing economic damage. The **economic threshold** (ET) is a population level somewhat below the EIL that allows sufficient lead time to implement control. By applying controls at the ET you improve the chances of achieving economic pest control.

The costs of different pest control strategies varies, and because crop susceptibility and market values vary, the EIL and the ET are not fixed values. There may be several values for each crop, depending on the end use, and for each pest. Chrysanthemums grown for cut flowers can tolerate some leafminers on lower leaves because only the top half of the plant is marketed. Potted chrysanthemums cannot have any significant leafminer damage. As a result, the thresholds for leafminers are higher on chrysanthemums grown for cut flowers than those for potted plants.

The above discussion assumes that the grower will purchase biological control agents. Some natural enemies invade greenhouses, but for the most part introductions are necessary to provide control. In a few situations, introduced natural enemies become established so that biological control is effective and permanent, requiring little if any ongoing economic input. However, regular releases are usually necessary to sustain biological control in greenhouses.

Figure 9. A hypothetical example of an uncontrolled pest population exceeding the economic injury level (EIL). Action should be taken at the economic threshold (ET) to avoid this problem.



SECTION

2

Practical approaches to the biological control of greenhouse pests

Biological control relies on living organisms that interact, often in complex ways, with the pests, the crop, and other environmental factors. The pest manager needs a different type of knowledge and skill, as well as extra effort and patience, to implement biological control instead of using chemical control. A good understanding of the relationships between pests, their natural enemies, and the environment is essential.

Successful implementation of biological control in greenhouses does not depend on natural enemies alone. To be effective it must be part of an integrated pest management program. **Integrated pest management** (IPM) is the ecologically sound use of all available methods to control pests. One of the goals of IPM is the reduction of pesticide use and, if sprays are necessary, the selection of those that are the least disruptive to natural enemies. That means incorporating many cultural practices to prevent or delay the appearance of pests in greenhouse crops. It also means monitoring pests regularly to detect their arrival early and keep track of pest and natural enemy populations throughout the growing season. In addition, this approach requires an understanding of all the alternative pest management options, both chemical and nonchemical. In the following sections on specific pests, the methods for using and conserving natural enemies in an IPM context are described in detail.

Sanitation is the most important cultural practice for preventing pest problems. Keep the greenhouse clean. The cleanest greenhouses usually have the fewest pest problems. Remove dead foliage, broken pots, and trash, and place it in areas away from the greenhouse operations. Keep areas beneath benches as dry as possible. Remove plastic, boards, and debris that may serve as hiding places for pests such as slugs or sowbugs. Eliminate standing water and algae growth; fungus gnats and shore flies breed in these conditions. Remove weeds under the benches and "pet plants" that are a refuge for insects. Aphids, thrips, mites, whiteflies, and other pests developing on weeds outdoors can enter the greenhouse through ventilators or unscreened doors. To minimize this, mow any grass or kill weeds in a 15–30 ft strip around the greenhouse.

Sanitation inside the greenhouse can be more important than preventing migration from the outside. Use screens on vents and doors if the pest populations entering the greenhouse from outside are large enough to justify the expense. Know where the pests are coming in before installing screens, so you don't install unnecessary ones. Remember that screens reduce air flow when placed around vents. The smaller the pore size of the screen, the harder it is to get air through. Screens may place severe strain on exhaust fans. To counteract airflow problems, expand the surface area of the intake vents. Work with reputable suppliers to develop proper designs for your needs. They should have information on the porosity of screens for airflow, the insects meant to be kept out, and screen installation. Screens must be cleaned regularly for proper airflow. Double door entries, with negative pressure to prevent pest entry, can provide a high level of pest exclusion for special situations, such as virus-sensitive crops and cuttings.

It is important to start with clean plants and keep them separate from infested plants. Pests can easily move from an infested crop to an uninfested one. Avoid starting new plants in a greenhouse with an existing crop. Hanging baskets often contain pests that easily fall onto the new crop. Carefully inspect all new plant material for pests before placing it in growing areas to prevent contamination of the entire range. Treat or quarantine any shipment that is infested. If only a few plants are infested, remove or destroy them. Also, start with steam-sterilized soil or soilless potting medium. Dispose of or pasteurize used media.

If pests are already present, rogue out severely infested plants. After harvest, remove all crop residue promptly from the greenhouse. Pest outbreaks in new crops can start from pieces of infested leaves or stems from the old crop. You should also institute policies to reduce the accidental spread of pests on workers' clothing or implements. Restrict movement through infested areas and always visit them last. Consider banning yellow and blue clothes from the greenhouse because they are attractive to whiteflies and thrips, respectively.

Plant management practices that promote healthy plants also help reduce pest problems. Many pests develop better on stressed or lush plants than on normal plants. Maintain proper soil moisture and avoid over- or under-fertilizing. High nitrogen levels are often associated with severe pest infestations.

Plant selection may make the difference between success and failure in biological control on a particular crop. Many pests develop better on some crop cultivars than on others. Select plants known to be the least sensitive to the pests that you are dealing with. Eliminate the most susceptible cultivars if possible, or isolate them to reduce contamination of other cultivars.

Monitoring pest and natural enemy populations on a regular basis is a crucial component of any biological control program. A good monitoring program will help detect the pests early, time the release of natural enemies for maximum effectiveness, and determine the result of natural enemy introductions. Finding pest infestations when populations are small increases the likelihood of success with biological control. It is also easier to determine which beneficials to use when you know the magnitude of the pest problem.

It is important to have a knowledgeable person, such as a consultant or trained employee, on site for monitoring. Weekly monitoring is necessary in most greenhouses. Monitoring usually entails counting pests caught on sticky traps placed over crops in the greenhouse as well as visual counts of pests and beneficial insects on leaves or other plant parts. When recording the number of pests and natural enemies, be sure to note the temperature, date, time of day, numbers caught per sticky trap, and location of infested plants and traps. Use a map of the greenhouse to update the location and density of pests. Different methods for monitoring different pests and their natural enemies are discussed in more detail in the following sections on specific pests.

Susan E. Rice Mahr

Augmentation is necessary to achieve effective control with most of the parasites, predators, and pathogens discussed, although a few invade greenhouses naturally and provide some control. The suggested release rates and methods for natural enemies that are produced commercially are only general guidelines. Specific release rates are difficult to provide because of the complexity of biological interactions in the greenhouse. Numerous variables affect the performance of natural enemies and therefore the number necessary to maintain pest populations below economic injury levels. These include the crop variety and growth stage, size of the pest population, environmental conditions, release methods, the quality of the natural enemies released, and the presence of other insects. Appropriate release rates often can be determined only through experience. Many suppliers provide recommendations for their products.

Ordering and receiving shipments of predators and parasites requires some advance planning. Determine which suppliers offer the natural enemies you need and contact them to confirm availability. One source of such information is *Suppliers of Beneficial Organisms in North America*, which is listed in the additional reading section at the end of this publication. If importing natural enemies from outside the country, it may be necessary to obtain import permits from the Animal and Plant Health Inspection Service (USDA-APHIS) well ahead of time. Also, some states have regulations regarding the interstate shipment of commercial natural enemies. If you are uncertain about such regulations, contact your state's agriculture department.

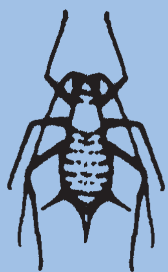
Decide which delivery service to use for your location and provide a delivery address where the shipment will not be exposed to extreme temperatures and will be cared for as soon as it arrives. Be prepared to make releases when the shipment arrives, or to provide the proper storage conditions until releases can be made. Check the shipment to make sure you received the species and quantities you ordered, that the shipment is not damaged, and that the natural enemies are viable. Contact the supplier immediately if there is any problem. Understand proper release procedures and make the introductions according to your supplier's recommendations. In general, releases should be made during the cooler part of the day, either in the early morning or late afternoon. Never release natural enemies during the heat of the day. Evaluate the success of the release by monitoring both the natural enemy and pest populations.

Residual broad-spectrum pesticides, including sulfur-containing fungicides (which are toxic to predatory mites) should not be used within a month of parasite or predator release. There should be no chemical residues on either the plants or the greenhouse structure before starting a biological control program. Determine the pest control history of incoming plant material since pesticide residues on new cuttings can also be toxic to natural enemies.

The rest of this section discusses the major pests of greenhouse crops. It includes an overview of the damage caused by each pest, a brief description of the pest and its life cycle, a statement on monitoring the pest, and detailed information on selected parasites, predators and pathogens of those pests. The possibilities for effective biological control of each pest are reviewed, as are alternative control methods, most of which are nonchemical. Some of the natural enemies discussed show promise for biological control in greenhouse crops but were not commercially available at the time of printing. Check natural enemy suppliers for current availability.

Aphids

Available natural enemies and their potential for control



Aphids have many predators and parasites that can be highly effective. The potential for successful biological control is high.

Order Homoptera: Aphids, leafhoppers, and scales

Family Aphididae: Aphids

Chrysanthemum aphid, *Macrosiphoniella sanborni*

Cotton or melon aphid, *Aphis gossypii*

Foxglove aphid, *Aulacorthum solani*

Green peach aphid, *Myzus persicae*

Potato aphid, *Macrosiphum euphorbiae*

Rose aphid, *Macrosiphum rosae*

Aphids are one of the most serious pests of greenhouse-grown crops. Almost all species of plants grown in greenhouses are susceptible to some aphid species. Of the numerous aphid species that infest greenhouse crops, the most common is the green peach aphid. It attacks a wide range of hosts, but especially the Solanaceae (tomato, pepper, eggplant) and chrysanthemums. The cotton, potato, and foxglove aphids are other common species with a wide host range. The cotton aphid is important on cucumbers and chrysanthemums, while the other two are important on Solanaceae. The chrysanthemum aphid infests chrysanthemums and the rose aphid infests roses. Many other aphid species may occur in greenhouses.

Damage

Aphids feed by inserting their mouthparts into leaves, buds, or stems and sucking out the sap. Chlorotic spots may develop where cell contents have been removed. Bud feeding results in distorted leaves and, at high densities, can cause stunting and/or wilting. Severe damage to the top of the plant may reduce the number of flowers produced. Aphids also excrete honeydew on which sooty molds grow, and some species may transmit viruses.

Aphids feeding on flowers make the plants unmarketable. Their presence is a nuisance on ornamental plants because they leave cast skins stuck to the plant when they molt, which detracts from the value of the plant.

Description and life cycle

Most aphids are 1⁄8 inch (2–3 mm) long. Their pear-shaped bodies have "exhaust pipes" (cornicles) protruding from the back end of the abdomen. Wingless forms of the green peach aphid are yellowish green in summer and pink to red in fall and spring. Winged forms are brown. Cotton aphids may be green, yellow, mottled, or blackish. Chrysanthemum aphids are maroon or dark brown, stem-feeding aphids. Most other aphids are green, gray, or yellow-green and feed on leaves or growing tips.

Each female aphid reproduces for a period of 20–30 days, giving birth to 60–100 live nymphs. The nymphs look like the adults but are smaller. The nymphs mature and can produce offspring within a week at greenhouse temperatures. Winged females that can migrate are produced when the food supply becomes short or the area becomes overcrowded. Males and eggs are produced only in northern areas, in response to colder temperatures and shorter days. Aphids overwinter as eggs outdoors in northern areas, but in greenhouses will continue to develop year-round.

Oregon State University Extension Service

The hollow remains, or mummy, of an aphid parasitized by a braconid wasp. The "trapdoor" was created by the adult wasp at emergence. Aphid mummies in a colony usually indicate that many of the apparently healthy aphids are also parasitized.

Monitoring

Look for aphids on as many plants as possible. Check the lower leaves, around the terminal or flower buds, and on the top 6 inches of the stems of older plants. Different aphid species prefer different parts of the plant. Cast skins, honeydew droplets, and sooty mold are indications of an infestation. Aphid infestations are often localized. Mark infested plants and check the progress of control efforts. Yellow sticky traps can be used to detect winged aphids moving into the greenhouse. However, if winged aphids are detected on yellow sticky traps in a closed greenhouse, this probably indicates a serious infestation is already present.

Natural enemies

Numerous parasites, predators, and pathogens attack aphids. Only those that have shown promise for use in greenhouses are discussed here. Most wasps have similar developmental processes. They are born in the aphid and, as larvae, consume it from the inside. They pupate inside the mummy and later emerge.

Parasites

The parasitic wasps that are important natural enemies of aphids do not have common names. Those discussed here are in the families Aphelinidae and Braconidae. The Braconidae includes the subfamily Aphidiinae, which is occasionally treated as a separate family, the Aphidiidae.

Aphelinus abdominalis. This solitary endoparasitoid parasitizes primarily potato aphid and foxglove aphid. The 1⁄8-inch (2.5–3 mm) adults are black with a yellow abdomen. Females prefer to oviposit in third instar nymphs. Adult wasps emerge from black mummies through a jagged hole. Females **host feed** on some species of aphids. It is commercially available.

Aphelinus flavipes. This is a parasite of cotton aphid similar to *A. semiflavus* (below) in size and development. *A. flavipes* also produces a black mummy. It is not available commercially.

Aphelinus semiflavus. This wasp parasitizes several aphid species, including the green peach aphid. Often confused with *A. asychis*, a European parasite of spotted alfalfa aphid, the stocky adults are very small (1⁄25 inch, 1 mm) with elbowed antennae. Females lay single eggs in an average of 200 early-instar aphids. The parasite pupates inside the mummy, which turns a dull black. The females also kill three to five young aphids each day by feeding directly on aphid body fluids that exude from holes made with the ovipositor. It is not yet available commercially.

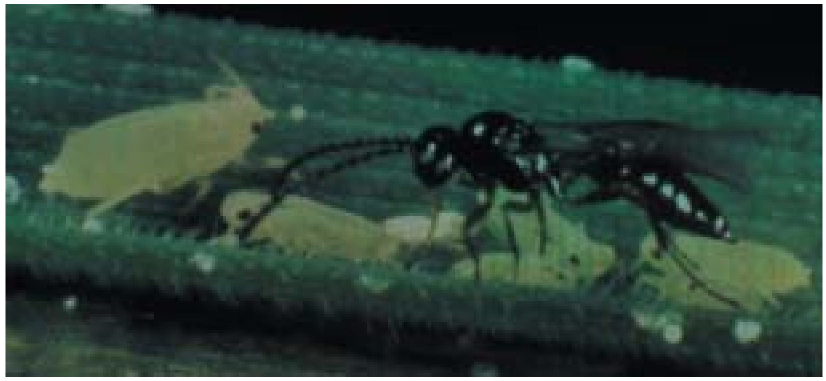
Aphidius colemani. This braconid wasp is **cosmopolitan**—that is, it occurs in most parts of the world. It reproduces well on cotton aphid, green peach aphid, and other species, but not on potato or foxglove aphid. The appearance, life cycle, and biology of this species is similar to *A. matricariae* (next page), but females lay more eggs—an average of 388—over their 4–5 day life span. It is commercially available in the United States.

Aphidius ervi. This cosmopolitan species parasitizes numerous aphid species in many different crops. In greenhouses, they parasitize larger aphids than does *A. colemani*, particularly potato aphid and foxglove aphid. The small black females can lay about 50 eggs a day during the first 5–7 days after emergence. Parasitized aphids turn into a golden yellow-brown mummy. The adult wasps emerge through a small round hole cut in the back of the mummy. A generation can be completed in 12 days at about 75°F. It is commercially available.

Koppert B.V.

Aphidius colemani, a braconid wasp, parasitizing an aphid.

***Aphidius matricariae*.** This 1⁄16 inch (2 mm) long, black braconid wasp from Europe is one of the most common and effective parasites of the green peach aphid. *A. matricariae* is not a good parasite of cotton aphid or potato aphid. Females lay 50–150 eggs singly in aphid nymphs of all sizes. The wasp larvae consume the aphids from inside. As the larvae mature and the aphids are killed, over about 7–10 days, the aphids turn into mummies—smooth, shiny, and light brown to silvery-gold. After the larvae pupate, each adult wasp emerges in about 5 days through a round exit hole cut in the mummy. In addition to killing aphids directly, mechanical disturbance of aphid colonies by the searching activity of the adult wasps causes many aphids to fall off the plants and die. This wasp is available commercially.



Max Badgley

Aphidius matricariae, a braconid wasp, parasitizing an aphid.

J. van Schelt, Koppert B.V.

The midge *Aphidoletes aphidimyza*. Females can lay up to 250 eggs among aphid colonies.

***Diaeretiella rapae*.** This cosmopolitan aphidiid species, probably native to Europe, is normally a parasite of the cabbage aphid, *Brevicoryne brassicae*, but it readily attacks green peach aphid in the greenhouse. Females lay an average of 85 eggs during their lifetime and prefer half-grown nymphs over first instars or adults. Parasitized aphids become golden brown mummies. This insect is sold commercially.

***Ephedrus cerasicola*.** This European aphidiid wasp parasitizes green peach aphid. The aphids become black mummies about 12 days after the female oviposits in the aphids. The parasitized aphids often move from the plant to the pot or support structures before becoming mummies. The adult wasps emerge about a week after mummies appear. *E. cerasicola* is not yet commercially available in North America.

Cliff Sadof

Midge larvae *Aphidoletes aphidimyza* are highly effective predators of aphids.

***Lysiphlebus testaceipes*.** This aphidiid wasp is an effective parasite of all instars of cotton aphid, but not of green peach aphid or potato aphid. The aphid mummies are yellowish brown to brown. It is adaptable to a range of climatic conditions. This wasp is commercially available.

Predators

***Aphidoletes aphidimyza*.** The larvae of this midge feed on over 60 aphid species, including all that occur on greenhouse crops. The adults are small—less than 1⁄16 inch (2 mm) long—black, delicate flies, similar in appearance to fungus gnats, that live for an average of 10 days by feeding on aphid honeydew. They hide beneath the leaves during the day and are active at night. Females deposit 100–250 tiny (less than 1⁄64 inch, or 0.3 mm), shiny orange eggs singly or in small groups among aphid colonies. The bright orange, slug-like larvae that hatch in 2–3 days inject a toxin into aphids' leg joints to paralyze them, then they suck out the aphid body contents through a hole chewed in the thorax. The larvae grow up to 1⁄8 inch (3 mm) long and each kills 4–65 aphids per day. Larvae can consume aphids much larger than themselves and may kill many more aphids than they eat when aphid populations are high. After 3–7 days, the larvae drop to the ground and burrow 3⁄4–1 1⁄2 inches into the soil to pupate. Optimal conditions for their development are 73°–77°F and a relative humidity of 80–90%. *A. aphidimyza* enters diapause under short day conditions. This insect is commercially available.

***Chrysoperla (=Chrysopa) carnea*— green lacewing.** The larvae of these lacewings are known as aphidlions for a reason—they are voracious feeders that can consume up to 425 aphids or other prey per week. The light-green adult lacewings have slender antennae, golden eyes, and large, veined, gauze-like wings that are 1⁄2–3⁄4 inch (1.3–2 cm) long. They are slow-flying, nocturnal insects that feed on nectar and pollen, and emit a foul-smelling fluid from special glands when captured. Female green lacewings usually lay up to 300 eggs in groups on leaves, over a period of 3–4 weeks. Each egg sits on the end of a slender stalk, about 1⁄3 inch (8 mm) long, attached to the leaf's surface. Freshly laid eggs are green, but they change to whitish gray as they get close to hatching.

The aphidlions that emerge look like green-gray alligators with mouthparts like ice tongs. An aphidlion seizes its prey, punctures it with its long jaws, then injects a paralyzing venom and sucks out the body fluids. In addition to aphids, aphidlions will feed on a wide variety of soft-bodied insects including thrips, mealybugs, immature whiteflies, and small caterpillars, as well as insect eggs and spider mites. They will also consume each other if no alternative prey is available. After growing to 3⁄8 inch (1 cm) long during a 2–3 week period, the larva spins a spherical, white silken cocoon in which it pupates, emerging in 5 days as an adult. The adults require pollen in order to reproduce. Green lacewings are available from many commercial suppliers.

***Chrysoperla comanche*—Comanche lacewing.** This commercially available species of green lacewing is closely related to *C. rufilabris* (below). It commonly occurs in orchards and vineyards at low elevations in the southern parts of Texas, New Mexico, Arizona, and California. Its biology and development is similar to *C. carnea*, but it is better adapted for development under dry conditions.

***Chrysoperla rufilabris*.** This is another species of green lacewing sold for control of soft-bodied pests, including aphids. It is common in tree crops in the northeastern United States. Its biology and development is similar to *C. carnea*, but it is better adapted for development under humid conditions than *C. carnea*.


Richard Lindquist, The Ohio State University

A green lacewing larva, also called an aphidlion, of *Chrysoperla comanche*.


Daniel L. Mahr

The distinctive stalked egg of the green lacewing, *Chrysoperla carnea*. The stalk is about 1⁄3 inch long.


Cliff Sadof

An adult green lacewing, *Chrysoperla rufilabris*.

***Deraeocoris brevis*.** This mirid bug feeds primarily on aphids and whiteflies, although it will attack thrips and small caterpillars. Both nymphs and adults are predaceous. The 3/16 inch (5 mm) long females lay up to 200 eggs in plant tissue. Nymphal development takes 25–30 days, and the adults live about 3 weeks. Optimum conditions are 64°–85°F with 30–60% relative humidity. *D. brevis* enters diapause when daylength is less than 10 hours and temperatures are below 73°F. This bug is commercially available.

***Hippodamia convergens*—convergent lady beetle.** Adults are the common red lady beetles with black spots on each wing cover. Although they will attack various soft-bodied insects, convergent lady beetles are sold primarily for aphid control. Each will consume as many as 2,000 aphids during its life. Females lay up to 1,500 orange, bullet-shaped, 1/25 inch (1 mm) long eggs in clusters on leaves near the prey. These hatch into tiny, black, alligator-shaped larvae with conspicuous orange markings. They are somewhat slender, with the body tapering to a point at the rear and prominent legs that stick out from the sides. They feed for 3–4 weeks, consuming 500–1,000 aphids or similar prey during their growth. They generally pupate where they were feeding. *Hippodamia convergens* is one of the most widely available lady beetles in North America.

Other lady beetles. Scientists have examined several species of lady beetles as potential biological control agents of aphids in greenhouses. Introduced at a ratio of one adult lady beetle to 20 aphids, *Cycloneda sanguinea* larvae controlled cotton aphid on cucumber. In a series of experiments on cucumbers in small greenhouses, the second and third generations of the beetle eliminated the cotton aphid. However, the commercially available *Coleomegilla maculata* was ineffective against cotton aphid on cucumber because it would not remain on the leaves. *Adalia bipunctata* and *Coccinella septempunctata* have been used experimentally in Finland for aphid control on chrysanthemums and roses. *Lemnia biplagiata*, imported from Vietnam for use in Russian greenhouses, controlled cotton aphid on cucumber and green peach aphid on peppers. Many of these beetles are not suitable for commercial production and only *C. maculata* is currently available.

University of Florida

A convergent lady beetle, *Hippodamia convergens*. Lady beetles are voracious feeders, consuming as many as 2,000 aphids in their lifetime.

University of Florida

Lady beetle larva feeding on aphids. Note that some aphids have already been parasitized by braconid wasps.

Macrolophus costalis. This mirid bug was investigated in Poland for controlling aphids on greenhouse crops. It feeds on aphids and greenhouse whitefly larvae and was able to control aphids at predator-to-prey ratios of 1:2 and 1:3. It reduced aphid numbers best when the aphid populations were high. It is not commercially available, although a related species, *M. caliginosus*, is offered as a predator of whiteflies.

Les Shipp

The minute pirate bug, *Orius* spp., is a generalist that feeds on aphids, thrips, spider mites, whiteflies, and caterpillar eggs, as well as pollen and plant juices.

Micromus angulatus. This brown lacewing has recently been investigated as a beneficial insect for the biological control of small, soft-bodied insect pests in greenhouses. Its prey includes small aphids, immature whiteflies, and insect eggs. It has been successfully mass reared in Germany but is not yet commercially available in North America.

***Orius* spp.** Several species of minute pirate bug, which are generalist predators, feed on aphids, thrips, spider mites, whiteflies, and caterpillar eggs, as well as pollen and plant juices. They are also cannibalistic under crowded conditions. The black, 1⁄16–3⁄16 inch (2–5 mm) long adults are ovoid and somewhat flattened, with distinctively patterned black and white wings. They lay their eggs in leaf tissues with one end of each egg sticking out. The tiny *Orius* nymphs are pinkish-yellow to light brown. Both nymphs and adults are very active and will feed on small aphids, although they will feed on other prey if available. Several species of *Orius* are available commercially.

Max Badgley

An *Orius* nymph.

Oregon State University Extension Service

The slug-like maggot of the syrphid fly can consume as many as 400 aphids during development.

Syrphid or hover flies. The larvae of many species of syrphids can control aphid populations rapidly. They occasionally move into greenhouses from outside, where they are common and important natural enemies of aphids. The adult flies, which are often seen on or hovering near flowers, are small to medium in size (3⁄8–3⁄4 inch, or 8–20 mm), often with a striped yellow and black body resembling honey bees or wasps. Females lay eggs near aphid colonies. The slug-like, pale green to yellow maggots feed on aphids, scales, and other insects, growing to 3⁄8–5⁄8 inch (10–15 mm) in length. Larvae can consume as many as 400 aphids during their development. Some species pupate on the foliage near the feeding site, whereas others leave the plant to pupate in the soil. The pupa is enclosed within a **puparium**—the hardened skin of the last larval instar—which is often teardrop-shaped, smooth, and tan colored. The life cycle of most species lasts 2–4 weeks. Syrphid flies are not commercially available.

Pathogens

***Beauveria bassiana*.** This is a common soil-borne fungus that occurs worldwide. It attacks a wide range of both immature and adult insects, including some natural enemies. As with all insect-pathogenic fungi, *Beauveria* produces spores that are resistant to environmental extremes and are the infective stage of the fungal life cycle. The spores (conidia) infect directly through the outside of the insect's skin. Under favorable temperature and moisture conditions, a conidium (singular of "conidia") adhering to the host cuticle will germinate. The fungal hypha growing from the spore secretes enzymes which attack and dissolve the cuticle, allowing it to penetrate the skin and grow into the insect body. Once inside the insect it produces a toxin called beauvericin that weakens the host's immune system. After the insect dies, an antibiotic (oosporein) is produced that enables the fungus to out-compete intestinal bacteria. Eventually the entire body cavity is filled with fungal mass. When conditions are favorable the fungus will grow through the softer parts of the insect's body, producing the characteristic "white bloom" appearance. Relative humidity must be 92% or more for *B. bassiana* to grow outside the insect. These external hyphae produce conidia that ripen and are released into the environment, completing the cycle. This fungus is commercially available.

***Metarhizium anisopliae*.** This insect pathogenic fungus infects over 200 species of insects. It occurs naturally in soils throughout the world. Green, cylindrical spores are produced in chains from infected insects. Because this fungus has a wide host range and infects some beneficial insects, including lady beetles, it may not be compatible with all aphid predators and parasites. However, it is not toxic to plants, honey bees, earthworms, fish, or humans. A formulation of this fungus can be applied like a conventional insecticide, but this is not yet registered for use in the United States on any greenhouse crops.

Don McLean, University of Vermont

The fungus *Metarhizium anisopliae* infecting a green peach aphid.

***Paecilomyces fumosoroseus*.** This insect pathogenic fungus has a wide host range, with several strains infecting insects in over 25 different families, including aphids, whiteflies, thrips, and some natural enemies. Fungal spores bore through the insect's skin. As the spores grow, they consume the insides of the insect, eventually killing the host. External mycelium on infected insects is white at first, then changes to shades of pink. The infected insect eventually becomes light gray when spores are produced on the outside of its body. The infection cycle is very rapid, with sporulation occurring within 72 hours of infection and peaking at 5–7 days. This fungus requires humidity over 90% for infection and germination is poor when humidity is below 98%, which limits its utility. Virulence varies among strains; the most virulent strains are being commercialized. This fungus is commercially available in Europe, but is not registered for use in the United States.

***Verticillium lecanii*.** This insect pathogenic fungus infects both aphids and whiteflies. The fungal strain with large spores infects aphids; the strain with smaller spores is specific to whiteflies. Relative humidity over 95% must be maintained for infection to occur. The fungal spores kill aphids by growing through the aphid's skin. The spores continue growing inside the insect, eventually consuming the internal contents. Aphids killed by this fungus remain on the plant, covered in spores. Under the right conditions spores stick to healthy aphids that touch them and initiate a new infection cycle. Vertalec and Mycotal are commercial formulations of the fungus specific to aphids that are available in Europe. They are not currently registered for use in North America.

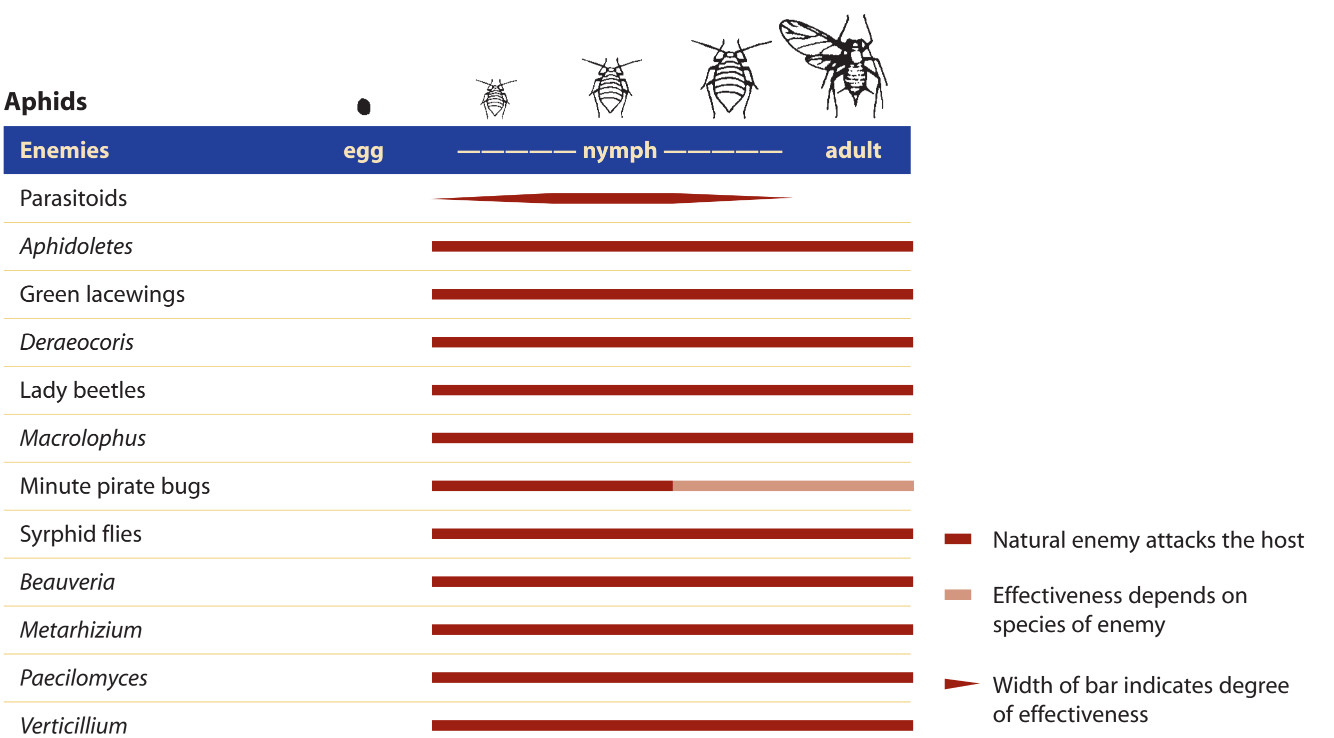
Possibilities for effective biological control

Aphids can be effectively controlled by several commercially available natural enemies, released singly or in combination. Aphid populations can increase very quickly, so it is best to release natural enemies while populations are low. If more than 10% of the plants are heavily infested, you should reduce aphid populations before you release parasites or slower-acting predators. Use either nonresidual chemicals (insect growth regulators, soaps, oils, etc.), or predators, such as green lacewing larvae, that will quickly eat large numbers of aphids.

Aphidoletes aphidimyza has been used successfully for biological control of aphids on cucumber, green pepper, tomato, chrysanthemum, rose, and many other ornamentals on a commercial scale. Unlike other predators, this midge reproduces during the growing season, so only a single release may be necessary, although two to four introductions are often required. *A. aphidimyza* may be more useful in a biological control program for aphids on greenhouse crops than lady beetles or green lacewings. However, many aphids killed by midge larvae remain attached to the leaves, which may detract from the value of ornamental plants.

Aphid midges are shipped as pupae (inside their cocoons) in moist vermiculite. Sprinkle the vermiculite with the cocoons on moist soil or root medium within the plant canopy. Adults will not emerge from cocoons that fall on dry areas in direct sunlight. The bright orange midge larvae should be visible among the aphids about a week after the adults have emerged. The adults hide beneath the leaves during the day and are active at night. Optimal conditions are 68°–81°F and 50–90% relative humidity. Recommended release rates vary depending on the plant type, growth stage, aphid species, and infestation level. Lower release rates may be used before aphids are observed for preventative control. Weekly or biweekly releases of one or two pupae per plant, or up to three pupae per 10 ft^2, or 2,000–6,000 pupae per acre are successful for controlling aphids on most plants. Two to four applications are often necessary to achieve control. Additional introductions of the midge will not be necessary if successive generations are produced during the growing season. If aphids can be tolerated on the lower leaves of the plants, the midge populations will build up quickly on the supply of aphids.

Biological control of aphids with *A. aphidimyza* is most successful in greenhouses with soil beds or gravel floors, probably because the midge larvae easily find suitable sites for pupation. Sprinkle a thin layer of sawdust or peat moss between the rows on concrete or plastic-covered floors to provide suitable pupation sites in these greenhouses. Without proper pupation sites on the floor, fewer midge offspring survive, and weekly releases may be necessary throughout the season to provide adequate control.



The midge can also be introduced from open rearing units or **banker plants** placed in the greenhouse. Aphid species that do not infest commercial greenhouse crops—such as the grain aphids *Sitobion avenae*, *Metopolophium dirhodum*, and *Rhopalosiphum padi*—are used as prey for *A. aphidimyza*. Place these aphids on wheat or barley plants (the banker plants) in open trays or boxes. The predators develop on these aphids, and the adult predators disperse to lay eggs on infested crop plants. The rearing units must be established early in the growing season and maintained for several weeks so that a large midge population has developed by the time pest aphids appear. This is not a practical method in large commercial greenhouses, but boxes containing growing barley with grain aphids can be purchased from some suppliers for this use.

One drawback of *A. aphidimyza* is that it enters into diapause under cool, short-day conditions. Diapause can be prevented by leaving on a few incandescent walkway lights all night during winter months (through late February). Larvae are very sensitive to light, so a single, 100-watt bulb will prevent over half of the midges within a circle with a diameter of 24 yards from diapausing. This will not be effective when plants are so large that light does not penetrate between the rows. If supplementary lighting to prevent the midges from diapausing is not feasible, and aphids are a problem in the fall or winter, other natural enemies, such as the parasitic wasp *Aphidius matricariae*, can be used for aphid control.

Because *Aphidius matricariae* does not diapause under winter greenhouse conditions as readily as *A. aphidimyza*, it can be an important part of a biological control program from fall through early spring. On chrysanthemum, green peach aphid has been controlled within 2 months of planting when the wasp was introduced in parasitized aphids, packaged in boxes of rooted cuttings (50 aphids per box of 500 cuttings). It is not as effective against cotton aphid as it is against green peach aphid.

A. matricariae performs best when it is established in the greenhouse early in the growing season. Native *A. matricariae* entering the greenhouse from outside sometimes become established and provide effective control. However, in the spring and summer these wasps are frequently attacked by their own native hyperparasites, which reduce the natural or introduced *A. matricariae* population. Adult *A. matricariae* are attracted to the color yellow, so yellow sticky cards should be removed before releases are made. A release rate of two per 20–800 ft^2 is recommended. It is effective when aphid populations are low, but should be used in combination with other natural enemies when populations are high. This wasp is not compatible with insect pathogenic fungi such as *V. lecanii* which kill the parasite larvae inside the aphid.

Diaeretiella rapae can be as effective as *A. matricariae*. It has eradicated green peach aphid on chrysanthemum in 6 weeks when released at a rate of one parasite per 500 aphids. Release rates vary by aphid species and stage of infestation and should be determined on an individual basis.

Aphidius colemani is a very promising candidate for biological control in greenhouses because of its high reproductive potential, short development time, and ability to parasitize several species of aphids, including cotton aphid, melon aphid, and green peach aphid. It is more efficient at parasitizing cotton aphid on cucumber than *A. matricariae* is.

Aphidius ervi and *Aphelinus abdominalis* are two other commercially available wasps that can be utilized against certain aphid species. *A. ervi* is most effective against potato and foxglove aphids when released before aphid populations build up. It should be released at a rate of about 0.15 adults per 10 ft^2 every week. If aphids are already present, suggested release rates are 0.5 per 10 ft^2 and introductions should be made every 3 days if aphid populations are high. *A. abdominalis*, another good parasite of potato and foxglove aphids, should be released in infested areas only since this wasp is not very mobile. Make weekly introductions of two to four adult wasps per 10 ft^2 depending on aphid population density until 80–90% of the aphids have become black mummies. After that time small quantities can be released.

Many general predators, such as lady beetles, lacewings and hover flies, also provide effective and rapid control of large aphid populations. Adults lay eggs only near large numbers of aphids. However, most species will not reproduce in the greenhouse. In order to obtain control you must release them every 2–3 weeks.

The convergent lady beetle can suppress high aphid populations quickly, but establishing a population in the greenhouse is difficult. Thus, convergent lady beetles are used most effectively to reduce high aphid populations that can then be kept under control by other predators, parasites, or pathogens. Most commercially available convergent lady beetles are not insectary-reared, but are collected from winter hibernation sites. Only when their stored winter fat reserves have been depleted will they become predaceous. Even then, after consuming many aphids, lady beetles often fly to the vents and leave to lay eggs outside. These beetles may also be parasitized. Repeated releases of convergent lady beetles are often necessary. Determine release rates on a case-by-case basis. Make releases in the evening, because bright sunlight encourages their flight. Keep the vents closed or screened to prevent the beetles from leaving the greenhouse.

Green lacewing larvae have controlled aphids effectively on green pepper, parsley, chrysanthemum, snapdragon, and many other kinds of ornamentals. In an experiment on snapdragon, the flower quality of plants with aphids controlled by green lacewings equalled the quality of flowers produced with chemical applications. Lacewings are most effective at high aphid densities, eliminating large aphid populations or reducing them to such low levels that additional control is often not necessary. The effect of a release will be apparent in 1–2 weeks. If additional control is necessary, the next release should be delayed until the larvae from the previous release have finished their development so these aphidlions do not eat the new lacewing eggs or larvae. Where aphid densities are low (four or fewer per plant) lacewing larvae are not effective, and the parasite *Aphidius matricariae*, which is more effective at low aphid densities, should be used. However, if this wasp is released while lacewing larvae are still feeding, the lacewings may consume parasitized aphids, thereby reducing the wasp population.


Ray Cloyd

Lady beetles can be good predators of aphids.

The number of lacewings needed for effective control depends on the crop, the growth stage, the aphid species, and the degree of infestation. Releases should be initiated early, when aphids are discovered on a few plants. You can achieve control at higher aphid densities, but the number of lacewing eggs needed is very high. Suppliers usually make recommendations based on specific situations. For control of moderate aphid infestations, 5–10 lacewing eggs per plant or 1,000 eggs per 200 ft^2 are recommended. Release recommendations for larger areas start at 5,000 per acre for each application. These insects are extremely effective, but cannot multiply in greenhouses and must be released at regular intervals—about every 2 weeks.

Green lacewings are usually sold as eggs but also may be sent as larvae or adults. Eggs are sent in a packing material to cushion and separate the emerging larvae during shipment. The material—rice hulls, wheat bran, or corn grits, along with moth eggs for food so the larvae will be less likely to eat each other—also makes it easier to distribute the very tiny eggs evenly. Lacewing eggs can also be mixed with Biocarrier, a material that helps to glue eggs to plants or containers. This is especially helpful in making applications in hanging baskets.

The lacewings should be released as soon as they begin to hatch. Releases are made by sprinkling the contents of the container onto infested plants. The newly hatched larvae will be very tiny (about the same size as the eggs) so you may have difficulty seeing them. The released aphidlions will travel a considerable distance, up to 100 feet, in search of prey. Making releases early in the morning or late in the day when it is cooler, or on a cloudy day, increases the chances the lacewings will survive. Larger larvae, which consume aphids at a faster rate than newly hatched larvae, are available from some suppliers. Because they are cannibalistic, lacewings purchased as large larvae must be shipped in individual containers which increases the cost of the product. Lacewings released as pre-fed adults that are ready to lay eggs can fly away upon opening the shipping container, so greater care must be taken when releasing lacewings at this stage to ensure their establishment in the infested area.

The commercially available mirid bug *Deraeocoris brevis* can also be used to control aphids. Since this insect can survive on pollen if prey are scarce, including some pollen-producing plants, such as pepper, may help retain the insect in the greenhouse. The bugs are shipped as adults with some nymphs present. Release rates should be provided by the supplier.

Several natural enemies of aphids that are not commercially available in the United States have been investigated in Europe. The parasites *Aphelinus flavipes, Ephedrus cerasicola*, and *Lysiphlebus testaceipes*, and the fungus *Verticillium lecanii* show promise as effective biological control agents against aphids in greenhouses. *Aphelinus flavipes* is most effective at cooler temperatures, so the parasite can overtake a slow aphid population increase. A high parasite-to-host ratio and early introduction are necessary for reliable control. *A. flavipes* was only able to control cotton aphid on cucumber when the parasites were introduced before or at the time of aphid infestation.

Ephedrus cerasicola was considered better than *A. aphidimyza* in Norway, although control by both species was similar, because (1) it does not diapause and therefore provides control throughout the season, (2) it can be introduced at lower aphid densities, and (3) fewer individuals need to be released. When *E. cerasicola* was released early in the season, it kept green peach aphid populations on peppers below damage thresholds and eliminated the aphids within 2 months.

These wasps are released as pupae inside aphid mummies. Mummies can be placed among the plants or introduced on banker plants in a cage in the center of the greenhouse. Parasite-to-host ratios of between 1:5 and 1:10 are probably sufficient. Two introductions at 10-day intervals of four mummies per plant should be effective when there is less than one aphid per plant. At higher aphid populations, a single introduction of one mummy per 10 aphids should suffice. New introductions may not be necessary because this wasp will multiply in the greenhouse. However, if the aphids begin to increase or the parasite dies out, additional releases should be made at the same ratio.

The aphidiid *Lysiphlebus testaceipes* has been released outdoors in Mediterranean areas for control of several aphid species and is being investigated for control of cotton aphid in greenhouses. It has considerable potential for biological control, but because it does not parasitize green peach aphid well, an additional parasite might be needed to assist in control.

Several brands and formulations of the fungus *Beauveria bassiana* are available for use in greenhouses. Because it takes 3–7 days to kill an insect with *B. bassiana*, it will take some time to suppress the pest population when using these products. Thorough spray coverage is essential because fungal spores must contact the insect for infection to occur. This fungus is more tolerant of lower humidity than many other insect pathogenic fungi, so high relative humidity is not necessary for infection to occur. This fungus is susceptible to some fungicides, so chemical fungicide applications should not be made within 48 hours of *B. bassiana* applications. Three to five applications may be necessary to achieve control.

Although *Verticillium lecanii* is not available for use in the United States yet, this fungus may eventually be registered and provide effective control of some species of aphids here. Under the appropriate conditions, it has the potential to eliminate the need for insecticide applications for aphid control. *V. lecanii* effectively controls most aphids, including green peach aphid, but does not control chrysanthemum aphid. A single spray of *V. lecanii* was sufficient to control green peach aphid on chrysanthemum, but the fungus did not control chrysanthemum aphid on the same plants. The cotton aphid often escapes contact with the spores because it does not move around much. Only 80–90% control of cotton aphid can be expected. Plants should be treated when small to keep the aphid population under control. Otherwise, the fluffy white aphid bodies stuck to the mature foliage will make the plants commercially unacceptable. The fungus also kills *A. matricariae* and whitefly parasites inside the pest body, but it seems to be compatible with parasites of other pests, such as the eulophid wasp, *Diglyphus begini*, that attacks leafminers.

V. lecanii is applied as spores suspended in water for spraying. High humidity is necessary for spore production and infection. When humidity is low, the performance of the fungus is unpredictable. Humidity can be increased by dampening the plants with water sprays. Late afternoon applications reduce spore injury by ultraviolet light and desiccation, since the greenhouse is more humid at night. Alternating two nights of fogging—to produce the elevated humidity necessary for infection—with two nights of ambient conditions may provide an adequate environment for control. However, this fungus may be practical for use only in humid areas with moderate temperatures, such as rooting benches and shade-cloth covered areas used to induce inflorescence in chrysanthemums. Repeated applications of *V. lecanii* will be necessary if humidity is not high enough to allow continuous infection. This fungus may be susceptible to some fungicides.

If aphids are numerous, other means of reducing their numbers (such as releasing lacewing larvae or chemical control) must be used before treatment with *V. lecanii*. Two to 3 weeks are required to control an aphid population. If after 3 weeks of treatment less than 90% of the aphids are infected by the fungus, you should employ other means of control.

Other fungi, such as *Metarhizium anisopliae* and *Paecilomyces fumosoroseus*, may also provide effective control of aphids if these products become available in the United States. In lab experiments, Russian wheat aphid was more susceptible to *P. fumosoroseus* than to *B. bassiana*.

Alternative control methods

Sanitation

Weeds may harbor aphids both inside and outside the greenhouse. Pull weeds or use commercially available herbicides; use barriers to prevent weed growth.

Insect screens

Screens on vents and doors will help prevent aphids from getting into the greenhouse, but often the most effective screens reduce air flow. The maximum hole size to exclude cotton aphid is 341 µ (micrometers). Be sure to screen the greenhouse before the crop growing season, when the potential for aphid problems is still low.

Host plant cultivar

Aphids feed preferentially or reproduce at different rates on different cultivars of chrysanthemum. In one experiment, for example, 40 times more green peach aphids were found on the cultivar Tuneful than on Portrait. Green peach aphids were found to reproduce much faster on Tuneful than on Golden Princess Anne.

Chemical control

Localized infestations and high populations that need to be reduced before predator or parasite introduction can be spot-sprayed with selective chemicals. Insecticidal soap can effectively control aphids, but should be used only if no predators, including predatory mites, or adult parasites are present because it will affect exposed natural enemies. Once the soap is dry, however, it is nontoxic. Thorough coverage of infested surfaces is essential, and more than one application may be required.

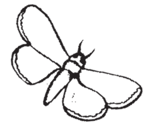
Horticultural oils, both refined petroleum distillate products and those made from vegetable oils, can kill aphids and other insects. These horticultural oils may be toxic to some plants. Many brands are registered for use on vegetables and ornamentals in greenhouses to control many pests, including aphids.

Pyrethrins are insecticides derived from the flowers of the pyrethrum daisy, *Chrysanthemum cinerariaefolium*. They are extremely fast–acting and cause immediate knockdown, but most insects can recover after a brief period of paralysis. Other ingredients can be added to prevent this recovery. Most pyrethrin products are sold commercially as a premix with rotenone, with piperonyl butoxide, or with piperonyl butoxide and diatomaceous earth.

Kinoprene is an insect growth regulator registered for use on ornamentals for control of aphids and other insects. It can be used when aphid mummies or predators are present. It has minimal activity on natural enemies but may damage some plants. Some rose varieties show delayed damage.

Azadirachtin is another insect growth regulator that can be used in rotation with kinoprene, although it generally acts as a feeding deterrent for aphids. This is a commercial formulation of an extract from the seeds of the neem tree (*Azadirachta indica*). Several formulations are registered for use on greenhouse ornamentals and vegetables.

Caterpillars



Available natural enemies and their potential for control

Bacillus thuringiensis (Bt) can be very effective against young caterpillars, but other natural enemies are of limited value.

Order Lepidoptera: Butterflies, moths, and skippers

Family Noctuidae: Owlet moths and underwings

- **Beet armyworm**, *Spodoptera exigua*
- **Black cutworm**, *Agrotis ipsilon*
- **Variegated cutworm**, *Peridroma saucia*
- **Cabbage looper**, *Trichoplusia ni*
- **Corn earworm or tomato fruitworm**, *Helicoverpa zea*

Family Pyralidae: Pyralid, grass, and wax moths

- **European corn borer**, *Ostrinia nubilalis*

The larval, or caterpillar, stages of several moths are occasional pests of many greenhouse crops, especially in summer when lights inside the greenhouse attract moths at night from outside through open vents. Beet armyworms are common on carnation, chrysanthemum, cyclamen, geranium, snapdragon, and other crops. Cabbage loopers are particularly damaging on carnation, chrysanthemum, geranium, nasturtium, and crucifer sets. Corn earworms prefer the buds of chrysanthemum, gladiolus, and rose, as well as small tomato fruits. European corn borers tunnel into the stems of plants, particularly chrysanthemum and dahlia. Variegated cutworm, a climbing species, is one of the most common species on ornamentals and often causes damage to tomatoes, carnations, and chrysanthemums. Black cutworms damage seedlings, vegetables, and flower crops. Many other species of cutworms, loopers, or other caterpillars may occasionally infest greenhouse crops.

Damage

Caterpillars chew off pieces of foliage and leave plants ragged in appearance. Some species also feed directly on flowers or fruit, which is often when people first notice the infestation. Foliage losses usually matter less than damage to buds. Damaged buds don't produce flowers but axillary shoots instead. Shoots tunneled into by European corn borers wilt and do not produce flowers.

Description and life cycle

The female moths, which are nocturnal, lay eggs on plants or other surfaces in the greenhouse. The caterpillars that hatch from these eggs feed on the underside of the leaf for several days, often leaving the upper leaf surface intact. As they grow larger they eat through the whole leaf and may feed on fruits or flowers. Caterpillars often feed at night or on cloudy days and hide during the day at the base of the plant or in camouflaged positions along midribs, leaf edges, or petioles. Caterpillars of noctuid moths can reach 2 inches (5 cm) in length. The different species vary in color. They all pupate on or just under the soil surface.

The grayish brown beet armyworm moths are about $\frac{3}{4}$ inch (2 cm) long. Females lay 100–150 eggs in small piles on the undersides of lower leaves. The smooth, green caterpillars have a wide black stripe down each side and grow to $1\frac{1}{8}$ inches (3 cm) long. After about 2 weeks they pupate in a loose cell on the medium surface.

Black cutworm adults are dark red to blackish-brown in color, with indistinct dark markings on the wings. The females lay eggs singly or in small groups on leaves or stems. The greasy-appearing larvae are gray to black along their back and pale underneath. They grow to $1\frac{1}{4}$–$1\frac{3}{4}$ inches (3.0–4.5 cm) long. They pupate under debris on the medium surface.

The adult variegated cutworm has a wingspan of about $1\frac{1}{2}$ inches (4 cm). The wings are a mottled dark gray with a purplish tint and two indistinct spots in the upper middle of each wing. The eggs are laid in clusters of 200–500 on the undersides of leaves. The caterpillars are gray or brown with blotchy gray and black markings and a row of pale, small, almost diamond-shaped spots along the sides. They grow up to $1\frac{3}{4}$ inches (4.5 cm) long. They pupate in the soil.

The 1-inch (2.5-cm) cabbage looper moths are mottled dark-brown and have a silvery figure 8 on each forewing. They lay round, white eggs singly or in small groups on the undersides of leaves. The caterpillars are light-green with faint white stripes down each side, and they taper from the tail toward the head, so the rear is fatter than the front. They grow up to 1 1/2 inches (4 cm) long. The caterpillars move with a characteristic looping motion produced by holding on with the front legs and arching the middle portion of the body to bring the prolegs (hind legs) forward, then extending the front of the body while holding on with the prolegs. Pupation occurs in a loosely woven cocoon attached by one side to a plant leaf.

Corn earworm moths vary considerably in color and markings, from tawny with faint markings to reddish-brown with heavier markings. The 3/4-inch (2 cm) females lay 500–1000 eggs singly on foliage. The caterpillars grow to 1 1/3 inch (3.5 cm) long and are highly variable in color—red, maroon, orange, yellow, green, and nearly black—with a yellow head and alternating dark and light stripes along the length of the body. They bore into the soil to pupate.

Female European corn borer moths are about 3/4 inch (2 cm) long, vary in color from yellow to light-brown, and have two zigzag lines across the outer parts of their wings. Males are slightly smaller and light-brown with yellow zigzag lines. Females lay 400–500 eggs in masses of 15–20, with the flat eggs overlapping each other like fish scales. The eggs are white when first laid but turn darker just before hatching. The caterpillars grow to 1 inch (2.5 cm) long and range in color from light brown to dark brown to pink or gray, always with a dark head and an indistinct stripe on the back. They pupate within flimsy cocoons inside tunnels in stems, or in other protected locations.

Monitoring

Moths are often attracted to a greenhouse's production or security lights, then enter through openings and proceed to lay eggs. Adult populations can be detected—and low numbers controlled—with blacklights or, for some species, **pheromone traps**. Small green fecal pellets near chewed foliage often indicate a caterpillar attack. Search plants for egg masses or young caterpillars when moths are caught in traps. These pests may also be brought into a greenhouse as eggs or young caterpillars on cuttings, so new shipments should be carefully inspected.

Natural enemies

Numerous parasites and many predators attack caterpillars, but few are suitable for control in greenhouses. Of the many nematodes, viruses, and bacteria that are used commercially for control of caterpillars, only one bacterium is useful on greenhouse crops.

Parasites

***Trichogramma* spp.** *Trichogramma* wasps attack the eggs of over 200 species of moths and butterflies. These almost microscopic wasps (1/64 inch, 0.5 mm) are very important in preventing crop damage because they kill their hosts before the insects can cause plant damage. The female *Trichogramma* lays an egg into a recently laid host egg. As the wasp larva develops, the host egg is killed and turns black. Each female parasitizes about 100 eggs. The wasp's short life cycle of 8–10 days allows their population to increase rapidly. These wasps are harmless to people, animals, and plants. There are many commercially available species, such as *T. pretiosum*, *T. minutum*, and *T. platneri*.

Predators

Many general predators will feed on caterpillars or their eggs. Larvae of the commercially available green lacewings *Chrysoperla (=Chrysopa) carnea* and *Chrysoperla rufilabris* are voracious predators that will feed on moth eggs and very small caterpillars. (See "Aphids" for more information.) Lady beetles and minute pirate bugs may also feed on eggs or small caterpillars if other prey is not available.

Richard Gagne, Minnesota Department of Agriculture, Biological Control Program

Trichogramma minutum wasps have a short life cycle allowing their population to increase rapidly.

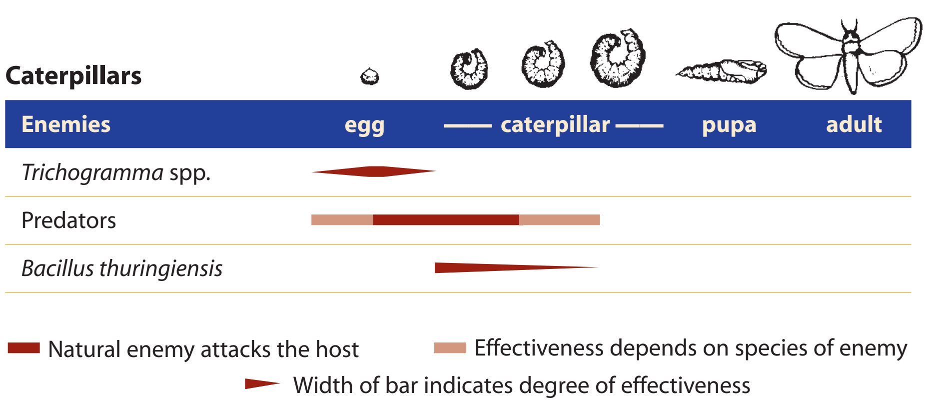
Pathogens

***Bacillus thuringiensis*.** This pathogen, commonly known as Bt, is a naturally occurring, soil-inhabiting bacterium that is highly selective and active mainly against caterpillars. There are many types of Bt and they differ both in specificity to and potency against a range of target insect species. Only two varieties are toxic to insects other than caterpillars: one affects the larvae of mosquitoes, blackflies, and some other types of flies; the other affects certain beetles. The varieties *kurstaki* and *aizawi* are available in commercial formulations for control of caterpillars. This bacterium is nonpolluting and safe to humans.

During sporulation Bt forms a parasporal body, or crystal, which is the source of its insecticidal properties. The crystals dissolve in the gut juices of susceptible insects and release toxic compounds. Later the spores germinate, and bacteria grow in the insect body. The first observable reaction after a caterpillar ingests Bt is paralysis of the gut and mouthparts, followed by cessation of feeding. Paralysis may happen in a matter of minutes, but death usually takes 30 minutes to 3 days following ingestion. Bt is available in several commercial formulations.

Possibilities for effective biological control

Bt can provide good control of the most common greenhouse caterpillar pests. However, Bt does not provide persistent control under greenhouse conditions because it does not disperse well enough and breaks down rapidly in ultraviolet light. It must be applied whenever pest populations develop and in a manner similar to conventional insecticides. Applications should not be made on a regular schedule, but should be timed based on the occurrence of eggs or caterpillars on the plants. Monitor moth flights to determine when to begin scouting for eggs. Because Bt must be eaten to be effective, apply it where the target insects are feeding. If infestations are localized, make spot applications. Bt is not effective against caterpillars feeding within plant tissues—for instance, inside stems, buds or nests of webbed leaves. Bt is more effective against earlier instars than later instars.



Trichogramma wasps provide good control of certain species of caterpillars in outdoor crop systems. In most greenhouses, caterpillar infestations are sporadic and minimal. Under these conditions egg parasites are not very effective, and spot applications of Bt would be more efficient. However, if large caterpillar infestations occur regularly, *Trichogramma* released at the first sign of moth flight through peak egg laying can provide control. Regular scouting to detect the appearance of caterpillar eggs is necessary to determine when wasps should be released so the appropriate stage will be available to maximize *Trichogramma* effectiveness. Most suppliers of *Trichogramma* can make recommendations about the species and number of wasps to release. Rates should be determined on an individual basis.

The wasps are shipped as immatures inside moth eggs glued to small cards that can be attached by hand to infested plants. Keep the cards in a warm, humid place out of direct sunlight until the emerging adults can be seen as small dots moving around in the closed container. A few tiny worms may also be found in the container because it is very difficult to obtain 100% parasitization of the moth eggs, but these worms are harmless to plants. When most of the adults have emerged, place the opened containers in a shaded spot in areas where you suspect moths are laying eggs. The adult wasps will fly onto the plants in search of new host eggs to attack. Do not put the cards out before the wasps start to emerge from the moth eggs because ants and other predators may eat them. The best time to make releases is early morning or evening when direct sunlight will not hit the cards. Avoid making releases when the temperature is above 85°F.

Green lacewing larvae can provide quick control of small, localized infestations. They prefer to feed on aphids, so their effectiveness will be limited if aphids are present. Where caterpillar eggs are present, releases should be made as described in the "Aphids" section.

Alternative control methods

Sanitation

Numerous plants can serve as reservoirs for beet armyworms or other caterpillars. Remove weeds that can be alternate hosts for these caterpillars from inside and outside the greenhouse. Sterilize new soil that may contain cutworm eggs, larvae, or pupae before bringing it into the greenhouse. Check new plant material entering the greenhouse for eggs or larvae and treat or quarantine any that are infested.

Insect screens

Screens on vents and side walls will prevent moths from getting into the greenhouse.

Hand picking

Frequent plant inspections and removal of all visible caterpillars may be impractical for large plantings, but is an option for small or spotty infestations. Inspect plants thoroughly to catch eggs and newly hatched caterpillars or those that may have escaped earlier detection.

Baits

Cutworms are attracted to bran baits. One recipe from the 1930s suggested moistening 12 pounds of bran with a mixture of 1 pint molasses, 1 ounce banana oil (amyl acetate), and an insecticide in about 1 gallon of water. Spread the poisoned bait late in the day so it will be fresh when the cutworms come out to feed.

Chemical control

Spinosad is an insecticide derived from natural metabolites produced under fermentation conditions by the actinomycete *Saccharopolyspora spinosa*. It has a high level of contact and oral activity and rapid speed of action. It is especially effective against caterpillars, leafminers, and thrips, but has low to moderate impact on beneficials. It is registered for control of many pests on landscape ornamentals; check with your chemical supplier on availability for use on greenhouse ornamentals.

Fungus gnats & shore flies

Available natural enemies and their potential for control

Nematodes, *Bacillus thuringiensis* (Bt), and predatory mites can provide excellent control of fungus gnats.

Order Diptera: Flies

Family Sciaridae: Darkwinged fungus gnats

Family Ephydridae: Shore flies

Fungus gnats, *Bradysia impatiens* and *B. coprophila*

Shore flies, *Scatella stagnalis*

Fungus gnats and shore flies, although only distantly related, both occur in the same environmental conditions. Both are nuisances, but only fungus gnat larvae injure plants directly, feeding on a variety of plants and on cultivated mushrooms.

Damage

Fungus gnat larvae usually feed on soil fungi, algae, and decaying organic matter. However, when populations are high, they may feed on root hairs and tunnel into roots and stems just under the soil surface. Affected plants may turn yellow, appear stunted, or wilt during the day under severe attacks. Cuttings, prior to setting callus tissue, and tender root systems of young seedlings are most susceptible to feeding injury by fungus gnat larvae. Plants may eventually die. In addition, adult fungus gnats deposit fecal droppings on plants that may reduce the aesthetic quality of the crop. The adults often get trapped in surface moisture on leaves, making plants less salable because they look "buggy."

Shore flies are algae feeders and do not normally damage plant material directly, although larvae will feed on roots infected with fungi. Black drops of excrement deposited by the flies on leaves can make the plant less attractive.

Both shore flies and fungus gnats can transmit some fungal diseases, including *Botrytis, Fusarium, Phoma*, *Pythium*, and *Thielaviopsis basicola* when they are larvae, and *Pythium*, *Fusarium,* and *Verticillium* when they are adults.

Description and life cycle

Adult fungus gnats are 3/16 inch (4–5 mm), dark brown to black flies that rest on the potting medium or plants. The delicate adults are thin with long legs and antennae. They run rapidly and are weak fliers. The wings have a distinct Y shape in the middle. Females lay clusters of 2–30 eggs on moist medium surfaces, producing a total of 100–300 small white eggs during a 7–10 day life span. The larvae are slender maggots that have a distinct black head and a transparent white body that is 1/4 inch (6–7 mm) long by the third and final instar. They live on or near the surface of the medium. The larvae feed for 5–14 days, then pupate in the soil and emerge as adults about a week later. Fungus gnats are most prevalent in wet soil mixes that are high in organic matter and new media that are microbially active.

Shore fly adults are about the same size as fungus gnats, but are darker and more robust, with short legs and antennae. They breed in algae and standing water or water-soaked areas in the greenhouse. Females scatter eggs on moist soil or algae. The larvae that hatch in 2–3 days live just below the soil surface, feeding on bacteria, yeasts, and algae for 3–6 days. The adults emerge after a 4–5 day pupal period and feed on algae.

Monitoring

Yellow sticky cards or stakes are very effective in monitoring adult fungus gnat populations. Blue sticky traps may be more attractive to shore fly adults than yellow cards. See "Whiteflies" for more detailed instructions.

Potato wedges cut into 1/4-inch sections and placed into the growing medium surface can be used to monitor fungus gnat larval populations. Leave the potato pieces on the medium for 72–96 hours. Fungus gnat larvae feeding on the exposed potato surface can be counted.

Natural enemies

Several natural enemies attack the larvae of fungus gnats and shore flies. A naturally occurring diapriid wasp parasitoid attacks fungus gnats in British Columbia, but little is known about it or any other parasitoids. A few predators and many pathogens, including bacteria, fungi, and nematodes, attack fungus gnat or shore fly larvae in the soil. Only a few have been examined and are useful for control of these pests in greenhouses.

Predators

***Hypoaspis (=Geolaelaps) miles*.** This laelapid mite is a native American soil dweller that feeds on many soil-inhabiting arthropods, including fungus gnat larvae. It is an aggressive predator that attacks individuals many times its size. The brown adult females are about 1/25 inch (1 mm) long; males are much smaller. Adults consume one to five fungus gnat larvae daily, killing more small prey than large prey. When insects are scarce, *H. miles* can survive by scavenging on algae and plant debris. Females deposit one to three eggs per day. Nonfeeding, six-legged larvae hatch in 2–3 days; they molt into eight-legged nymphs within about a day. This stage lasts 4–5 days, during which the nymphs consume 16–33 young fungus gnat larvae. All stages of the mite are found in the top inch of the soil or potting medium, and prefer moist soil with an open structure. They become inactive below 59°F, but do not diapause in the winter. *H. miles* is offered commercially.

Pathogens

***Bacillus thuringiensis* var. *israelensis*.** There are many types of the naturally occurring *Bacillus thuringiensis*, a soil-inhabiting bacterium commonly called Bt. The types differ both in specificity and potency against a range of target insect species. Most are highly selective and active against caterpillars (the larvae of butterflies and moths), but the variety *israelensis* (Bti) is toxic to the larvae of fungus gnats, mosquitoes, blackflies, and some other types of flies. Fungus gnat larvae stop feeding and become limp within 24 hours of ingesting Bti. After 2 days the larvae disintegrate. Bti is more effective against earlier instars than later instars. This bacterium is commercially available as a microbial insecticide. See "Caterpillars" for more information on Bt.

Max Badgley

The soil-dwelling laelapid mite *Hypoaspis miles*.

Ray Cloyd

The mites *Hypoaspis miles* are applied by shaking the container onto the soil or potting medium.

Nematodes. Several **entomopathogenic** (insect-pathogenic) nematodes occur naturally in the soil and parasitize a variety of soil-inhabiting insects, including fungus gnat larvae. Nematodes are small, long, slender roundworms. They are about $^1/_{64}$ inch (0.5 mm) long, transparent, and practically invisible to the naked eye. They require moist soil to survive. When they find an insect, they enter it through natural openings and release a bacterium that kills the host within 48 hours. The bacterium itself serves as a partial food source for the nematodes, which complete their development inside the dead insect. The next generation of nematodes leaves the insect in search of new hosts. Unlike plant parasitic nematodes, these nematodes have no mouthparts and do no damage to plants.

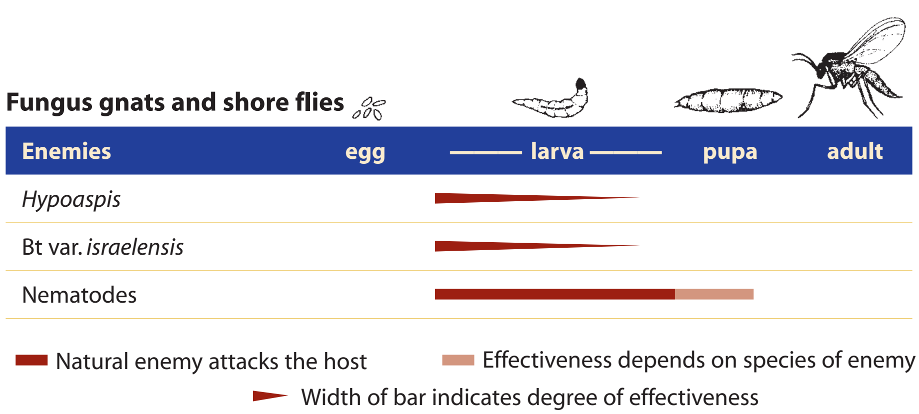
Several species of entomopathogenic nematodes, including *Steinernema feltiae (=Neoaplectana bibionis)*, *S. carpocapsae*, *S. riobravis*, and *Heterorhabditis* spp. are sold commercially for biological control of fungus gnats. *H. megadis* is sold in Europe for fungus gnat control. The mermithid *Tetradonema plicans* can control fungus gnats, but it is not available commercially. These nematodes are harmless to people, animals, beneficial above-ground insects, and earthworms.

Possibilities for effective biological control

You can control fungus gnats easily by using biological methods and good sanitation practices. Shore flies are more difficult to control with biological methods.

The biological insecticide Bti controls fungus gnats but is not effective against shore flies. A commercial formulation of this bacterium, Gnatrol, is registered for the control of fungus gnats on ornamentals. Because Bt does not persist in the soil, it must be applied whenever pest populations develop. Applications as a soil drench once per week for 3 weeks are recommended. Potting medium, soluble salts, soil temperature, moisture, and pH, can all influence the effectiveness of Bt in greenhouses.

Nematodes can also be applied to crops in large quantities as a biological insecticide. Several species and isolates of nematodes are marketed under various trade names, but not all are equally effective against fungus gnat larvae. Check the label or contact the supplier to confirm that the product is effective against these pests. They should be applied to moist, but not saturated, soil. The area to be treated should be watered before and after application. The soil temperature must be above 50°F for nematodes to be effective. Application in the early evening or the morning is recommended to avoid exposing the nematodes to extreme heat and sunlight. Nematodes are applied as a spray or a drench on the soil surface. Since they can withstand pressures up to 300 psi, nematodes can be applied with the same equipment used for the application of chemical



pesticides and through irrigation or injector systems. Always check that the nematodes are alive before applying them. Examine a drop of the dilute spray with a magnifying glass. The nematodes should be squirming. Inactive nematodes bent at sharp angles are usually dead. Nematodes are most effective at soil temperatures of 65°–85°F. They should be applied weekly for 4–8 weeks.

Although both Bti and nematodes can be effective against fungus gnats, their control may not always be satisfactory to the grower.

For long-term control, the soil-inhabiting predatory mite *Hypoaspis miles,* introduced early in the crop cycle, can maintain fungus gnat populations at acceptable levels. These mites are most effective when released before fungus gnat populations are established. *H. miles* seems to thrive in the top 1–2 inches of the growing medium and in moist areas where fungus gnats breed. Excellent control of fungus gnats has been achieved with experimental releases on poinsettia and bedding plants. This mite also works well in combination with nematodes or Bti. Commercially produced mites are shipped in vermiculite, bran, peat, or a similar carrier. Sprinkle the mite mixture over flats, trays, capillary mats, and floors. Shake the container occasionally to keep the mites evenly distributed throughout the container. For potted plants, 1⁄4 teaspoon of the mite mixture sprinkled around the roots of every second pot, is recommended. Release rates vary by crop and pest populations, from 10,000–20,000 per acre for greenhouse vegetables to 10–50 per ft^2 for bedding plants. Additional releases will be necessary to maintain control if pots are removed and replaced regularly. Researchers are investigating the possibility of inundating propagation beds with excessive numbers of mites so that they will be distributed to individual pots.

Alternative control methods

Sanitation

The elimination of breeding areas will reduce fungus gnat and shore fly problems quickly. Drain wet areas and repair drip irrigation systems to remove standing water and algae where flies can breed. Dispose of or sterilize infested growing media so that emerging flies will not reinfest new plantings. Remove all used potting medium and plant debris from the greenhouse as this is a place where fungus gnats can pupate.

Cultural control

Avoid overwatering plants as this allows growing media to remain saturated and promotes the growth of algae which provides an ideal environment for fungus gnat and shore fly growth and development.

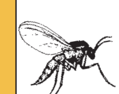
Choose the correct planting medium. Although soilless root media are considered excellent for plant growth, they are also ideal for the growth and development of fungus gnats and shore flies. In a test of several different media, the fewest adult pests emerged from media containing pine bark or no bark, while the most came from media containing some hardwood bark. Potting media may also influence nematode effectiveness.

Avoid over-fertilizing plants. Excess fertilizer promotes algae growth where fungus gnats and shore flies can breed.

Chemical control

Several insect growth regulators, such as diflubenzuron, cyromazine and fenoxycarb, are registered for use on ornamentals to control fungus gnat and shore fly. These insecticides should be applied as a drench when fungus gnats or shore flies are first observed. The drenches will not harm natural enemies but may damage some types of plants. Read the label carefully for phytotoxicity information.

Horticultural oils are registered for use against fungus gnats on some greenhouse crops. Several other synthetic insecticides are available for the control of fungus gnats or shore flies, but most are very toxic to beneficial insects.



Leafminers

Available natural enemies and their potential for control

A few parasites are effective against the species of leafminers commonly found in greenhouses. The potential for successful biological control is high on vegetable crops and moderate on ornamentals.

Order Diptera: Flies

Family Agromyzidae: Leafminer flies

Liriomyza trifolii

Vegetable leafminer, *Liriomyza sativae*

Chrysanthemum leafminer, *Chromatomyia syngenesiae*

Pea leafminer, *Liriomyza huidobrensis*

Several different species of leafminers attack greenhouse crops. The most common are *Liriomyza trifolii* and the vegetable leafminer. *L. trifolii* is a cosmopolitan species, originally from the Caribbean, that attacks numerous plant species. It is a problem on vegetable crops, including tomato, cucumber, lettuce, and pepper, and ornamentals such as alstroemeria, cineraria, chrysanthemum, gerbera, gypsophila, and snapdragon. The vegetable leafminer is a problem on a wide range of vegetables. Other important species include the chrysanthemum leafminer which is a pest on chrysanthemum and cineraria, and the pea leafminer, a pest of aster, carnation, gypsophila, and some vegetable crops, especially in the coastal valleys of California, Mexico, and South America. *Liriomyza bryoniae*, a European species that attacks vegetable crops, mainly tomatoes, is not known in North America.

Damage

Leafminer larvae tunnel within leaves between the upper and lower surfaces, making unsightly white blotches or twisting lines. Different species produce different types of mines that may vary with the host plant. The adult female flies also make numerous punctures in the leaves that show up as white spots on the upper surface. The mines and punctures interfere with photosynthesis and, if numerous, can reduce crop yields. Young seedlings may be destroyed. Infestations on edible portions of vegetable crops and on ornamentals make the plants unmarketable. Although tomato plants can tolerate high levels of damage with little effect on yield, leafminer feeding accelerates leaf drop above the developing tomato fruits, making them vulnerable to sunburn. In addition, punctured and mined tissue is more susceptible to diseases, such as bacterial leaf spot on chrysanthemum.

Description and life cycle

Adult leafminers are shiny black flies with yellow markings and are slightly smaller than fruit flies, at $^{1}/_{16}$ inch (1.3–2.5 mm) long. Most species appear very similar, except chrysanthemum leafminer, which is slightly larger and dark gray. The female punctures leaves with the ovipositor, leaving a small white spot at the point of entry. Both female and male flies feed on the sap that oozes from the punctures. Pale, oval eggs are inserted into about 15% of these punctures. Each female produces an average of 60 eggs in her 2- to 3-week life span. The area of the plant preferred for oviposition depends on the leafminer species and the host plant. The white or yellow maggots hatch in a few days and tunnel through the leaf tissue for up to 2 weeks. This produces the narrow, winding, white mines visible on leaves. The width of the mines increases as the larvae grow. Once larval development is complete, the maggots drop out of the leaf and pupate inside their hardened skins, or puparia, in cracks in the soil, on benches, or within cupped leaf surfaces. The barrel-shaped pupae change from bright yellow to brown. Adults emerge in about 10 days.

Monitoring

Begin weekly monitoring of susceptible greenhouse crops after transplanting them. Monitor leafminers in two ways. Use yellow sticky traps to detect leafminers moving into the greenhouse and to keep track of adult populations. Examine the plants visually for both adult and larval damage. In fast-growing crops the damage of the first generation may be hidden by new foliage. You may not observe the infestation until the second generation attacks the upper leaves of mature plants.

Yellow sticky traps are easier to handle and assess than other sampling techniques, such as sweep nets or pupal trays. The traps are commercially available or can be made by the grower. Place the sticky traps just above the crop canopy and adjust the height of the traps as the crop grows. Also place traps near doors, air-intake vents, among newly arriving plants, and near more susceptible varieties to detect new infestations. The number of traps needed depends on the crop, but on average they should be spaced 18–23 meters (20–25 yards) apart. Count the leafminer adults on the traps once or twice per week.

Even when sticky traps are used it is still important to check the crop visually. Inspect plants regularly for flies and for white spots on the upper surfaces of leaves, which are the oviposition and feeding punctures of the adults. Sample leaves weekly to estimate larval leafminer densities. Select leaves randomly from plants throughout the greenhouse or mark plants with colored tape for continual monitoring of the same plants through the season. Record the number of mines per leaf on three leaves from either the middle or bottom of each plant, wherever most of the leafminers are found. Sample a minimum of 10 plants per greenhouse.

Leaf samples can also provide information on parasite activity, although many growers do not have the time or expertise to do this. Learn to recognize adult parasites and mines containing parasites. Carefully cut open the mines on sampled leaves and examine them for the presence of parasites or leafminer larvae that have been killed by adult parasite feeding. A 10X–15X magnifier or hand lens, or a dissecting microscope will help you observe the insects in small mines. Parasite pupae and prepupae can easily be seen through the leaf by holding it up to a light. Record parasitism and mortality rates weekly. Parasitism can also be checked by collecting leafminer pupae that fall into trays placed beneath the plants. Make sure trays have small drain holes so they won't fill with water. Place the pupae in clear plastic containers and keep the samples at room temperature, out of direct sunlight, until parasites or flies emerge.

A sequential sampling plan for *L. trifolii* in chrysanthemum or gerbera crops has been developed in California. An estimate of adult leafminer populations is determined from the number of flies caught on yellow sticky traps spaced uniformly throughout a uniform crop. Larval densities are estimated from leaf samples taken during crop growth or at harvest. Treatments should be applied when larval and adult populations reach certain thresholds established in the plan.

The methods that have been developed for sampling leafminers provide fairly accurate assessments of leafminer populations, but the infestation level does not always correlate well with plant damage or aesthetic injury, especially on ornamentals. Although it is usually acceptable to have a maximum of 10% mined leaves, this maximum varies with the crop, the time of year, and the market for the product. For example, cut chrysanthemums can have mining damage on the lower leaves (which are removed at harvest), while the same plants grown for sale as potted plants cannot have any mines on the mature foliage. Vegetable crops, such as tomatoes, can tolerate fairly heavy leafminer damage without any effect on yield. Information on the population levels present will provide a basis for making pest management decisions, especially for determining how many parasites to introduce.

Natural enemies

Numerous wasp species parasitize leafminers, but few predators or pathogens attack leafminers.

Parasites

All of the parasites of leafminers parasitize the larval and/or pupal stages. Only those that have been studied as possible biological control agents in greenhouses are mentioned below. These wasps are in the families Braconidae, Eulophidae, and Eucoilidae, for which there are no common names.

Dacnusa sibirica. This European braconid wasp is a solitary endoparasite of all instars of *L. bryoniae*, *L. trifolii*, and the chrysanthemum leafminer. The adults are black and 1⁄8 inch (2–3 mm) long, with extended, flexible antennae. Using their antennae and ovipositors, the females locate leafminer larvae within the leaf and deposit single eggs in the larvae. They are best at finding late-instar larvae and prefer these for oviposition. Each female lays up to 90 eggs during a 2-week life span. The eggs hatch in 4 days, and the larvae complete their development in about 2 weeks in the living leafminer larvae. Adult wasps emerge from the leafminer puparium. The adults do not host feed. This wasp prefers cool conditions (65°–75°F). It is commercially available.


R. Buhl, Stuttgart, Germany

The European braconid wasp *Dacnusa sibirica*.

***Diglyphus isaea*.** This Eurasian eulophid wasp parasitizes *L. trifolii*, *L. bryoniae*, and chrysanthemum leafminer. The 1/16-inch (1–2 mm) adults are black with short antennae. Females detect leafminer larvae by drumming their antennae along the mines. When a larva is found, the female drills through the leaf and into the leafminer body with the ovipositor, paralyzing the larvae. The female then either feeds on the body fluids of the leafminer larva or lays one to five eggs on the body of the host, depending on its size. The wasp larvae feed inside the leafminer body for 3–5 days, then pupate inside the mine. Feeding by the wasps stops leafminer and mine development. The adults emerge about a week later. The females live for 3–4 weeks and lay approximately 60 eggs. Over half of the leafminer mortality is caused by adult host-feeding, which is necessary for egg production. This wasp prefers warm conditions (75°–90°F). It is commercially available.

Other *Diglyphus* species. Several other species of *Diglyphus* have been studied as possible biological control agents for leafminers in greenhouses. The appearance, life cycle, and biology of these species are similar to that of *D. isaea*. None of these wasps are commercially available in the United States:

- *D. begini*, a **facultative**—or environmentally adaptable—gregarious wasp, attacks all leafminer species. It develops much faster than *L. trifolii*.
- *D. intermedius* host feeds on all instars of *L. trifolii* but prefers the third instar for oviposition. It also attacks the vegetable leafminer and chrysanthemum leafminer.
- *D. pulchripes* parasitizes the vegetable leafminer.

***Ganaspidium utilis*.** This eucoilid wasp, native to subtropical areas of North America, is a larval-pupal parasite of vegetable leafminer and *L. trifolii*. The robust 1/20-inch (1.2-mm) adults are black with slender antennae. Females oviposit in leafminer larvae. The eggs hatch after the leafminer pupates, and the wasp larvae feed on the pupa within the host puparium. It is not commercially available.

Richard Lindquist

The adult wasp *Diglyphus begini* attacks all leafminer species. It is not yet commercially available in the United States.

R. Buhl, Stuttgart, Germany

The Eurasian eulophid wasp *Diglyphus isaea*. Adult females feed on leafminer larvae or lay eggs in them.

***Opius dimidiatus*.** This American braconid wasp is one of the most abundant larval-pupal parasites of the vegetable leafminer and *L. trifolii*, both outdoors and in greenhouses in the United States and in southern Ontario, Canada. It will also parasitize *L. bryoniae*. It is not commercially available.

***Opius dissitus*.** This braconid wasp is a native parasite of the vegetable leafminer in Florida that will also parasitize *L. trifolii*. The 1⁄16-inch (1.5-mm) females oviposit in leafminer larvae of any instar. After eggs hatch the wasp larvae consume the leafminers within their puparium. Adult wasps emerge about 2 weeks after the eggs are laid. This wasp is not commercially available.

***Opius pallipes*.** This European braconid wasp is a solitary endoparasite of all instars of *L. bryoniae* and chrysanthemum leafminer larvae. It will lay eggs in *L. trifolii*, but the leafminer kills the eggs. Females locate larvae by drumming their antennae and inserting the ovipositor into the mine. They lay single eggs into larvae. After the wasp completes development in the leafminer, the host dies and the wasp emerges from the mine to pupate. Females do not host feed. This wasp is commercially available in Europe.


Richard Lindquist

Diglyphus begini larva developing externally on a leafminer larva.

***Oscinidius (=Chrysocharis) parksi*.** This American eulophid wasp is a solitary, larval-pupal endoparasite of *L. trifolii* and the vegetable leafminer. The 1⁄25-inch (1-mm) adults are metallic black with white legs. Females lay eggs in third-instar leafminers. The wasp larvae hatch and begin development in the leafminer larvae. Leafminers complete their larval development, then drop to the ground. They die when the wasp larvae start to pupate. The adult wasps emerge from the host puparium. By host-feeding, the females kill more leafminers than they need for reproduction. This wasp is not commercially available in the United States.

Predators

A few general predators, such as spiders and ants, will feed on adult or larval leafminers, but none are specific to leafminers. The tomato bug, *Crytopeltis modestus*, a facultative mirid predator of *Liriomyza* spp., has been investigated in California for leafminer control on chrysanthemum and tomato. Older nymphs and adults suck out the body contents of leafminer larvae within the mine and larvae that have emerged to pupate. However, because *C. modestus* feeds on tomato stems and only the older stages eat leafminers, this bug is considered a pest. Much more research is necessary before it can be recommended as a biological control agent.

Pathogens

***Steinernema (=Neoaplectana) carpocapsae*.** This nematode is a common species with considerable potential as a biological control agent because of its rapid infectious action and environmental safety. (See "Fungus Gnats and Shore Flies" for a description and life cycle information.) The nematodes enter the mines through small tears in the leaf or punctures made by the adult leafminer, then infect second- and third-instar leafminer larvae through body openings. Nematodes may also be able to infect leafminer pupae in or on the growing medium. Foliar applications of nematodes may be effective against leafminer larvae in leaves, but very high relative humidity is required. The need for constant moisture is a major limitation in their effectiveness.

Possibilities for effective biological control

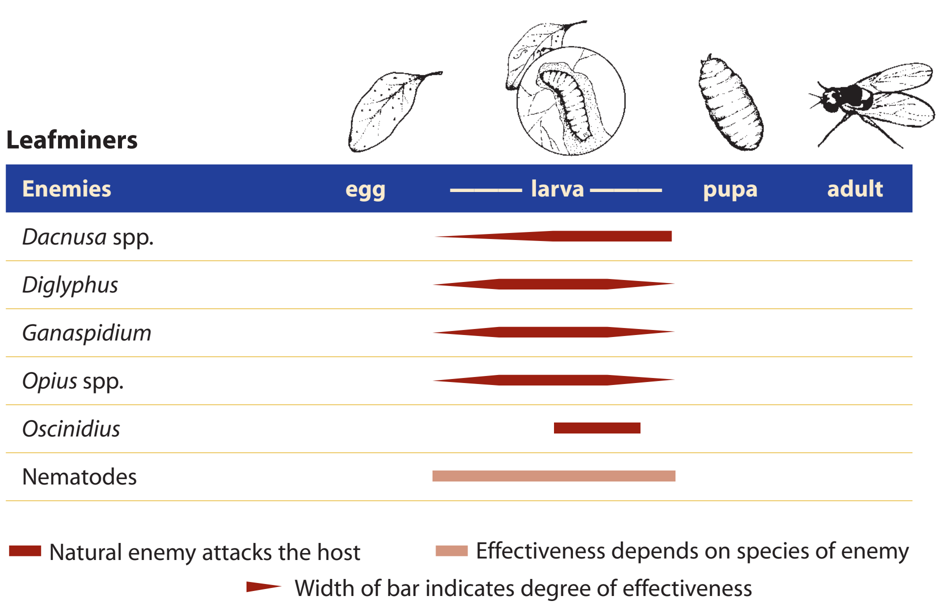
Biological control of leafminers is possible on many crops. Natural populations of parasites that often enter unscreened greenhouses from outdoors in early summer may provide some control. Releases of both larval and larval-pupal parasites can maintain leafminer populations at acceptable levels. However, the high cost of these parasites and uncertain availability may detract from their usefulness. Also, adequate biological control of leafminers on floral or foliage crops is difficult, because even a low population of leafminers may produce cosmetic damage.

Dacnusa sibirica is often used to control the first generation of leafminers, while *Diglyphus* spp. is used against later generations, but appropriate wasp selection depends on your specific circumstances. *D. sibirica* prefers cool temperatures, while *Diglyphus isaea* favors warmer conditions. *Diglyphus* may control subsequent generations more effectively if temperatures are around 80°F. Because *D. sibirica* attacks late-instar leafminers when mines are already well developed, this wasp is best for use on crops with little aesthetic value, such as cut flowers where the foliage is not harvested, or on young plants that will outgrow any early damage before harvest. *Diglyphus* attacks young larvae before mining damage is extensive, and therefore is particularly suitable for use on flower crops. *Diglyphus* can parasitize leafminers already parasitized by *D. sibirica*, so it usually becomes the dominant parasite under warm conditions.

Although your best guides are personal experience and the supplier's instructions, results of recent research using leafminer parasites on specific crops can help in selecting the proper natural enemies. *Dacnusa sibirica*, *Diglyphus begini*, *D. pulchripes*, and *Oscinidius parksi* have all been shown to be successful as biological control agents on greenhouse tomatoes in various countries. *D. pulchripes* and *Opius dimidiatus* nearly eradicated leafminers on tomato in an experimental greenhouse in Ohio within 8 weeks. *Dacnusa sibirica* moved from open rearing units to a lettuce crop to control nearly 100% of pea leafminer in the Netherlands. *D. intermedius* effectively controlled *L. trifolii* on cut chrysanthemums in experimental greenhouses in California. When *D. begini* was introduced early in the crop cycle it virtually eliminated leafminers on marigolds within 2 months and maintained control for another 2 months, even at high leafminer densities. The lower, older leaves were damaged, but the upper portions were free of injury.

Leafminer parasites are shipped either as pupae in small cardboard boxes or as adults in plastic tubes. Open the parasite shipment in the greenhouse in case some wasps have already emerged from the puparia. Distribute the parasites evenly throughout the greenhouse, but place extra wasps in leafminer hot spots or near especially susceptible cultivars.

Proper release rates depend on the leafminer species, the crop, the growth stage of the crop, and the time of year. A single inoculative release of parasites may succeed if made early in the growing season. However, multiple releases are more likely to provide effective control. Suppliers should provide detailed instructions on the use of natural enemies. Introduce the parasites as soon as the first leafminers are detected on yellow sticky traps or when feeding punctures are observed. It is difficult to control high populations of leafminers even with very high release rates if the releases are not made early. Provide the optimal environmental conditions of 60°–85°F and 50–90% relative humidity. Do not use residual insecticides within a month of parasite release. If the leafminer population is high, you can use a nonresidual spray, such as horticultural oil, azadirachtin, or natural pyrethrins (*not* pyrethroids), to reduce the number of leafminers before releasing the wasps.



Tomato crops can tolerate relatively high leafminer populations without yield loss. Weekly releases of one parasite for every 10 new mines on the crop are suggested for the first 6 weeks of an infestation on tomato. On chrysanthemum, the recommendation is to release three adult *Dacnusa sibirica* for every 1,000 plants (500 per acre) in the week after planting. Make a second parasite release at the same rate in the sixth week after planting to control the progeny of any surviving leafminers. *Diglyphus isaea* is often preferred for the second introduction. Releases of 500 *D. sibirica* adults per acre every 2 weeks can be made instead. Either parasite should control an infestation of one mine per six plants.

Monitor carefully after the releases to be sure that parasitism is high. Even if 90% of the first leafminer generation is parasitized, the population can still increase from one mine per 100 plants to about one mine per plant in the next generation. Make weekly introductions of wasps until a well-established population is present. Weekly introductions take into account natural mortality of the wasps. Cool, cloudy weather and the use of pesticides will reduce the effectiveness of the parasites. Introduce up to 400 parasites per acre each week if less than 90% of the leafminer larvae are parasitized. Even when introductions are done properly the results may vary, and extra parasite releases or chemical control may be necessary in some cases.

Scientists at the University of California-Davis have developed grower-friendly software to help simplify biological control efforts against *L. trifolii* infesting cut chrysanthemums. The program determines the number of *Diglyphus* to release each week for the duration of the crop to eradicate *L. trifolii* before marketable foliage develops. A salable cut crop was produced without using any pesticides following the program's recommended release rate.

Jim Ducy

Currently parasites are the best option for biological control of leafminers. More research must be conducted on predators and pathogens before they can be used to control leafminers. Nematodes, however, may be useful for suppressing leafminer populations. If constant moisture can be maintained for at least 24 hours, which may be difficult to achieve in a commercial greenhouse, foliar applications of the nematode *S. carpocapsae* are about as effective as abamectin, but neither treatment eliminates severe leafminer infestations. Make applications in late afternoon or evening because the nematodes may be killed by sunlight or desiccation. Allow several hours of drying time to give the nematode time to move to the leafminer larvae. The optimal temperature for infection is about 70°F.

Alternative control methods

Sanitation

Avoid introducing any new plant material that may contain leafminer eggs or larvae into the greenhouses. Rogue out severely infested plants. Promptly remove or destroy all crop residue containing larval leafminers that could continue to develop after harvest. Use physical barriers, such as hanging sheets of plastic, to prevent adults from flying to other areas of the greenhouse during harvest.

Host plant cultivar

Leafminers prefer and develop better on certain crop cultivars. A plant's chemical content, nutritional value, and the distribution and density of its hairs influence the plant's attractiveness to leafminers. Eliminate the most susceptible cultivars, if possible, or isolate them to reduce contamination to other cultivars. Chrysanthemum cultivars vary widely in their susceptibility to foliar damage by leafminers. In general, standard chrysanthemum cultivars suffer less damage than spray types. In one experiment, White Iceberg and Yellow Iceberg had significantly more mines than 15 other cultivars, while Statesman had the fewest mines. In other experiments, foliage of the cultivars Albatross, Bright Yellow Tuneful, Colonel Comfort, Divinity, Nob Hill, Pink Marble, and Sea Foam had less damage than did Iceberg.

Insect screens

Leafminers may invade greenhouses during the summer. Screens on vents, side-walls and doors will help prevent leafminers from migrating into the greenhouse from outside. However, proper screen installation is necessary in order to avoid reducing air flow. The maximum hole size to exclude *L. trifolii* is 640 µ.

Greenhouse floor

The material beneath benches affects adult leafminer emergence. Fewer leafminer pupae survive in gravel under the benches than in soil. Leafminers that tried to pupate on polyethylene sheeting under tomato plants drowned when the greenhouse was watered. Ants killed many of the prepupae when the plastic was dry. However, pupal parasites of leafminers, such as *Dacnusa sibirica* or *Opius* spp., were also killed.

Fertilization

Nutrient inputs can affect pests as well as the plant. High levels of nitrogen are associated with leafminer problems, as well as spider mite infestations, on chrysanthemum. Avoid over-fertilizing crops.

Traps

Yellow sticky traps can be used for mass-trapping adult leafminers, as well as monitoring them. The traps do not catch many parasites of leafminers. Trapping adults reduced *L. trifolii* damage on chrysanthemum by 50% in experiments in Canada.

Chemical control

Localized infestations, or high populations that need to be reduced before predator or parasite introduction, should be spot-sprayed with selective chemicals.

Horticultural oils, both refined petroleum distillate products and those made from vegetable oils, can kill leafminers and other insects. These horticultural oils may be toxic to some plants. Various brands are registered for use on vegetables and ornamentals in greenhouses to control many pests, including leafminers.

Azadirachtin is the active ingredient in commercial formulations of extracts from seeds of the neem tree. This natural compound is an insect growth regulator that has a very low mammalian toxicity. It is also effective as a repellent or anti-ovipositional treatment. Foliar applications kill leafminer larvae in the mines, and reduce leafminer pupation and adult emergence. Solutions of azadirachtin also have controlled leafminers on chrysanthemum for 4 weeks after soaking rooted cuttings for 2–4 hours. It is registered for use on greenhouse ornamentals and vegetable crops.

Abamectin is an insecticide derived from the naturally occurring soil microorganism *Streptomyces avermitilis*. It is not a selective chemical, so it should be used only as a rescue treatment if biological control fails. It is registered for control of leafminers and spider mites on ornamental plants in greenhouses.

Spinosad is an insecticide derived from natural metabolites produced under fermentation conditions by the actinomycete *Saccharopolyspora spinosa*. It is especially efficacious against leafminers, caterpillars, and thrips, but has low to moderate impact on beneficials. It is registered for control of many pests on landscape ornamentals; check with your chemical supplier on availability for use on greenhouse ornamentals.

Mites

Available natural enemies and their potential for control

There are many highly effective predators of mites. The potential for successful biological control is high.

Order Acari: Mites and ticks

Family Acaridae: Acarid mites

- **Bulb mite,** *Rhizoglyphus echinopus*

Family Tarsonemidae: Tarsonemid mites

- **Cyclamen mite,** *Phytonemus pallidus*
- **Broad mite,** *Polyphagotarsonemus latus*

Family Tetranychidae: Spider mites

- **Twospotted spider mite,** *Tetranychus urticae*
- **Carmine spider mite,** *Tetranychus cinnabarinus*
- **Lewis mite,** *Eotetranychus lewisi*

Mites are not true insects because the adults have only two main body regions and eight legs. The newly hatched young, called larvae, have only three pairs of legs. After the first molt, all subsequent instars, called nymphs, have four pairs of legs. Mites are abundant in soil and organic matter, and many parasitize vertebrates or invertebrates. Others are predaceous, scavengers, or plant eaters. There are numerous families of mites and ticks, but only those species of economic importance for greenhouses are discussed here.

Acarid mites

Bulb mites infest the bulbs of many plant species, including Easter lily, onion, daffodil, tulip, and hyacinth.

Damage

Bulb mites feed on the underground portion of bulbs, weakening the plant tissue. Feeding damage also promotes the secondary invasion of plant pathogens such as *Fusarium*, *Pythium*, and *Rhizoctonia*. On Easter lily (*Lilium longiflorum*), typical symptoms include rosetting, cessation of growth at a height of 3–6 inches, chlorosis, and occasionally death.

Description and life cycle

The slow-moving adult bulb mites are 1/25 inch (1 mm) long and pearly white with short, red legs. Females produce 100–150 eggs, laid singly or in groups on the bulb's surface, near injured or decaying tissue or between bulb scales. A generation can be completed in 10 days at 81°F.

Monitoring

Bulb mites are difficult to observe until their damage becomes apparent. If bulb mites damage your crop one year, plan control efforts the next year based on that experience.

Natural enemies

Bulb mites have few natural enemies, and no known parasites or pathogens control them.

Predators

***Hypoaspis aculeifer*.** This soil-dwelling, laelapid mite is a nonspecialist predator of arthropods, but appears to feed and reproduce best on bulb mites. The light brown adults are less than 1/25 inch (1 mm) long and spend all their time on or in the soil. Adults consume up to 30 bulb mites daily. Females deposit one to three eggs per day. White, nonfeeding, six-legged larvae hatch from the eggs and become eight-legged nymphs in about a day. The nymphal stage lasts 4–5 days. During this phase nymphs consume an average of 15 bulb mites. Both immature and adult predators prefer the larval stage of the bulb mite as prey. Development is faster on larval and egg stages than on adult prey. Adults may live up to 60 days. They are inactive when temperatures are below 57°F. This species is available commercially.

A related species, *H. vacua*, has similar biology and feeding habits. In small-dish trials in laboratory studies, *H. vacua* consumed 33 bulb mite nymphs during development, while adult females ate about 13 mite nymphs per day. *H. vacua* is not available commercially.

Possibilities for effective biological control

Hypoaspis aculeifer or other species may have potential as a biological control agent against bulb mites. In small-scale laboratory experiments *H. aculeifer* was able to suppress bulb mites to very low levels on lily bulbs. The predators did not leave the bulbs until almost all prey were eaten. In closed plastic bags filled with lily bulb scales and vermiculite (similar to lily bulb propagation conditions), *Hypoaspis* was also able to suppress the bulb mite to very low numbers. However, no research has been conducted on introducing this predator to greenhouses for bulb mite control. The related species *H. miles*, sold commercially for fungus gnat control, died out without noticeable impact on the bulb mite population.

Alternative control methods

Sanitation

Avoid introducing infested plants. If only a few plants are infested, remove or destroy them to prevent adjacent plants from becoming infested. Avoid transporting mites on tools.

Tarsonemid mites

These very small mites infest a wide range of host plants, and because they are so small their damage can become extensive before the population is recognized. Preferred hosts of the cyclamen mite include African violet, azalea, cyclamen, fuchsia, geranium, ivy, and snapdragon. Broad mite is an important pest of gerbera, and may also be found on other hosts including cyclamen, geranium, hibiscus, impatiens, ivy, and peperomia, as well as vegetable bedding plants such as bean, pepper, and tomato. These mites cause problems in cool, moist conditions, unlike spider mites, which thrive in a warm and dry environment.

Damage

Specific symptoms depend on the plant species. They range from leaf distortion, stunting, and bronzing to plant death. Damage often resembles pesticide injury or nutritional problems. However, unlike those **abiotic** causes, the distribution of mite damage within a greenhouse is patchy. Cyclamen mite infestations first distort young leaves, which become rough and wrinkled. Later this results in stunted growth and a dwarfed appearance. Damaged gerbera leaves have bronzed areas along the midribs. Flowers on infested plants may be distorted or may not open. Shoots of plants infested with broad mite appear open, distorted, shrivelled, and burned. Broad mites feeding on the underside of young foliage of gerbera cause the leaves to become rigid and curl downward. Infested tissue on other plants becomes brown and distorted, and small leaves and flowers may fall off. Fruit on tomato, cucumber, peppers, or eggplant may be russetted or distorted.

Description and life cycle

The adult cyclamen mite is semitransparent and pinkish orange, while the immature stages are translucent. Broad mite adults are straw-colored with a prominent white stripe down the center of the back. The adults of both species are very small—less than 1⁄100 inch (0.3 mm) long. The life cycles of different tarsonemid mites are similar. Their white, opaque, ovoid eggs are laid singly. Cyclamen mites lay their eggs on upper leaf surfaces, while broad mites usually lay eggs on leaf undersides or dark, moist places on plants. In 2–7 days, whitish larvae hatch from the eggs. They develop for 1–4 days, then pass through an inactive nymphal stage before molting into adults. Broad mites can produce a generation in 10 days; cyclamen mites require 18 days. Relative humidity around 80%, low light, and moderate temperatures around 61°F favor the increase of both mites.

Monitoring

Frequent visual inspection of symptomatic plant parts is the best method for detecting infestations. Tarsonemid mites avoid light, prefer high relative humidity, and tend to be found in the crown of their host, between the densely packed young leaves of the leaf bud. Cyclamen mite is usually found within buds, whereas broad mite tends to be on more exposed surfaces. It may be necessary to use a low-power microscope to confirm the presence of these tiny mites.

Natural enemies

No parasites or pathogens provide effective control of tarsonemid mites. A few species of predatory mites feed on cyclamen or broad mites.

Predators

Euseius (=Amblyseius) stipulatus. This phytoseiid mite is a predator of citrus red mite, *Panonychus citri,* and feeds on broad mite in greenhouses as well as outdoors on avocado, chili pepper, citrus, coffee, cotton, mango, tea, and tomato. It consumes all stages of prey except nymphs, and will also feed on pollen and honeydew. This mite does not reproduce at relative humidities below 50%, nor at very high temperatures. It is not available commercially.

***Neoseiulus (=Amblyseius) cucumeris*.** This commercially available phytoseiid mite is used mainly for controlling thrips, but it will also feed on cyclamen mite on strawberry. However, it is not recommended for cyclamen mite control in greenhouses.

Possibilities for effective biological control

Although some predatory mites will feed on broad or cyclamen mite, little research has been conducted on techniques for using these predators in greenhouses.

Alternative control methods

Sanitation

Avoid introducing infested plants. If only a few plants are infested, remove or destroy them to prevent adjacent plants from becoming infested. Avoid transporting mites on tools.

Chemical control

Localized infestations and high populations that need to be reduced before predator introduction should be spot-sprayed with selective chemicals. Insecticidal soap controls exposed tarsonemid mites but also kills predatory mites and other natural enemies. However, it is nontoxic once it is dry. Thorough coverage of infested surfaces and several applications are necessary to achieve control.

Spider mites

Spider mites are one of the most serious pests of ornamental crops, especially in hot, dry conditions. The twospotted spider mite is the most important mite species infesting floral crops. It has an extremely wide host range, short generation time, and continuous reproduction when not in diapause.

Damage

Twospotted spider mites feed on the underside of leaves, removing leaf cell contents. This results in a chlorotic, stippled appearance on the leaves of most plants. However, this stippling may not be as apparent on thick-leaved plants such as chrysanthemum. Leaves often dry out and fall off. Large populations can severely defoliate or kill plants. Webbing produced by spider mites can cover foliage and flowers, detracting from the appearance of the plant. Flower quality and yield is reduced on roses. Northern greenhouses may receive a respite from spider mites beginning September and continuing through February, if they go into diapause.

Carmine spider mites do not produce the typical speckling of leaves. Instead, infested leaves become prematurely chlorotic with small, transparent lesions. This type of damage resembles magnesium deficiency. Bright yellow patches develop that eventually turn dark and spread over the entire leaf. This damage may be caused by a toxin injected during feeding. Even small populations of carmine spider mites can cause extensive damage.

Feeding damage from the Lewis mite creates a distinctive stippled appearance on the leaves. Eventually the entire leaf becomes bleached, dies, and falls off.

Description and life cycle

Spider mites are small, usually only 1⁄50 inch (0.5 mm) long when mature. Twospotted spider mites range in color from light yellow or green to dark green or brown. All have two dark spots visible on the abdomen. The carmine spider mite is plum red. Males tend to be smaller and thinner than females.

Twospotted spider mite females lay eggs in webbing on the underside of the leaves. Each female produces up to 120 eggs, depending on the host plant. On chrysanthemums an average of 14 eggs are laid over a 5-day life span, whereas on rose they can lay 112 eggs over 15 days. The pearly white, perfectly spherical eggs hatch into larvae in 4–6 days. The larvae are small and white with only six legs. They molt into eight-legged nymphs and look like the adult. Adults appear after a second nymphal stage.

Lewis mites are slightly smaller than twospotted mites and have up to three spots on each side of their body. Their biology is similar to twospotted mites, but they do not diapause. This mite has been a problem on poinsettia since the mid-1990s, although it will feed on other plants such as cucumber.

Spider mites can produce a generation in 7–14 days in warm temperatures. In cooler temperatures, generations take more than 40 days; below 54°F, development stops. In northern greenhouses adults may go into diapause for several months, hibernating in cracks and crevices from September through February/March. The diapausing mites, which are reddish and do not feed, may be confused with predators or carmine spider mites.

Monitoring

Frequent visual inspection of plant parts is the best method for detecting infestations of spider mites. Because of their small size and cryptic behavior, they are often overlooked until their feeding damage or webbing becomes apparent. They can be found on all areas of the plant, but they most often infest the older, middle-age leaves, and the midrib.

Small-scale growers could consider using plants that spider mites prefer more than the crop plant to detect small populations of mites before damage occurs on the crop—but this is not practical in large operations. Highly preferred plants that can be used this way, as "indicator plants," include lima beans (tall plants that easily attract blowing mites) and radishes (much shorter plants that show dramatic symptoms of leaf distortion).

Ray Cloyd

Container of *Neoseiulus californicus*, a predatory mite.

Natural enemies

Predators are the only effective natural enemies of spider mites. Numerous species of predatory mites, some beetles, and a few thrips feed on spider mites. Mites of the family Phytoseiidae are the most important predators of spider mites and the most commonly used natural enemies for controlling spider mites in greenhouses.

Predatory mites

***Euseius* spp.** Several phytoseiids in this genus are commercially available, but these predatory mites have not been evaluated for use on greenhouse crops. *E. delhiensis* (=*rubini*) will feed on spider mites, broad mites, thrips, and whitefly eggs. *E. hibisci* feeds on various mites, as well as thrips and sweet potato whitefly eggs. *E. scutalis* occurs mainly on trees and shrubs in North Africa and the Middle East, where it is associated with tetranychid mites, whiteflies, and tenuipalpid mites. Although it is a general feeder and will attack thrips, spider mites, and whitefly eggs, *E. scutalis* prefers pollen and tetranychid eggs. *E. stipulatus* will develop on twospotted spider mite, but it does not lay eggs when feeding on this mite without supplemental food such as pollen or honeydew. Eggs of this species fail to hatch at relative humidities less than 50%.

***Galendromus (=Metaseiulus, =Typhlodromus) occidentalis*—western predatory mite.** This phytoseiid mite is smaller than *Phytoseiulus persimilis* (next page) and develops best at cooler temperatures, but it tolerates a wide range of relative humidities (40–80%). It is able to regulate spider mite populations at lower densities and for longer periods of time than *P. persimilis*, although it will not control spider mite populations as quickly. It can also survive long periods without prey. Nondiapausing strains have been developed that allow control of spider mites through the winter, when days are short. Some strains are resistant to a number of organophosphate insecticides (such as azinphos-methyl, diazinon, and phosmet) and a carbamate (carbaryl). Several different strains are commercially available.

***Mesoseiulus (=Phytoseiulus) longipes*.** This predator is similar to *P. persimilis* in activity, but can tolerate warmer temperatures—up to 70°–90°F—and relative humidity as low as 40%. It is available commercially.

***Neoseiulus (=Amblyseius) californicus*.** This predatory mite is similar to *P. persimilis*, but is smaller, pale, and does not suppress spider mite populations as quickly. However, it is useful for keeping low populations under control because it can survive longer periods without prey. It is commercially available.

Some other species of *Neoseiulus*, such as the commercially available *N. fallacis*, feed on a variety of tetranychid mites and are commercially available, but little is known of their utility in greenhouses.

Phytoseiulus macropilis. This mite has been investigated for greenhouse use on dieffenbachia, dracena, parlor palm (*Chamaedorea elegans*), and schefflera (*Brassaia actinophylla*). The globose, light- to deep-red females lay oval orange eggs that hatch into six-legged larvae. Both larvae and nymphs have a similar white to light orange color. Males are identical to females in shape and color but are smaller. These mites have a strong preference for immature spider mites over adults. Each predator consumes four to six spider mite eggs or larvae during its development and an average of eight eggs per day as an adult. *P. macropilis* has a very short life cycle in comparison to many spider mite species, allowing it to build up quickly to suppress pest populations. In the absence of spider mites they will prey on their own immatures. *P. macropilis* occurs naturally in Florida and is available commercially.

Phytoseiulus persimilis. This predatory phytoseiid mite was accidentally brought from Chile to Germany on orchid roots and was subsequently sent to other parts of the world. The 1/25-inch (1 mm) adults are a shiny orange-red and pear-shaped, with long front legs and no spots. Each female produces about 50 football-shaped eggs that are twice the size of twospotted spider mite eggs. The eggs hatch in about 3 days into nonfeeding, six-legged larvae. A day later they molt into eight-legged nymphs that consume 10–12 spider mite eggs or small mites during their development. The immatures are pale salmon in color and oval in shape. The optimum temperature range for development is 70°–81°F. Development ceases and oviposition and longevity decline sharply at relative humidities below 60%. Under warm and humid conditions, the adults of these predators consume 30 eggs or 24 immature spider mites per day. At favorable temperatures and humidity this predatory mite can develop twice as fast as its prey. Both pesticide-susceptible and organophosphate-resistant strains of this predatory mite are available commercially.

Other predators

***Feltiella acarisuga* (=*Therodiplosis persicae*).** This predatory gall midge occurs throughout Eurasia and North America. It feeds on all stages of spider mites, but generally prefers the eggs or larvae. Adult gall midges are small, delicate, pink-brown flies with long legs. They do not feed and only live 3–4 days after emergence from the cocoon. Each female lays an average of 30 yellow eggs near high densities of mites, usually where webbing occurs. The yellow- or orange-brown midge larvae grow to about 1/16 inch (2 mm) long. They can consume over 300 mite eggs as they complete their development in about a week in the greenhouse. They then spin fluffy white cocoons on the underside of leaves, usually along a leaf vein. This midge is commercially available. There are several closely related species that are also good mite predators, including *F. minuta*, a common predator in British Columbia.

Macrolophus nubilis. This mirid bug is a voracious predator of spider mites in Europe. It was a promising candidate in trials in greenhouses in Uzbekistan, but it is not commercially available. A related species, *M. caliginosus*, is offered commercially as a predator of whiteflies.

***Scolothrips sexmaculatus*—sixspotted thrips.** Both the adult and larval stages of this predatory thrips feed on spider mites. The tiny, slender, pale amber adults have three dark spots on each forewing. Females deposit eggs in soft plant tissue. The larvae that hatch are white or yellow, without dark markings. The robust, yellow pupae occur on the leaf surface in the mite colonies. *S. sexmaculatus* prefers spider mite eggs, but adult females will consume other mite stages. The rate of predation depends on temperature. Adult females consume 50 spider mite eggs per day at 86°F but only 21 eggs per day at 68°F. It is commercially available.


University of Florida

Phytoseiulus persimilis is the most commonly released predatory mite used in greenhouses.

***Stethorus* spp.** These spider mite predators are small black lady beetles. Both the larval and adult stages are predaceous on all mite stages, but their use in greenhouses has not been evaluated. *S. punctillum*, a predator of European red mite—a pest of fruit trees—is commercially available.

Oregon State University Extension Service

The small black lady beetle *Stethorus* spp.

Possibilities for effective biological control

In Europe, predatory mites have been used successfully for several decades to manage spider mites in greenhouse vegetable production. Predatory mites have effectively controlled spider mites on chrysanthemum, rose, and other ornamental crops under experimental conditions. However, the need to prevent cosmetic damage on floral or foliage crops may make biological control of mites difficult, especially when pesticides that kill predatory mites are used to suppress other pests and/or diseases. Your spider mite control strategy may depend on the crop you raise and conditions in your greenhouse, especially temperature and humidity. *Phytoseiulus persimilis* is the most commonly available and most commonly released predatory mite in greenhouses. However, there are a few crops on which *P. persimilis* cannot be used. For example, *P. persimilis* slips off the stems and leaves of carnations. It also does not do well on tomatoes because the mites become trapped on glandular hairs on the leaf petioles and stems, and they are affected by toxic compounds in the leaf. Other predatory mite species listed in the "Natural Enemies" section also provide good control. *Galendromus occidentalis* and *Neoseiulus californicus*, for example, may be better suited for use on semi-permanent greenhouse crops such as rose or gardenia than on short-term vegetable crops. These predatory mites can often be used in conjunction with other predators as well.

Long-term control may result from a single inoculative release of these predators, especially if nondiapausing, insecticide-resistant strains are used. However, chemical control with selective miticides may be required during establishment and occasionally thereafter. If there is an average of more than one spider mite per leaf, a chemical spray with low toxicity to predatory mites, such as insecticidal soap or horticultural oil, should be applied to reduce the spider mites to less than 10% leaf infestation. Do not use residual pesticides within a month of releasing predatory mites, including sulfur-containing fungicides, because they are highly toxic to mites.

Predatory mites are most effective when introduced while spider mite populations are low, ideally at or before the first sign of spider mite damage. In greenhouses with a history of spider mite problems, the first releases should be made 1 week after plant emergence. If you are using indicator plants, release the predatory mites as soon as those plants show the first visible signs of damage. Proper timing is essential to achieve economic control, especially for carmine spider mites, which cause extensive plant damage at low populations. Mite damage and reproduction can continue for 1–3 weeks before the predators can destroy the mites. Most failures of biological control occur when the predator is released too late.

Species selection and release rates vary considerably depending on the plant species and the environmental conditions such as temperature and humidity which influence the growth rate of both predator and prey. *P. persimilis* is an excellent predator of spider mites on low-growing plants in humid greenhouses with moderate temperatures. *P. macropilis* performs better than *P. persimilis* on ornamental plants under warm, humid conditions. *Mesoseiulus longipes* is frequently used to control spider mites in hot, dry greenhouses on taller plants. It tolerates lower humidity than does *P. persimilis*. *N. californicus* does well on most potted plants in greenhouses with moderate temperatures and average humidity. A combination of predators released at regular intervals works best in greenhouses or interior plantscapes with a variety of plants and growing conditions.

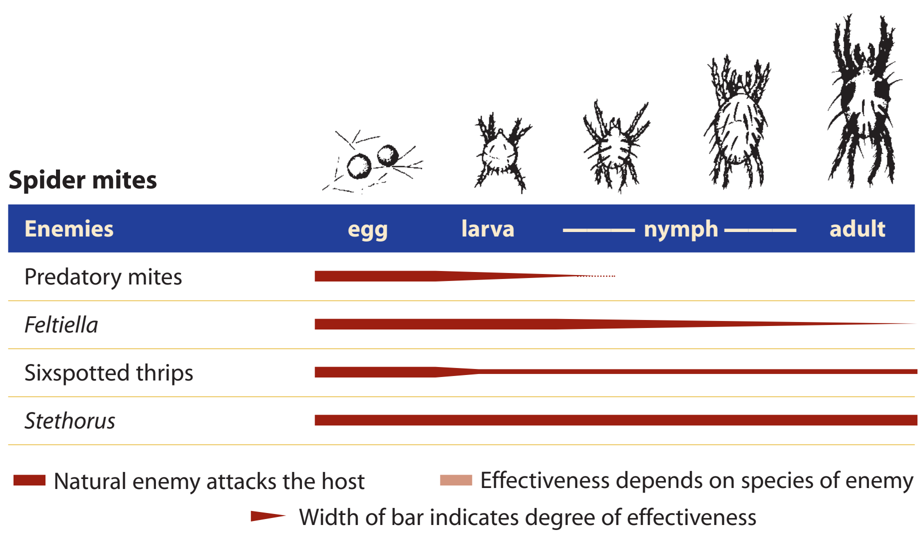
Plant density and plant architecture influence the distribution of spider mites on a plant species and the ease with which the predators can find patches of prey. For example, *P. persimilis* is very efficient on cucumbers that have large leaves and vines that intermingle, but less so on peppers with smaller leaves that don't touch. *P. persimilis* is also less effective on cut rose varieties with fewer leaves because the mites cannot move around as easily on these plants. *N. californicus* is a better choice for control of spider mites on roses, if introduced early. Arranging plants so that leaves touch may improve biological control on some plant species.

On average, one predator for every five twospotted spider mites, or a rate of 10 predators per ft^2, should be more than adequate for control. Other predator-to-pest ratios that have been successful under specific circumstances are 1:6, 1:10, and 1:25, but specific ratios can only be determined by experience. In greenhouses a rate of two predators per ft^2 (or two per plant if the plants are small) is suggested. On vegetables, a predator-to-prey ratio of 1:50 may be sufficient, but on ornamental floral or foliage plants that cannot sustain any aesthetic injury the ratio may have to be reduced to 1:10 or 1:5. In the United Kingdom, one predator for every 10 chrysanthemum cuttings released 2–3 weeks after planting, before damage is apparent, has given satisfactory control. For the carmine spider mite, a rate of 50 or more predators per plant is suggested because of the potential for rapid plant damage at low pest populations.

Predatory mites are usually released according to one of three distributional patterns: uniformly, in infested patches, or from banker plants. Uniform distribution of predators throughout the greenhouse is the most common method of introduction. It provides predictable levels of control. Introduction in patches of mite damage will often result in better control than uniform distribution. The live mites are usually shipped mixed in vermiculite, bran, or a similar material to cushion them in transit. The carrier-mite mixture can be sprinkled directly onto the foliage of infested plants and the mites will disperse on their own. (Be sure to shake the container occasionally to distribute the mites throughout the container evenly.) However, treating infested plants only requires regular inspection of all plants until predators are well established, which may be commercially impractical. If indicator plants are used to detect the first infestation, you can release the predators on the indicator plants and allow them to move out into the crop.

Inundation of a crop with predators at extremely high rates can also reduce pest populations—effectively and quickly—but this method may be prohibitively expensive. Another successful technique uses "banker" cucumber plants at either end of the greenhouse. The plants are intentionally infested with spider mites and predators are released on them when damage begins to show. Within a month thousands of predators are available for release on the main crop. On tomatoes, predators can be moved to hot spots by workers during harvesting operations. This may not be practical in large operations.

The predatory gall midge *Feltiella* can also be used for spider mite control in conjunction with *P. persimilis*. The predatory mite has low dispersal ability, so it may fail to find patches of high pest density. *Feltiella* is good at finding hot spots, so the two predators are complementary. *Feltiella* is particularly useful on hairy-leaved plants (such as tomatoes) that *P. persimilis* does not work well on, and it can also effectively control carmine spider mite. Even though *Feltiella* larvae eat at least five times as many spider mites per day as does *Phytoseiulus*, the midge alone is usually not able to control spider mites.



The midges are shipped as cocoons on leaves or the carton. The carton should be opened and placed on the soil surface of plants in the greenhouse, protected from direct sunlight, for at least 1 week. Adults emerging from the cocoons in the container will fly to spider mite colonies. High humidity improves midge emergence. Optimal conditions for *Feltiella* are 68–81°F and relative humidity greater than 60%, although larvae can tolerate a wider range of conditions than can the adults. Weekly releases of one per 10 ft^2 of plant material are recommended, but because of the high cost of these insects many growers use only one per 40 ft^2 and allow the population to build up over time.

Sixspotted thrips appears to be a good predator for use in greenhouses. Unlike predatory mites, thrips can fly away to find new prey. Release rates will vary depending on the crop and mite density. Contact the supplier for recommended rates.

Spider mite populations should be monitored by observing foliage of susceptible plants at least weekly. Additional predator releases may be necessary every 2–4 weeks to achieve good control within 6 weeks.

Alternative control methods

Sanitation

Remove any weeds or old plants that may harbor spider mites. Avoid spreading mites on workers' clothing or implements by restricting movement through mite-infested areas. Always visit mite-infested areas last.

Irrigation and fertilization

Maintaining proper soil moisture, and misting or hosing off plants helps prevent mite populations from developing and dispersing to other plants. High nitrogen levels are often associated with severe mite infestations.

Manipulation of the greenhouse environment

High humidity produced by misting suppresses spider mite populations and favors *P. persimilis* and *Feltiella*.

Chemical controls

Localized infestations, or high populations that need to be reduced before predator introduction, should be spot-treated with selective chemicals. Integrating chemical control on the upper portion of the canopy with biological control on the lower part of the plant has worked well for commercial rose production.

There is good potential for the integration of predatory mites and insecticidal soap applications to control spider mites on ornamental foliage plants. Insecticidal soap controls spider mites, but when wet it also kills predatory mites and other natural enemies. It has a slight effect on spider mite eggs but does not affect predator eggs. Once insecticidal soap dries, it is nontoxic. Thorough coverage of infested surfaces and several sequential applications are necessary to maintain spider mite populations at low levels.

Horticultural oils, both refined petroleum distillate products and those made from vegetable oils, can kill mites. These horticultural oils may be toxic to some plants. Various brands are registered for use on vegetables and ornamentals in greenhouses to control many pests, including spider mites.

Abamectin is an insecticide/miticide derived from the microorganism *Streptomyces avermitilis*. It is registered for control of spider mites and leafminers on ornamental plants in greenhouses.

Spinosad is an insecticide based on natural metabolites produced under fermentation conditions by the actinomycete *Saccharopolyspora spinosa.* The product is fast acting and works both on contact and when ingested. It is very effective against thrips; control of spider mites is inconsistent, but is improved with the addition of certain adjuvants. It is registered for control of many pests on landscape ornamentals; check with your chemical supplier on availability for use on greenhouse ornamentals.

Scales & mealybugs

Available natural enemies and their potential for control

There are many different species of scales and mealybugs. For some you can expect to achieve good biological control with the available natural enemies; for others the potential for successful biological control is lower.

Order Homoptera: Aphids, leafhoppers, planthoppers, scales, and mealybugs

Superfamily Coccoidea: Scale insects

Family Coccidae: Soft scales

- **Brown soft scale**, *Coccus hesperidum*
- **Hemispherical scale**, *Saissetia coffeae*
- **Black scale**, *Saissetia oleae*
- **Nigra scale**, *Parasaissetia nigra*

Family Diaspididae: Armored scales

- **Boisduval scale,** *Diaspis boisduvalii*
- **Florida red scale,** *Chrysomphalus aonidum*
- **California red scale,** *Aonidiella aurantii*
- **Fern scale,** *Pinnaspis aspidistrae*
- **Ivy or oleander scale,** *Aspidiotus nerii*
- **Greedy scale,** *Hemiberlesia rapax*
- **Latania scale,** *Hemiberlesia lataniae*
- **Pineapple scale,** *Diaspis bromeliae*
- **Dictyospermum scale,** *Chrysomphalus dictyospermi*
- **Cactus scale,** *Diaspis echinocacti*

Family Pseudococcidae: Mealybugs

- **Citrus mealybug**, *Planococcus citri*
- **Longtailed mealybug**, *Pseudococcus longispinus*

The Superfamily Coccoidea is a large and diverse group, closely related to aphids and whiteflies. They are divided into three main groups: soft scales, armored scales, and mealybugs. They all feed in a similar manner, by sucking plant juices through their needle-like mouthparts. Many also excrete honeydew, which supports the growth of sooty molds that are cosmetically damaging. Heavy scale infestations can threaten plant health.

The adult males and females appear very different. Females and immatures are wingless and often legless and don't look like insects. Adult males look somewhat like tiny gnats but lack mouthparts and cannot feed.

Soft scales

The soft scales are the more important of the two groups of scales found in greenhouses. A wide variety of the flowering and foliage ornamentals, from orchids to ferns, are good hosts for soft scales. The brown soft scale attacks a broad range of hosts, while the black scale prefers woody plants. The hemispherical scale favors ferns, asparagus fern, schefflera, and many nonwoody evergreen plants. Plants in the family Acanthaceae, such as Crossandra and the zebra plant (*Aphelandra squarrosa*), are especially susceptible to the hemispherical scale. Another common greenhouse species is nigra scale. Woody plants such as weeping fig, citrus, ivy, and holly are common hosts.

Damage

A heavy infestation of soft scales will cause yellowed leaves, distorted foliage especially at the growing tips, twig dieback, or defoliation. But the main damage comes from the growth of sooty mold on the clear, sticky honeydew excreted by scales.

Description and life cycle

Soft scales are round to oval, dome-shaped on top, and $1/16$–$1/4$ inch (2–6 mm) long when mature. Immature scales start out light in color and darken at maturity. Brown soft scale females are pliable, oval, and somewhat flattened. They have a pale brown, yellow, or gray color that is mottled, shiny and crossed by a dark brown grid-like pattern. They produce live young, not eggs. The female hemispherical scale is hard, circular, steeply convex, smooth brown, and shiny. Numerous eggs pile up underneath their cup-like bodies. The black scale adult female is dark, oval, globular, and has ridges on the scale that form an "H" pattern. The nigra scale varies in size, shape, and color depending on its host. It tends to be more oval on leaves and more elongated on petioles or thin stems.

Female soft scales produce 50–2000 eggs or live young, depending on the species. Mobile, crawler-stage nymphs hatch from eggs after 1–3 weeks. They move to a suitable part of the plant, where they settle for the remainder of their lives. The nymphs go through three instars. A waxy covering envelops the female after she becomes an adult. The covering adheres tightly to the body of the female and cannot be separated from it. All three of these soft scales feed on the **phloem** and are often associated with stems or leaf veins.

Soft scales are most troublesome in greenhouses at temperatures around 68°F, and development does not usually occur above 86°F. In greenhouses there may be as many as six generations per year, with a new generation produced every 40–80 days, depending on temperature. All stages may be present simultaneously throughout the year.

Monitoring

Early detection will prevent many pest management problems. The best way to detect soft scales is to inspect plants visually, especially new shipments of plants. If scales are present, you will usually find them on the undersides of leaves and on stems, although some species may occur on upper leaf surfaces on some plants. The presence of ants, wasps, or bees may be a sign that soft scales are present. They are often attracted to the honeydew produced by scale insects. Yellowed foliage or sooty mold on leaves often indicates the presence of scales.

Ray Cloyd

The adult wasp *Metaphycus helvolus* is about 1/25 inch (1 mm) long.

Natural enemies

Numerous parasitic wasps, predators, and several pathogenic fungi attack soft scales, but only a few have been investigated as candidates for use in greenhouses.

Parasites

The parasitic wasps that are important natural enemies of soft scales are all in the family Encyrtidae.

***Coccophagus lycimnia*.** This cosmopolitan wasp will parasitize over 47 species of soft and armored scales, and has been shown to be effective against brown soft scales in citrus orchards and ornamental crops. Females oviposit in late first- to third-instar hosts but prefer second instars. The scale insect continues to develop after being parasitized but dies before maturity. This wasp is available commercially at least in Europe.

***Metaphycus helvolus*.** This small encyrtid wasp from South Africa attacks young nymphal stages of several species of soft scales. The male wasp is dark brown. The females are orange-yellow and about 1/25 inch (1 mm) long. Each female lays up to five eggs per day under the bodies of late second and early third instar scales and kills up to 20 more nonparasitized scales of various ages by feeding on them. The females lay an average of 400 eggs over their relatively long lives. Wasp larvae develop singly inside the scale bodies. After about 2 weeks the adult wasp emerges by cutting a small hole in the scale. *M. helvolus* readily attacks black and hemispherical scales, as well as brown soft scale, nigra scale, citricola scale (*Coccus pseudomagnoliarum*), and European fruit lecanium (*Parthenolecanium corni*). This parasitic wasp is commercially available.

***Metaphycus luteolus*.** This wasp, closely related to *M. helvolus*, has provided effective biological control of brown soft scale outdoors in California. Both the males and females of this species are lemon-yellow. Females lay 5–10 eggs per day in host scales over their 1-month life span. The larvae are gregarious internal parasites of all stages of the brown soft scale, but solitary parasites of black scales. This wasp will also parasitize early stages of other scale species. Larval development is very rapid; at 75°F adults emerge after 11 days. *M. luteolus* is not available commercially. Another species, *M. zebratus*, is commercially available in Europe.

Microterys flavus. This encyrtid is another internal parasite of brown soft scale, and of various other soft scales. It is available commercially for release in citrus groves. There are several strains with preferences for different host scales. For example, the California strain, probably of East Asian origin, prefers the brown soft scale and will not attack black scale. This wasp is solitary in small hosts but often gregarious in larger ones. Females readily feed on young scales.

Other parasitic wasps. *Encyrtus infelix* and *Encyrtus lecaniorum* have been used successfully alone and in combination with *Metaphycus helvolus* for scale control in French greenhouses. *E. lecaniorum* (commercially available in Europe) has parasitized hemispherical and soft brown scale more effectively than *M. helvolus* or *C. lycimnia*. *E. lecaniorum* mimics the ants that tend the scales, thereby preventing the other parasites from attacking the scales. These three wasps, used individually, have controlled hemispherical scale on ferns, peperomia, and dieffenbachia. A combination of *M. helvolus* and either *E. lecaniorum* or another wasp, *Diversinervus elegans*, gave satisfactory control of black scale on *Aphelandra* and *Aralia*.

Predators

Several species of lady beetles are well-known predators of soft scales outdoors in different parts of the world. Adults and the four larval instars all feed on scales. Females lay eggs on or under the scale. The elongated, flattened, spiny larvae that hatch consume large numbers of scales as they develop over a period of 2–4 weeks. Pupation normally occurs on the plant. Two to four generations are produced each year.

Chilocorus infernalis. This beetle from the foothills of the Himalayas is more cold tolerant than *C. nigritis*. It is not available commercially, but some closely related species (*C. baileyii* and *C. circumdatus*) are available as armored scale predators in other countries.

Chilocorus nigritis. This beetle, indigenous to India and East Asia, is a voracious predator with a wide host range including both soft and armored scales. The adult is a 5/32-inch (4-mm), black beetle with yellow edges on the thorax. A single female may lay over 350 eggs. One reason for its success in biological control programs is that adults and large larvae completely remove the adult female scale from the plant surface. Both beetle larvae and adults lift scales from the host plant with extremely sharp mandibles and then eat the soft parts below. *C. nigritis* is available in Europe, but not in North America.

Rhyzobius (=Lindorus) lophanthae. This small black lady beetle is mainly a predator of armored scales (see "Armored Scales" for more information), although they will eat some soft scales, mealybugs, and smaller insects. Both adults and larvae feed on the scales. It is commercially available.

Other lady beetles. Many lady beetles will feed on soft scales if their normal prey is not available. The mealybug destroyer, *Cryptolaemus montrouzieri*, will feed on soft scales in greenhouses if mealybugs are not present. The alternate-host scales allow the mealybug destroyer to survive between mealybug outbreaks. Several species of *Scymnus* are known to attack soft scales. The convergent lady beetle, *Hippodamia convergens*, may provide limited control of soft scales if released in large numbers.

Green lacewing larvae. These will feed on immature scales, but because they also feed on a wide range of other insects, including many natural enemies, they are not recommended for use when other natural enemies are already present.

Pathogens

Verticillium lecanii. This fungus has been reported to infect and kill certain soft scales. Preliminary investigations indicate it is a promising biological control agent for the scale *Philephedra tuberculosa* on *Annona squamosa* in Florida. However, no research has been conducted on its ability to infect or control soft scales in greenhouses.

Oregon State University Extension Service

Predatory lady beetle larva feeding on soft scale.

Possibilities for effective biological control

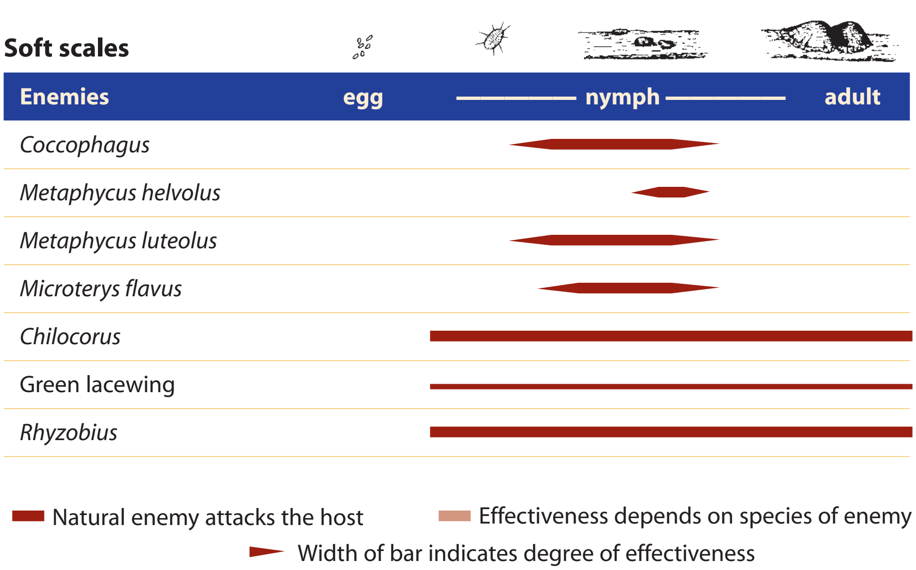
The natural enemies described above can control some soft scales in certain situations. Parasitic encyrtid wasps, especially *Metaphycus helvolus*, have been particularly effective. *M. helvolus* works well against hemispherical scale and has provided control of black scale in several parts of the world, but it does not reduce brown soft scale populations on some plants. However, it has provided satisfactory control of brown soft scale on poinsettia and in combination with other wasps on *Ficus*, certain cacti, and cymbidiums, as well as other orchids. This wasp is most effective in semi-tropical conditions.

For soft brown scale control, *Microterys flavus* or *Coccophagus lycimnia* may be a better choice than *M. helvolus*. However, no research has been conducted on the use of either species in greenhouses. In the field, competition from other parasites limits the effectiveness of *M. flavus*.

To improve control with natural enemies, avoid the use of residual insecticides for a month. Reduce scale populations with insecticidal soap or horticultural oil, and wash scale honeydew from plants before releasing wasps. Some scales must be present, however, to establish the natural enemy population in the greenhouse.

Release live *M. helvolus* adults two or three times at 2-week intervals and at a rate of three per ft^2 or up to 1,000 parasites per acre. Scatter the parasites on plants evenly throughout the infested area. These parasites can search and find the scales quite easily. The best time to release the wasps for control of hemispherical scale is just before the scale reaches the third instar—which is evident by the appearance of a ridged "H" on the scale surface. Wasp emergence holes should be visible after 2 weeks. Control should be achieved in 2–3 months. Periodic additional releases may be necessary to maintain control.

Predation by lady beetles, such as *Rhyzobius lophanthae* or *Chilocorus nigritis*, which feed on all developmental stages of scales, complements parasite activity, which tends to be more stage- or size-specific. Releasing a predator along with a parasite may offer the strongest potential for control. *R. lophanthae* is most effective at cooler temperatures (59°–77°F) and relative humidity of 20–90%. Release adult beetles at a rate of three to six beetles per 10 ft^2 for light infestations or five to seven beetles per 10 ft^2 for heavy infestations.



Alternative control methods

Sanitation

Remove heavily infested plants or spot-treat them chemically to keep crawlers from spreading to adjacent plants. Wash off honeydew and dislodge crawlers with water sprays or mists. Inspect new plant material for pests before placing it into general growing areas. Starting with clean plant material will help prevent scale problems.

Chemical control

Spot treat if there are two or more adult scales or large numbers of crawlers per leaf. Widespread application of traditional insecticides will interfere severely with natural enemy activity. Insecticidal soap or horticultural oil will kill soft scale crawlers as well as exposed natural enemies.

Insect growth regulators are registered for use on ornamentals for control of soft scales and other insects in a preventative program. These have minimal effects on natural enemies. Azadirachtin, a commercial formulation of neem seed extract, is an insect growth regulator that can be used. It is sold under several brand names.

Armored scales

Armored scales get their name from the hard, waxy coating that covers their bodies. They are not as economically damaging in greenhouses as are other scale insects because armored scales infest limited types of plants, mainly trees and shrubs, and they don't produce honeydew. They can be important pests in conservatories.

Damage

The plant damage caused by armored scale feeding is similar to that caused by soft scales. They inject toxins while feeding on leaf tissue. The toxins kill cells around the feeding site, causing a yellow or brown halo. Heavy feeding results in premature leaf drop. However, since armored scales don't produce honeydew, sooty mold is not a problem.

Robert F. Luck, University of California-Riverside

Adult *Aphytis melinus* parasitizing an armored scale.

Description and life cycle

Armored scales are soft-bodied insects that live beneath a hard cover made of wax and protein. They are smaller than soft scales, varying in size from 1/25–5/32 inch (1–4 mm). Armored scales vary in shape from circular to elongated (elliptical or like an oyster shell), in texture from smooth to rough, and in color. The insect body beneath the covering is usually yellow or orange. The males' coverings tend to be smaller and more elongated than those of the females. Most females lay eggs beneath their scale, but certain species produce live young under the scale. The crawlers move to other plant parts and settle for the remainder of their lives. A waxy covering that incorporates the shed skin of the crawler and subsequent stages builds up around the immature insect. Unlike soft scales, the scale covering on armored scales is easily removed from the scale's body. The adult female, which is legless, remains under its covering. Up to six overlapping generations may be produced in a year, depending on the species and environmental conditions.

Monitoring

Visual inspection of plants is the best way to detect armored scales. They are generally smaller than soft scales, not raised and bumpy, and are more easily overlooked. You can find them on lower leaf surfaces and stems, often forming thick crusts. New plant shipments should be checked carefully.

Natural enemies

Of the many parasites and predators that are known to attack armored scales, only a few have been utilized in greenhouse biological control efforts.

Parasites

Many parasites attack armored scales, including various *Aphytis* species that have been used against several armored scales in the greenhouse. The two species mentioned are in the families Aphelinidae and Encyrtidae, respectively.

Aphytis melinus. This ectoparasitic wasp from India and Pakistan attacks certain species of armored scales, including especially California red scale, but also ivy scale, San Jose scale and oleander scale. The tiny yellow wasp lays its eggs on the soft body under the waxy scale of third-instar nymphs. After developing as a larva for 2–3 weeks, the adult parasite emerges through a round exit hole cut in the scale. The adults can live 3–4 weeks, with each female killing more than 30 scales. This wasp does best at temperatures of 76°–85°F and relative humidity of 40–50%. This wasp is produced commercially for control of California red scale in citrus groves, but has not been evaluated for use in greenhouses. Pesticide-resistant strains are available. Another species, *Aphytis lingnanensis*, sold commercially in Israel and Australia for California red scale control, has not been evaluated in greenhouses.

***Comperiella bifasciata*.** This is another commercially available wasp that attacks a variety of armored scales. Females prefer to oviposit in second-instar female scales. The adult wasps emerge from mature scales. It has not been investigated for greenhouse use.

Predators

Lady beetles are the most important predators of armored scales. Their life cycle and basic biology are discussed in the section on predators of soft scales.

***Chilocorus bipustulatus*.** This beetle is an important predator of armored scales in the Mediterranean and Middle East. It also attacks some soft scales. Its life cycle is similar to that of *C. kuwanae*, but tolerates higher temperatures than *C. kuwanae*. *C. bipustulatus* is not commercially available in the United States.

***Chilocorus kuwanae*—Korean twice-stabbed lady beetle.** This is an efficient predator of at least 23 species of armored scale in China, Korea, and Japan. It has been used in other countries for release in fruit orchards and is now established in the eastern United States for control of euonymus scale, *Unaspis euonymi*. The adults are 1⁄8 inch (3 mm) long and shiny black with one red spot on each wing cover. They feed on all stages of the scale by chewing holes in the scale covering or by pushing under the scale to feed on the eggs or body beneath. As with other *Chilocorus* species, the eggs are deposited singly or in small numbers under empty scale coverings or in cracks and other protected places. Shiny black larvae hatch from the eggs in about 8 days. The larvae feed for 2–4 weeks, depending on the availability of food. Each larva consumes several hundred scales during its development. Pupation often occurs in small groups on the plant where the larvae developed. There are three generations per year with extensive overlap of all stages during the growing season. These beetles overwinter as adults that become active when outside temperatures rise above 50°F. It is intolerant of high temperatures and cannot complete its development above 90°F. It is not commercially available.

John Davidson, University of Maryland

An adult Korean twicestabbed lady beetle, *Chilocorus kuwanae*.

***Chilocorus nigritis*.** This species, discussed in the soft scales section, is also a good predator of certain armored scales. Two related species, *C. baileyii* and *C. circumdatus*, are also available commercially in other countries for armored scale control, but not in North America.

***Rhyzobius (=Lindorus) lophanthae*.** This polyphagous lady beetle occurs across the southern United States from Maryland south to Florida and west to California. It was introduced into California from Australia between 1889 and 1892 to control black scale, but it became established as a predator of a wide variety of armored scales. The 1⁄16-inch (2-mm) adults are reddish brown with a faint, green metallic tint and yellowish-brown head, legs, and underside. Adults and larvae consume all scale stages by chewing large, jagged holes in the scale wax armor. *R. lophanthae* may be sensitive to high temperatures during some of its life stages. It does best at temperatures of 59°–77°F, but can tolerate humidity from 20–90%. This commercially available beetle will also feed on soft scales.

Other predators. Limited control of some armored scales may be provided by green lacewing (*Chrysopa* and *Chrysoperla* spp.) larvae.

Cliff Sadof

The larva of the Korean twicestabbed lady beetle, *Chilocorus kuwanae*.

Alternative control methods

Sanitation

Start with clean plant material. This will help prevent scale problems, and removal or chemical spot treatment of heavily infested plants will reduce the spread of crawlers to adjacent plants.

Chemical control

Spot treatments should be applied when less than half of the crawlers present are parasitized and the infestation is spreading. Use insecticidal soap or horticultural oil if no predators or parasites are present; these treatments will kill exposed natural enemies.

Insect growth regulators are registered for use on ornamentals for control of armored scales and other insects as a preventative treatment. These can be used when parasites or predators are present. They do not affect natural enemies but may damage some plants. Azadirachtin (several brands) can also be used. This insect growth regulator is a commercial formulation of neem seed extract.

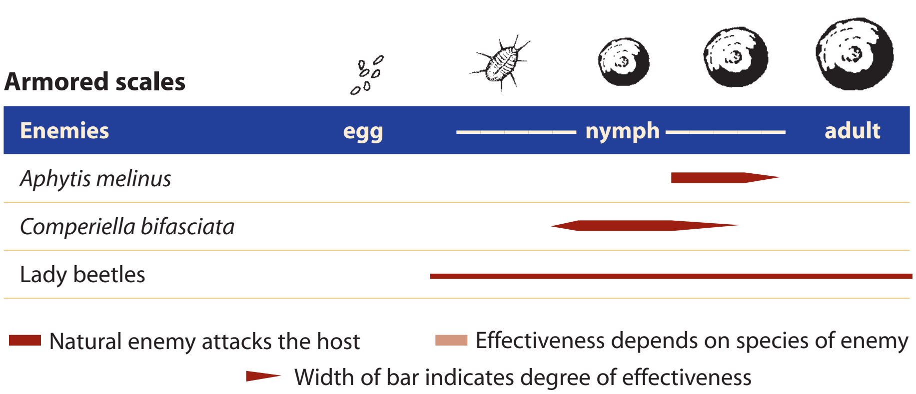
Possibilities for effective biological control

Selected species of armored scales should be susceptible to biological control using *Aphytis melinus* and/or lady beetles. If your greenhouse crop is infested with an armored scale, try introducing these natural enemies to find whether they will control it. No research has been conducted on wasp release rates for armored scales in greenhouses (three applications at a rate of one wasp per ft^2 is suggested for outdoor use), but it has been suggested that procedures similar to those for the soft scale parasite *Metaphycus helvolus* be used. The wasps will disperse readily from the release site. You can release wasps by opening the container and allowing them to fly out as you walk through the greenhouse.

Suggested release rates for lady beetles, such as *R. lophanthae*, are four to six beetles per 10 ft^2 for light infestations, and slightly more for heavy infestations. Make two releases about 3 weeks apart.

Mealybugs

Mealybugs are common pests in greenhouses and interior plantscapes. Unlike the soft and armored scales, most retain their legs throughout life and are free-moving. The citrus mealybug, which is a native of the tropics and subtropics, is the most common and most damaging. It feeds on numerous flowering plant species in over 25 families, especially soft-stemmed and succulent plants such as coleus, fuchsia, croton, and cactus. The host range of the longtailed mealybug is more restricted, but still very diverse. Dracena is the preferred host. Other foliar-feeding species found in greenhouses include the cactus mealybug (*Hypogeococcus festerianus*), Mexican mealybug (*Phenacoccus gossypii*), and obscure mealybug (*Pseudococcus affinis*). The ground mealybug (*Rhizoecus falcifer*) is the most common soil mealybug, occurring on the roots of many house plants, especially African violets.



Damage

Most mealybugs feed on the above-ground parts of plants, especially stem tips, leaf junctures, and new growth, but some are root feeders. Feeding causes stunting, foliar yellowing, defoliation, wilting and general plant decline. Citrus mealybugs inject a toxin while feeding that causes plant malformation. Secondary damage results from sooty mold growth on honeydew excreted by the mealybug, which impairs photosynthesis and reduces crop marketability.

Description and life cycle

Mealybugs are pink, soft-bodied insects covered with a white, waxy, cottony material. The wax filaments at the end of the body of the longtailed mealybug are slender and as long as or longer than the body, while those of the citrus mealybug are very short. The citrus mealybug females are wingless, 1/16 inch (1–3 mm) long, and ovoid. They lay up to 600 small (1/100 inch or 0.3 mm long), yellow eggs within a protective mass of white, cottony threads. Egg production is temperature dependent, with fewer eggs laid under warmer temperatures. The longtailed mealybug does not lay eggs but produces live young, similar to aphids. After depositing the egg mass or live young over a period of 5–10 days, the female mealybug dies. The immatures search for feeding sites on which to settle. Male nymphs settle and spin an elongated, white waxy cocoon. Females have three instars and are mobile throughout their lives. Adult males are tiny, winged insects. Under normal greenhouse conditions, the production of a generation takes 1–3 months.

Monitoring

Visual inspection is the best method for detecting infestations of mealybugs on leaves and stems. Both the insects themselves and the eggs in their masses of waxy threads may look like white cotton on the plant. Inspect these cottony masses carefully so as not to confuse mealybugs with the beneficial mealybug destroyer larvae that resemble mealybugs. On some plants mealybugs concentrate on the growing tips, and on other plants they are more dispersed. The longtailed mealybug frequently conceals itself in leaf whorls. Ants, wasps, or bees may be present as they are often attracted to the honeydew produced by the mealybugs and the sooty mold on leaves. Underground infestations are more difficult to detect. Yellowed or wilting foliage may indicate the presence of mealybugs on the roots. Small white cottony masses around the drainage holes of pots also indicate the presence of mealybugs.

Natural enemies

A number of natural enemies, including several parasitic wasps and predators, are known to attack mealybugs.

Parasites

A wide range of host-specific wasps in the family Encyrtidae attack mealybug species. All develop in a similar manner, as solitary internal parasites within the body of the host mealybug. The female wasp stings an appropriately sized mealybug and lays a single egg in it. The wasp larva develops within the mealybug body before pupating in the mummified host. Most research has centered on the control of the citrus mealybug.

Anagyrus pseudococci. This Mediterranean wasp is very similar to *Leptomastix dactylopii* (next page), but it attacks half-grown to full-grown citrus mealybug nymphs. It is a solitary internal parasite. The 1/16-inch (1.5-mm) females are yellow with black markings and distinctive white antennae. The males are smaller (1/25 inch, 0.8–0.9 mm) and black with yellow markings. Each female lays about 45 eggs. This wasp's life cycle is a day or two shorter than that of *L. dactylopii*. It reproduces best at 86°F. This wasp is available commercially; a related species, *A. fusciventris* is available in Europe.

Leptomastidea abnormis. This wasp attacks only young, second-instar citrus mealybugs and develops as a solitary endoparasitoid. The adult wasp is 1/16 inch (2 mm) long, pale yellow-brown and has distinct bands on the wings. The female produces more eggs than *Anagyrus pseudococci* and *Leptomastix dactylopii*. The species has a longer life cycle, requiring from 19 days at 86°F to 46 days at 65°F. *L. abnormis* reproduces best at 75°F and has a longer life span at 86°F than *L. dactylopii* or *A. pseudococci*. This wasp is better adapted to the wide range of temperatures that occur in temperate greenhouses and parasitizes a higher percentage of pests than do *A. pseudococci* and *L. dactylopii*. It is commercially available, primarily from European suppliers.

Cliff Sadof

The wasp *Leptomastidea abnormis*.

Leptomastix dactylopii. This Brazilian wasp is the most widely used parasite for control of citrus mealybug. It is a 1/8-inch (3-mm) long, yellow-brown wasp that attacks large nymphs and adult female citrus mealybugs. It has a characteristic short, hopping flight and taps its long antennae on the surface as it walks. Females produce 18–20 eggs a day, preferring to oviposit in third-instar and young adult citrus mealybugs. Parasitized mealybugs become legless, brown swollen mummies covered with fine threads. The emerging adult cuts an opening at one end of the mummy. The life cycle of this solitary internal parasite takes from 18 days at 81°F to 45 days at 64°F. Adult females can live up to 35 days. Maximum reproduction occurs at 86°F, but the females are fairly short-lived at this temperature. This wasp is available commercially. A related species, *L. epona*, is available in Europe.

Pauridia (=Hungariella) peregrina. This wasp is a solitary endoparasitoid of the longtailed mealybug. It mainly attacks the first and second instars. It will attack a few other mealybug species but not the citrus mealybug. It is very tolerant of high temperatures. At higher humidity levels, the wasp is better able to tolerate higher temperatures and its life span lengthens. *H. peregrina* has been used successfully on various crops outdoors in subtropical areas, and in greenhouses on ferns and, in conjunction with the mealybug destroyer, on dracena. Because it prefers small instars, it complements the action of other wasps that attack later mealybug stages. It may be available from some commercial suppliers.

Ray Cloyd

The Brazilian wasp *Leptomastix dactylopii* is the most widely used parasite for control of citrus mealybug.

Predators

***Cryptolaemus montrouzieri*—mealybug destroyer.** This predatory Australian lady beetle is probably the most successful natural enemy of mealybugs. Both adults and larvae feed on all stages of mealybugs, and on aphids and immature scales when mealybugs are not available. The adult beetle is about 5/32 inch (4 mm) long and dark brown or black except for its orange head, wing tips, and abdomen. Females lay up to 500 eggs at a rate of 10 eggs per day, singly in mealybug egg masses. Eggs hatch in 6–7 days at 75°F. The larvae can grow up to 1/2 inch (13 mm) long. They resemble a mealybug with long waxy filaments covering the body. The voracious larvae consume an average of 1400 mealybug eggs, nymphs, and adults during their 12–20 day development period and provide better mealybug control than adults. Young beetle larvae and adults prefer mealybug eggs and small nymphs, but older larvae will consume mealybugs of any size. Other insects, such as soft scales, may be eaten if mealybugs are scarce, or the larvae may eat each other. Generation time ranges from 25 days at temperatures around 86°F to 72 days at around 65°F. They are inactive below 50°F, and the lower temperatures and

Cliff Sadof

The mealybug destroyer, *Cryptolaemus montrouzieri*, is probably the most successful natural enemy of mealybugs.

shorter days of winter seem to reduce their activity, although the mealybugs will continue to increase under these conditions. Beetles are available from several commercial insectaries.

Other lady beetles. Many coccinellid beetles are important predators of mealybugs in other cropping systems, but few have been investigated for biological control of mealybugs in greenhouses. *Diomus flavifrons* is native to southern Australia where it commonly feeds on the longtailed mealybug. The beetle was introduced into Texas for control of citrus mealybug on citrus. The small black adults consume about 800 mealybug eggs over a 70-day period. *Scymnus (=Nephus) reunioni* and *S. bipunctatus* are two other coccinellids available commercially for mealybug control in other countries.

Green lacewing larvae. *Chrysopa* and *Chrysoperla* larvae will feed on young mealybugs but will also feed on other natural enemies that are present.

University of Florida

The larva of the mealybug destroyer resembles a mealybug.

Possibilities for effective biological control

Biological control of citrus mealybug is a promising alternative to chemical pest control on commercial greenhouse crops. Mealybug species other than citrus mealybug are more difficult to control biologically because parasitoids are not as widely available. The natural enemies of citrus mealybug tend to be specific, and several effective ones are available from commercial suppliers.

The mealybug destroyer has been successfully used against citrus mealybug on various ornamentals, such as gardenia and chrysanthemum, when temperatures remain above 70°F. Plants grown in large numbers or with dense bushy growth are better suited to mealybug control with the mealybug destroyer. Because the beetle needs to oviposit among mealybug egg masses, it may be less effective against longtailed mealybug, which produces live young. It is ineffective against mealybug infestations on roots. To enhance control, avoid using residual pesticides in the month prior to beetle release and control any ants in the area by using a boric acid bait. Otherwise, the ants will protect the mealybugs from predators and parasites. To favor the mealybug destroyer, adjust temperatures to 72°–77°F and relative humidity to 70–80% so that maximum control may be achieved. The pest population does not need to be reduced to a lower level before introducing the predator.

Adult mealybug destroyers should be released as soon as the shipment arrives, although they can be stored in a refrigerator for a short time. Release beetles in early morning or late evening onto plants at various infestation sites. Vents and windows should be screened to prevent the beetles from escaping, and during distribution workers should avoid wearing white clothing, which will attract the beetles. Optimal release rates will vary depending on the crop, but two to five beetles per 10 ft^2 is a good general guideline. Researchers have achieved control with one beetle per plant on gardenia and one beetle per two plants on chrysanthemum. Mealybug destroyers should control the mealybug population in about 10 weeks. Periodic releases may be necessary if other natural enemies are not being used.

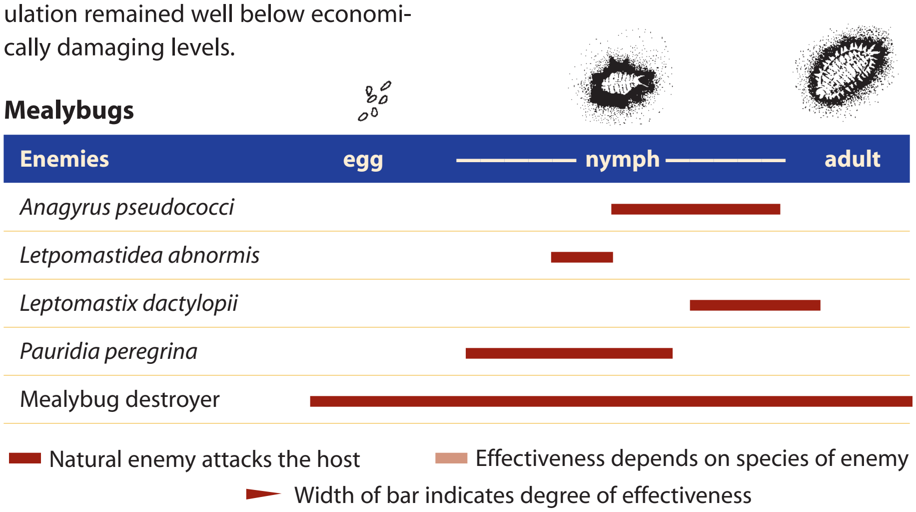
Citrus mealybug can be effectively controlled within 3 months using the parasitic wasp *Leptomastix dactylopii*. For best results, reduce heavy mealybug populations first either by releasing mealybug destroyers or by hosing off dense accumulations and then spraying with insecticidal soap (if no other natural enemies are present) or kinoprene. Also, adjust the greenhouse temperatures to 75°–81°F. No other residual pesticides should be used for a month prior to wasp release. Adult wasps should be released at several sites throughout the infested area at a rate of five wasps per 10 ft^2. Place the wasps as close to the mealybug infestations as possible. Periodic releases may be necessary to maintain control.

The best biological control of citrus mealybug has been achieved using a combination of natural enemies, especially supplementing the mealybug destroyer with parasitic wasps. However, experimental results have been quite variable, depending on the plant species, the greenhouse temperature, and the greenhouse size. When used together in French greenhouses, the mealybug destroyer and *L. dactylopii* completely controlled citrus mealybug on clivia (Kaffir lily) and crotons, and provided reasonable control on geraniums, African violets, cattleya orchids, and *Pilea*. The wasp *Leptomastidea abnormis*, the mealybug destroyer, and three other natural enemies were used to reduce high citrus mealybug infestations to less than 1% in gardenia within 3 months in a California commercial greenhouse.

Releases of 19,300 *L. dactylopii* and 600 mealybug destroyers over a 4-month period reduced citrus mealybug infestation on commercially grown *Stephanotis* from 66% to zero in a small California greenhouse maintained at 70°F and above. The mealybug destroyers were able to maintain a small population in the greenhouse after the disappearance of citrus mealybug by using hemispherical scale as an alternate food source. Even after an accidental re-introduction of citrus mealybug into the greenhouse several months later, the mealybug population remained well below economically damaging levels.

Researchers in the Netherlands used two wasps (*L. dactylopii* and *L. abnormis*) and two beetles, mealybug destroyer, and *Scymnus (=Nephus) reunioni*, against citrus mealybug on 50,000 *Stephanotis* plants grown for cuttings in a commercial greenhouse. They released over 1300 adult beetle predators in areas with heavy mealybug infestation, and released 13,330 *L. dactylopii* and 15,520 *L. abnormis* approximately every other week from May through October. Citrus mealybug was controlled during the summer months, but not during the winter, when temperatures were 55°–63°F and the parasites were inactive.

The predatory beetle *Scymnus (=Nephus) reunioni*, has been used with some success in greenhouses in France, but no published research on this predator has been conducted in the United States. In combination with *L. dactylopii*, it achieved excellent control of citrus mealybug on bromeliads. Similar control on a wide range of ornamentals was noted in the United Kingdom.



Alternative control methods

Sanitation

Starting with clean plant material will help prevent mealybug infestations. Removing heavily infested plants or spot treating them with chemicals will reduce the spread of mealybugs to adjacent plants. Remove soil accumulations beneath plant pots where root mealybugs are established to eliminate this potential source of future infestations.

Chemical control

Spot treat female mealybugs when egg masses are present and natural enemies are not, especially if growing tips are infested or the plant is sensitive to damage. Insecticidal soap or horticultural oil should be used only if no predators or adult parasites are present because the treatments will kill exposed natural enemies.

Use insect growth regulators (IGRs) when parasitized mealybugs or predators are present. IGRs are registered for use on ornamentals to control mealybugs, scales, and other insects. They do not affect natural enemies but may damage some plants. Azadirachtin (several brands), an insect growth regulator, may be used. It is a commercial formulation of neem seed extract.

Thrips

Available natural enemies and their potential for control

There are some predators, pathogens, and parasites available for control of thrips. However, even when used in combination, they will provide only moderate control. Other remedies may be necessary when pest populations are high.

Order Thysanoptera: Thrips

Family Thripidae: Common thrips

- **Western flower thrips**, *Frankliniella occidentalis*
- **Onion thrips**, *Thrips tabaci*
- **Eastern flower thrips**, *Frankliniella tritici*
- **Greenhouse thrips**, *Heliothrips haemorrhoidalis*
- ***Thrips palmi***

Thrips are important pests of cucumbers, peppers, and a broad range of ornamental greenhouse crops. These very small insects commonly hide in flowers, buds, and leaf axils, and often go unnoticed until damage appears. Western flower thrips (the word "thrips" is both singular and plural) is of special importance because it transmits the tomato spotted wilt virus and impatiens necrotic spot virus to many greenhouse floricultural and horticultural crops. It is replacing many of the other thrips as the predominant thrips pest in greenhouses throughout the world. *Thrips palmi*, native to Southeast Asia, is a severe pest of numerous vegetable and ornamental crops. It is now present in Florida and may spread to other parts of the United States.

Damage

Both larval and adult thrips have rasping mouthparts that they use to puncture the plant surface. They feed on the sap that is exuded from the resulting wound. Plants are also injured when female thrips lay their eggs in the plant tissue. The damage appears as white or silver speckles on the leaf or flower petal, arranged in streaks rather than the stipples caused by mite or aphid feeding. These spots eventually dry up and turn tan or brown on some plants but remain silver on others. Thrips can enter flowers while still in the bud stage and after color shows. Blossoms turn brown, or buds fail to open completely. Petals become distorted, develop brown edges, and stick together. As they feed, thrips excrete brown droplets on petals and leaves, and the droplets turn to black spots when they dry.

Leaf feeding reduces plant vigor and diminishes the yields of vegetable and ornamental crops. Feeding on the growing tips and blossoms of plants causes deformities in the new leaves, flowers and fruit, reducing the plant's marketability. Tomato spotted wilt virus and impatiens necrotic spot virus, transmitted by western flower thrips, cause lesions on leaf tissue and can reduce crop yields. Viral symptoms vary depending on the plant species; on cyclamen the lesions appear as ringspots. Affected ornamental plants are not marketable. Thrips will also bite people, causing a mild stinging sensation.

Description and life cycle

Adult thrips are slender insects 1/16 inch (1–2 mm) long with narrow fringed wings. They may be yellow, tan, brown, or black depending on the species or strain. Western flower thrips are yellow to brown with an orange thorax. Onion thrips are a uniform tan or brown. Greenhouse thrips are dark brown or black. *T. palmi* are clear yellow with black hairs. Males are typically smaller and lighter in color than females.

Thrips can reproduce year-round in greenhouses, producing 12–15 generations per year. The female thrips inserts minute, opaque eggs through holes cut into leaf, flower, or fruit tissue with her sawlike ovipositor. They lay 60–100 eggs during their lives. The nymphs hatch in 2–7 days, feed during the first two instars, then pass through two nonfeeding pseudopupal stages (the "prepupa" and the "pupa") in protected parts of the plant such as leaves or flowers, in leaf litter, or in the soil. Although thrips have a simple metamorphosis, and thus don't actually pupate, these pseudopupal stages are similar to the pupal stage of insects with a complete metamorphosis. Therefore, thrips nymphs are often referred to as larvae. They do not feed or move unless disturbed during the 2–5 day "pupal" stage.

Thrips often remain together in large numbers on a single leaf or flower. Onion thrips often feed along prominent veins. Western flower thrips are usually found within developing terminal foliage or at the base of flower petals where they feed on pollen. Greenhouse thrips are found primarily on developed leaves. *T. palmi* feed along leaf midribs.

Monitoring

Effective population monitoring is essential for timing the application of biological controls and for gauging their effect. Early visual detection of thrips is difficult because they are small and often hide within young, terminal foliage and developing flowers. Let previous experience guide you in deciding when to begin monitoring. Using sticky traps and sampling plant parts, including flowers, can give you some idea of the thrips population in your greenhouse.

Yellow or blue sticky traps are most useful for detecting the first infestation of thrips and determining where they are invading the greenhouse. The traps, which are commercially available, are also useful for monitoring population trends within a greenhouse. Begin monitoring early in the cropping cycle, especially before flower buds form. It is easier to see dark-colored thrips on yellow traps, but blue traps are more attractive to some species of thrips and therefore will detect lower populations. The blue traps will highlight light-colored species. Traps should be placed so that the bottom of the trap hangs 1–2 inches above the crop canopy. In mature commercial cucumber crops, place traps 8 ft above the floor to catch the most western flower thrips. Be aware that there is no correlation between trap catch and actual plant damage or the number of thrips in flowers. This is because thrips catches may be influenced by the presence and color of flowers, light intensity, placement of traps relative to crops, and crop type. These factors can make population counts inaccurate.

Although sticky traps are very useful for detecting the presence of thrips, plant part sampling can track thrips populations more accurately. For immature thrips, counting the number found on leaf samples is the best indicator of population trends. Sample leaves from the middle of the plant to save time without reducing accuracy. Monitoring immatures is still more costly and time consuming than adult monitoring.

Blossom sampling is the best method for monitoring populations of adult western flower thrips, which concentrate in flowers. To sample a flower, place it into a 25 ml (0.85 oz) plastic vial filled with 70% alcohol and seal it immediately. Pour the vial contents through a funnel lined with filter paper. Then count the flower thrips by examining the filter paper under a dissecting microscope. The flower may need to be dissected to find all the thrips. Although not as accurate, a quick visual assessment of the number of thrips per flower can be done by merely blowing into open flowers. The carbon dioxide agitates thrips and causes them to move around so they can be counted. A combination of sticky traps, blowing into flowers, and flower monitoring allows quick detection of potential problem areas.

Natural enemies

A few parasites and pathogens attack thrips, and so do many general predators, including mites, minute pirate bugs, lacewings, syrphid larvae, and other predacious thrips. Predatory mites are the most commonly used natural enemies to control thrips in greenhouses.

Parasites

A few trichogrammatid and mymarid wasps parasitize thrips eggs. Most of the parasitic wasps that have been found to attack thrips larvae are tropical or subtropical species in the family Eulophidae. Few are currently commercially available.

***Ceranisus (=Thripoctenus)* spp.** These eulophid wasps develop inside thrips larvae. After female wasps lay single eggs in young thrips larvae, the thrips continue to appear and behave normally while the wasps develop inside them. The thrips die when the parasites

Susan E. Rice Mahr

Hang blue sticky traps 1–2 inches above the crop canopy to detect thrips.

pupate inside their hosts. The adult wasps also kill young thrips by feeding on body fluids from holes made with the ovipositor. Several other species have potential as biological control agents of thrips. *C. brui* occurs in Japan, Indonesia, Europe, and the Caribbean. It was introduced and established in Hawaii in 1933–34 for control of onion thrips, the most important vector of yellow spot virus of pineapple, but has not been evaluated as a biological control agent for thrips in greenhouses. *C. menes* is a solitary endoparasitoid that attacks the first instar of western flower thrips. It occurs worldwide, and has been found parasitizing western flower thrips on alfalfa and roses in California. It is being investigated for western flower thrips control in European greenhouses. Thrips feeding on exposed plant parts are likely to be attacked by this parasitoid, but it may not be able to find thrips that enter flower and/or terminal buds. Researchers at the University of Florida are studying another species of *Ceranisus* from Thailand for possible importation as a biological control agent of *T. palmi* in subtropical areas of the United States. None are commercially available.

Jim McMurtry, University of California-Riverside

Two thrips larvae; the larva on the left has been parasitized by *Thripobius semiluteus*, the other is unparasitized.

Thripobius semiluteus. This parthenogenic wasp was introduced in 1987 from Brazil and Australia as a possible control agent for greenhouse thrips in avocado orchards in southern California. Females lay 15–20 eggs singly in thrips larvae and the developing wasp kills the thrips before it reaches the pupal stage. The adults also host feed on immature thrips, in addition to feeding on nectar and honeydew. Under optimal conditions (65°–75°F and 50–60% relative humidity) development from egg to adult takes about 3 weeks. It enters diapause when temperatures fall below 40°F. This species is commercially available.

Predators

Many generalist predators will feed on thrips in addition to other insects. Numerous species of predatory mites and a few bugs are more specific predators of thrips. Phytoseiid mites are the most important predators.

Predatory mites

***Euseius* spp.** Several phytoseiids in the genus *Euseius* are commercially available in Europe, but have not been evaluated for use on greenhouse crops. *E. delhiensis (=rubini)* will feed on thrips, spider mites, broad mites, and whitefly eggs. *E. hibisci* is predatory on many small insects, including thrips. It has been used successfully in inoculative field releases in California to control citrus thrips. It also feeds on various mites and sweetpotato whitefly eggs. *E. scutalis* is widely distributed in the warm climates of North Africa and the Middle East, where it occurs mainly on trees and shrubs. It prefers to feed on pollen and spider mite eggs but will attack thrips, spider mites, and whitefly eggs as well.

Hypoaspis (=Geolaelaps) miles. This soil-dwelling laelapid mite is a native of North America. It feeds on many soil-inhabiting arthropods, including thrips pupating in the soil. Adults can kill 15–30 prey per day, targeting more small prey than large prey. Females deposit one to three eggs per day. The mites complete a life cycle in 13–22 days, during which each nymph consumes 16–33 prey. It does not diapause in the winter. This mite is available commercially.

Max Badgley

Euseius hibisci feeding on citrus thrips.

***Neoseiulus barkeri*.** This phytoseiid mite—formerly called *Amblyseius mckenziei*—is still listed by some commercial suppliers, even though this species is now considered to be a strain of *N. cucumeris*.

***Neoseiulus (=Amblyseius) cucumeris*.** This predatory phytoseiid mite, previously known as *Typhlodromus thripsi*, feeds on young thrips. The pear-shaped adults are a pale brown and are noticeably smaller and flatter than the spider mite predator *Phytoseiulus persimilis*. Females lay an average of two small white eggs per day over a period of 20 days, often attaching them to plant hairs. Adults live up to 30 days, consuming three to six immature thrips per day. Although they prefer first-instar thrips, they will feed on spider mites and their eggs, broad mite adults, and pollen of various plants if thrips are not available. When no food is available they will resort to cannibalism. This mite will coexist with *Phytoseiulus*, although both prey on each other to some extent. Some strains of the mite enter diapause during the winter months in response to shorter photoperiod (less than 12.5 hours daylight) and temperatures below 69°F. Both diapausing and nondiapausing strains are available commercially. *Neoseiulus cucumeris* prefers humidity levels above 65%; eggs will not hatch at lower humidity levels.

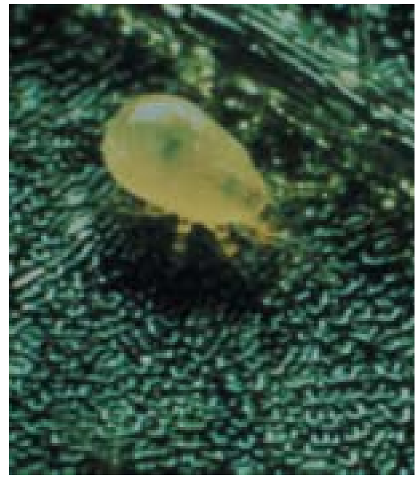
***Neoseiulus* (=*Amblyseius*) *degenerans*.** This species is very similar to *N. cucumeris* in appearance and biology, but it does not enter diapause. The dark brown adults are found in flowers and on the underside of leaves. Larvae have a brown X shape on the back. This species can tolerate lower humidities than *N. cucumeris* can. It is commercially available.

Other predators

***Dicyphus tamaninii*.** This mirid bug is an important predator of whiteflies, but it has also been shown to be effective against western flower thrips in cucumber greenhouses. (See "Whiteflies" for more information.)

***Macrolophus caliginosus*.** This mirid bug is primarily a predator of whiteflies, but will consume thrips and other pests. (See "Whiteflies" for more information.)

***Orius* spp.** These minute pirate bugs are common in gardens and many agricultural crops, and are often found in flowers. The black, 1/16–3/16 inch (2–5 mm) adults are ovoid and somewhat flat, with distinctively patterned black and white wings. The eggs are laid in leaf tissues with one end barely sticking out. The nymphs are pinkish-yellow to light brown. First-instar nymphs are about the same size as thrips larvae and are found in the same places. Both minute pirate bug nymphs and adults are very active and feed on all active stages of thrips. They consume 5–20 thrips per day, living up to 25 days as an adult. Because they are found in flowers, they are effective predators of western flower thrips. They also feed on spider mites, aphids, whiteflies, and caterpillar eggs, as well as pollen and plant juices. Several species of *Orius* are available commercially.


Koppert B.V.

The predatory mite *Neosiulus cucumeris*.


Koppert B.V.

Adult minute pirate bug, *Orius* sp., feeding on thrips.


Les Shipp

Orius nymph feeding on western flower thrips larva.

Pathogens

Several fungal pathogens and some nematodes infect thrips naturally. Onion thrips are susceptible to *Beauveria bassiana, Metarhizium anisopliae, Paecilomyces fumosoroseus, Verticillium lecanii*, and several species of *Entomophthora*. However, natural fungal infections do not provide effective control despite high rates of mortality because epizootics occur when thrips populations have already grown large and damaging. These pathogens are useful only if the active stages of the fungi can be introduced early and under environmental conditions suitable for infection. *Beauveria* is the only fungus currently commercially available for control of western flower thrips.

Fungi

Beauveria bassiana. This fungus attacks many insects, including thrips (see "Aphids" for more information). At least two strains of the fungus are commercially available.

Entomophthora parvispora. This fungus causes significant thrips mortality outdoors in Europe, but in greenhouses it usually changes quickly to the resting spore stage that does not infect or spread. Shortly after the thrips is infected by a conidial spore, the body becomes filled with fungal growth that kills the host insect in 3–6 days. Active spore preparations could be useful for greenhouse applications, but the fungus would not spread beyond the initial application. It is not commercially available.

Entomophthora thripidum. Fungal epizootics in onion thrips in European greenhouses are usually caused by this fungus. Where it occurs, it can almost eliminate a thrips population within a few weeks. The fungus completes its life cycle in the insect host in 4 days. Only the abdominal organs are infected, so even after the fungus breaks through abdominal coverings, the thrips remains alive as long as the fungus continues to sporulate. Infected thrips often move to an elevated part of the leaf before the fungus breaks through to facilitate spore release. Sporulation occurs on cloudy days when the humidity is greater than 80%, but ceases in bright sunshine. It is not commercially available.

Metarhizium anisopliae. This fungus attacks many insects, including thrips (see "Aphids" for more information). All mobile stages of thrips are susceptible to this fungus, although the immature stages are more resistant to infection. This fungus is not registered for use in the United States on any greenhouse crops.

Paecilomyces fumosoroseus. This fungus has been investigated in Florida for control of western flower thrips on greenhouse ornamentals (see "Aphids" for more information). This fungus requires humidity over 90% for infection, which limits its utility. It is commercially available only in Europe.

Verticillium lecanii. This fungus controls aphids and whiteflies and has strong potential for controlling both onion thrips and western flower thrips. Although it is commercially available in Europe, this product is not expected to be available in North America for use against any greenhouse pests in the near future.

Nematodes

***Heterorhabditis bacteriophora* (=*heliothidis*).** This nematode has been shown to reduce adult emergence of western flower thrips by 40%. In addition, infection may reduce the number of progeny produced by adults that survive, and reduce the ability of thrips to transmit virus diseases. *H. bacteriophora* has good searching capabilities and attacks thrips pupae deeper in the soil profile than do other nematodes, such as *Steinernema feltiae*. Rates necessary to control thrips are extremely high and may not be economically feasible. It is commercially available.

Thripinema nicklewoodii. This nematode infects both larval and adult thrips. The infective stage of the nematode bores into the host thrips' body and multiplies in its abdominal cavity. The mature nematode burrows into the thrips' digestive tract, then passes out with its **frass**. Nematode infection in adult female thrips prevents egg production. Up to 20% of western flower thrips in California are parasitized by indigenous populations of this nematode. However, *T. nicklewoodii* has not been investigated for use in greenhouses and is not commercially available.

Mike Brownbridge

The fungus *Verticillium lecanii* infecting a thrips larva.

Possibilities for effective biological control

Most of the research on the biological control of thrips has focused on vegetable crops, especially pepper and cucumber. Biological control can be used on other greenhouse crops for thrips control, but it may not suffice for ornamentals that cannot tolerate cosmetic damage or the potential for viral transmission. In vegetable crops, success often depends on the individual grower's tolerance for foliar damage during the initial control phase—damage that will not affect fruit production. Other limitations to the biological control of thrips include reinfestation from surrounding outdoor plants during warm weather, the propensity of western flower thrips to hide in flowers or buds, and the difficulty of protecting crops from tomato spotted wilt virus and impatiens necrotic spot virus if present in a thrips population. Nevertheless, if selected and released appropriately for your thrips problem, predatory mites, minute pirate bugs and soil mites may control thrips. They may work best when used in combination, as detailed below.

The most commonly used natural enemies for thrips control are the two phytoseiid predatory mites *Neoseiulus cucumeris* and *N. degenerans*. *N. cucumeris* is effective against both the western flower thrips and onion thrips, especially on cucumber. Most strains of *N. cucumeris* do not reproduce during short winter days with night temperatures below 65°F. By contrast, *N. degenerans* does not enter diapause and will continue to develop under cool conditions. The eggs of this species are also better able to tolerate low humidity, which can severely reduce hatching of *N. cucumeris* eggs. Both species are efficient at low thrips densities and feed on spider mites, broad mites, and pollen in the absence of thrips. The two species together may provide control over the range of conditions characteristic of greenhouses.

The greenhouse crops themselves influence the effectiveness of predatory mites. On peppers, *N. cucumeris* tends to establish easily, even without thrips. Therefore, it can be introduced to peppers in low numbers before thrips are detected for earlier control. However, *N. cucumeris* is not as efficient a predator on cucumber, perhaps because the trichomes on cucumber leaves interfere with the mite's ability to search. Repeated releases are often necessary for successful establishment on this crop. Pollen is critical for optimal reproduction of *N. cucumeris*, so it is not as successful on nonflowering plants and those that do not produce sufficient pollen. Thrips reproduction also can vary on different cultivars, and even a slight decrease in thrips reproduction may allow the mites to prevail.

The greenhouse conditions into which predatory mites are released also influence the mites' effectiveness. Thrips that migrate from outdoors in summer can overwhelm the ability of the mites to get the thrips under control. Environmental conditions such as relative humidity and temperature also affect predator efficiency and egg survival. Optimal conditions for predatory mites include moderate temperatures (around 86°F) and high humidity (80–90%). Thrips thrive at 70–90% humidity, but their mortality increases above that humidity level. The mites will also be more efficacious if plant leaves are touching, so that the mites are able to easily move from plant to plant.

Predatory mites are shipped in a carrier or packing material. If you receive the mites in loose packing material, sprinkle the material (often cereal bran) onto plants. If the material is in slow-release packets (sachets), hang them on plants. Because some strains of *N. cucumeris* diapause during the winter months, when the temperature drops below 70°F and daylight lasts less than 12.5 hours, the mite is not usually released in greenhouses in the upper Midwest until March or April. However, warm night temperatures in the greenhouse, even during winter, will prevent diapause in a large proportion of the mites. *N. degenerans* can be released during fall and winter.

Success with these predators depends on releasing them as soon as thrips are detected on sticky traps or plants. For cucumbers, releases of 50 predatory mites per plant plus an additional 100 per infested leaf are recommended. For peppers, recommended release rates are 10 predatory mites per plant plus an additional 25 per infested leaf. The initial pest density does not seem to be important as long as introductory rates are high. Repeated releases of predatory mites are recommended for good protection of peppers or cucumbers. Make weekly releases until there is one predatory mite for every two thrips. The mites only attack thrips in their first and second instars, so it may take several months for biological control to work.

Making regular releases of predatory mites is also the only way to control thrips on ornamental crops, such as chrysanthemum. You should release the mites weekly, biweekly or monthly, depending on the crop and the thrips pressure. Before thrips are present, introduce the mites at 10–50 per ft^2, depending on the crop. Good results have also been obtained on chrysanthemum using *N. cucumeris* at rates of 100 mites per individual cutting. Additional releases of three mites per leaf are sufficient where adult thrips pressure is intense. Under less pressure, you can gain control with fewer mites per leaf, but regular releases are still necessary. Remember, your own experience is your best guide to the timing and rates of natural enemy releases.

Minute pirate bugs (*Orius* spp.) may be more effective than mites for control of thrips in some situations. Mites feed on thrips for only a small portion of their lives. The nymphal and adult minute pirate bugs prey on both adults and immature stages of the thrips. They also feed in flowers, where female western flower thrips, which are directly responsible for population growth, concentrate. Minute pirate bugs will also feed on other pests, such as spider mites, as well as pollen and plant juices, so they can exist for long periods at low thrips densities. *Orius* are most effective when they reproduce in the crop, but the adults do not lay eggs equally well on all plants. *O. insidiosus* reproduces best on chrysanthemum, gerbera, cucumber, and peppers, but oviposition is so poor on roses and carnations that the bugs provide no control when thrips are present in the flowers. *O. laevigatus* and *O. albidipennis* are able to control western flower thrips on peppers and strawberries, but not on cucumbers, due to the absence of pollen and the numerous hairs on the cucumber leaves which inhibit movement. Other *Orius* species may have different plant preferences.

Minute pirate bugs are shipped as adults in a carrier or packing material, such as bran, rice hulls, or vermiculite, along with a food source. Shake the packing material onto the plants, and the bugs will readily disperse and locate prey. Distribute the insects evenly throughout the greenhouse, but place extra bugs in thrips hot spots, such as open flowers. Release the bugs in the early morning or late afternoon, or on a cloudy day, to reduce the chances they will fly out of the greenhouse. Keep the vents closed or screened to prevent the bugs from leaving the greenhouse.

One minute pirate bug per plant was sufficient to control western flower thrips within 5 weeks in small-scale experimental trials on greenhouse cucumbers. Release rates of one *Orius insidiosus* per 20 ft^2 provided control of western flower thrips on peppers in some trials in European greenhouses, but higher rates may be necessary on other crops. On peppers an initial introduction of three to five *Orius* per 10 ft^2 is suggested in areas of pest activity. This should be followed by an introduction of two *Orius* per 10 ft^2 throughout the greenhouse 2–4 weeks later. On cucumber and eggplant, use 5–10 *Orius* per 10 ft^2 in specific areas of pest activity, followed 2–4 weeks later by a general introduction of one to two per 10 ft^2. Additional research on a larger scale is necessary to make recommendations for release rates on other crops in commercial greenhouses. Minute pirate bugs can also be used in conjunction with predatory mites, although the bugs will eat the mites if insufficient food (thrips) is available.

Minute pirate bugs enter a reproductive diapause in late fall, so more regular releases become necessary after late October to keep populations high enough for thrips control. The use of supplemental blue light has been shown to reduce the number of *O. insidiosus* entering diapause, which may allow these bugs to suppress western flower thrips in short-day flowering crops such as chrysanthemums.

The predatory bug *Dicyphus tamaninii* was effective at controlling western flower thrips in a Mediterranean cucumber greenhouse. A ratio of three late-instar nymphs to 10 pests kept thrips under the economic injury level. A lower ratio was successful only when thrips populations were low. Releasing late-instar nymphs would not be as practical in a commercial greenhouse as releasing adults which could disperse to find the thrips, but might also leave the greenhouse.

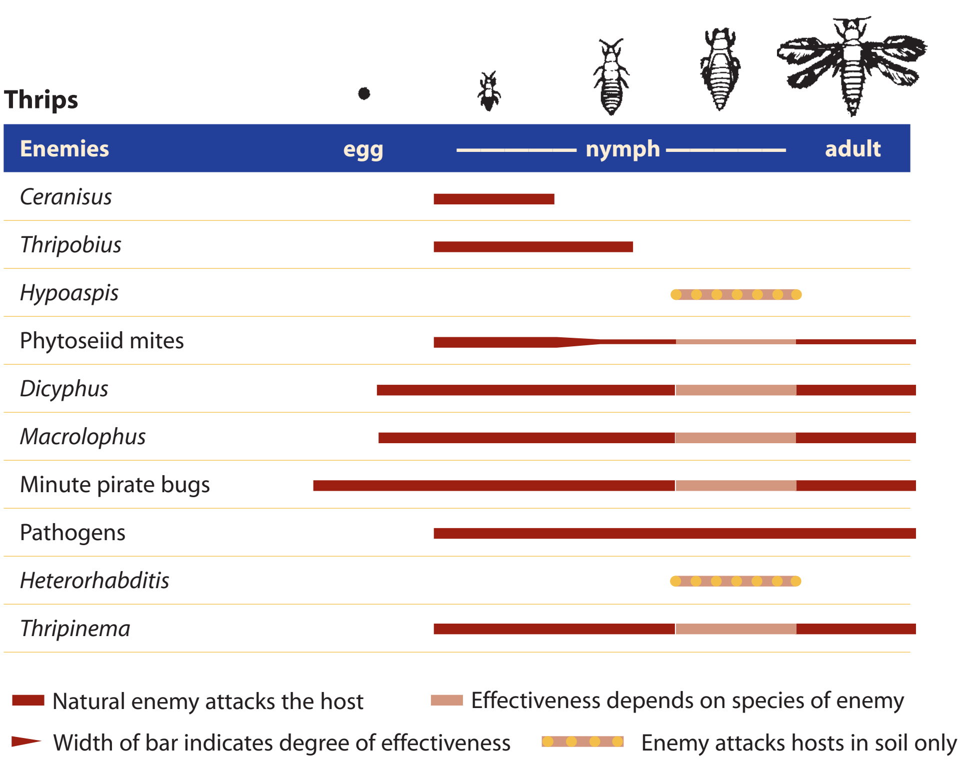
The soil-dwelling predatory mite *Hypoaspis*, which is not a phytoseiid, will attack thrips pupae in the soil when placed around the roots of each plant. These mites work best when the soil or medium is moist, with an open structure, and soil temperature is at least 59°F. It cannot be relied on as a sole source of control for thrips in a commercial greenhouse, but it could enhance biological control by predators that feed on immature thrips and adults on leaves. In small-scale experiments this mite reduced adult thrips by about 70%.

These mites are also shipped in a carrier, such as vermiculite, and are distributed by shaking the contents onto the soil or potting medium. *H. miles* does not need to be applied to every pot and/or flat of plants because it will disperse some distance on its own. It must be applied early in the growing season to allow establishment before thrips begin pupating in the soil.

Using phytoseiid mites, minute pirate bugs, and *Hypoaspis* together should offer the best control of thrips. The predatory mites consume immature thrips but do not kill adult thrips, which can continue to damage the plants for several months until they die. Minute pirate bugs will prey on adult thrips, as well as immatures on the foliage. *Hypoaspis* will feed on thrips in the soil, where the other predators do not occur. Releases of *Hypoaspis* and phytoseiids together provided excellent control on chrysanthemum in Canadian greenhouses. Release the mites before thrips are detected, and release *Orius* in hot spots when thrips are found. If additional releases are necessary, alternate weekly between phytoseiids and *Orius*. The phytoseiid mites perform best under humid conditions and often die out when humidity declines. *Orius* tolerates drier conditions, so the two are complementary.

The parasite *Thripobius semiluteus* can be used for control of greenhouse thrips only. Because it only accepts this species of thrips it is important to know what species you have before contemplating releasing this insect. The wasps are shipped in the pupal stage and should be held at 65°–75°F until adults emerge. The highly mobile adults will disperse throughout the greenhouse to find greenhouse thrips. Release rates vary considerably depending on the crop, thrips population levels, and other natural enemies being used at the time of release. Minimum rates begin at one wasp per 20 ft^2. Two releases should be made 2–3 weeks apart. Monitor for wasp reproduction and establishment by observing immature thrips. Parasitized thrips have a milky appearance. Once the parasite pupates inside the thrips, the host body turns black and hard, but still remains attached to the plant surface.

Pathogens can also be used to suppress thrips populations. Adult western flower thrips appears to be most susceptible to fungi possibly because they generally occur in flowers where humidity is higher and conditions more favorable for infection. The higher humidity in the flowers increases the potential for the fungus to sporulate and infect additional thrips. The commercially available *Beauveria bassiana* suppresses western flower thrips on rose, gerbera, carnation, and other flowers as well as currently registered insecticides do. However, none of these materials provide satisfactory control of western flower thrips. The fungus and predatory mites or *Orius* need to be used together to achieve acceptable control.



Several brands and formulations of *B. bassiana* are available for use in greenhouses. The fungus takes 3–7 days to kill an insect, so it will take some time to suppress the thrips population when using these products. Thorough spray coverage is essential because fungal spores must contact the insect for infection to occur. This fungus is susceptible to some fungicides, so chemical fungicide applications should not be made within 48 hours of *B. bassiana* applications. Multiple applications are usually necessary to achieve control.

The whitefly strain of *V. lecanii* also affects thrips. When humidity is high and temperatures are 64°–77°F, this fungus can cause considerable mortality of thrips. In experiments on cucumbers, *V. lecanii* killed more than 80% of the thrips within 4–6 days. In comparative assays, *Metarhizium anisopliae* caused more adult mortality of western flower thrips than *V. lecanii*. The efficacy of *M. anisopliae* increases as temperatures increase, with an optimal range of 75°–82°F. *Paecilomyces fumosoroseus* has also been shown to be effective against thrips in some tests.

These pathogens are applied as spores suspended in water for spraying. High humidity is necessary for infection. When humidity is low, the performance of the fungus is unpredictable. Humidity can be increased by dampening the plants with water sprays. Late afternoon applications reduce spore injury by ultraviolet light and desiccation, since the greenhouse is more humid at night. However, these fungi may be practical for use only in humid areas with moderate temperatures, such as rooting benches and shade-cloth covered areas used to induce inflorescence in chrysanthemums. Repeated applications will be necessary if humidity is not high enough to allow continuous infection. Since these fungi do not impair natural enemies, their use can be integrated with predatory mites or bugs.

Alternative control methods

Sanitation

This is the most important cultural practice for preventing thrips problems. Remove weeds that can act as a refuge for thrips or harbor viruses from inside and outside the greenhouse. Remove and immediately destroy crop residues after harvest. In addition, remove any soil debris which could contain thrips pupae. Avoid wearing yellow and blue clothing in the greenhouse because they attract thrips and facilitate the spread of the pest.

Insect screens

Thrips migration into greenhouses can be a continual problem. Monitor the greenhouse with sticky traps to determine where thrips are entering, and install screening to exclude them. Screens on greenhouse vents and doors will help block thrips' entry from outside. Screening just the side of the greenhouse that faces into the prevailing winds can also be effective at reducing thrips, even for passive air intake systems. The maximum hole size to exclude thrips is 192 µ. Thrips can easily get through commercial whitefly-proof screens or unwoven polyester filters.

Soil sterilization (pasteurization)

Steam sterilizing the soil or the used planting medium between crops will kill immature thrips that are pupating in the soil.

Environmental control

Misting to increase relative humidity near 90% will reduce thrips populations on cucumber. Soil that is kept wet and frequently waterlogged will drown thrips pupae or allow fungal epizootics to kill them. However, wet soil may also increase plant disease, fungus gnat, and shore fly problems.

Traps

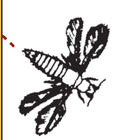
Yellow or blue sticky traps can be used for mass trapping of thrips. For western flower thrips, which pupate mainly in the soil, place the traps near the soil to catch large numbers of newly emerged thrips before they move into the crop. Blue traps may be more effective for mass trapping than yellow traps.

Resistant cultivars

Certain chrysanthemum cultivars appear to be more tolerant of western flower thrips than others. Dutch researchers have found differences in susceptibility of cucumber cultivars. If possible, select varieties that do not show as much injury from thrips feeding.

Chemical control

Spinosad is an insecticide derived from natural metabolites produced under fermentation conditions by the actinomycete *Saccharopolyspora spinosa*. It has a high level of contact and oral activity and rapid speed of action. It is very effective against thrips but has low to moderate impact on beneficials. It is registered for control of many pests on landscape ornamentals and can be used on ornamentals in shade houses and lath-houses.



Weevils

Available natural enemies and their potential for control

Insect-parasitic nematodes can be very effective against weevil larvae.

Order Coleoptera: Beetles

Family Curculionidae: Weevils

Black vine weevil, *Otiorhynchus sulcatus*

Strawberry root weevil, *Otiorhynchus ovatus*

The black vine weevil is a cosmopolitan pest that caused economic damage to greenhouse plants as early as 1834 in Germany. It is an imported species but is established throughout the northern United States. It has a host range of over 140 plant species, including many common greenhouse ornamentals such as ferns, geranium, gloxinia, primrose, rose, and especially cyclamen, as well as strawberry, yew, and numerous other nursery plants. The host range of strawberry root weevil, also an introduced species, is more restricted.

Damage

Larvae of both species feed on roots and other underground portions of plants. They feed on the smaller roots first, then tunnel through the larger roots and move up into the crown. This reduces plant vigor and in heavy infestations may kill the plant. The feeding damage may also make plants susceptible to diseases. Adult weevils feeding on the foliage may cause cosmetic damage, but otherwise they do little damage.

Description and life cycle

The adult weevils are $\frac{3}{8}$ inch (8–9 mm) long. The shiny black beetles feed on foliage or flowers at night and do not fly. Each female may lay over 600 eggs, scattering them randomly over the soil surface. The larvae hatch in approximately 2 weeks and feed on roots as they go through five to six instars. The larvae are whitish, wrinkled, legless grubs up to $\frac{3}{8}$ inch (1 cm) long. The mature larvae hollow out earthen cells in the soil and enter the prepupal stage, which lasts from 3 weeks to several months, depending on temperature. After 2–3 weeks in the pupal stage, the adult remains in the pupal cell for an additional week as the body hardens and darkens before emerging. In the greenhouse the length of the life cycle depends on temperature rather than time of year.

Monitoring

Pitfall traps, trap boards, and burlap traps have been developed for monitoring both black vine weevil and strawberry root weevil adults. Inspect the traps once or twice per week. Record the number of weevils in each trap to calculate the average number of weevils per plant or determine where localized infestations occur.

Natural enemies

No parasites or predators attack root weevils specifically, although some generalist predators, such as carabid beetles and ants, may occasionally kill larvae. Nematodes are the only natural enemies developed for commercial use.

Pathogens

Several entomogenous nematodes occur naturally in the soil and parasitize a variety of soil-inhabiting insects, including weevil larvae. Nematodes are long, slender roundworms. They are about $\frac{1}{64}$ inch (0.5 mm) long, transparent, and practically invisible to the naked eye. They seek out insects in moist soil; moisture is essential to their movement and persistence. They enter an insect through natural openings and release a bacterium that kills the host within 48 hours. The bacteria then serve as food for the nematodes, which complete their development inside the dead insect. The next generation of nematodes leaves the insect in search of new hosts. Unlike plant-parasitic nematodes, these nematodes do not damage plants. Neither do they harm people, animals, beneficial above-ground insects, or earthworms. Entomogenous nematodes are propagated and packaged to use as biological insecticides.

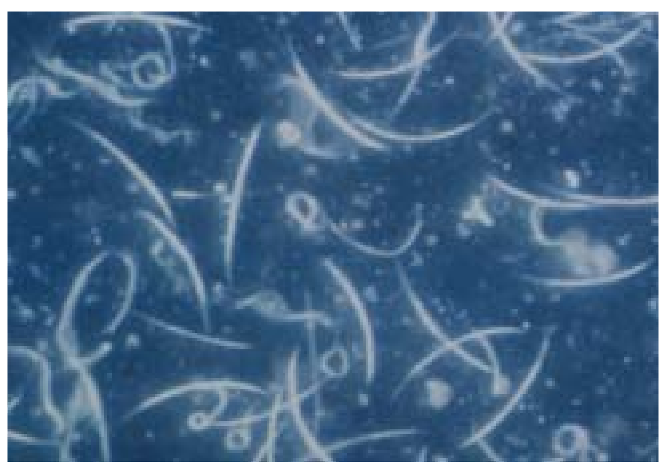
***Heterorhabditis bacteriophora* (=*heliothidis*).** This nematode attacks black vine and strawberry root weevils, as well as numerous other insects. Although larvae, pupae, and adults can become infected, the larvae are the most susceptible. The bacteria carried by the nematodes will kill larvae within a few days. The nematodes reproduce in the dead host insect, and only the infective larval stage lives free in the soil. Several thousand infective juvenile nematodes emerge from host cadavers within 2–3 weeks of the host's death. This nematode is commercially available.

***Steinernema* (=*Neoaplectana*) *carpocapsae*.** This nematode has considerable potential as a biological control agent because of its rapid action and environmental safety. It attacks weevils in a manner similar to *H. bacteriophora*. You can achieve good control with this nematode if they are well-distributed throughout the potting medium. Several commercial brands are available.

***Metarhizium anisopliae*.** This insect-parasitic fungus has considerable potential as a microbial control agent for weevils on a number of potted plant species, but it is not commercially available. Various fungal strains have been investigated that differ in efficacy against weevil larvae, the persistence in soil or potting media, and optimal temperature ranges. Also, the host plant affects the efficacy of the fungus. Control on some plants, such as cyclamen, is lower than on other plants, such as azalea, begonia, impatiens, and kalanchoe. The best control is achieved when the fungus is applied as a soil drench before the eggs hatch. The larvae quickly move down into the soil after hatching and are easily infected when moving through the concentrated spores in the upper layers of the soil. The fungus can also be incorporated into potting media before planting, and may provide better control of weevils on certain plants than a drench will. This fungus is not registered for use in the United States on any greenhouse crops.

Ralph E. Berry, Oregon State University

Nematodes *Heterorhabditis bacteriophora* look like spaghetti inside a black vine weevil larva. The top larva is not infected.



Ray Cloyd

Steinernema carpocapsae nematodes.

Possibilities for effective biological control

Nematodes are an economical and effective method for controlling black vine weevil and strawberry weevil on potted plants in commercial greenhouses. They are very cost effective, readily available, and easy to apply with existing chemical application equipment. Nematodes are as effective as or better than many chemical controls.

To be effective, nematodes must be applied shortly after weevil eggs hatch. Applications made before weevil eggs hatch provide no control. Unfortunately, timing the application is difficult because adults do not begin laying eggs until about a month after they emerge. Egg laying occurs over a 4–6 week period. After that, the eggs take only about 2 weeks to hatch, opening a window of opportunity for biological control. Try applying nematodes 6–8 weeks after your peak weevil catch. Most eggs should have hatched by then.

To apply the nematodes, simply mix the package contents with water, as directed on the package. Occasionally, improper storage or shipment has resulted in non-viable nematodes. After adding the nematodes to water, examine with a magnifying glass to be certain that the nematodes are moving. You can apply nematodes as a soil drench to potted plants. Nematodes can withstand pressures of up to 300 psi, so you can apply them with the same equipment used for chemical pesticides. Application rates of 40,000 nematodes per 6-inch pot and 80,000 nematodes per 8-inch pot caused 100% weevil mortality in experimental trials. Application to the soil surface is suitable for plants with shallow root systems, such as cyclamen. At a rate of 20,000 nematodes per liter (1 quart) of soil, a surface application killed 90% of the beetle larvae in pots. For plants with roots throughout the pot, soil injection would be much more effective, but it is twice as time consuming as surface application.

Nematodes should be applied to moist, but not saturated, soil. This may require watering the area to be treated before application. The soil and water temperature must be above 65°F for the nematodes to be effective. Application in the early evening or morning is recommended to avoid exposing the nematodes to extreme heat and sunlight. It is important to keep the treated pots moist after the application.

It may take 10–30 days for root weevil populations to decline, but control can occur 2–5 days after treatment if the larvae are close to the soil surface. More than one application of nematodes may be necessary if soil conditions are not suitable for nematode persistence—that is, moist and moderately warm.

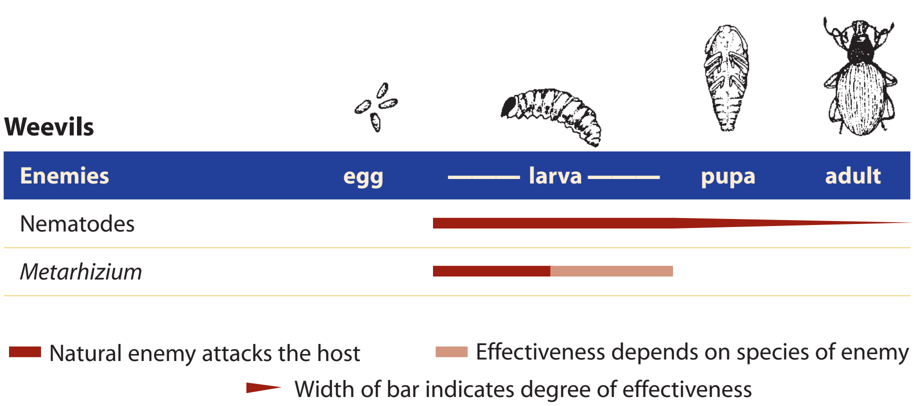
Alternative control methods

Sanitation

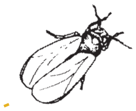
Sterilize soil to kill all stages of the weevil. Eliminate old strawberry beds in the vicinity of greenhouses that serve as breeding places for the adult weevils.

Insect screens

Screen vents and doors to prevent adult weevils from crawling into the greenhouse.



Whiteflies



Available natural enemies and their potential for control

There are a few available parasites of whiteflies. Some predators and pathogens can be used along with the parasites to improve control. The potential for successful biological control varies from moderate to high.

Order Homoptera: Aphids, leafhoppers, planthoppers, mealybugs, scales, and whiteflies

Family Aleyrodidae: Whiteflies

Greenhouse whitefly, *Trialeurodes vaporariorum*

Sweetpotato whitefly, *Bemisia tabaci*

Silverleaf whitefly, *Bemisia argentifolia*

Bandedwing whitefly, *Trialeurodes abutilonea*

Whiteflies infest a wide range of greenhouse crops. The greenhouse whitefly is a tropical species that has become established worldwide in greenhouses. It is a particularly destructive pest of cucumber, tomato, fuchsia, geranium, hibiscus, gerbera, and poinsettia. It attacks hundreds of other vegetable and ornamental crops. The greenhouse whitefly is the most common species found in northern greenhouses. The sweetpotato whitefly, from tropical and warm temperate regions, is also worldwide in distribution and attacks hundreds of ornamental plant species. The silverleaf whitefly, formerly known as the B strain of the sweetpotato whitefly, attacks poinsettia, hibiscus, rose, and other plants. It extracts much more sap than does the sweetpotato whitefly and also causes squash silverleaf, phytotoxemia in poinsettia, and irregular ripening disorders in tomato. Until 1993 the silverleaf whitefly was not distinguished from the sweetpotato whitefly, so much of the literature concerning sweetpotato whitefly may actually refer to silverleaf whitefly. The bandedwing whitefly is less common than the greenhouse, sweetpotato, or silverleaf whiteflies but occurs on many plant species. It commonly enters the greenhouse in late summer and early fall.

Damage

Whiteflies damage plants by removing plant sap and excreting large quantities of honeydew. The clear, sticky honeydew is often seen on the lower leaves. Honeydew serves as a medium for growth of black sooty mold fungus which interferes with photosynthesis and transpiration, and detracts from the beauty and marketability of the crops. Large numbers of adults and nymphs feeding on the leaves cause the leaves to wilt or turn yellow and drop, and may seriously reduce the yield of vegetables.

On ornamentals, whiteflies are pests primarily because their presence reduces the aesthetic value of a plant. Heavy infestations of silverleaf whitefly can cause stem and bract whitening on red poinsettia cultivars.

Whiteflies also act as efficient vectors of several viral diseases. The greenhouse whitefly can transmit the beet pseudo yellow virus to cucumbers, while the sweetpotato whitefly can transmit several viruses such as those causing tomato yellow leaf curl and cucumber vein yellowing.

Description and life cycle

Adult whiteflies are about 1/16 inch (1–3 mm) long and covered with a white, waxy powder. Most species appear very similar, but they can be distinguished from each other. Greenhouse whiteflies hold their wings rather flat over the abdomen. Sweetpotato and silverleaf whiteflies hold their wings roof-like and close to the sides of the abdomen. The bandedwing whitefly has light gray bars across the wings. The adults of all these species congregate on the undersides of leaves, usually at the top of the plant.

Female greenhouse whiteflies lay 6–20 eggs daily, in a perfect circle or a portion of a circle, on the underside of the leaf. The cigar-shaped eggs are deposited as the female moves around in a circle with her mouthparts inserted in the plant as a pivot. Sweetpotato whitefly eggs are laid randomly, in small groups or singly, which makes them more difficult to detect. The eggs are white when first laid but later turn dark brown. They hatch in 7–10 days into mobile first-instar nymphs —"crawlers" that resemble scale crawlers—which search for a suitable place to settle, seldom moving more than 3/4 inch from the eggshell. The next two instars are sessile, translucent green or yellow, rather flat, scale-like, and inconspicuous. The fourth and final instar, often referred to as the pupa (although this species undergoes simple metamorphosis), becomes opaque yellow and mounded.

The nymphs and pupae of many species have distinctive white, waxy spines, but the sweetpotato whitefly has no spines. Greenhouse whitefly pupae are cake-shaped with erect side walls, whereas the sweetpotato and silverleaf whitefly pupae are mounded. In the greenhouse the generations usually overlap completely. Greenhouse whiteflies develop best at moderate temperatures around 75°F, while sweetpotato and silverleaf whiteflies prefer temperatures over 81°F.

Monitoring

Biological control of whiteflies will be difficult unless the infestation is detected early. The greenhouse should be thoroughly inspected for problems before the crop is introduced. Check hanging baskets and weeds under the benches. Begin monitoring susceptible greenhouse crops at planting. Whiteflies are generally not found uniformly throughout a crop at first. They will be concentrated in a few areas and many areas will be without insects. As the population grows, the infested areas expand and multiply.

You should monitor whiteflies in two ways. Use yellow sticky traps to detect the first adult whiteflies and to monitor adult whitefly populations. In addition, visually examine plants to determine the number of immatures present. Yellow sticky traps placed throughout the crop will detect adults at very low levels—one adult for every 10 plants. Traps are commercially available or can be made by the grower. Hang the traps just above the crop canopy to detect greenhouse whitefly. You can place the traps within the crop canopy, or even on the ground or on a greenhouse bench for detecting sweetpotato whitefly, especially in tall crops. Also place traps near doors, air-intake vents, and among newly arriving plants. The number of traps needed depends on the crop, but on average space them 45–60 ft apart (one per 1000 ft^2). Check the traps once or twice weekly. Counting the whiteflies on a 1-inch wide vertical band of either side of the sticky traps gives a good approximation of total trap densities and saves time.

Ray Cloyd

Place yellow sticky traps throughout the crop to detect adult whiteflies.

Sticky traps are useful for detecting the first invasion of whiteflies, and they provide information on the relative abundance of whitefly adults. But many variables, such as trap size and shape, amount of sunlight, and air movement affect trap catches. Do not rely on traps alone to monitor whitefly populations. If adults are detected, eggs and nymphs will be present, and visual plant inspection should be performed.

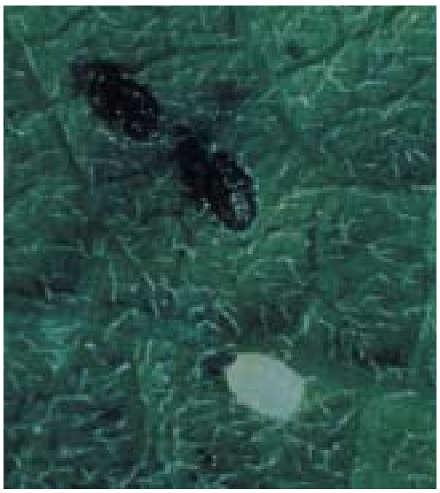
You can see whiteflies most often on relatively new or young tissue. Turn the leaves over to examine the undersides for whiteflies. Adult whiteflies can easily be seen, but a 10X–15X magnifier or hand lens is helpful for observing immature stages. Whitefly populations will vary considerably on different plants and even on different cultivars of the same type of plant. Maintain scouting records of observed pest levels for all plant species and cultivars. Review these records to determine which plants should be monitored more carefully.

On many crops there can be mixed infestations of different species of whiteflies. Determine which species are present before implementing control, as natural enemy efficacy can vary depending on the whitefly species present.

If you are using *Encarsia formosa* wasps for biological control, monitor both the whitefly and the wasp populations. Some adult parasites will also be caught on yellow sticky traps. Learn to recognize the tiny adult wasps and black parasitized nymphs. Record parasitism rates weekly until the whitefly populations are under control, and periodically thereafter. Remove yellow sticky traps before releasing wasps and then put them back up 3–4 days after releases are made.

Natural enemies

Natural enemies of whiteflies include many parasitic wasps, predators, and several species of fungus. Exploration for and evaluation of new natural enemies, including many not mentioned below, continues.



Cliff Sadof

The black whitefly nymphs are parasitized by the encyrtid wasp *Encarsia formosa*; the white nymph is unparasitized.

Parasites

Several tiny parasitic wasps that attack whiteflies have been used successfully for biological control. None of these wasp families or species have common names. Those discussed here are in the families Aphelinidae and Platygastridae. The taxonomy of these wasps is very confused, and the true identify of many species or strains is questionable. The encyrtid *Encarsia formosa* is widely used to control the greenhouse whitefly in greenhouses. Most of the other wasps listed below are not yet commercially available.

Amitus fuscipennis. This Central American platygastrid wasp is less than 1⁄25 inch (1 mm) long. The adults are black with reddish brown legs and antennae, and brown wings. Their larvae parasitize whitefly nymphs, and the adult wasps emerge from the whitefly pupae. The females are very short-lived, but they can parasitize many hosts if they are available during this time. *A. fuscipennis*' effectiveness against greenhouse and sweetpotato whiteflies on poinsettia is being studied. This wasp is produced by a grower cooperative in Colombia but is not commercially available in the United States.

Encarsia formosa. This wasp originated in the semitropical areas of the New World and was one of the first recorded parasites in greenhouses. It has been used since the 1920s to control the greenhouse whitefly in warm greenhouses. *E. formosa* will also parasitize sweetpotato whitefly in greenhouses, but this whitefly is not a good host for this wasp, so control is not as effective. The tiny females, about 1⁄40 inch (0.6 mm) long, are black with a yellow abdomen and opalescent wings. Males are somewhat larger than females, completely black, and extremely rare. The **parthenogenic**—or asexually reproductive—females deposit 50–100 eggs individually inside the bodies of third-instar nymphs or pupae. The wasp larvae develop through four instars in about 2 weeks at optimal temperatures. As the larvae grow they kill the whiteflies. Parasitized pupae of greenhouse whitefly turn black in about 10 days, while the pupae of parasitized sweetpotato whiteflies turn amber brown. Both are easily distinguished from unparasitized pupae. Wasp larvae pupate within the whitefly body. Adults emerge about 10 days later. The adult wasps also kill whitefly nymphs by feeding on them through holes made with the ovipositor. This species is widely available commercially.

Koppert B.V.

Encarsia formosa is a tiny wasp that parasitizes greenhouse whiteflies.

Ray Cloyd

Encarsia formosa larvae have pupated and emerged as adults from these whitefly nymphs.

***Encarsia luteola* (=*E. deserti*).** This species resembles *E. formosa* but is slightly smaller, lighter brown, and males are produced regularly. In the field it is usually found on upper leaves. It will parasitize greenhouse whitefly in the lab, but parasitized nymphs do not turn black. Researchers in southern California and Arizona are evaluating *E. luteola* for control of sweetpotato and silverleaf whitefly. This species is commercially available.

***Encarsia pergandiella* (=*E. bemisiae*=*E. tabacivora*=*E. versicolor*).** This aphelinid wasp, native to North America, parasitizes greenhouse, sweetpotato, and bandedwing whiteflies. The 1/40-inch (0.5-mm) adults are yellow and brown. Over a 2-week period, females lay an average of 50 eggs singly inside whitefly nymphs, preferring second or third instars. Parasitized whitefly nymphs do not turn black. The adults also feed on body fluids of third-instar nymphs and pupae. This wasp develops faster than *E. formosa* under cool conditions. However, its use in greenhouses may be limited because some strains hyperparasitize their own larvae or those of other *Encarsia* species to produce males. This wasp is not available commercially in the United States.

Other *Encarsia* species. Several other species of *Encarsia* have been mentioned as possible biological control agents for whiteflies in greenhouses. The development of these species varies only slightly from that of *E. formosa*. These potentially useful species include

- *E. inaron* (=*E. aleyrodis*=*E. partenopea*), a Mediterranean species that parasitizes the pupae of greenhouse and sweetpotato whitefly;
- *E. lutea* parasitizes sweetpotato whitefly pupae;
- *E. meritoria*, from California, will parasitize bandedwing, greenhouse, and sweetpotato whiteflies but prefers other species, such as the iris whitefly (*Aleyrodes spiraeoides*). Females are golden yellow, and males are brown with yellow heads and legs;
- *E. transvena* (=*E. sublutea*), a tropical species. The lemon-yellow adult females parasitize third-instar nymphs of greenhouse or sweetpotato whiteflies and host feed on second-instar nymphs and pupae, as well as on whitefly honeydew; and
- *E. tricolor*, a European parasite of the greenhouse whitefly that oviposits in pupae, but whose efficiency in greenhouses is lower than that of *E. formosa*. It does not survive above 93°F.

None of these species is commercially available yet.

***Eretmocerus eremicus* (=*californicus*).** This aphelinid wasp, indigenous to desert areas of California and Arizona, is a parasite of greenhouse, bandedwing, silverleaf, and sweetpotato whiteflies. The 1/32-inch (0.75-mm) adult females are lemon-yellow with green eyes. The males are yellow with light-brown markings. Both sexes have very long antennae. Females lay eggs beneath whitefly nymphs of any stage but prefer the second and third instars. They will not lay eggs near whitefly pupae. The first instar wasp larvae feed externally until the host pupates. Then the wasp larvae chew inside the host and complete their development. The adults do not host feed on all species of whitefly, but do host feed on sweetpotato and silverleaf whiteflies on poinsettia. This wasp does not reproduce well on sweetpotato whitefly on poinsettia, but it reproduces very well on the same whitefly on other plants, such as hibiscus. It does best under hot conditions as would be found in late summer in desert valleys (80°–110°F), but its longevity is considerably reduced. At 70°–75°F its development is too slow to control whitefly outbreaks. This species is commercially available.

Koppert B.V.

The female *Eretmocerus eremicus* lays an egg beneath a whitefly nymph.

***Eretmocerus haldemani*.** This is primarily a parasite of sweetpotato and bandedwing whiteflies, although sometimes it will parasitize greenhouse whiteflies. Females are lemon yellow and males are dark yellow with brown markings. Females lay eggs beneath whitefly nymphs. First-instar wasp larvae feed externally for 3–4 days, then enter the whitefly nymph and molt to second instars. The second instars continue development only after the host pupates. Its development is similar to that of *E. eremicus*. It is also most effective under hot conditions. *E. haldemani* is not commercially available.

***Eretmocerus mundus*.** This Mediterranean parasite of sweetpotato whitefly lays eggs under any nymphal whitefly stage, although it prefers second and third instars. The eggs hatch only after the host pupates. The wasp larvae then enter the whitefly bodies and develop. In the field they are usually found on the lower leaves of the plants. *E. mundus* is not commercially available.

Predators

A handful of specialists and many general predators feed on various stages of whiteflies. Only a few have been investigated for their ability to control whiteflies in greenhouses.

***Chrysoperla* (=*Chrysopa*) *carnea*.** The larvae of green lacewings feed primarily on aphids but will also feed on immature whiteflies and other insects in the absence of aphids. They develop more slowly on whiteflies than on aphids and rarely reproduce in greenhouses. Green lacewings are available from many commercial suppliers. (See "Aphids" for a description and life cycle information.)

***Chrysoperla comanche*—Comanche lacewing.** This is another green lacewing species that feeds on aphids and a variety of other insect pests. In the absence of aphids, the larvae feed voraciously on whitefly eggs and nymphs, and will occasionally consume adults. This species is closely related to *C. rufilabris*, but is more adapted to dry conditions. It is commercially available.

Richard Lindquist, The Ohio State University

The tiny black lady beetle *Delphastus pusillus* adult consumes more than 150 whitefly eggs and nymphs per day; larvae eat nearly 1000 eggs during development.

***Chrysoperla rufilabris*.** This species is similar to *C. carnea* in biology and development, but it is better adapted for development under humid conditions than *C. carnea*. This generalist predator is commercially available.

***Delphastus pusillus*.** This small, black lady beetle feeds on bandedwing, greenhouse, silverleaf, and sweetpotato whiteflies. Females are all black, while males have a brown head. The adult females and larvae feed primarily on whitefly eggs but will also eat whitefly nymphs and spider mites. However, they do not reproduce well without whitefly eggs. Females, which can live up to 2 months, consume more than 150 whitefly eggs or nymphs per day. They lay their eggs at the tops of plants near whitefly eggs. The beetle larvae eat nearly 1000 eggs each during their 2-week developmental period. They discriminate between parasitized whitefly nymphs (those in which the parasite has developed for at least a week) and nonparasitized ones, and avoid feeding on the parasitized nymphs. They pupate on the lower leaves, in leaf litter, or in other protected locations. If they pupate in saucers at the bottom of potted plants or other places that hold water, the beetles will drown when the plants are watered. This beetle is commercially available.

Other lady beetles. Larvae and adults of *Coleomegilla maculata* and the convergent lady beetle (*Hippodamia convergens*) have been reported as predators of bandedwing whitefly, feeding on eggs, nymphs, and pupae. *C. maculata*, *Coccinella septempunctata*, *Cycloneda sanguinea*, and several others have been reported as predators of sweetpotato whitefly. None of these is as efficient as the other described predators, and they do not reproduce in greenhouses.

***Dicyphus tamaninii*.** This Mediterranean mirid bug eats a wide range of prey and is an important predator of whiteflies and other insect pests on tomatoes in southern Europe. The bugs prefer whitefly nymphs to other insects, tending to feed on prey on the underside of leaves. When prey is scarce they will feed on tomato fruit but not cucumber fruit. They require approximately 19 days to complete development at 77°F. This bug is not commercially available.

***Geocoris punctipes*.** This 1/16–3/16 inch (2–4 mm) bigeyed bug, endemic to the southwestern United States, is usually dark brown or black. During nymphal development and as adults, they consume numerous aphids, small caterpillars, nymphal and pupal stages of whiteflies, other small insects, and spider mites. Supplementary green plant material and seeds in their diet improves development, reproduction, and survival. Sunflower seeds scattered on plants have enhanced *Geocoris* populations in experimental vegetable crop fields. This bug has not been investigated for use in greenhouses, but is commercially available.

***Macrolophus caliginosus*.** This predatory mirid bug attacks all stages of whitefly, but prefers eggs and nymphs. It will also feed on aphids, and to a lesser extent spider mites, moth eggs, leafminer larvae, and thrips, but populations develop most rapidly on whiteflies. The slender adult bugs are bright green, about 1/4 inch (6 mm) long with long legs and antennae. Females lay 100–250 eggs in leaves and stems, depending on temperature and food. The eggs take about 2 weeks to hatch. The yellowish-green nymphs are found mainly on the underside of leaves where their prey is. Both nymphs and adults actively search for their prey. Adults eat 40–50 whitefly eggs per day. They insert their mouthparts into the whitefly and suck out the contents, leaving only the skin behind. This bug will feed on plant sap, but does not cause damage on most crops. It can cause damage to gerbera flowers, and may reduce tomato fruit set on some cultivars when prey is limited. This predator is commercially available in Europe where it is widely used to control whitefly, thrips, mites, and caterpillars. It is not currently permitted to be imported into North America, although some Canadian suppliers advertise it.

***Orius* spp.** Several species of minute pirate bugs are generalist predators that feed on whiteflies, thrips, spider mites, aphids, and caterpillar eggs, as well as pollen. They are also cannibalistic under crowded conditions. The black, 1/16–3/16 inch (2–5 mm) long adults are ovoid and somewhat flattened, with distinctively patterned black and white wings. Their eggs are laid in leaf tissues with one end sticking out. The tiny *Orius* nymphs are pinkish-yellow to light brown. Both nymphs and adults are very active and feed on all stages of whiteflies. Most species enter diapause under short days and lower temperatures. Several species of *Orius* are available commercially.

Predatory mites. Several phytoseiid mites are known predators of sweetpotato whitefly on cotton in Sudan. *Amblyseius aleyrodis* feeds on whitefly eggs and nymphs, as well as spider mite eggs, pollen, and plant juices. Immature mites require 15–20 whitefly eggs or nymphs for their development and the adults consume up to three eggs or two nymphs daily. *Euseius delhiensis* (=*rubini*), *E. scutalis*, and *Amblyseius swirskii* have also been reported as predators of sweetpotato whitefly eggs. None of these predatory mites has been investigated as whitefly predators in greenhouses, but *E. delhiensis* may be commercially available.

Ray Cloyd

Adult *Orius insidiosus*.

Pathogens

Several fungi kill whiteflies. Most require high humidity for infection and development, so they will be most useful in high-humidity greenhouses. Because they are considered pesticides, they must be approved by the Environmental Protection Agency before they can be sold commercially.

***Aschersonia aleyrodis*.** This fungus, first described on citrus whitefly nymphs in Florida, is highly specific to whitefly nymphs. The older the whitefly nymph, the less likely it is to be infected by this fungus. Infected whitefly nymphs typically have a "fried egg" look, with a yellowish discoloration in the center of the body. Under humid conditions bright orange, slimy spore masses form on the outside of infected nymphs. The first signs of infection, a change in color from normal whitish to yellow, occurs in 24–48 hours. White external mycelial growth begins in 4–6 days, and the orange color develops under the appropriate conditions in 7–9 days. Infection is limited by relative humidity, just like for other fungi. It tolerates a wide range of temperatures (59°–86°F), but does best at 73°–77°F. It does not appear to infect parasitized nymphs and is harmless to adult parasites. It is not commercially available.

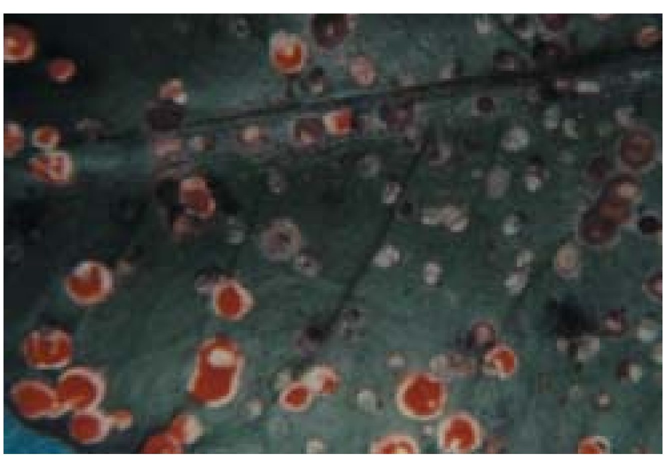
***Beauveria bassiana*.** This fungus infects numerous species of insects, including whiteflies, thrips, and aphids (see "Aphids" for more information). All stages of the whitefly may be infected. Several brands and formulations of *Beauveria* are commercially available for use in greenhouses.

***Metarhizium anisopliae*.** This soil-borne fungus infects over 200 species of insects, including whiteflies and aphids (see "Aphids" for more information). It is not registered for use in the United States on any greenhouse crops.

***Paecilomyces fumosoroseus*.** This fungus infects all stages of whiteflies, as well as thrips and aphids, but it is most effective against whitefly nymphs (see "Aphids" for more information). Subsequent reinfections are not common in greenhouses, so reapplication may be necessary. This fungus is limited by the fact that it requires a relative humidity of around 90% for infection. It has been investigated in several states for use on greenhouse ornamentals and is commercially available in Europe, but is not available in North America.

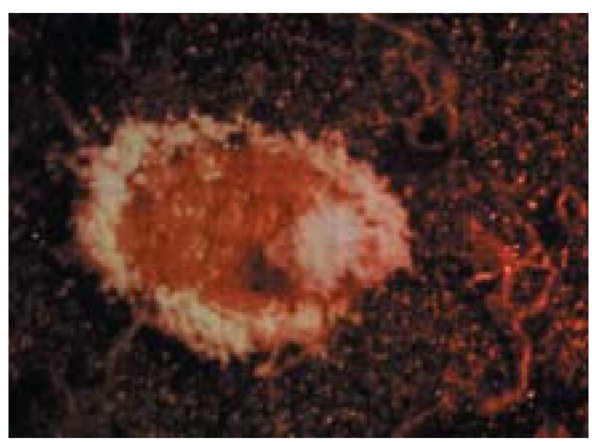
University of Florida

The fungus *Paecilomyces fumosoroseus* consumes its host from the inside out. The powdery spores turn the infected insect white at first, then change to shades of pink.



University of Florida

Whitefly nymphs infected with the fungus *Aschersonia aleyrodis*. In humid conditions bright orange spore masses form on the outside of infected nymphs.



Mike Brownbridge

Spores of the fungus *Beauveria bassiana* on whitefly produce the characteristic "white bloom" appearance.

***Verticillium lecanii*.** This insect-parasitic fungus infects both aphids and whiteflies. The fungal strain with large spores infects aphids; the one with smaller spores infects whiteflies. *V. lecanii* grows and multiplies in the greenhouse at temperatures of 59°–77°F. Fungal spore germination and infection occurs only when the relative humidity is greater than 90% for at least 10 hours per day. The spores germinate and bore through the whitefly, then grow inside it, killing it. The fungus appears as cottony white fluff on infected whiteflies which detracts from the appearance of some ornamentals. The fungus also causes some mortality of whitefly parasites inside the pest's body, but it seems to be compatible with other parasites. A commercial formulation of the fungus specific to whiteflies is available in Europe. *V. lecanii* is not yet registered for use in North America.

Possibilities for effective biological control

Although there are many different strategies for biological control of whiteflies in greenhouses, certain principles apply in most cases. Natural enemies are most effective if introduced when whitefly numbers are low. Biological control often fails if initiated after whitefly populations exceed one adult per 10 upper leaves on vegetable crops and fewer on ornamentals. Biological control usually does not eradicate whiteflies but maintains the pest population at a low density. On many crops, especially poinsettia, there may be a mixed infestation of greenhouse and silverleaf whiteflies. It is important, therefore, to correctly identify the whiteflies in your crop so that the proper rates of the most effective natural enemies can be released. Residual insecticides should not be used within a month of parasite or predator release. If the whitefly population is high, reduce the number of whiteflies with a nonresidual spray, such as insecticidal soap, horticultural oil, natural pyrethrins (*not* synthetic pyrethroids), or insect growth regulators before releasing natural enemies. Natural enemy species introduced alone may provide effective whitefly control in certain situations. However, a combination of parasite releases, predator releases, applications of nonresidual insecticides, and leaf removal are often necessary to produce commercially acceptable crops.

The parasite *Encarsia formosa* is the most widely used insect for biological control of whiteflies. It has been used extensively for many years in commercial vegetable greenhouses throughout the world. It can control whiteflies on vegetable crops, including cucumber and tomatoes, and several ornamental crops, such as poinsettia. On vegetable crops that can tolerate a few whiteflies, such as tomato, a single inoculative release of *Encarsia formosa* may be sufficient for control. However, on most vegetable crops or short-term crops with a much lower tolerance for whiteflies, such as poinsettia cuttings, multiple inundative releases will be necessary. Many other promising natural enemies can be used in conjunction with *Encarsia* wasps.

The best time to introduce *Encarsia* is when the whitefly population is low. Wasp efficiency is seriously impaired when whitefly nymphs are too numerous (30–60 per in^2). The wasps spend more time cleaning the excessive honeydew from themselves than searching for and parasitizing whiteflies. Consult the section on monitoring whiteflies for instructions on estimating whitefly populations.

Encarsia wasps are shipped in the pupal stage, glued to small cards that can be hung directly on the plants. Sometimes the adult *Encarsia* have already emerged, so open the parasite shipment in the greenhouse. Distribute the cards on the plants near whitefly infestations as soon as possible after the shipment arrives. Be sure to distribute the pupae evenly throughout the greenhouse because these very small wasps will disperse only about 6 feet from the release point. Place extra wasps in whitefly hot spots. Save several cards from each shipment to check for the percentage of wasps emerging from the pupal stage; quality can vary between shipments and suppliers.

Greenhouse growers typically introduce *Encarsia* wasps either by inundation or seasonal inoculation. Inundation, in which massive numbers of the parasite are released into the greenhouse at once, is the simplest but can be expensive. The more common method uses successive introductions of smaller numbers of parasites. Make the first release as soon as, or before, the first adult whiteflies are detected, either by visual inspection or on yellow sticky traps. Continue to make regular releases weekly or every other week until 60–80% of the whitefly pupae are parasitized. It is important to know how to recognize adult parasites and their parasitized whitefly pupae. Check the crop every 3–4 days to make sure adult *Encarsia* are present. The first parasitized whitefly pupae should be visible 2–3 weeks after the first release. As a general guide, about 25% of the whitefly pupae should be parasitized within 1 month of the first introduction, 50% after 2 months, and 80% after 3 months. To determine the percentage parasitized, count the number of black (parasitized) and white (nonparasitized) whitefly pupae on the underside of the leaves. Do not count pupae from which adult whiteflies or parasites have emerged.

There is a third, do-it-yourself method for introducing *Encarsia* to the crop—using banker plants. In an area that is separated from the production area, infest young tomato, cucumber, or tobacco plants with whiteflies when the plants have about six leaves. Three weeks later introduce enough *Encarsia* adults to parasitize at least 85% of the whitefly nymphs. Check in 2–3 weeks to be sure that the wasps have parasitized large numbers of pupae. A week or two before introducing the banker plants into the crop, treat the plants with a nonpersistent insecticide, such as pyrethrum, to kill any adult whiteflies.

Place the banker plants uniformly throughout the greenhouse no more than 20 ft apart. This provides a continuous source of parasites emerging over 8–10 weeks that will disperse to whitefly-infested crop plants. When only a few whiteflies are present in the crop, the emerging parasites survive on the whiteflies and honeydew present on the bankers. The banker plants must be established early in the growing season so that a large wasp population, up to 10,000 per plant, has developed by the time whiteflies infest the crop. This may not be practical in large commercial greenhouses.

Whatever your introduction method, be aware that excessive leaf removal can eliminate many parasites when they are about to emerge. Check the leaves for black parasitized pupae. If there are many black pupae that lack exit holes, leave the prunings in the greenhouse for a week or two to allow time for the *Encarsia* to emerge. If there are more white than black whitefly nymphs, discard the prunings. Otherwise, you should remove leaves regularly and frequently so that large numbers of leaves with parasites are not removed all at once.

Recommended release rates vary considerably depending on the whitefly density, the time of year, the crop and its growth stage, and the type of whitefly. Most suppliers provide detailed instructions for the release and use of *Encarsia* and can make recommendations about the number of wasps to release based on specific situations. However, the number of *Encarsia* that actually emerge may be considerably different from the number promised by the insectary. Use quality parasites from reliable insectaries. Large differences from the expected numbers can drastically affect control. Check each parasite shipment for the number of emerging wasps, and adjust release rates as necessary. To check wasp emergence, count exit holes on several cards at initial release and 1 week later. Or, place several cards within airtight containers with transparent lids, place the containers out of direct sunlight, and check the number of adults that emerge after 1 week.

In general, for very low initial infestations of less than one whitefly per plant, release rates of 1.5 parasite per 10 ft^2 are recommended. For higher initial infestations (still less than one whitefly per upper leaf), releases of 3–9 parasites per 10 ft^2 should be made at 10–14 day intervals. For greenhouse tomatoes and peppers, weekly releases of one wasp per every four plants is suggested. For cucumber the rate is one wasp per every two plants, and on poinsettias, two wasps per plant, released weekly. Release rates are better established for vegetable crops than for ornamentals, which have to be virtually pest-free to be marketable. *Encarsia* can provide control comparable to conventional insecticides on many ornamentals, although a final "clean up" treatment with an insecticide may be necessary prior to sale. Initial whitefly infestation on poinsettia usually occurs during plant propagation. For greenhouse whitefly, release one parasite per plant per week on the stock plants to achieve long-term control of a light infestation. Weekly introductions of 50 *Encarsia* per 150 newly potted poinsettia cuttings provide good control of a low infestation of greenhouse whitefly. This rate should also be suitable for fuchsia, gerbera, and other ornamentals. In one trial, four *Encarsia* per ft^2 controlled greenhouse whitefly on gerbera so the plants were only marginally infested at the end of the experiment.

Most of the information on the use of *Encarsia* was obtained against greenhouse whitefly, so modifications may be necessary for control of other whiteflies. *Encarsia* parasitizes sweetpotato and silverleaf whitefly, for example, but not as effectively as it does greenhouse whitefly. On sweetpotato whitefly, *Encarsia* reproduces less, takes longer to mature, and produces lower-quality offspring. The fact that the wasp is produced commercially almost exclusively on greenhouse whitefly may explain these problems. The rearing history of *Encarsia* can affect its acceptance on subsequent hosts. Also, there are different strains of *Encarsia* that vary in their effectiveness against different whitefly species. Double or triple release rates and regular introductions throughout the cropping season may be necessary to compensate for these problems.

The host plant also influences the ability of *Encarsia* to control whiteflies. Large, dense hairs (trichomes) can interfere with parasites searching for prey and reduce its efficiency. Biological control with *Encarsia* may be improved by selecting plant varieties with fewer hairs or none. In one experiment, wasps were able to parasitize 20% more whiteflies on a hairless cucumber than on a normal, hairy cucumber. By contrast, certain host plants are particularly good hosts for whiteflies, making it harder for the wasp to keep up with whitefly populations. On plants such as cucumber and eggplant, whiteflies produce more eggs, develop faster, and live longer than they do on plants such as tomato. Large populations on favorable host plants produce excessive honeydew excretion, which interferes with normal parasite searching behavior. To compensate for the better pest development on highly susceptible plants, introduce more parasites. For example, release rates of 14 wasps per plant are suggested for eggplant, but only five per plant are needed for tomato.

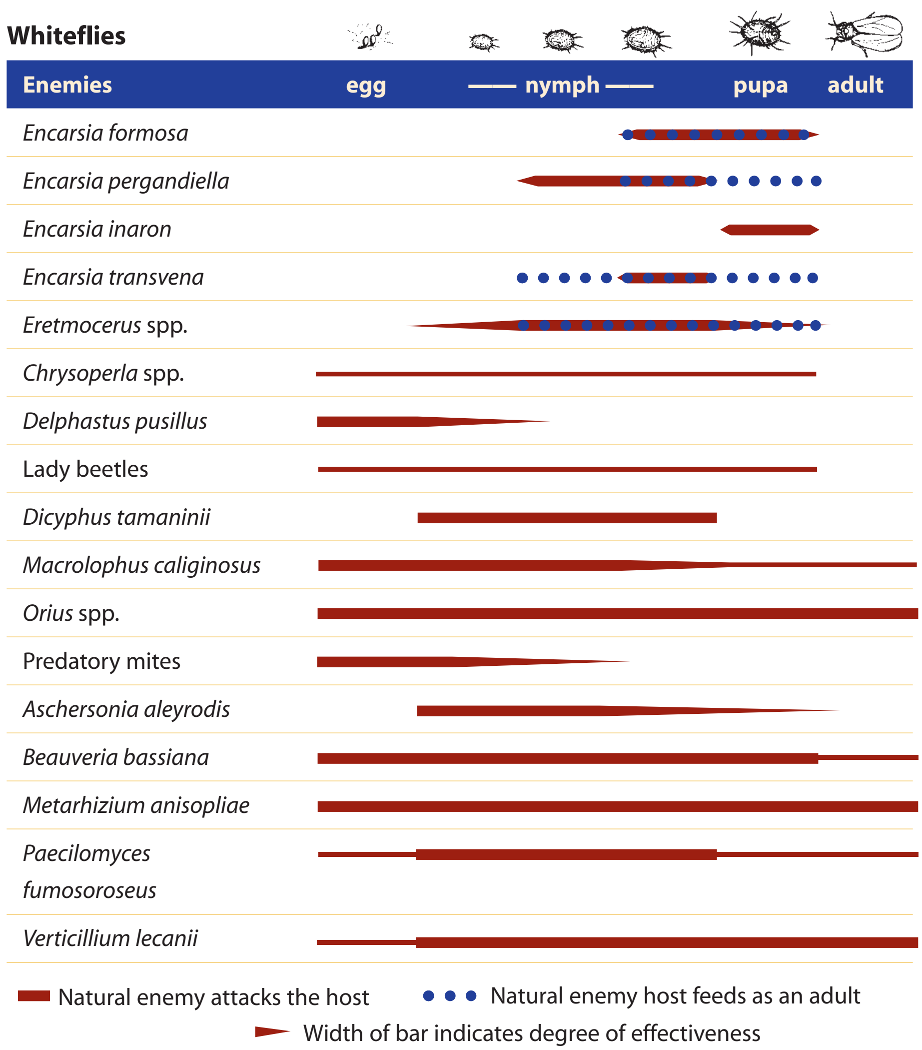
Encarsia wasps fly and lay eggs best in warm (61°–82°F), bright greenhouses. For maximum whitefly control, keep relative humidity at 50–70% and daytime air temperature around 75°F. Low temperatures allow the whitefly to multiply faster than the parasite, resulting in poor control. Cool, cloudy conditions and the low light levels of winter also reduce *Encarsia*'s ability to control whiteflies. Dutch researchers are developing a strain that is more effective at lower temperatures. Under cool conditions, you may need to increase release rates or complement control using other natural enemies or a fungal pathogen such as *Beauveria bassiana*. If you release more wasps, you may also need to decrease the distance between release sites to compensate for slower reproduction and remove adult whiteflies in the tops of plants by vacuuming the upper foliage or by hanging numerous yellow sticky traps or ribbons. Whiteflies are strongly attracted to yellow sticky traps, while the parasites are less attracted—as long as sufficient whitefly nymphs are present. If you find more than 15 whiteflies caught on yellow traps in vegetable crops, consider spraying with a nonresidual insecticide.

Many wasps other than *Encarsia* are also good parasites of whiteflies. *Eretmocerus eremicus* is better than *Encarsia* against silverleaf whitefly because of its greater mobility and ability to attack more nymphs. This species is also less susceptible to pesticides than *Encarsia*. It is often shipped as pupae mixed in a carrier, such as bran or vermiculite. Sprinkle the mixture into leaf axils or around the base of plants. Be sure that ants, which can carry off the pupae, are not present.

Recommended release rates are similar to those for *Encarsia*; release two wasps per 15 ft^2 every 1–2 weeks as a preventative measure. When whitefly infestations are established, a minimum of three weekly introductions at rates of 3–9 wasps per 10 ft^2 (depending on whitefly density) is suggested.

Predators of whiteflies can also be effective in biological control programs. Most of them do not feed exclusively on whiteflies, but these predators will provide control if whiteflies are the predominant pest. The lady beetle *Delphastus pusillus* is the most whitefly-specific predator available, although it will feed on spider mites if no whiteflies are available. It prefers high whitefly numbers, so it is particularly useful for release in whitefly hot spots. It may eradicate whiteflies if the population is not very dispersed. A release rate of seven per 10 ft^2 is suggested.

The mirid *Macrolophus caliginosus* is another good predator of whiteflies, particularly when used in combination with other natural enemies. It remains active at relatively low temperatures, and therefore can successfully supplement control by other species that are active only at higher temperatures. The bugs must be released early in the season because of a slow population build-up. They are supplied as adults and nymphs mixed with vermiculite. The mixture can be shaken directly from the container



onto leaves. Release 5–10 bugs per 10 ft^2 into the first whitefly hot spots on a weekly basis. Continue releasing until populations of *M. caliginosus* reach 0.5–2 per 10 ft^2 throughout the greenhouse (at least 2 months). Do not use this mirid on gerbera because the bug can cause damage to the flowers.

The green lacewings *Chrysoperla carnea*, *C. rufilabris*, and *C. comanche* are most efficient when leaves of adjacent plants touch because the larvae are better able to spread among the plants. Releases of 8–25 *C. rufilabris* larvae per plant controlled sweetpotato whitefly on hibiscus in Texas greenhouses—well enough that all of the plants were marketable. However, lacewing development was not normal, indicating that the whiteflies alone were not an adequate food source. *Orius* spp. also provide some control of whiteflies and other pests.

Many of these predators can be released in conjunction with *E. formosa*. Supplementary releases of green lacewings or the lady beetle *Delphastus pusillus* will control whiteflies on many crops, especially vegetables. These predators may feed on the same instars parasitized by the wasp, but the beetles avoid feeding on whiteflies in the late stages of parasitism. If the beetles are released 2 weeks after the parasite, the wasps should be developed enough that beetles avoid them. Otherwise, you may wish to release these predators only in areas of high whitefly numbers.

The fungus *Beauveria bassiana* has been effective in controlling whiteflies under a wide range of commercial production conditions. The fungus has controlled whitefly on hibiscus, mandevilla, poinsettia, and tropical foliage plants in the greenhouse. It worked as well as or better than the best conventional insecticide programs, even where infestations had reached critical levels. Beneficial insects are not affected unless sprayed directly, so this pathogen could be used in conjunction with *Encarsia*. Unlike parasites, fungi are able to control high whitefly populations. Fungal applications may be useful in reducing whitefly populations before introducing *Encarsia* or in conjunction with the parasite. Under the appropriate conditions, fungi may eliminate the need for insecticides to control whiteflies. However, *B. bassiana* must be used within an IPM framework because all fungi may be killed by certain fungicides used to control plant diseases.

The fungi *Aschersonia aleyrodis, Metarhizium anisopliae, Paecilomyces fumosoroseus*, and *Verticillium lecanii* are promising biological control agents but are not currently available for use in the United States. Whiteflies can be suppressed for several months following a single application of *V. lecanii* if the temperature remains between 59° and 77°F and the humidity is greater than 90% for at least 10 hours per day. This fungus can kill 80–97% of the nymphs, and subsequent infection kills many adults emerging from surviving nymphs. *V. lecanii* is pathogenic to *Encarsia* when applied directly, but whiteflies are even more susceptible, so the fungus and wasp can coexist.

Experimental sprays of *Paecilomyces fumosoroseus* significantly reduced sweet potato whitefly populations on ornamentals (hibiscus, mandevilla, poinsettia, and crossandra) when applied weekly. *P. fumosoroseus* kills sweetpotato whitefly more quickly and with higher mortality than other fungi. Under normal greenhouse conditions infection is detectable 7–10 days after application. However, many of the whiteflies killed by the fungus do not show the typical coloration unless placed in humid conditions to allow sporulation. *P. fumosoroseus* also provides better control than conventional insecticides because it kills all whitefly stages, including adults and eggs, whereas most conventional chemicals do not. It is compatible with *Encarsia*, *Eretmocerus,* and the predator *Delphastus pusillus* and is tolerant of some fungicides.

Aschersonia aleyrodis requires several applications in order to control whiteflies. This fungus is effective mainly against the younger nymphal stages of the whitefly and does not affect *Encarsia formosa*, which oviposits in old nymphs or pupae, so the two are very compatible for use together in greenhouses.

Fungi are applied as spores suspended for spraying in water that contains a wetting agent and other adjuvants. The first diseased whiteflies appear 3–7 days after the spore application, but whitefly numbers do not decline until a week or two after spraying. High humidity is necessary for fungal sporulation and infection. When humidity is low, performance is unpredictable. You can increase humidity by dampening the plants with water sprays (be cautious; this may encourage plant disease). Late afternoon applications reduce spore injury by ultraviolet light and desiccation, since the greenhouse is relatively more humid at night. Humid areas with moderate temperatures, such as rooting benches and shade-cloth covered areas used to induce inflorescence in chrysanthemums, may be the only practical areas for application. Multiple sprays are necessary for *A. aleyrodis, B. bassiana*, and *P. fumosoroseus*, which will not spread in the greenhouse, and for *V. lecanii* if humidity is not high enough to allow continuous infection. These fungi are killed by many fungicides.

Alternative control methods

Sanitation

This is the most important cultural practice for preventing whitefly problems. Remove weeds, hanging baskets, or "pet plants" that serve as alternate hosts for whiteflies from both inside and outside the greenhouse. Whiteflies can easily move from an infested crop to an uninfested one. Be cautious about introducing new plant material into greenhouses. Remove and immediately destroy crop residues after harvest. Wait several days before bringing in new crops after an infested crop has been completely removed from the greenhouse. To starve any remaining adult whiteflies, maintain the greenhouse at production temperatures and free of whitefly hosts during this time. Hang strips of heavy plastic in doorways between ranges to restrict whitefly movement. Rogue out severely infested plants.

Insect screens

Screens on vents and doors will help prevent whiteflies from moving into the greenhouse from plants outside, but often the most effective screens reduce air flow. To counteract air-flow problems, the surface area of intake vents can be expanded by building screen boxes around the vents' openings. Screens must also be cleaned regularly. The maximum hole size to exclude whiteflies is 462 μ.

Repellents

SunSpray 6E Plus horticultural oil showed some repellency against greenhouse whitefly for at least 11 days after treatment on chrysanthemums. Adults landing on treated plants quickly left, so fewer eggs were laid on treated foliage. In another experiment, rooted poinsettia cuttings surrounded by white plastic mulch harbored significantly fewer greenhouse whiteflies than plants with red or black plastic mulch.

Plant selection

Whiteflies prefer certain plant species, listed in the introduction to this section, so if you have a choice, avoid growing these species. Within the same plant species there are also differences in whitefly preference for and survival on distinct cultivars. For example, whiteflies prefer geranium cultivars with larger, less hairy leaves. Poinsettia cultivars with white bracts are often more heavily infested than those with pink or red bracts, but such cultivar preferences are not consistent and may actually be based on plant odor rather than bract or foliage color. Although all poinsettia cultivars are readily infested, whitefly nymph numbers vary consistently among certain cultivars. Some of the cultivars most susceptible to whiteflies are also the most susceptible to infestation by mealybugs and spider mites. Cultivar differences may also affect *Encarsia* performance.

Fertilization

Nutrient inputs can affect pests as well as the plant. Avoid over- or under-fertilizing, as whiteflies may develop better on stressed or lush plants than on normally fertilized plants.

Traps

Yellow sticky traps collect large numbers of whiteflies and on vegetables effectively keep whitefly populations low when used from the beginning of the crop. Canadian experiments suggest one trap per 8–10 tomato plants. In Hungarian greenhouses, *Encarsia* was more effective when introduced after using traps than when used alone.

Whitefly movement within a greenhouse with multiple crops may also be reduced by erecting plastic barriers, perhaps coated with vegetable oil. Such barriers around mature crops during harvest will trap whiteflies when they are disturbed.

Chemical control

Localized infestations and high populations that need to be reduced before predator or parasite introduction should be spot sprayed.

Insecticidal soap can be used to reduce whitefly populations with no residual effects on natural enemies. Soap sprays are most effective against nymphs and adults, but pupae are killed as well. Whitefly eggs are tolerant to soap sprays. Direct application to natural enemies will kill some, but once the soap dries it is nontoxic. Treat shortly before the initial release of parasites or predators. Thorough coverage of infested surfaces and several applications are necessary to suppress whiteflies. Follow label directions to avoid plant damage.

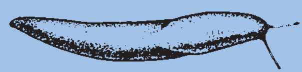
Horticultural oils can kill whiteflies and other insects, but they may be toxic to some plants. Various brands are registered for use on vegetables and ornamentals in greenhouses to control many pests, including whiteflies.

Azadirachtin is the active ingredient in the commercial formulation of extract from seeds of the neem tree (*Azadirachta indica*). Sold under various brand names, this natural compound is an insect growth regulator and repellent that has very low mammalian toxicity. It has provided good control of sweetpotato whitefly when applied at 7-day intervals on poinsettia. It is registered for use on greenhouse vegetables and ornamentals.

Kinoprene is a synthetic insect growth regulator registered for use on ornamentals for control of whiteflies and other insects. It is especially effective as a spot treatment to control local populations. It has minimal effects on natural enemies but may damage some plants.

Miscellaneous pests

Available natural enemies and their potential for control



Few effective natural enemies are available for slugs, symphylans, springtails, and sowbugs. Cultural or other controls can alleviate problems with these minor greenhouse pests.

Slugs

Phylum Mollusca, Class Gastropoda

Order Stylomatophora: Snails and slugs

Family Limacidae: Slugs

Symphylans

Class Symphyla: Symphylans

Family Scutigerellidae: Symphylans

Garden symphylan, *Scutigerella immaculata*

Springtails

Order Collembola: Springtails

Various families

Sowbugs

Class Crustacea: Crustaceans

Order Isopoda: Pillbugs and sowbugs

Family Asellidae: Sowbugs

Slugs, symphylans, springtails, and sowbugs do not occur regularly in greenhouses. They often move into greenhouses from outside during the warmer months and become a problem only when populations are high or when they contaminate plants for sale. In addition to the minor pests listed, numerous other insect and other arthropod pest species may infest greenhouses and cause damage. These four pests are among the most likely to become nuisances on your greenhouse crop.

Slugs

Slugs are not insects but mollusks, a group that includes snails, clams, scallops, oysters, squid, and octopus. Slugs are omnivorous but prefer to eat vegetation, and they thrive in moist places like the humid greenhouse environment. Several species of both native and imported slugs may cause damage in greenhouses on most vegetable and ornamental crops, especially orchids.

Damage

Slugs are nocturnal feeders that eat seedlings or chew holes in succulent leaves, stems, or roots. During the day they hide in dark, damp places beneath benches, pots, or litter on the ground. Like caterpillars, slugs damage plants by rasping away plant tissue when young and by eating irregular holes when older. The slime trails they leave on plants reduce the salability of ornamentals.

Description and life cycle

Slugs range in length from 1/2 to 4 inches (1.3 to 10 cm) and are usually gray or brown. They leave behind a characteristic mucous trail as they move. The **hermaphroditic** adults (individuals have both male and female organs) lay clusters of 20–100 gelatinous eggs in moist soil crevices protected by debris or covered by containers. Eggs hatch in 10 days or less, and the slugs mature in 3 months to a year, depending on the species. Eggs are resistant to desiccation and will persist in the soil for a long time.

Monitoring

Silvery slime trails indicate the presence of slugs. Relative population levels can be determined by counting the number of slugs that are attracted each night to shallow pans of beer placed at ground level or boards placed on moist soil. Growers should determine their own threshold levels for initiating control measures.

Natural enemies

Although there are many parasites, predators, and pathogens of slugs and snails, few have been investigated for commercial control of these pests.

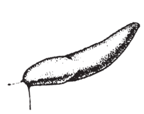
Predators

***Euthycera* spp.** The larvae of several species of flies in the family Sciomyzidae are known to be slug-killers, but none has been investigated for use in greenhouses. The European *Euthycera cribata* lies in wait, poised for attack. When it encounters a slug it rapidly attaches itself with its mouth hooks, climbs onto the prey and enters into the tissues. In a few minutes it disappears almost completely, with only its breathing tube remaining visible. First-instar larvae feed until the slug is dead, then move on to another prey; later instars continue feeding on the slug after it dies. This species has only one generation per year. Two other European species of *Euthycera* also attack slugs. No *Euthycera* species are commercially available.

Rumina decollata. This predatory snail attacks, kills and consumes slugs, common brown snails, and garden snails. It is a burrowing species, normally occurring in the upper inch of the soil. It has a brown, elongated spiral shell tapering to a blunt end. These snails prefer to feed on slugs and organic matter but will eat living vegetation if these foods are not available. It may take a few years for the snails to provide control outdoors. Their use in greenhouses has not been investigated but decollate snails are commercially available. They are legally sold only to residents of certain southern California counties but might be obtained with a letter from your county agricultural commissioner or similar local official stating that possession of the decollate in your county or state is not illegal and that interstate shipments of decollates are permissible.

***Staphylinus* (=*Ocypus*) *olens*.** This European rove beetle, often called the devil's coach horse in England, is a promising predator of slugs and of the brown garden snail in California. Both the $1\frac{1}{4}$-inch (3.2-cm) black adults and the black bristly larvae, which grow to 1 inch (2–2.5 cm) at maturity consume at least their weight in slugs or snail bodies every day. They pupate in earthen cells in the soil. Little research has been conducted on this insect as a biological control agent of slugs and it is not commercially available.

***Tetanocera* spp.** The larvae of the widely distributed species of the sciomyzid fly, *T. elata*, uses fresh slime trails to track slugs and immobilize their prey with a toxic injection. The larvae are host-specific as first-instar larvae, but this selectivity later disappears, and third instars attack many different genera of slugs and even snails. Each larva can kill four to nine slugs during its development. There are two to three generations per year. Three other North American species of *Tetanocera* have the same feeding method. This fly may be commercially available.



Pathogens

Nematodes. The nematodes *Steinernema carpocapsae*, *S. feltiae*, and *Heterorhabditis bacteriophora* will infect, kill and develop in slugs under laboratory conditions. However, other species of nematodes may be more effective for use against slugs. The predatory nematode *Phasmarhabditis* sp. that attacks snails is commercially available in Europe. Research is underway to find slug-parasitic nematodes that could be commercialized in the United States.

Alternative control methods

Sanitation

Keep areas beneath benches dry and clean. Remove plastic, boards, and debris that may serve as hiding places for slugs. Eliminate excess moisture. If empty pots or flats must be stored under benches, stack them on a clean, dry, wooden pallet on their sides, and keep them dry. Gravel under the benches allows for good drainage and is not a suitable habitat for slugs.

Inspect all new plant material carefully before bringing it into the greenhouse. Quarantine any possibly infested shipments to prevent contamination of the entire range.

Barriers

Slugs receive a mild shock when they come in contact with copper, so they usually do not cross copper bands. Tack or staple copper strips or bands to the frames of raised beds or greenhouse benches, or wrap the copper around containers to prevent slugs from moving into the beds. Slugs are less likely to cross gravel than they are moist organic soil, organic mulch, or soil overgrown with vegetation. To capitalize on this, spread gravel around the perimeter of the greenhouse to discourage entry.

Repellents

A repellent called Snailproof, composed of sawdust and shavings of the incense cedar, repels snails and slugs. They do not like to travel over this material but will if it becomes packed down.

Hand picking

Removing all visible slugs by hand will have a noticeable effect on the population, although this method would not be practical on a large scale. Since slugs feed at night, that is the best time to collect them.

Traps

Place shallow pans of beer or rubbing alcohol at ground level in the evening to attract slugs. They fall into the liquid and die. You can also place boards or bricks in damp spots on the soil. The slugs that collect under these can be smashed or killed with hot water. Commercial traps are also available.

Poison baits

A bait that contains an extract of quackgrass, identified previously as a slug-specific molluscicide, was very effective in field tests against the slug *Arion subfuscus*, an important pest species. However, at present no commercial product contains this material.

Metaldehyde or methiocarb pelleted bran baits are commonly used to control slugs, but these baits have several drawbacks. They mold rapidly and must be replaced frequently. Also, some slug populations have developed resistance to metaldehyde. Predatory snails are susceptible to poison baits, so you must quit using baits at least 2 months before releasing predatory snails.

Symphylans

Symphylans are very active arthropods found in damp soils rich in organic matter. They are closely related to centipedes and millipedes, so are not insects. They are often confused with springtails, but symphylans are larger, have more legs, move faster, and do not jump. They tend to be found in moist soils. Symphylans are general feeders and may attack many vegetable and ornamental crops. Garden symphylans injure germinating seeds and seedlings in particular, and they can be a serious problem on African violets when the pots are placed in moist sand or soil on the bench.

Damage

These animals normally feed on algae, fungi, and decaying organic matter in the soil and usually are no more than a nuisance. However, any stage of symphylan may feed on sprouting seeds or plant roots. They prefer to eat root hairs or chew holes in larger roots and crowns. This causes wilting and a blue discoloration, and also encourages infection by disease organisms. Infested plants are stunted and do not respond to fertilization.

Description and life cycle

Symphylans are slender, white or translucent myriapods, 1⁄4–3⁄8 inch (6–8 mm) long with 15 body segments, 12 pairs of legs, and long antennae. Females deposit clusters of up to 20 eggs in the soil. They hatch in about 10 days. At hatching the immatures have only 10 segments and six pairs of legs. Each time the symphylan molts it adds a pair of legs until it has 12 pairs. The immatures reach maturity in 3–6 months under greenhouse conditions, and the adults may live for 4 or more years. Populations increase fastest at about 75°F.

Monitoring

Examine the soil where infestations are suspected. Symphylans tend to run away from the light when disturbed and escape quickly into the soil, so observe carefully. Start control measures when you find 10 or more symphylans on a single root system. Symphylans in greenhouses tend to be more abundant and destructive during the fall and winter.

Natural enemies

Several natural enemies attack garden symphylans, including predatory mites, beetle larvae, centipedes, and diseases, but none has been used effectively in greenhouses.

Predators

***Lamyctes* spp.** These centipedes are small, reddish-brown and asexual. In one experiment, five adult centipedes each in 4-inch pots quickly cut a symphylan population of 40 adults per pot in half, and greatly reduced symphylan injury to the plants. The centipedes do not feed on plants, even in the absence of prey. These and other centipedes, including *Lithobius forficatus* and *L. bilabiatus*, have also been reported as predators of symphylans but are not available commercially.

***Pergamasus quisquiliarum*.** This predaceous mite was observed feeding on symphylans in the field in Corvallis, Oregon. In laboratory experiments each mite consumed an average of seven symphylans during their 12-day development. Each adult female laid an average of 33 eggs and consumed an average of 14 symphylans, although they ate more at higher pest populations. *P. quisquilarum* has not been investigated for use in greenhouses and is not commercially available.

Pathogens

Several pathogens infect garden symphylans and may cause up to 90% mortality under optimal conditions. Neither of the best pathogens—*Entomophthora coronata* and *Metarhizium anisopliae*—has been developed for control of symphylans or other pests in greenhouses.

Nematodes, such as *Steinernema carpocapsae*, will invade and kill active symphylans within 24 hours. Their use in controlling symphylans in greenhouses has not been specifically investigated. (See "Fungus Gnats and Shore Flies" or "Weevils" for more information on nematodes.)

Alternative control methods

Sanitation

Prevent symphylans from entering the greenhouse on the roots of plants or in soil. Symphylans commonly occur outdoors in composted materials, such as manure piles and leaf mold. Steam sterilize this material to kill symphylans and their eggs before using it in the greenhouse.

If possible, grow plants on raised beds to prevent pots from touching the soil. If crops are grown in ground beds, put solid bottoms in the ground beds to permit steam sterilization of the soil mass.

Cultivation

Cultivate in-ground beds thoroughly to disrupt the symphylans' movement through the soil.

Springtails

Springtails are small, jumpy arthropods that are similar to insects. When disturbed, they use a forked structure on the bottom of the abdomen to jump 3⁄4–2 inches. They are common and abundant in the litter layer of natural ecosystems. In greenhouses, a few species cause problems occasionally on seedlings and young plants. They are unlikely to be a problem for plants grown in a soilless medium.

Damage

Springtails feed on decaying matter, algae, and fungi and are normally only a nuisance. Some species, however, will feed on living plants. They chew pinholes in seedlings and young plants or scrape their foliage. Springtails may also feed on roots, causing plants to wilt and increasing susceptibility to plant pathogens.

Description and life cycle

Springtails are small and wingless. They vary in color, but most are white. Females lay up to 120 smooth, spherical, cream-colored eggs in small groups in the soil. The immatures resemble the adults but are smaller. They grow through six to eight instars (depending on the species) in about 1 1⁄2 months and attain sexual maturity before they reach maximum size. Springtails tend to mass together in enormous numbers.

Monitoring

Large populations of springtails may be visible on the soil surface. They can also be detected by floating the soil or submerging potted plants in a bucket of water. The springtails will come out of the soil and be visible on the surface of the water.

Natural enemies

Many natural enemies attack springtails in natural ecosystems. Most are opportunistic general predators, but a few are specific to springtails or have been observed attacking springtails in greenhouses.

Predators

***Hypoaspis* (=*Geolaelaps*) spp.** These tiny mites feed upon small, soil inhabiting insects, mites, and all stages of springtails. They are aggressive predators, consuming 15–30 prey daily, killing more small prey than large prey. *H. miles* and a *Geolaelaps* sp. are offered commercially, although little is known about their ability to control springtails in greenhouses.

Other predators. It is hard for active predators to catch springtails because they jump when they are touched. However, three genera of ground beetles from the Northern Hemisphere (*Loricera, Leistus,* and *Notiophilus*) feed specifically on springtails. Some other arthropods, such as spiders, mites, and pseudoscorpions, are known springtail predators.

A grower in Finland found that numerous *Pardosa amentata* spiders were living on springtails which were very abundant in the peat used as a growing substrate for the lettuce crop in the greenhouse.

None of these predators is commercially available or has been investigated for use in greenhouses.

Pathogens

The nematodes *Steinernema feltiae* (=*Neoaplectana bibionis*) and *Heterorhabditis bacteriophora* (=*heliothidis*) infected one species of springtail in laboratory experiments. Because springtails live in the soil, there is good potential for nematodes to infect them. These nematodes are commercially available. (See "Fungus Gnats and Shore Flies" or "Weevils" for more information on nematodes.)

Alternative control methods

Sanitation

Prevent springtails from entering into the greenhouse on the roots of plants or in soil. Steam sterilize soil to kill springtails and their eggs before using it in the greenhouse.

Sowbugs

Sowbugs are crustaceans, related more closely to crayfish and crabs than to insects. They are common throughout North America, although they came from Europe originally. When disturbed they tend to curl up into a ball. They are mainly scavengers feeding on decaying vegetation, rotting wood, manure, and soil arthropods. Sowbugs also feed on the roots and leaves of plants. They will feed on almost all greenhouse plants, but cause problems especially on orchids.

Damage

Sowbugs are nocturnal feeders that hide during the day under pots and debris, in damp, sheltered places. They collect in pots or beds and feed on the fibrous roots of plants. Their feeding may retard plant growth. Sowbugs also may chew through the stems of seedlings at or below soil level, and they occasionally chew holes in foliage.

Description and life cycle

Sowbugs are gray, oval, flat crustaceans about 1/2 inch (14 mm) long. The body is covered with a series of overlapping armored plates, and seven pairs of legs attach to the underside. Females carry broods of 25–75 in a pouch on the abdomen for 1–2 months. The young are released from the maternal brood pouch about 7 days after the eggs hatch. The young, which are similar to the adults in appearance, take about a year to reach maturity. They may live several years and several generations may occur each year in greenhouses.

Monitoring

Observe sowbugs at night or trap them to determine relative population levels. See "Alternative Control Methods" below for trapping instructions.

Natural enemies

The sowbugs' heavy exoskeleton protects them from natural enemies. Only a few carabid beetles are known predators of sowbugs, and a few species of tachinid flies have been found to parasitize these isopods in the United States. But no parasites, predators, or pathogens have been used to control sowbugs outdoors or in greenhouses. Desiccation seems to be the most important cause of death for outdoor populations.

Nematodes, such as *Steinernema* spp. and *Heterorhabditis* spp., will infect and kill sowbugs in laboratory experiments. Because sowbugs live in the soil, nematodes may be able to control them. However, most nematodes prefer insects to sowbugs because the body disintegrates quickly, restricting nematode development. Several species of nematodes that may infect sowbugs are commercially available.

Alternative control methods

Sanitation

Use sterile soil and take precautions to prevent sowbugs from being introduced into the greenhouse. For example, check pots brought in from outside. Also, remove objects that can serve as hiding places for sowbugs during the day.

Traps

Scatter wood or bark chips on the soil surface to provide hiding places for the sowbugs. For traps you might also use inverted, hollowed potato halves or damp pots left on the ground. The sowbugs will collect under these traps, then you can crush them or kill them with hot water.

Baits

Sowbugs are attracted to sweet baits, such as brown sugar bait and bran baits. Brown sugar bait is simply brown sugar mixed with an insecticide. An old recipe for making a bran bait requires moistening 12 pounds of bran with a mixture of 2 pints molasses, 1 ounce banana oil (amyl acetate), and an insecticide, then placing all these ingredients in a gallon of water.

Chemical control

Pyrethrum dusts or diatomaceous earth applied to beds, walkways, and other surfaces may be effective against sowbugs.

Possibilities for effective biological control

Most of these miscellaneous pest do not offer many possibilities for biological control. Although some natural enemies have been identified, none has been researched for implementation in greenhouses and most are not commercially available. Sanitation and other cultural controls are probably the best methods for dealing with these pests.

Where allowed, predatory snails might be used for the control of slugs. These molluscs have provided very effective biological control of brown garden snail outdoors in southern California, but their use in greenhouses has not been explored. Because they will feed on living plants in the absence of slugs or organic matter, they may not be a good choice for use in greenhouses.

The general mite predator *Hypoaspis miles*, discussed in "Fungus Gnats and Shore Flies," feeds on many soil-dwelling pests and might provide some control of springtails or symphylans.

Nematodes are often effective for the control of pests in soil and have potential for controlling symphylans, springtails, and sowbugs. Nematodes have not been investigated specifically for controlling these pests in greenhouses, so directions for their use and suggested application rates have not been developed.

SECTION

3

Overview of biological control of greenhouse pests

Contemporary biological control

Biological control of insects and mites in greenhouse crops began in England during the late 1920s when *Encarsia formosa* was used to control greenhouse whitefly on tomatoes. The use of *Encarsia* stopped, however, after the development of synthetic organic pesticides in the 1940s. Using natural enemies for pest control in greenhouses became popular again in the 1960s when twospotted spider mite populations in European greenhouses became resistant to many pesticides and devastated cucumber crops. Growers introduced predatory mites to control the spider mites, and because pesticide use had to be limited, *Encarsia* was again utilized for whitefly control on cucumbers and tomatoes. Researchers developed most of the early techniques necessary for biological control in greenhouses at the Glasshouse Crops Research Institute in Littlehampton, England and the Research Station for Vegetables and Fruit Under Glass in Naaldwijk, The Netherlands. Today, researchers in North America also play an important role in developing and implementing biological control strategies for greenhouse production.

Increasingly, greenhouse growers around the world are replacing pesticides with biologically based controls. Why? Biological control offers a way to control pests that are resistant to insecticides, may reduce the cost of insect control, often achieves better control of the pests, and usually increases yields by eliminating the subtle deleterious effects of repeated applications of chemicals. In addition, public demand for pesticide-free produce is growing and governmental regulation is reducing the options for agricultural pesticides. Pesticides are still the main means of insect control in most U.S. greenhouses, but the loss of effective chemicals through regulation, increasing pest resistance, and the escalating cost of developing new pesticides is encouraging greater adoption of biological control methods.

Integrated pest management is now used in many European and Canadian commercial vegetable greenhouses. Biological control has been very successful on vegetable crops, such as tomatoes and cucumbers, because these crops can tolerate some insect or mite damage without affecting yield. Vegetable growers also use biological control because it is easier to maintain harvest schedules without pesticide re-entry restrictions. Bumble bees can be used for more cost-effective pollination when pesticides are not used, and produce without pesticide residues may be more marketable or sold for higher prices.

However, certain obstacles must be overcome for the continued adoption of biological control in greenhouses. The greenhouse industry is shifting from seasonal production to nearly year-round production in the same greenhouses. This may influence the effectiveness of biological control. There is no longer a host-free period in which pests starve to death, so newly introduced plant material may become infested almost immediately. Natural enemies may move from one crop to the next along with the pests, but there will likely be a lag time and hence some damage to the new crop. Worse, some of the available natural enemies enter diapause under winter greenhouse conditions—short days and cooler nights—and will not provide adequate control during this time. To prevent natural enemies from entering diapause, you can increase night temperatures or extend daylength by using artificial lighting. Increasing release rates, using nondiapausing natural enemies or integrating selective pesticides can also help to control pests during this period.

Biological control may not be practical in the production of certain ornamental plants or in multicropping. On ornamentals the presence of any insects or mites, whether pests or natural enemies, reduces the aesthetic value and salability of a plant. An IPM or biological control program on ornamentals must be modified to eliminate both the pests and the natural enemies prior to sale. In addition, since the entire ornamental plant is often sold, it can tolerate very little vegetative damage. Control measures must reduce pest populations before they damage the marketable portion of the crop. But there is usually a delay between natural enemy introduction and the reduction of pest populations, during which plant damage can occur. Effective commercial natural enemies may not be available and specific recommendations may not be developed for biological control of certain pests on many ornamentals. Multicropping in the same greenhouse also presents a challenge: maintaining biological control on several different plant species simultaneously. Certain plant production programs, or crop mixes within a greenhouse, may prohibit or severely restrict biological control.

Among the biggest obstacles to the implementation of biological control in greenhouses are the negative attitudes of some growers or the unrealistic expectations of others. Many growers are unwilling to invest adequate time to learn how to succeed with biological control. It takes a fair amount of time and effort to convert from reliance on pesticides to using natural enemies. Every situation is unique, and specific protocols must be developed for each greenhouse if biological control is to be effective. Experimentation may be required to adapt recommended release rates and timing to each situation. Sometimes growers' first attempts to implement biological control fail. But these failures often lead to a greater understanding of how to utilize natural enemies successfully—if the grower sticks to it.

Some growers believe that pesticides are the only way to provide sufficient control for high plant quality. Certainly there are excellent pesticides and application methods that can sometimes provide virtually pest-free plants. However, even ornamental crops produced under conventional chemical control—particularly those seen in mass-marketing outlets—are not pest-free. Biological control can be used during at least a portion of the production of many ornamental plants to produce plants that are equal to those produced with chemical pesticides. Pesticides may be necessary just for the final clean-up.

Some of the best candidates of floricultural crops for biological control are rose, alstroemeria, chrysanthemum and gerbera for fresh cut-flowers, plus poinsettia and numerous foliage plants. These plants are attacked by a limited number of pest species or can tolerate some pest injury, although aphids and thrips can be difficult to control in floricultural crops. Biological control is most likely to succeed on cut flowers, such as chrysanthemums or gerbera daisies, because only the top portion of the plant or flower stalk is harvested. About the top 32 inches of the chrysanthemum plant is marketed and the bottom 5–16 inches of each stem is stripped of all leaves. Damage to the lower portion of the plant when young (the first 4–6 weeks of plant growth) does not affect the marketable portion when harvested. With gerbera daisies grown for cut flowers, only flower stalks that totally lack foliage are harvested.

Even for crops where biological control of foliage and flower pests is difficult, there exist excellent opportunities for biological control of soil pests such as fungus gnat larvae.

Permanent plant collections, such as conservatories for public display or horticultural greenhouses for research or educational purposes, are also excellent places for implementing biological control. Marketability of conservatory plants is not a factor, so tolerance for injury may be higher.

Biological control in the hobby greenhouse

A great diversity of plants are grown in hobby greenhouses, and these plants are equally as susceptible to pest attack as crops in commercial greenhouses. Often, the pest species present in commercial and hobby greenhouses are the same. Many of these are general feeders, such as greenhouse whitefly, aphids, mealybugs, and twospotted spider mite. The natural enemies that are commercially available can be used in the hobby greenhouse, often quite successfully.

However, the hobby greenhouse may present some logistical problems when biological control is attempted. Many natural enemies require protection from heat, intense light, and low humidity. The small hobby greenhouse may not have sophisticated environmental controls found in commercial greenhouses, and therefore natural enemies may experience unfavorable or even lethal conditions. At the extreme are hobby greenhouses that are set up specifically for growing cacti and succulent plants; these may have a lower humidity and higher light intensity, and possibly higher temperatures than are tolerated by many natural enemies. Under such conditions, certain natural enemies may not be reliably effective and other controls may be necessary. Smaller greenhouses also may not provide the diversity of habitats and nutritional resources (such as nectar and pollen) necessary to maintain natural enemies over an extended time period; therefore more frequent releases may be necessary to achieve effective control.

The collection of plant species grown in a hobby greenhouse might be very specialized, such as orchids, cactus, or palms, or a bit more generalized, such as tropicals from a variety of plant families, or very eclectic, including both ornamental and food plants. Some hobby greenhouses are used primarily to start bedding or vegetable plants to be set out into the garden in spring. The nature of the plant collection may impact the success of biological control. More specialized pests may occur in specialized plant collections, and these pests may not have been researched for their biological control potential, or appropriate natural enemies may not be commercially available. Therefore, some pests may require other approaches that can vary from hand removal to the use of conventional pesticides. As with pests in any crop or situation, the first step in determining control options is to correctly identify the pest. Your local county or state university Extension service should be able to help in this regard. Once the pest is identified, contact a commercial natural enemy supplier to determine the availability of effective natural enemies. Keep in mind that for certain more obscure pests, even though specialized natural enemies may not be available, generalist natural enemies such as lacewings, pirate bugs, or insect pathogens may provide some control.

Another potential problem with small greenhouses is that occasionally it may be necessary to control a pest species for which there are no acceptably effective natural enemies. For some pests, the only alternative may be a broad-spectrum house plant insecticide available from the local garden store. If you are using biological controls, use such insecticides as carefully as possible because they will also harm the natural enemies. If possible, remove those plants that need to be treated from the greenhouse and don't return them to the greenhouse for a few days after treatment to allow residues to dissipate. If it is not possible to remove plants for treatment, try to leave protected refuges for natural enemies by treating only those plants that are infested. Even using this approach, it may be necessary to make new natural enemy releases starting a few weeks after the pesticide application.

As with all types of biological control, no easy recipes exist for success in the hobby greenhouse. However, there are often many useful natural enemies available for release, and the level of success can be high. The best way to determine the potential for success in your own greenhouse is to learn about the options, discuss possibilities with commercial natural enemy suppliers, and give it a try.

Integration of biological control of all pests: Examples

Tomatoes

The production of fresh-market tomatoes poses a considerable challenge to greenhouse producers interested in using biological control because of the industry's high cosmetic standards. Whiteflies are the worst pest for many growers. They reduce fruit size and coat fruit with honeydew, which serves as a medium for the growth of black sooty mold fungus. At present, the greenhouse whitefly is the most commonly encountered problem on tomatoes in many northern and central U.S. greenhouses. Sweetpotato whitefly is not found frequently.

Dribble (inoculative) releases of the parasitic wasp *Encarsia formosa* have been used successfully by many tomato growers to control greenhouse whitefly. This regular release of small numbers of wasps throughout the growing season allows natural enemy populations to build before whiteflies get out of control. The success of this method is partly due to the fact that growers are starting plants in winter when greenhouses are closed. This allows an extended period of plant growth prior to the entrance of pests from outdoors during spring and summer. However, this requires the use of transplants that are completely free of whiteflies.

The intensive labor associated with pruning plants provides growers with frequent opportunities to monitor for pests before they become widespread. When small infestations of other pests such as aphids and spider mites are found, they can be controlled by either physically removing the pests, or by spot-spraying pesticides with low residual toxicity then releasing their natural enemies.

Disease problems such as leaf mold and Botrytis blights can occur under humid greenhouse conditions. These can be controlled by increasing air movement and by applying a fungicide that does not kill *Encarsia* wasps. Smoke formulations of chlorothalonil have been used with some success.

Greenhouse tomato producers who have used biological control enjoy more than just the benefits of high-quality produce. They reduce their labor greatly by employing bumble bees rather than human workers to pollinate the tomatoes. In the absence of pesticide residues, colonies of *Bombus impatiens* and *B. occidentalis* can survive in greenhouses and pollinate tomato flowers. Instructions for their use vary by region and are available from some suppliers of *Encarsia*.

Chrysanthemum

Management of greenhouse cut and potted chrysanthemums is most successful when the specific standards for each of these crops is considered. Cut chrysanthemums are managed to produce flowers, whereas potted chrysanthemums are managed for both the foliage and flowers. Consequently, managers of cut chrysanthemums are primarily concerned with insects such as western flower thrips that damage flower buds and open flowers. Insects that feed on flowers reduce the crop quality directly through feeding, or indirectly, by opening wounds that allow disease organisms, such as *Botrytis*, to enter. In contrast, managers of potted chrysanthemums need to protect the foliage and flowers. Insects can damage foliage directly by removing tissue, as caterpillars do, by distorting their shape, as thrips do, or by discoloring them, as leafminers and thrips do. Indirect damage to foliage occurs when sucking insects, such as aphids and whiteflies, cover foliage with honeydew that fosters growth of black sooty mold.

Biological control of chrysanthemum pests will be most successful when combined with proper cultural practices, a regular monitoring and record-

keeping program, and early releases of natural enemies. You can reduce the flow of new pests into the greenhouse by purchasing quality chrysanthemum cuttings from reputable suppliers that have been checked for insects. Removal of weeds, plant debris, and old blooms is critical, because these act as reservoirs for insects, which can migrate onto the main crop. Screens on greenhouse side vents, ridge vents, and side walls prevent migrating insects from entering the greenhouse in the summer.

Monitoring techniques should be implemented along with biological control. Growers must inspect both flowers and foliage weekly to determine the numbers of pests and natural enemies. In addition, yellow sticky traps should be examined on a weekly basis. When recording the number of pests and natural enemies, be sure to note the temperature, month, time of day, numbers caught per sticky trap, and location of plants and traps.

All the major insect pests of cut and potted chrysanthemums, including aphids, caterpillars, leafminers, western flower thrips, fungus gnats, and whiteflies, can be controlled by a variety of natural enemies described in earlier chapters. The application of natural enemies in cut and potted chrysanthemum production should follow an inoculative release program. This involves periodic releases before pest populations build up. Order natural enemies from a reliable supplier at least 3 weeks in advance of the date when pests have appeared in previous years. Release the natural enemies when insect pests are first detected. To control leafminers on chrysanthemum, for example, make early and weekly releases of the parasite Diglyphus isaea. This improves the chances of delivering sufficient live natural enemies to the crop at the appropriate time. Late releases are ineffective.

Poinsettia

Many growers are interested in integrating biological control into their poinsettia IPM program. The primary insect pests of poinsettia are greenhouse whiteflies, sweetpotato whiteflies, silverleaf whiteflies and fungus gnats. Whiteflies are pests primarily because their presence diminishes the appearance of the plant. Fungus gnats are nuisance pests as adults, but the larvae can damage the roots of the plant directly and are capable of transmitting certain plant pathogens. Both whiteflies and fungus gnats can be managed with biological control.

Successful whitefly biological control programs are built on a foundation of sanitation, regular monitoring, and early releases of natural enemies. The natural enemy used most commonly to control whiteflies is the parasitic wasp *Encarsia formosa*. Another whitefly parasite, *Eretmocerus eremicus*, which is available commercially, may be more useful than *E. formosa* against silverleaf whitefly. Fungal pathogens, such as *Beauveria bassiana*, can also be used for whitefly control. Growers must rely primarily on releases of these or other natural enemies for control, and use insecticides only as a back-up. A typical spray program for whiteflies and fungus gnats will not be compatible with predators or parasites. Plan an initial small-scale trial for the first season to gain familiarity with the natural enemies before implementing biological control on a large scale.

A good pest monitoring routine will detect potential problems before they develop into severe problems. Establish and test a monitoring program for at least one poinsettia crop before beginning your biological control program. Once you start the biological control program, keep track of what your parasites are doing. For example, record numbers of adult parasites and dead and parasitized whitefly nymphs on the plants in the scouting reports.

Begin biological control with a clean greenhouse planted only with poinsettia. The greenhouse should be inspected for sources of whiteflies well before the poinsettias are introduced. Any other plants, including weeds or hanging baskets, should be eliminated. Inspect the incoming cuttings for whitefly adults and nymphs. If necessary, reduce whitefly numbers with pesticides that do not leave a residue that is harmful to the natural enemies. Parasites and predators will not be able to control whiteflies adequately if the initial infestation is too severe.

Release one to five *Encarsia formosa* per plant per week beginning soon after planting the crop. Hang the cards containing parasite pupae on foliage near the base of the plant canopy but not on the soil, distributing the cards evenly throughout the greenhouse. When hot spots of whiteflies are detected during routine monitoring, be prepared to release the predatory beetle *Delphastus pusillus* or spot treat with compatible insecticides.

Fungus gnats can be controlled easily with natural enemies. If released at the start of the crop, the soil-dwelling, predaceous mite *Hypoaspis miles* can become established in the growing media and provide season-long larval control. Drenches of *Bacillus thuringiensis* var. *israelensis* (Gnatrol) can be applied for additional larval control, and entomogenous nematodes are also available.

Many growers report successful use of biological control on their stock plants and on the blooming crop until late October, when smokes and aerosols are used for final clean-up. These growers often comment that plants in biological control greenhouses look healthier and more attractive than those in regularly sprayed greenhouses.

Summary

Biological control can be a highly effective means of managing many of the pests that attack greenhouse crops, although biological management programs have not been developed yet for all crops. Biological control is not based on recipes containing set responses to particular pest problems. Many variables contribute to the effectiveness of biological control, and every greenhouse presents a unique combination of these variables. Therefore, growers must become familiar with the specific conditions of their operations. What problems have occurred in the past? How much damage can be tolerated before the market value of the crop begins to drop? Are natural enemies commercially available for controlling the pests? These are just a few of the questions to consider as you plan your biological control system. Consider all the options and evaluate whether they are compatible with each other and with your chosen control practices. The best approach may be to coordinate several control methods rather than relying on a single solution.

Additional reading

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Considerations when ordering and using commercially available natural enemies for biological control

Before ordering

- Know the specific pests that you need to control. Identifying the pest as simply "whitefly" or "aphid" is not sufficient because different species of these pests require different natural enemies.
- Determine the general level of infestation. If it is very high, it may be necessary to use other methods to reduce the pest population to allow biological control a better chance to be effective.
- Know the best natural enemies available for the specific pests. In some cases, combinations of natural enemies may work better than individual species.
- Know the proper timing of release of natural enemies, based on the life cycles of both the pest and the predator or parasite. Often in greenhouses there may be overlapping and continuous generations of the pest, resulting in the presence of the susceptible stage in its life cycle at all times.
- Know the proper release rate for each natural enemy.
- Calculate the amount of natural enemies needed, based on the release rate, the level of infestation, and the area to be covered.
- If multiple releases are necessary, know the recommended frequency of release. A program of multiple shipments can be arranged with a call to your supplier.
- Provide your supplier with a safe delivery address, where the shipment will be cared for as soon as it arrives and where it will not be exposed to temperature extremes.
- Understand proper release practices so that you will be prepared to make the release as soon as the shipment arrives.
- Know proper storage conditions in case release can not be made immediately after arrival.
- Be sure all greenhouse vents are adequately screened to prevent escape of the released natural enemies (important for most insects, but not for predatory mites).
- Do not apply broad-spectrum insecticides for at least 2-3 weeks prior to an intended release of natural enemies.
- If you have questions about any of these matters, be sure to discuss them with your supplier. If you are just starting a biological control program, contact several suppliers initially and pick one that seems competent and professional in dealing with your specific pest problems.

When the shipment arrives

- Minimize exposure to hot or cold temperatures.
- Inspect the shipping container and contents for damage.
- Determine if you received the species and quantities you ordered.
- Attempt to assess the condition of the natural enemies. This is easier to do with larger insects shipped in mobile stages than with very tiny insects or mites, or with insects shipped as inactive eggs or pupae. Mobile natural enemies should not be stressed. It's not unusual for a few to die during shipping, but most should be in good condition.
- Make release as soon as possible after receipt.
- Store under proper conditions if it is necessary to delay release. In many cases, predatory and parasitic insects can be stored only a few days before they start to lose vigor and effectiveness.
- Make releases based upon recommendations of your supplier. Releases should generally be made during a cooler part of the day.
- As you are making releases, check once again for quality characteristics.

After release

- Check during the following few days to see if the natural enemies appear to be active and searching for the pests.
- Attempt to evaluate the impact by monitoring changes in the pest population and by checking for evidence of predation or parasitism (such as mummified aphids or parasite cocoons).
- Keep records of your releases and their results. Biological control programs sometimes need modification and adjustment and your previous records will be essential in this process.

Glossary

Abiotic control. Those natural environmental factors that help control the numbers of a pest population that do not involve living organisms or life processes. Weather events that kill many insects, such as severely cold winters and heavy rains, are good examples of abiotic controls.

Action threshold. A level of pest population at which controls should be applied to prevent economic damage to the crop. See also economic injury level (EIL); economic threshold (ET).

Augmentation of natural enemies. One of the three general approaches to biological control. It is the periodic release of captured or commercially produced natural enemies to supplement those that occur naturally; it increases the effectiveness of biological control. Also called augmentative biological control. See also inoculation; inundation.

Banker plant. An alternate host plant used to raise hosts and natural enemies in large numbers in a greenhouse for later movement into the crop.

Biological control. The management of pest populations by the purposeful manipulation of beneficial organisms called natural enemies. See also augmentation of natural enemies; conservation of natural enemies; importation of natural enemies; natural enemies.

Cocoon. A silken case formed by an insect larva as protection for pupation.

Complete metamorphosis. Type of insect development in which the insect passes through a pupal stage before becoming an adult.

Conservation of natural enemies. One of the three general approaches to biological control. It is the provision of food, shelter, and other needs for natural enemies, and the avoidance of practices that kill natural enemies or interfere with their beneficial activities, such as the use of broad-spectrum insecticides.

Cosmopolitan. Occurring throughout most of the world.

Diapause. A period of prolonged inactivity in insects.

Economic injury level (EIL). The population level at which pests cause economic damage if left untreated.

Economic threshold (ET). The pest population level at which control measures should be initiated to prevent the population from exceeding the economic injury level (EIL).

Ectoparasite. A parasite that feeds and develops on the outside of its host.

Endoparasite. A parasite that feeds and develops inside its host.

Entomopathogenic. Capable of causing disease in insects.

Exoskeleton. The external skeleton of an insect, composed of hard cuticle (the "skin").

Facultative. Organisms that normally are free-living but have the ability to adapt to a parasitic or semi-parasitic mode of life.

Frass. Fecal material and food fragments produced by an insect in feeding.

Gregarious parasite. A species in which numerous immature individuals develop within a single host.

Hermaphroditic. Having both male and female reproductive organs; the nature of an individual possessing both ovaries and testes.

Host-feeding. A form of predation. Many adult parasitic wasps feed from the same types of hosts as they deposit eggs in. Although such wasps are usually described as parasites or parasitoids, these terms properly refer to the feeding method of the larval stage. The adult wasps may also be beneficial by preying on other individuals of the same species used as hosts for their offspring.

Hyperparasite. A parasite whose host is another parasite.

Importation of natural enemies. One of the three general approaches to biological control. Undertaken primarily by the U.S. Department of Agriculture, universities, and state departments of agriculture, importation involves seeking natural enemies in the native home of the pest, and introducing and permanently establishing these natural enemies in the pest's present habitat. This approximates permanent natural control.

Inoculation. A preventive method of augmentative biological control in which relatively small numbers of natural enemies are released periodically for sustained management of the pest population below damaging levels. Also called inoculative release. See also augmentation of natural enemies; inundation.

Insectary. A facility for rearing insects. The term is often used in biological control for companies that mass-produce beneficial predators and parasitic insects for release in augmentative biological control.

Instar. The stage of an insect between successive molts.

Integrated pest management (IPM). The use of all available and appropriate methods to control pest populations in an effective, economic, and environmentally sound manner.

Inundation. A curative method of natural enemy augmentation that uses large-scale releases of natural enemies for the immediate reduction of pest populations that are at or near damaging levels. Also called inundative release. See also augmentation of natural enemies; inoculation.

Larva (larvae). The immature form of an insect that undergoes complete metamorphosis; the stage between the egg and pupa. Compare with nymph.

Microbial insecticide. A commercial preparation of living microorganisms (such as bacteria, viruses, or fungi) that are pathogenic to specific groups of insects. These preparations can be mixed with water and applied with conventional pesticide-application equipment. Microbial insecticides are regulated as pesticides by the Environmental Protection Agency, so users must follow specific labeling and use guidelines.

Molt. The process of shedding the skin between developmental stages (instars).

Natural enemy. A beneficial organism that kills or interferes with pests. These are the biological components of natural control; when manipulated by people they are the essential components of biological control. The natural enemies of insect pests include predators (such as predatory insects), parasitic insects, and microorganisms that cause insect diseases.

Nymph. The immature form of an insect that undergoes simple metamorphosis. Between hatching and the winged adult stage. Compare with larva.

Oviposit. To lay or deposit eggs.

Ovipositor. The egg-laying structure of a female insect.

Parasite. An organism that derives its food from the body of another organism (the host). A parasitic insect spends its immature stages in or on the body of a host, which dies just before the parasite pupates. See parasitoid.

Parasitoid. An insect that parasitizes and kills other insects. Many biological control workers prefer this term over parasite, which more properly refers to those types of organisms, such as fleas and lice, that do not kill their hosts.

Parthenogenesis. Egg maturation without fertilization. In some insects, offspring are commonly produced without the need of egg fertilization. This commonly occurs in the parasitic wasps and their relatives, where female offspring are derived from fertilized eggs and male offspring are derived from unfertilized eggs.

Pathogen. An organism capable of causing disease.

Pest resurgence. A pest outbreak that results from the elimination of the pest's natural enemies, such as after an insecticide application. Even though the pesticide may initially control the target pest, the pest can recolonize and reproduce rapidly because its natural enemies have been eliminated. Compare with secondary pest outbreak.

Pheromone. A chemical substance secreted by an organism that causes a specific reaction by other individuals of the same species. Often used in traps to lure insects for pest monitoring purposes.

Phloem. Plant tissue which transports food over long distances within vascular plants.

Proleg. A fleshy, unsegmented abdominal leg of caterpillars.

Pupa (pupae). A nonfeeding, inactive stage during which an insect changes from a larva to an adult.

Puparium (puparia). A protective case created by the hardening of the larval skin in which the pupa develops. Produced by flies.

Secondary pest outbreak. A rapid increase in the population of one pest that occurs after treatment for another type of pest. The increase results from the elimination of the natural enemies of the secondary pest, as after insecticide application. Compare with pest resurgence.

Simple metamorphosis. Type of insect development in which the insect does not pass through a pupal stage before becoming an adult. Immatures are similar in shape to adults, but they are smaller and lack wings. Also called incomplete metamorphosis.

Solitary parasite. A species in which only one individual develops within a single host. Compare with gregarious parasite.

Species. A group of interbreeding individuals or populations, similar in structure and physiology, that are different from all other groups and produce fertile offspring.

Thorax. The body region between the head and abdomen. Bears the wings and legs.

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Numbers in **boldface** indicate pages with photos.

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