Greenhouse IPM with an Emphasis on Biocontrols

Produced by the Pennsylvania Integrated Pest Management Program

Aphidoletes larva

Cryptolaemus montrouzieri larva

Blue scouting card

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PA IPM

The PA IPM Program
is a collaboration between the
Pennsylvania Department of Agriculture and
The Pennsylvania State University
aimed at promoting
Integrated Pest Management
in both agricultural and nonagricultural settings.

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College of Agricultural Sciences
Agricultural Research and Cooperative Extension
Department of Entomology
Department of Plant Pathology

Pennsylvania Department of Agriculture

Preface

The Pennsylvania Integrated Pest Management Program (PAIPM) is pleased to provide *Greenhouse IPM with an Emphasis on Biocontrols*, designed to help greenhouse growers implement biological control (biocontrol) and Integrated Pest Management (IPM). PAIPM is a collaboration of the Pennsylvania Department of Agriculture and The Pennsylvania State University. PAIPM strives to promote IPM in agricultural, urban, and suburban environments. For a full description of PAIPM, visit our Web site: http://paipm.cas.psu.edu/.

This manual was produced in response to the lack of material on greenhouse IPM and biocontrol. It begins with an introduction to IPM and its principles, information on starting an IPM/biocontrol program and using compatible pesticides, and then addresses many of the most common greenhouse pests and their biocontrols. The emphasis throughout is biocontrol. This manual is designed to educate commercial greenhouse operators, crop consultants, and IPM scouts to develop biocontrol systems for greenhouses that will maximize yields while reducing pesticide usage. Not all biocontrols or all pests are included in this manual; it focuses on some of the most common pests and the biocontrols used to manage them. Pesticides mentioned in this manual are current as of January 2005.

Greenhouse production is rapidly growing in Pennsylvania and surrounding states, providing plentiful food and ornamental crops. At the same time, the public is demanding greenhouse-grown food produced with minimal pesticide applications. IPM provides an avenue to meet these demands by heavily relying on alternatives to pesticides such as biocontrol and good horticultural practices, and turning to pesticides only when absolutely necessary.

The institutional collaboration embodied by PAIPM allows us to draw on Department of Agriculture technical experts and Penn State faculty. Moreover, more than 10 years of effort in implementing biocontrol and IPM in working, commercial greenhouses in Pennsylvania means that the information contained in this manual is very practical and designed to instruct greenhouse operators through a stepwise process. For instance, PAIPM has provided one-on-one instruction for greenhouse growers in implementing IPM including pest monitoring, biocontrol, starter plant inspection, and proper pesticide selection. In addition, this program provided a training opportunity for PDA plant inspectors, cooperative extension personnel, and others so that the IPM message could be carried across the state.

We hope that this manual will encourage growers to develop their own IPM programs and train their employees to become familiar with IPM practices.

—Cathy Thomas, PDA PA IPM coordinator;
Ed Rajotte, professor of entomology and Penn State PA IPM coordinator

Acknowledgments

Project Coordinator

J. Kenneth Long Jr., PA IPM program assistant, Penn State

Primary Author

Cathy Thomas, PA IPM coordinator, Pennsylvania Department of Agriculture

Editorial Modifications

James Steinhauer, former PA IPM coordinator, Pennsylvania Department of Agriculture

Contributing Authors

Dr. R.A. Dunn, Institute of Food and Agricultural Sciences, University of Florida

Dr. Gary W. Moorman, professor of plant pathology, Penn State

Dr. Ruth Welliver, virologist, Pennsylvania Department of Agriculture

PA IPM Program Staff

Cathy Thomas, PA IPM coordinator, Pennsylvania Department of Agriculture

Dr. Ed Rajotte, professor of entomology, Penn State, PA IPM Coordinator

Kristie Auman-Bauer, public relations and outreach coordinator, Penn State

Lyn Garling, education specialist, Penn State

Kristine Kuhn, IPM information specialist, Penn State

J. Kenneth Long Jr., PA IPM program assistant, Penn State

Reviewers

David Bingaman, chief of conservation and agricultural technology division, Pennsylvania Department of Agriculture

Carol Glenister, president and entomologist, IPM Laboratories, Inc.

Rayanne Lehman, entomologist, Pennsylvania Department of Agriculture

Dr. Ed Rajotte, professor of entomology, Penn State

Jim Stimmel, entomologist, Pennsylvania Department of Agriculture

Dr. Karl Valley, chief of Plant Protection Division, Pennsylvania Department of Agriculture

Designer

Barbara First, graphic design specialist, Penn State

Editor

Amanda Rudisill, writer/editor, Penn State

Photo Credits

Cathy Thomas, PA IPM coordinator, Pennsylvania Department of Agriculture

Tracey Olson, plant pathologist, Pennsylvania Department of Agriculture

Sandy Gardosik, entomologist, Pennsylvania Department of Agriculture

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Getting Started with Greenhouse IPM

Definition of IPM

Integrated Pest Management (IPM) is an approach to managing pests by using appropriate physical, cultural, biological, and chemical tactics that are safe, profitable, and environmentally compatible. One of the tactics included in IPM is using biocontrols—enlisting predators, parasites, or pathogens of pest organisms to help manage the pests. IPM allows growers to use fewer chemical pesticides and still produce a quality product.

Biocontrol

IPM/biocontrol requires a hands-on approach over an extended period to learn and apply successfully. Growers need to learn pest monitoring techniques, pest and parasite life cycles, timely release of parasites, population assessment of both parasitized and nonparasitized pests, how to determine economic pest thresholds, appropriate biocontrols available, and, when necessary, the blending of compatible chemical controls with biocontrols to manage the pest complex.

This manual enables growers to develop a practical management strategy within the production constraints of their own greenhouses. Experience has shown that growers using IPM/biocontrol systems have been able to increase crop quality and yield. The program also reduces pesticide resistance in target pests, creates a safer working environment, and reduces grower dependence on pesticides, thus potentially lowering costs of production and increasing income levels through the marketing of high-quality, higher-yielding crops.

Pennsylvania greenhouse IPM projects with cooperating growers have been funded by grants from the United States Environmental Protection Agency—Region 3, Pesticide Environmental Stewardship Program, the Pennsylvania Department of Agriculture, The Pennsylvania State University, the Pennsylvania Vegetable Growers Association, and Sustainable Agriculture Research and Education (SARE).

HISTORICAL ACCOUNT OF EUROPEAN BIOCONTROL

Most past successes in greenhouse biocontrol have occurred in the Netherlands and the United Kingdom, mainly because at one time these two countries contained more than half of the world's greenhouse vegetable acreage. In the late 1960s, cucumber grower Jan Koppert cautiously started experimenting with predatory mites to control red spider mites. The success of these experiments laid the foundation for biological crop protection. Koppert is currently the international market leader in biological greenhouse crop protection. Large-scale production of natural enemies such as *Encarsia formosa* and *Aphidius colemani* takes place in the main facility located in the Netherlands. In addition to Koppert, several other large producers include Biobest (Belgium), a leader in bumble bee pollination and biocontrol production; Syngenta Bioline (England and California); and Applied Bio-Nomics Ltd., Canada's largest producer of biocontrols.

Principles of IPM

Integrated Pest Management: A Combination of Management Tactics

IPM involves the integration of cultural, physical, biological, and chemical pest management techniques such as exclusion, sanitation, scouting, using compatible pesticides, accurate pest identification, threat assessment, and record keeping. The main focus of this manual is biocontrol, but the basic principles of IPM are scouting and thresholds. Scouting is simply inspecting the crop (usually weekly) for the presence of pests. Thresholds are simply deciding whether pests are abundant enough to require a control treatment. If scouting and thresholds were the only IPM methods practiced by a grower, pesticide use could usually be reduced by at least 50 percent compared to spraying on a regular schedule.

Understanding the life cycle and behavior of insect pests is important in developing an effective control strategy. Knowledge about the weak link in a pest's life cycle can help growers choose the most appropriate control strategy. Knowledge of the biocontrol organism's life cycle is also essential for a proper biocontrol release strategy.

SCOUTING

Scouting is accomplished in various ways including using sticky traps, pheromone traps, baits, visually inspecting plants, among others. Specific scouting tactics for pests are listed where appropriate.

Various resources are available to help identify the pests that may occur in greenhouses. A monthly guide from Cornell and Rutgers, *Northeast Greenhouse IPM Notes*, is available at http://www.rce.rutgers.edu/pubs/greenhouseipmnotes/ (accessed 6/3/2004).

THRESHOLDS

Economic threshold (ET) is the number of pests whose injury to the plants cause a crop loss in dollars greater than the amount of money managing the pest would cost. Basically, the ET is the level that actually produces damage that is more expensive than intervention. The ET is usually expressed in numbers of pest individuals per some unit (e.g., pests per square foot, per plant, per feet of row).

The purpose of the ET is to give growers time to implement a management tactic before economic loss is reached, thereby saving as many dollars as possible while making sure that it is cost-effective to implement the management tactic. The ET is the signal to take action.

In practice, many crops have no established ET. Over time, growers must determine their individual ETs for a given pest. One grower may accept 10 to 15 thrips per sticky card per week, while another grower with a history of Impatiens Necrotic Spot Virus (INSV) will not accept five thrips per sticky card per week. Or the ET may depend on the growth stage of the crop. A generally acceptable threshold for whiteflies might be one-half per card per day when the crop is young, and two per card per day as the crop reaches maturity. In some cases, biocontrol organisms should be released as soon as a pest is detected.

County extension educators can provide current information on pest outbreaks as well as other recommendations on management.

REFERENCES

Calvin, D. D., et al. 2001. *Field Crop Integrated Pest Management Training and Reference Manual*. The Pennsylvania State University.

Greer, L., and S. Diver. 1999. *Integrated Pest Management for Greenhouse Crops: Pest Management Systems Guide.* Appropriate Technology Transfer for Rural Areas. http://attra.ncat.org/attra-pub/gh-ipm.html#general/ (accessed 11/20/2003).

IPM Techniques

Exclusion

How can pest problems be prevented before they start?

CLEAN TRANSPLANTS

In many cases, serious pest and disease problems that plague growers throughout the growing season result from purchasing infested transplants, cuttings, or plugs. Inspect what you are buying! Selecting a reputable grower ensures a quality transplant. If you are growing your own transplants, follow strict sanitation procedures and inspect seedlings weekly for pest and disease development. Preventing a problem before it becomes established can save a lot of time, effort, and expense.

- Insect screens can exclude aphids, whiteflies, and thrips from entering through doors and ventilating systems.
- Cover all soil floor surfaces with concrete, black plastic, or weed barrier.
- Inspect incoming plants immediately to prevent unwanted pest entry.
- Keep people and “pet plants” out of crop areas as much as possible.
- Keep doors closed.

Cultural Control

What can be done to develop healthy, resistant plants?

Making the greenhouse less friendly to pests is possible by manipulating the greenhouse environment. Varying the time of planting or harvesting, applying water and fertilizer, and rotating crops in greenhouses may have a significant effect on the survival and growth of pest populations. Other cultural tactics include using a proper growing medium (correct pH, consistency, texture, etc.), controlling the temperature and humidity, maintaining appropriate amounts of nutrients and water, and choosing resistant varieties of plants.

Sanitation

How can weeds and crop residue be managed to prevent a pest recurrence?

SANITATION

Weed management is critical to the success of a biocontrol program both before and during crop production. Weeds serve as reservoirs for pests and diseases and may upset the predator–prey balance you are trying to establish in the crop. Maintaining a weed-free zone around the outside perimeter of the greenhouse is also critical for the same reason. Using an herbicide to quickly knock down a well-developed weed population will have pests scrambling for another food supply, which will probably be your crop. Physically remove weeds and destroy them on a continuing basis (Figure 1).

To prepare for next year’s spring greenhouse crop, the end-of-season cleanup is critical to prevent carryover of pests and diseases into the next crop cycle.

- Remove and destroy all plant debris including weeds both inside and outside the greenhouse, especially those near doors and vents. If plants are infested with pests, place them in a bag and destroy. Do not place infested plant material in dump piles near greenhouses.
- Pressure-wash the interior of the greenhouse with a disinfectant solution.
- Increase greenhouse temperature (after crop removal) to over 80°F for several weeks. This increases the metabolism of pests left in the greenhouse, causing them to starve in the absence of a food source. High sunlight and temperature can pasteurize the greenhouse. Heat treatment is preferred over cold treatment since cold temperatures induce insect hibernation rather than starvation.

Figure 1. Remove and destroy weeds both inside and outside the greenhouse because they harbor insect pests and diseases.

- Eliminate areas of standing water—insects will survive with a water source.
- Remove areas of algae since it is a food source and breeding area for fungus gnats and shore flies.
- Consider installing insect screens over vents to prevent whiteflies, thrips, and winged aphids from entering.
- The soil or growth medium should be treated for pests and diseases through crop rotation and/or steaming. This will reduce carryover of pests such as thrips and spider mites, which tend to hide in sheltered areas until favorable environmental conditions return. Steaming is effective in eliminating insects, diseases, weeds, and nematodes.

After crop removal and other greenhouse treatments, place yellow sticky cards in the empty greenhouse to monitor for any lingering winged pests. Check the cards weekly to determine if further action is required. Some growers find it helpful to monitor for pests by placing sticky cards in the greenhouse 1 to 2 weeks before planting the next crop.

Always use the cleanup procedures listed above before using a chemical treatment. This will reduce the need for chemicals at the beginning of the next crop cycle when plants are young and tender. If pesticides are used as a corrective measure to destroy pests from a previous crop and natural enemies or bumble bees for pollination will be used in the next crop cycle, use the following guidelines:

- Use selective pesticides that are nontoxic or only slightly toxic to natural enemies (check biocontrol supplier for current recommendations).
- Use pesticides with short residual activity. Some compounds persist for a few days and others persist for many months. If you plan to use biocontrols for pest control or bumble bees for pollination, do not use long residual pesticides.
- Some of the long residual pesticides to avoid include synthetic pyrethroids, carbamates, chlorinated hydrocarbons, and organophosphates. For example, Endosulfan (Thiodan®) requires a three-month waiting period before using bumble bees.
- Some short residual compounds include pyrethrins (Pyganic®, listed by the Organic Materials Review Institute), insecticidal soap, horticultural oil, and azadirachtin (insect growth regulator).

For specific information on chemicals and their effects on natural enemies, consult a biocontrol supplier. For specific information on many compounds, see http://www.koppert.nl/e0110.html and http://www.biobest.be/ (accessed 9/27/2004).

Scouting

Which pests are present?

Crop scouting is the cornerstone of a successful IPM program. Early detection and treatment of pests is critical in high-value greenhouse vegetable and ornamental crops. With regular (weekly) scouting, insects, diseases, and cultural problems are detected early before they become major problems. Instead of relying on a weekly spray program, use this time to scout the crop to determine if a spray treatment is really necessary. Growers who scout weekly feel they save money by avoiding unnecessary sprays in addition to making the environment more worker friendly.

Designate one employee (two people for larger operations) who will be trained to scout for pests and evaluate the effectiveness of pest control treatments. Many growers find that hiring a crop/IPM consultant is worth the cost since this person is experienced in identifying problems.

SCOUTING TOOLS

- hand lens at least 10x or greater (Figure 2)
- scouting report forms and clipboard
- flagging tape
- sticky cards (traps), both yellow and blue
- clothes pins to attach sticky cards
- insect sample vials
- labels for vials
- marking pen
- forceps
- plastic spoons for collecting soil samples
- plastic bags for plant samples
- pH meter
- soluble salt meter (to determine presence of total dissolved salts in media)
- min/max thermometer

Figure 2. A hand lens is a critical IPM tool for proper pest identification. Choose a hand lens with 10x power or greater.

POINTS FOR DEVELOPING A SCOUTING PROGRAM

- Maintain a notebook with scouting records; record weekly data from sticky cards and plant inspection.
- Allow at least 3 hours of scouting time per acre. This time may vary with the type of crops grown and experience level of the scout.
- Scout least-infested areas first, heavily infested areas last.
- Inspect plants using a zigzag pattern between benches. Stop at a minimum of ten spots within a 1,000-square-foot area.
- Use sticky cards as a guide; do not depend on them to determine if the controls are working. Sticky cards should always be combined with crop inspection.
- Use flagging tape to designate hot spots for biocontrol placement or pesticide treatments.

Sticky Cards

Sticky cards, an important tool in any IPM program, alert growers to the presence of certain pests. Adult stages of flying pests such as whiteflies, western flower thrips, fungus gnats, shore flies, and winged aphids may be detected on sticky cards. Adult trapping alone may not always be a good indicator of damage being caused by immature life stages; therefore, weekly plant inspection should be used in combination with sticky card monitoring. The information obtained from sticky card monitoring can be used to determine if a treatment is needed, to properly time treatment (biological or chemical), and to help evaluate the effectiveness of control actions.

TYPES OF STICKY CARDS

Rectangular 3 x 5 inch cards are typically used in greenhouse crops. Sticky tapes and ribbons can be used, but these are primarily used to control insects. Bright-yellow cards are most commonly used to trap most species of insects (Figure 3). Change cards at least every other week.

Figure 3. Bright-yellow sticky cards used to trap most species of insects.

If pest populations are high, cards will need to be changed more frequently; maintain a notebook of scouting notes (Figure 4).

Blue cards are most attractive to most thrips species and therefore should be used in crops that are sensitive to thrips damage and require close monitoring, such as impatiens (Figure 5). Below are some suggestions for using sticky cards:

- Use at least one card per 1,000 square feet. Additional cards may be placed near doors, vents, and in areas of insect-susceptible plant species.
- Reduce the number of cards if you are using winged beneficial insects because they may get caught on the cards.
- Replace cards weekly if insect populations are high or if there is debris on cards.
- Place cards in houses before introducing crops to monitor for overwintering pests. A card placed just above the floor level can detect thrips or fungus gnats.
- Place cards 1 to 2 inches above plant canopy and move the cards as the plants grow.

Figure 4. Inspect sticky cards and plant material on a weekly basis.

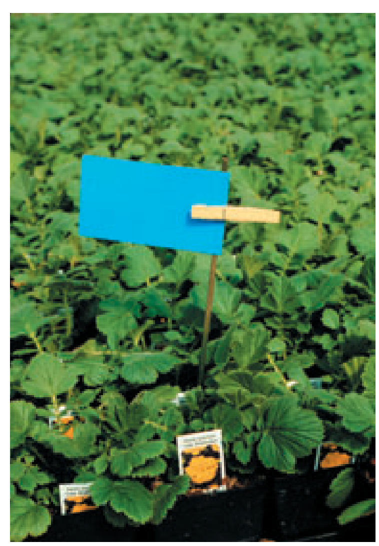


Figure 5. Blue sticky cards.

- Place cards near plants that are favored hosts for certain pests (e.g., thrips on African violets, impatiens, and chrysanthemums).
- Reduce or eliminate blue cards if you are using bumble bees for pollination since they are attracted to blue.

IDENTIFYING INSECTS ON YOUR STICKY CARDS

Correctly identifying the most common insects on your sticky traps will help you choose the correct control strategy. Species that resemble small, dark flies, such as shore flies, fungus gnats, and leaf miners, require very different controls; whiteflies may be confused with thrips; and aphids also have winged forms that are attracted to yellow sticky cards.

To get serious about differentiating small insects that are gummed up in adhesive, you need some magnification. A 10x hand lens works well and is relatively inexpensive.

When insects alight on a yellow sticky card, they immediately struggle and become ensnared in the adhesive, often in awkward positions. However, the wings are either free of the adhesive or glued down securely. This is important, as the wings are useful for identification. The antennae on the head of the insect are also important, but these are so fragile that they often break off or are damaged. The diagram on the next page provides some of the broad diagnostic features to look for.

Don't forget to have a supply of some waterless hand cleaner nearby to remove any of the adhesive from your hands following scouting and examination of the cards.

Aphids

The wings of aphids often settle symmetrically into the adhesive to either side of the body. Sometimes trapped aphids give birth to one to five nymphs before they die and their bodies shrivel up; after only a few days, only parts of the aphid can be recognized. The front wings usually have two parallel veins close to the outer or front edge. These veins end at a dark, skinny part. The legs and antennae of aphids are long and thin.

Fungus Gnats

These are small, dark, mosquito-like flies with gray wings. The wing has a distinct, Y-shaped vein at the tip. Fungus gnats have relatively long, skinny legs and antennae.

Leafminers

Leafminer flies are shaped like fruit flies but are smaller. Unless the specimen is completely mired up in the adhesive, seeing a conspicuous yellow spot on each side of the body is possible. These flies have short antennae and moderately long legs.

Parasitoid Wasps

There may be a few parasitoid wasps on your cards even before the release of specific beneficial species. Parasitoid wasps usually have antennae with elbows like those of ants, and the forewings have only one vein, which zigs toward the front margin and zags away. Usually parasitoid wasps are more pointed at the rear than flies.

Shore Flies

Shore flies are the largest common flies found on sticky traps (occasionally a housefly or horsefly may get stuck). These are about the size of fruit flies but with dark eyes, legs, and wings. They have pale spots on their wings, short antennae, and moderately long legs.

Thrips

Thrips are the tiniest insects you will find in any number on sticky cards. Their wings usually are folded neatly over the abdomen, making them appear spindle shaped with the wings protruding at the rear. With magnification, hairs that line the edges of the wings may be visible. Often the stocky antennae protrude in a V-shape at the front.

Whiteflies

Whiteflies lose their white, waxy bloom as they are entrapped by the adhesive. The insect shows its true orange color and its fragile nature when trapped. Whiteflies are only a little larger than thrips. Usually enough of a wing or leg or other part protrudes above the adhesive so that the white bloom reveals the identity of the whitefly. Whiteflies tend to disappear into the adhesive after only a few days.

Miscellaneous

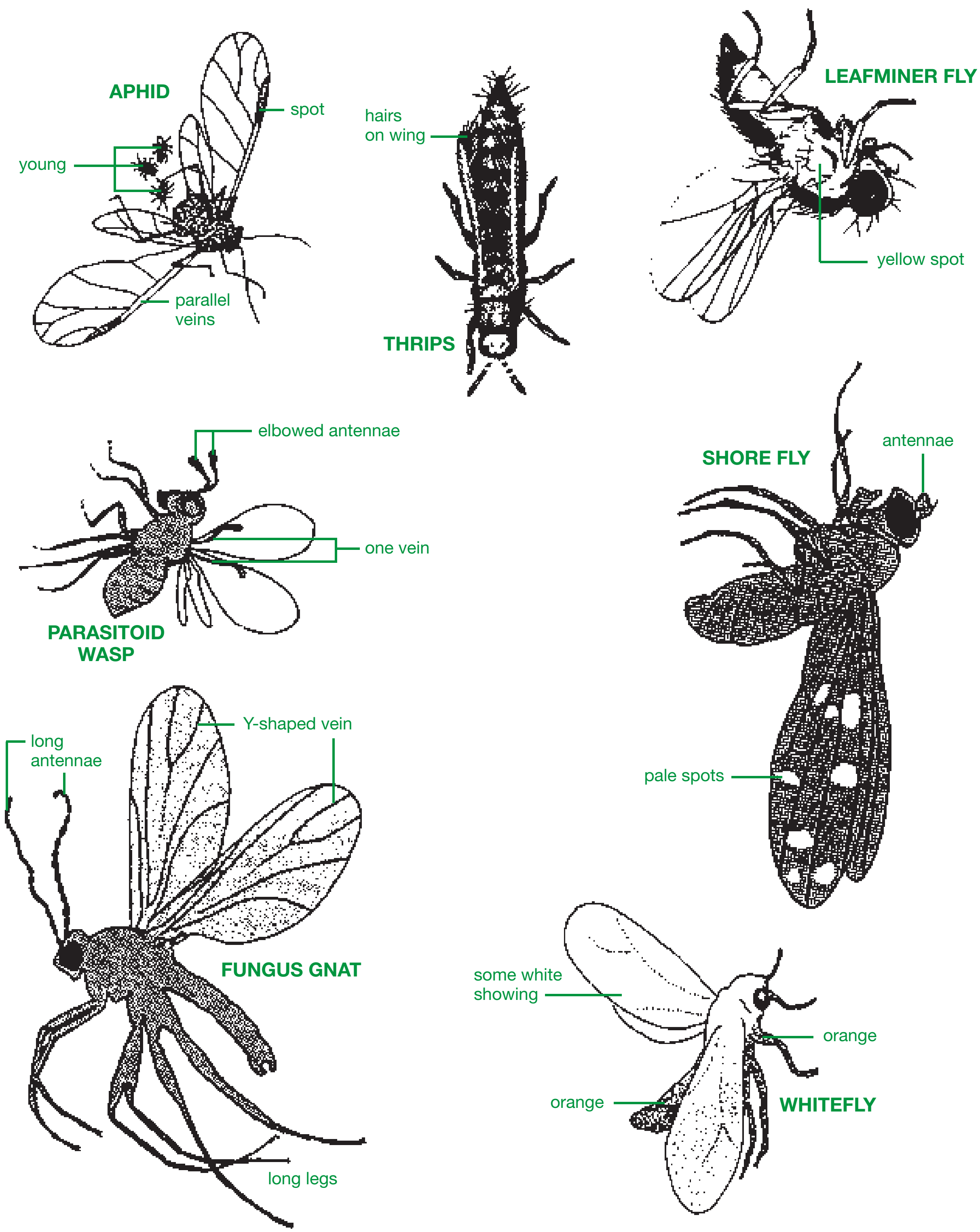
There are many different kinds of insects. If you cannot identify all of the trapped insects, do not despair. This guide will help you identify the most common and most important. If you find large numbers of an unidentified species, seek the assistance of your extension educator, crop specialist, or crop consultant.

Remember to check your sticky cards regularly; too many insects on the card makes counting and identification difficult or impossible.

Reference

Baker, J. R. 1986. "Identifying Insects on Your Sticky Cards." *North Carolina Flower Growers Bulletin* 30(1): 12, 13. Used with permission from the author.

Insects on Sticky Traps



Used with permission from Dr. James R. Baker, extension entomologist, North Carolina State University, Raleigh, N.C.

Indicator Plants

Indicator plants (susceptible varieties of plants) provide an early detection system for locating thrips. Certain petunia varieties are very effective in detecting thrips and INSV. Petunias attract thrips and may show symptoms of virus infection; however, the petunias do not become a reservoir for the virus. More information on this subject can be found in the section on thrips (see page 47).

Proper Pest Identification

Many insects can be found in the greenhouse; which of them are pests?

To identify insects on sticky cards, a 10x or 16x power hand lens will be necessary. Cards should be checked once a week or every 2 to 3 days if you suspect a problem. Examining cards weekly will give you an idea of population trends. Record the number and type of pests caught on each card; keep this information for future use. Refer to the guide on identifying insects on sticky cards (see pages 10–11) or explore http://www.ipm.ucdavis.edu/PMG/selectnewpest.floriculture.html (accessed 9/27/2004 for more information.

Several books listed in the resource section are helpful for identifying insects. County extension educators can also help identify pests you may encounter.

Threat Assessment (Economic Thresholds)

Are enough pests present to cause concern?

By keeping records of pest numbers and costs of control, the grower can establish ETs for pests found in individual situations.

Tactic Selection

What type of management activity is necessary? Will biocontrols work? Are pesticides needed?

This manual will help you choose which biocontrol should work best for pests found in your greenhouse. Check individual chapters for specific pests. Other tactics include:

- proper choice of pesticide and proper timing of application
- proper application procedure
- insect growth regulators (insecticides that interfere with normal insect development or the molting process)

Record Keeping

What has worked in the past? What has failed? What reduced pesticide use? What strategy saved money?

Records should be maintained to evaluate past methods of control as well as to help determine future pest management options. The records should contain monitoring results, tactics used, costs of control, effectiveness of biocontrols or other methods used, and so forth. See the sample scouting sheet (Appendix B: IPM Crop Information Reporting Form) for suggestions.

Results Evaluation

Was the management action successful? Do I need to do anything else?

Biocontrol

Getting Started

START SMALL

As with any new technology, start small. Learn the system in one greenhouse and expand as you gain confidence and knowledge.

NO PESTICIDE RESIDUES

Discontinue using insecticides with long residual activity at least 1 to 2 months prior to introducing biocontrols. Insecticide residues on plants and greenhouse fixtures can be deadly to biocontrol agents. To be certain about the compatibility of a compound that has been applied, consult biocontrol suppliers for current information on specific products. Also check the compatibility chart on page 19.

SOFT PESTICIDES

Consider the use of "soft" or "reduced-risk" compounds (e.g., insecticidal soap, ultra-fine horticulture oil, neem compounds) for treating pest outbreaks that occur while managing with biocontrols. For compatibility information, check the compatibility chart or consult your biocontrol supplier before spraying. Some growers prefer having a sprayer designated only for soft pesticides, thus avoiding contamination with more toxic insecticides.

ORDERING, PRODUCING, AND DISTRIBUTING BIOCONTROL ORGANISMS

Koppert is currently the international market leader in the field of biological greenhouse crop protection. Large-scale production of natural enemies such as *Encarsia formosa* and *Aphidius colemani* takes place in the main facility located in the Netherlands. Several other large producers include Biobest (Belgium), a leader in bumble bee pollination and biocontrol producer; Syngenta Bioline (England and California); and Applied Bio-Nomics, Ltd. (Canada), largest producer of greenhouse biocontrols. More than twenty producers in the United States specialize in the production of many species of predatory mites, lacewings, *Trichogramma* parasitoids, beneficial nematodes, and filth fly natural enemies.

These biocontrol producers have distributors in the United States and Canada. Many of them have technical support staff including full-time entomologists to answer pest control and pollination questions. A list of some distributors is included in the appendix; also check the Association of Natural Biocontrol Producers (ANBP) Web site at http://www.anbp.org/ (accessed 9/27/2004) for a list of distributors. This professional organization's membership includes researchers and producers, distributors, and users of natural enemies.

Because most greenhouse biocontrols are shipped from Europe or Canada, most distributors require orders to be placed by Thursday for delivery the following Wednesday. So, growers must plan ahead. Products are delivered directly to growers via UPS, Airborne, or FedEx. Insist on guaranteed live delivery and overnight express only.

Most natural enemy producers screen for quality and use packaging or best-used-by dates. Be cautious of suppliers who do not put dates on their materials. When biocontrols arrive, check for viability. Predatory mites can be checked by shaking material onto a white sheet of paper and looking for movement. For biocontrols shipped as pupae, a small portion of each shipment should be set aside in small, sealed containers, such as plastic bags or yogurt cups, and observed for adult emergence.

Parasitoids such as *Aphidius colemani* (shipped in bottles) should be placed in the greenhouse within 24 hours of receipt. Mortality of parasitoids can be determined by checking emergence rate. During warm weather, biocontrols should be shipped with cooling material. Inform employees that you will be receiving biocontrols so that the materials can be stored in a cool area if they cannot be distributed immediately.

Biocontrols are available for all of the major greenhouse pests, including aphids, caterpillars, fungus gnats, mealybugs, scales, shore flies, spider mites, thrips, and whiteflies.

Types of Biocontrol Organisms

Before starting a biological control program, recognizing the characteristics of predators and parasitoids and how they are used for each unique pest management situation is important. Most biocontrol organisms fall into the following categories and are described further in the section starting on page 73.

PREDATORS

A predator kills and consumes many prey individuals as food, and they are usually as large or larger than their prey and quite capable of moving around to search for their prey. Predators can be beetles, mites, mantids, flies, and bugs. In addition to ladybird beetles, many other predators are commercially available for introduction into crops.

PARASITOIDS

Parasites, by definition, feed on or in a host without killing it directly and therefore are usually not effective in controlling pest populations. Parasitoids, on the other hand, develop within the body of its host, killing it directly. For consistency in this manual, the term parasitoid will be used when referring to biocontrol agents that invade their hosts, eventually killing them.

Parasitoids are usually smaller than their prey. One or more grow and develop in or on a single host. As the parasitoid larvae feed and mature, the host is slowly killed. Adult parasitoids (usually wasps or flies) are highly mobile and parasitize many individuals. Parasitoids attack many different species of pests, such as aphids, whiteflies, caterpillars, leafminers, flies, and scales.

PARASITES

A group of organisms parasitic on insects are often referred to as entomopathogenic (insect-parasitic) nematodes. Nematodes are simple roundworms lacking segments or appendages and may be parasitic, free-living, or predaceous. Entomopathogenic nematodes have a symbiotic association with bacteria (*Xenorhabdus* spp.) that is lethal to many soil-dwelling insects but do not affect animals and plants. The two genera of insect-parasitic nematodes used for pest control include *Steinernema* and *Heterorhabditis*. Insect-parasitic nematodes have been used successfully to control soil-dwelling pests in greenhouses, nurseries, strawberries, mushrooms, and turf, replacing traditional synthetic pesticide drenches. Nematodes require moist soil to be effective, and soil temperatures should remain between 60°F and 90°F. Because of the high degree of safety, nematode applications are exempt from reentry intervals and worker protection standards and do not require a mask or other safety equipment. Nematodes can be applied like most conventional pesticides using a pull-behind sprayer, fertigation system, or backpack sprayer.

PATHOGENS

Entomopathogenic fungi (mycoinsecticides) are pathogens that infect and kill insects. Fungal spores must have direct contact with insects to be effective. As spores attach to the insect cuticle, they germinate and the fungus grows into the body cavity. *Beauveria bassiana* (Balsamo) Vuillemin is an entomopathogenic fungus that may control infestations of whiteflies, some thrips, and certain species of aphids. (BotaniGard™ and Naturalis T&O™ are two commercially available products.) Hyphae—small tubes that grow from the spores—enter the body cavity of the pests and then attack the internal organs. The infected insect stops feeding and dies within a few days.

Sources for Biocontrol Organisms

See Appendix E for list of sources and contacts for biocontrol organisms.

REFERENCE

Gill, S. A., et al. 2003. *Integrated Pest Management for School Greenhouse Operations*. Maryland Cooperative Extension, University of Maryland.

Pesticide Compatibility

Knowing the history of pesticide usage in the greenhouse is one of the most important considerations before starting a pest control program using biocontrols. Avoid using conventional classes of insecticides such as carbamates, chlorinated hydrocarbons, organophosphates, and synthetic pyrethroids because they can persist for many months on plants and on the greenhouse structure itself. Insecticides from these classes usually have a negative impact on beneficial insects and on bumble bees used for pollination.

The next most important consideration is determining which insecticides you can use along with the introduction of natural enemies. If a pest outbreak requires a spray treatment, use a selective insecticide and spot spray when possible. A selective insecticide has the following qualities:

- Nontoxic or slightly toxic to natural enemies (soft chemistry)
- Short persistence
- Does not inhibit development or reproduction of the natural enemies

Some compounds (e.g., pyrethrins) may be harmful to beneficials at the moment they are applied but may have a short persistence. After the recommended time period has elapsed, beneficial insects can be introduced again. Always consult your biocontrol supplier before applying any pesticide. Online information about the side effects of pesticides on beneficial insects can be obtained at http://www.koppert.nl/e0110.html (accessed 9/27/2004). A list of materials approved for organic production can be found at the Organic Materials Review Institute Web site: http://www.omri.org/ (accessed 9/27/2004).

Points to Consider When Using Pesticides with a Biocontrol Program

- Transplants, plugs, or cuttings should not be treated with pesticides having long residual activity. If not raising your own plant materials, check with your propagator for a history of pesticide use.
- Designate a sprayer for soft pesticides to be used only in biocontrol houses.
- Pesticide vapors from a nonbiocontrol area may negatively impact biocontrols.
- Always read and follow pesticide labels to determine if the intended use has been approved.

Biorational Pesticides

These pesticides are biological in origin (e.g., viruses, bacteria, fungi, pheromones, natural plant compounds) in contrast to synthetic chemicals.

These products do not affect humans and are generally safe for beneficial insects and nontarget species. Many of these pathogens are commercially available for use on lawns, gardens, and agricultural pests.

Bacterial Bioinsecticides

One of the most widely used bacterial pathogens is *Bacillus thuringiensis* (Bt). Bt products are produced commercially in large industrial fermentation tanks. Until the early 1980s, commercial Bt products were effective only against caterpillars. In recent years, however, additional isolates that kill other types of pests have been developed. Bacterial insecticides must be ingested by target insects to be effective; they are not contact poisons. After feeding on treated areas, the insect gut becomes paralyzed, feeding stops, and the pest dies. Because target pests must ingest Bt spores, some feeding damage will occur before pests are controlled. Bt insecticides include:

- *Bacillus thuringiensis* var. *kurstaki*—The best-known and most widely used Bt insecticides are formulated from *Bacillus thuringiensis* var. *kurstaki* (Btk) isolates that are pathogenic only to larvae of the butterflies and moths (Lepidoptera). Highly compatible with a biocontrol system, this pesticide targets caterpillars.
- *Bacillus thuringiensis* var. *israelensis* (Bti)—Used exclusively for controlling dipteran pest (flies) such as mosquitoes, black flies, and fungus gnat larvae. Gnatrol™, a commercial product containing Bti, is used in the greenhouse and nursery to control fungus gnat larvae.

Other groups of Bt isolates, including those from *Bacillus thuringiensis* var. *san diego* and *Bacillus thuringiensis* var. *tenebrionis*, are toxic to certain beetles.

Fungal Bioinsecticides

A distinct advantage to using a fungus is that it has the ability to directly infect the pest insect by penetrating its cuticle, which a bacterium or virus cannot do. When applied, fungal spores adhere to the cuticle. Under appropriate environmental conditions, spores germinate, penetrate the cuticle of the pest, and enter its body. The fungus grows throughout the body, produces toxins, and eventually causes death. When death occurs, the fungus grows out through the softer parts of the cuticle, covering the insect with a layer of mold. Depending on the fungus, the insect may appear white, pink, or some darker color.

- *Beauveria bassiana* (fungus)—This is the most common commercially formulated fungus used to control a broad range of insects and can be applied with standard spray equipment. Some of the products labeled for the greenhouse and nursery industry include Botanigard ES™, Botanigard 22 WP™, and Naturalis T&O™.

Viral Bioinsecticides

A large number of viruses may offer potential insect control. Those with the greatest potential are in the Baculoviridae (nucleopolyhedroviruses or NPV) and the Granuloviruses (GV) groups. Several products have been released in the United States to control pests on cotton, tomatoes, legumes, and grapes.

Plant Elicitors

A new class of biopesticides called plant elicitors offers growers a new tool for an IPM program. Plant elicitors are unique compounds that send a message to the plant to mobilize its defense mechanisms against pests. These biopesticides offer a distinct advantage over traditional pesticides because they are naturally occurring, are active at very low doses, and have no direct toxicity to pests, natural enemies, or other nontarget organisms.

The plant elicitor Messenger® is commercially available from Eden Bioscience Corporation; see http://www.edenbio.com/ (accessed 9/27/2004). Messenger® contains one of a group of proteins called harpins. This product stimulates the plant's pest-suppression system and enhances plant growth. Messenger® may be used for crops in greenhouse, shadehouse, nursery, and field production (consult label for list of crops). Nearly 500 field trials have been conducted worldwide on more than 40 crops, including high-value crops such as tomatoes, peppers, cucumbers, and strawberries; traditional agronomic crops such as wheat, rice, citrus, cotton, and tobacco; and ornamental crops such as roses. In addition to disease control comparable or superior to conventional fungicides, Messenger® increases seed germination, promotes earlier flowering and fruit maturation, and has been shown to increase fruit quality and yields (Horne, 2002).

Biofungicides

(For Control of Plant Pathogens)

These substances kill or inhibit the growth of pathogenic fungi.

Diseases in greenhouse vegetables and floriculture crops can be managed effectively with biological fungicides (biofungicides). A biofungicide is composed of beneficial microorganisms such as specialized fungi and bacteria that attack and control plant pathogens and the diseases they cause. These specialized fungi and bacteria are microorganisms that normally inhabit most soils. Biofungicides can be a viable alternative to chemical fungicides and can be used as part of an integrated disease management program to reduce the risk of pathogens developing resistance to traditional chemical-based fungicides.

An example of a widely used commercial biofungicide in the greenhouse industry is *Trichoderma harzianum* (TH) strain T-22 (Plantshield™). TH protects plant roots from pathogens such as *Pythium*, *Rhizoctonia*, *Fusarium*, *Sclerotinia*, and *Thielaviopsis*. TH will also suppress foliar diseases such as *Botrytis* and powdery mildew. To optimize the effectiveness of TH or any other biofungicide, apply before the onset of disease development (preventative treatment) since biofungicides will not "cure" pre-existing pathogens. Early application of the biofungicide protects the roots against pathogenic fungi, allowing for better development of root hairs. Always use biofungicides in conjunction with standard disease cultural controls including sanitation and weekly scouting.

BIOFUNGICIDE MODES OF ACTION

Biofungicides control other microorganisms by four mechanisms:

- *Direct competition*—before root infection can occur, pathogens must gain access to the zone closely associated with the root called the rhizosphere. A biofungicide "shields" the root by growing a defensive barrier around the roots, thus preventing the harmful fungi from attacking the root.
- *Antibiosis*—the biofungicide produces a chemical compound such as an antibiotic or other toxin that kills the target organism.

- *Predation or parasitism of the target organism*—the biofungicide attacks and feeds on the pathogen. For this mechanism to be effective, the biofungicide must be present in the rhizosphere at the same time or before the pathogen appears.
- *Induced resistance to the host plant*—the biofungicide triggers the plant to turn on its own defense mechanisms.

BIOFUNGICIDE PRODUCTS

Biofungicides, like chemical fungicides, must be registered by the Environmental Protection Agency (EPA). Growers must read and follow the label to determine if the intended use has been approved. Below are a few examples of biofungicides used in the greenhouse industry:

AQ10™

- Biocontrol Organism—*Ampelomyces quisqualis* isolate Q-10
- Target Pathogen—powdery mildew
- Crops—apples, cucurbits, grapes, ornamentals, and tomatoes
- Manufacturer—Ecogen, Inc., 2005 Cabot Blvd. West, PO Box 3023, Langhorne PA 19047-3023

Companion™

- Biocontrol Organism—*Bacillus subtilis* GB03 bacteria
- Target Pathogens—*Pythium*, *Rhizoctonia*, *Phytophthora*, and *Fusarium*
- Crops—bedding plants, foliage plants, and woody ornamentals
- Manufacturer—Growth Products, http://www.growthproducts.com/

Mycostop™

- Biocontrol Organism—*Streptomyces griseoviridis* strain K61
- Target Pathogens—*Fusarium* spp., *Alternaria brassicola*, *Phomopsis* spp., *Botrytis* spp., *Pythium* spp., and *Phytophthora* spp.
- Crops—ornamental and vegetable crops
- Manufacturer—Kemira Agro Oy
- Distributor—AgBio Development, Inc., http://www.agbio-inc.com/ (accessed 9/27/2004)

Plantshield™

- Biocontrol Organism—*Trichoderma harzianum* strain T-22
- Target Pathogens—*Pythium* spp*, Rhizoctonia solani*, *Fusarium* spp, *Sclerotinia*, and *Thielaviopsis*
- Crops—trees, shrubs, transplants, ornamentals, cabbage, tomato, and cucumber
- Manufacturer—Bioworks, Inc., http://www.bioworksbiocontrol.com/ (accessed 9/27/2004)

Soilgard™

- Biocontrol Organism—*Gliocladium virens* GL-21
- Target Pathogens—*Rhizoctonia solani* and *Pythium* spp.
- Crops—ornamental and food crops grown in greenhouses, nurseries, homes, and interiorscapes
- Manufacturer—Certis, Inc., http://www.certisusa.com/ (accessed 9/27/2004)

A list of commercially available biological fungicide products can be found at http://www.oardc.ohio-state.edu/apsbcc/productlist.htm (accessed 9/27/2004).

ADVANTAGES OF USING BIOFUNGICIDES

- Reduce the use of chemical fungicides.
- In most cases are safer to use and have a lower reentry interval than chemical fungicides.
- Organic growers can use many of these products; check the Organic Materials Review Institute Web site at http://www.omri.org/ (accessed 9/27/2004).
- In most cases, they are less phytotoxic.
- Many products can be used in rotation with chemicals (e.g., fungicides, insecticides, fertilizers, rooting compounds).

DISADVANTAGES OF USING BIOFUNGICIDES

- Do not eradicate the disease or “rescue” the host plant from infection.
- May have shorter shelf life than chemical controls.

Look for more of these biological fungicides to be developed and registered for the greenhouse industry.

Botanical Pesticides

Pesticides whose active ingredients are plant extracts with insecticidal properties are referred to as botanicals.

- Pyrethrins (PyGanic™)—A somewhat compatible botanical with short residue but very broad spectrum that can be used to clean up a pest population 1 to 2 weeks before biocontrols are introduced (check with biocontrol supplier).
- Azadirachtin (Azatin-XL+™)—A compatible insect growth regulator derived from seeds of the neem tree used to control larval stages of insect pests.

Insect Growth Regulators (IGRs)

IGRs are a class of chemicals considered to be biorational or a compound that is less harmful to humans and beneficial insects. Most IGRs have minimal reentry restrictions. IGRs interrupt or inhibit the life cycle of a pest in one of several ways:

- Mimic juvenile hormones so that insects never enter the reproductive stage of development (become an adult)
- Interfere with the production of chitin, which makes up the shell of insects
- Interfere with the molting process

Timing and application of these compounds is critical since they only affect immature life stages of insects. IGRs typically take several days or weeks to have an effect on pest populations, so don't expect quick results. In some cases, an insecticide must be used in conjunction with an IGR to provide adult knockdown. Inspecting your crop for the insect stages that are present before using an IGR is very important. Because IGRs do not affect mature insects and have no toxic residues, adult beneficials released into the greenhouse after an IGR application are not likely to be affected. For example, poinsettia growers may use an insect growth regulator in conjunction with a parasitoid to control whiteflies. This integrated control technique offers growers a safety net when using biological controls and reduces the risk of developing unmanageable whitefly populations. For information on chemical compatibility, contact your biocontrol supplier or visit the Koppert Web site at http://www.koppert.nl/e0110.html, or Biobest at http://www.biobest.be/ (accessed 9/27/2004).

Most IGRs are synthetic compounds. However, one IGR is derived from the tropical neem tree, *Azadirachta indica*. Azadirachtin, an isolate from neem seeds, is a potent disrupter of growth in many insect orders. Several products containing azadirachtin are now commercially available to producers and may contain varying amounts of the active ingredient. Two products currently available to growers are Azatin-XL+™ and Neemix 4.5™. These products control many different pests on both vegetable and ornamental crops.

Conventional Pesticides

Many of the conventional pesticides are not compatible with the use of biocontrol. A partial list of several categories of pesticides and their compatibility follows. See your county extension educator for additional recommendations.

"Soft" Pesticides

- Horticultural oil—Compatible with biocontrols, inactive when dry, used to kill soft-bodied insects; pupal stage parasitoids are not killed.
- Insecticidal soap—Compatible with biocontrols, inactive when dry, used to kill soft-bodied insects; pupal stage parasitoids are not killed.

REFERENCES

Horne, D. M. 2002. *EPA Biopesticide Fact Sheet: Harpin Protein* (006477). U.S. Environmental Protection Agency. http://www.epa.gov/pesticides/biopesticides/ingredients/factsheets/factsheet_006477.htm (accessed 6/23/2004).

McCullough, D. G., S. A. Katovich, D. L. Mahr, D. D. Neumann, C. S. Sadof, and M. J. Raupp. 1999. Extension Bulletin E-2679. *Biological Control of Insect Pests in Forested Ecosystems: A Manual for Foresters, Christmas Tree Growers, and Landscapers*. Michigan State University.

Effects on Beneficials of Some Pesticides Used in Greenhouses

Use this guide only as a suggestion. Consult suppliers of biocontrols for more current information.

L = Low toxicity, M = Medium toxicity, H = High toxicity. The wait period is the time recommended before introducing biocontrols after using the pesticide.

Pesticide	Pred. Mites	Other Biocont.	Bees	Comments (common name; pest; additional trade names; wait time)
Adept	L	L–M	L	Diflubenzuron (IGR); fungus gnats; wait 0 days
Avid	L–H	H	H	Abamectin; mites, leafminers; wait 21 days
Bacillus thuringiensis	L	L	L	Bt; caterpillars; Dipel DF; wait 0 days
Beauveria bassiana	L	L–M	L	Insect-pathogenic fungus; aphids, thrips, whiteflies, mealy bugs; BotaniGard, Naturalis T&O; wait 0 days
Citation IGR	L	M	L	Cyromazine; leafminers, thrips, fungus gnats; wait 0 days
Conserve SC	L	L–M	M	Spinosad; thrips, whiteflies, caterpillars; wait 7 days
Decathlon WP	H	L–H	H	Cyfluthrin; broad spectrum; wait 3 months
Distance IGR	L	L	L	Pyriproxyfen (IGR); whiteflies, fungus gnats, leafminers, scales; wait 3 days
Endeavor	L	L	L	Pymetrozine; aphids, whiteflies; wait 3 days
Enstar II	L	L	L	Kinoprene (IGR); whiteflies, aphids, scales; wait 3 days
Flagship	M	M	H	Thiamethoxam; chewing and sucking pests; wait 2 weeks
Floramite SC	L	L	H	Bifenazate; mites; wait 0 days
Gnatrol	L	L	L	Bti soil drench; fungus gnats; wait 0 days
Hexygon 50 DF	L	L	L	Hexythiazox; mite eggs only; wait 0 days
Horticultural Oils	L–H	L	L	Horticultural oils; scales, aphids, mites; Omni, Volck, Target, Sunspray, Neem oil; wait 1 day
Marathon 1G, 60WSP, II	L	M	H	Imidacloprid; whiteflies, thrips, aphids; wait 1 week
Mavrik	H	M	L	Fluvalinate; mites, aphids, whiteflies; wait 3 months
Neem Products	L	L	L	Azadiractin; mites, scales, whiteflies, aphids, mealybugs; NeemGuard, Ornazin; wait 0 days
Nematodes	L	L	L	Entomopathogen; fungus gnats; BioVector, Scanmask, Guardian, Cruiser, Grubstake; wait 0 days
Orthene PT1300TR	H	H	H	Acephate; broad spectrum; wait 3 months
Preclude TR	L	L	L	Fenoxycarb; whiteflies, thrips, scales, aphids; wait 3 days
Paecilomuces fumosoroseus	L	L	L	Insect-pathogenic fungus; whiteflies; PreFeRalWG; wait 0 days
Pylon	H	H	H	Chlorfenapyr; mites, thrips; wait 3 months
Pyrenone CS	H	H	H	Pyrethrins; broad spectrum, quick knockdown; wait 4 days
Pyrellin EC	H	L–H	H	Pyrethrin + rotenone; broad spectrum; wait 4 days
PT 1100 Pyrethrum	H	L–H	H	Natural pyrethrum; broad spectrum; wait 7 days
Resmethrin EC, PT1200TR	H	L–H	H	Resmethrin; Caterpillars, aphids, beetles; wait 14 days
Sanmite 75WSB	M	M	M	Pyridaben; mites, whiteflies, mealybugs; wait 3 months
Soap, insecticidal	L–M	L	L	Soaps; mites, aphids, scales; M-pede, Ringer, Murphy; wait 1 day
Talstar GH	H	L–H	H	Bifenthrin; mites, aphids, whiteflies; wait 3 months
Talus IGR	L	L	L	Well suited to programs that utilize beneficial insects and mites; labeled for greenhouse tomatoes
Tame 2.4EC	H	L–H	H	Fenpropathrin; broad spectrum; mites, mealybugs; wait 8 weeks
Thiodan 3EC, 50WP	M	M	H	Endosulfan; broad spectrum; borers; wait 4 weeks

Source: Adapted from Gill, S.A., et al. 2003. *Integrated Pest Management for School Greenhouse Operations.* Maryland Cooperative Extension, University of Maryland; and Mizell, R. F. 2001. *Pesticides Registered for the Nursery and Landscape and Their Impact on Beneficials and Nontarget Organisms*. University of Florida. http://biocontrol.ifas.ufl.edu/Natural_enemies/mizell.pdf/ (accessed 5/17/2004).

Key Greenhouse Pests

Most of the pests discussed in this manual are arthropods (insects and mites), which can be generally classified as soil dwellers, sucking pests, or leaf-chewers. Other pests included are plant pathogens such as bacteria, fungi, viruses, nematodes, and phytoplasmas. Discussion of the pests will follow in this order.

SOIL DWELLERS include fungus gnats, shore flies, and symphylids. Fungus gnats are common greenhouse pests that infest cuttings, other tender plant materials, and potted and long-term crops such as greenhouse vegetables. Larvae found in the soil usually eat rotting plant material, algae, and fungi but will also feed on root hairs or stem and leaf tissue. Young seedlings and plugs are particularly prone to attack. Shore flies feed on algae and are not known to feed on healthy plant tissue. Both fly pests can spread fungal pathogens. Symphylids resemble small centipedes. They feed on organic matter as well as sprouting seeds, plant roots, and root hairs.

SUCKING PESTS include aphids, mealybugs, mites, soft scales, thrips, and whiteflies. Many species of aphids occur in Pennsylvania greenhouses; this manual discusses green peach aphids, potato aphids, and melon aphids. They feed on plant sap to acquire proteins and sugars needed for reproduction. Aphids excrete excess sugars in the form of honeydew—a sticky substance that coats leaf surfaces and supports the growth of black sooty mold. This sooty mold may affect photosynthesis and possibly reduce plant yields. Aphids can also transmit plant viruses.

Mealybugs are small, white, fuzzy insects often found on foliage plants and a wide range of other plants. The two main species in Pennsylvania greenhouses are citrus and longtailed mealybugs. These also excrete honeydew.

Mites are relatives of spiders, not insects, because they have eight legs when mature. The most economically important mite—the twospotted spider mite—has a broad host range and can reproduce rapidly during hot, dry periods. Larvae, nymphs, and adults cause damage by piercing plant cells and sucking out their contents. Nymphs and adults produce fine webbing that can completely cover plants if populations are high. Other mites included are the false spider, broad and cyclamen, and eriophyid mites.

Scale insects, especially the soft scales, are also major pests in greenhouses. Brown soft scales, the most common scale found on indoor plants, are reported to feed on hundreds of plant species. Their feeding can affect a plant's health by causing leaves to turn yellow and drop and by stunting new growth. As with aphids, a byproduct of scale feeding is honeydew and subsequent growth of sooty mold. Hemispherical scale can also be found in Pennsylvania greenhouses but is usually only a problem with plants that remain in the greenhouse for long periods of time. This manual is specific for seasonal plants; hemispherical scale is not discussed. Biocontrols for brown soft scale can be used for hemispherical scale.

Several species of thrips attack greenhouse crops, but western flower thrips is the most serious. It can transmit Impatiens Necrotic Spot Virus (INSV) and several strains of Tomato Spotted Wilt Virus (TSWV). Western flower thrips feed by scraping the surface of the plant tissue and sucking up exposed juices. As the damaged leaves or flowers grow, they appear deformed, streaked, or have a silvery appearance. Western flower thrips has a broad range of host plants.

Three species of whiteflies are of primary concern in Pennsylvania greenhouses; they are greenhouse, banded-winged, and silverleaf whiteflies, although several other species attack greenhouse crops. Whiteflies have sucking mouthparts and, like aphids and scales, cause direct feeding damage to plants and excrete honeydew. Whiteflies can also transmit plant viruses through their feeding action.

LEAF-CHEWERS include caterpillars, leafminer flies, and snails and slugs. These pests chew on the leaves, reducing the leaf surface. Caterpillars are more common in open greenhouses or high-tunnel operations in which moths or butterflies have access. In many cases, hand-picking can keep these under control. Leafminers are tiny flies whose larvae feed between the upper and lower leaf surfaces, forming tunnels. Slugs and snails can make ragged holes in plant leaves if they gain access to greenhouses. Currently there are no invertebrate biocontrols for these pests. However, some IPM tactics are effective.

A key for identifying which group of pests may be found in the greenhouse is located online at http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/key.htm (accessed 6/3/2004).

PLANT PATHOGENS include bacteria, fungi, viruses, nematodes, and phytoplasmas. Bacteria cause leaf spots, stem rots, root rots, galls, wilts, blights, and cankers. Fungi include mildews and molds, rusts, damping-off diseases, and wilt diseases. These may attack different parts of the plant, resulting in symptoms from reduced growth to death of the plant. Viruses can multiply only inside a living cell. While some viruses such as cucumber mosaic die quickly when outside a cell or when the cell dies, other viruses such as tobacco mosaic retain their ability to infect for years after the infected plant part dies. Many different viruses can infect plants. There are no cures for plant viruses.

Foliar nematodes, also known as bud and leaf nematodes, attack plant parts above ground. They may cause dwarfing, distorted and deformed leaves, or yellow spots or blotches that may cause the plant to shrivel and die.

Phytoplasmas are responsible for the "yellows diseases" that until recently were thought to be caused by viruses. Diseases caused by phytoplasmas are tomato big bud and aster yellows in carrot and onion. Hosts for aster yellows phytoplasma include aster, chrysanthemum, gloxinia, and other perennials and flowering plants. Phytoplasmas are transmitted by insect vectors such as leafhoppers, psyllids, and planthoppers. Infected stock can infect other plants through naturally formed root grafts.

Sanitation and exclusion are important tactics in managing any type of plant pathogen.

Soil Dwellers

Dark-Winged Fungus Gnats: Diptera: Sciaridae

DESCRIPTION AND IDENTIFICATION OF PEST

Dark-winged fungus gnats (*Bradysia* spp., and *Orfelia* spp.), common greenhouse pests, are known for infesting cuttings and other young plant materials as well as potted and long-term crops such as greenhouse vegetables. Fungus gnats are small (3-millimeter-long), delicate flies that resemble tiny mosquitoes and have dark-brown bodies, dusky wings, small heads, long legs, and long antennae. The Y-shaped vein on the tip of the wing separates them from shore flies, which have five clear spots on their wings and shorter antennae than those of fungus gnats (Figure 6).

Figure 6. Adult fungus gnat.

When disturbed, adults run rapidly or take flight, which usually consists of short darting or hovering movements over a small area.

Fungus gnat larvae are white, slender, legless maggots, with shiny black head capsules and transparent bodies. When fully grown, they may be 6 millimeters long. Pupae are initially white, becoming dark shortly before adult emergence.

The "Key to Most Common Fly Pests Found on Flowers and Foliage Plants," which includes fungus gnats, is available online at http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/flykey.htm (accessed 6/3/2004).

LIFE CYCLE

Females live about a week and lay 30 to 200 eggs singly or in batches on the soil. Eggs hatch in 4 to 7 days. Larval development takes about 8 to 20 days. Most larvae inhabit the top 2.5 centimeters of soil but move near the surface where they pupate. Life cycle from egg to adult takes 15 to 32 days; warmer temperatures speed up the process. Several generations can overlap per year.

DAMAGE TO PLANT

Fungus gnat larvae have shiny, black head capsules and transparent bodies (Figure 7). They usually feed on decaying plant material, algae, and fungi but may also feed on root hairs, stems, and leaf tissue. The most common symptoms on affected plants are wilting and slowing of growth. Young seedlings and plugs are particularly prone to damage (Figure 8). Indirect damage can occur when larval feeding on roots creates entrance sites for soilborne pathogens such as *Pythium*, *Phytophthora*, and *Thielaviopsis*. Adult fungus gnats do not damage the plants directly but are capable of spreading fungal disease spores. High populations of adults create a nuisance problem.

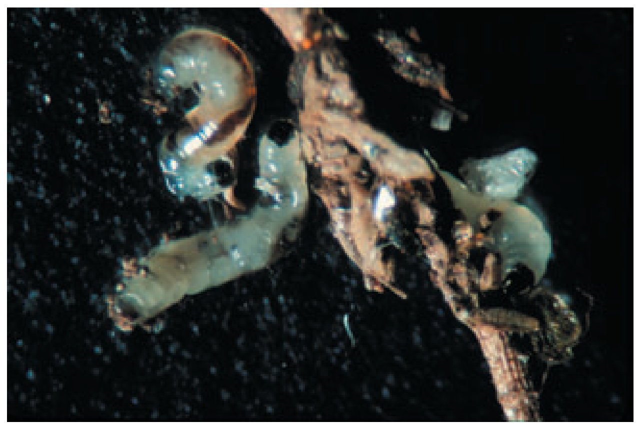


Figure 7. Fungus gnat larvae.

Figure 8. Fungus gnat larvae damage to young seedlings.

SCOUTING AND THRESHOLDS

Begin monitoring with yellow sticky cards in the greenhouse to determine if fungus gnats or other pests are present before starting seedlings. This practice allows growers to catch pest problems in their earliest stages—when they are most easily controlled. Continue monitoring throughout the crop cycle.

Adult fungus gnats are usually found on the soil surface. They are weak fliers and often run or rest on growing media, foliage, or litter. Adults can also be detected on yellow sticky cards. Horizontal placement of cards just above the soil surface is more effective than vertical placement. Since vertical placement is more effective for monitoring shore flies, a combination of horizontal and vertical placement is recommended. Cards placed under benches, close to intake vents, near doorways, and outside the greenhouse can pinpoint breeding areas.

Larvae occur in the top inch (2.5 centimeters) of soil but can be hard to see without a hand lens. Use potato plugs on the soil surface to monitor for fungus gnat larvae. Larvae may be seen within 24 to 48 hours on the potato surface and on the media below the potato plug. Raw potato disks (2.5 to 5 centimeters in diameter) pressed about 1 centimeter into the soil surface can also be used to monitor fungus gnat larvae in propagation areas (Figure 9). Potato wedges (French fry shape, 1 centimeter square, and 4 to 5 centimeters long) inserted vertically into the soil are more effective in established, deeper-rooted crops. Place the disks every 100 square feet in propagation areas, and the wedges every 1,000 square feet in production areas. Count the larvae feeding on the potato pieces 48 hours after placement. Replace old potato pieces with fresh ones each week.

Economic thresholds for fungus gnat larvae in propagation areas are as few as three to five larvae per disk. This amount can cause significant damage to the small, shallow root systems. Alternatively, when using potato wedges in a 6-inch pot, 15 to 20 larvae may be required for any significant root damage to occur (Willmott, 2004).

MANAGEMENT

Biocontrol

Fungus gnat larvae can be controlled biologically with the insect-parasitic nematode *Steinernema feltiae* and the predatory soil mite *Hypoaspis miles.* These biocontrols should be applied when pest populations are at low levels.

Steinernema feltiae, a Parasitic Nematode for Fungus Gnat Larvae

Parasitic nematodes can be applied through an irrigation system, a power sprayer with screens removed, or with a watering can. *Steinernema* are shipped as either a wettable clay powder or liquid suspension (Figure 10). A pack may contain 50 million infectious juvenile nematodes, which can treat a surface of 50 to 100 square yards or 5,000 quarts of potting media. The infective juvenile stage of the nematode *Steinernema feltiae* surrounds the pest insect and enters it through natural body openings. (Figure 11). Follow label directions for application. Once in suspension, apply nematodes to the compost/soil surface as a drench.

Figure 9. Raw potato disk placed on the soil surface to monitor for fungus gnat larvae.

Figure 10. Package of *Steinernema feltiae.*

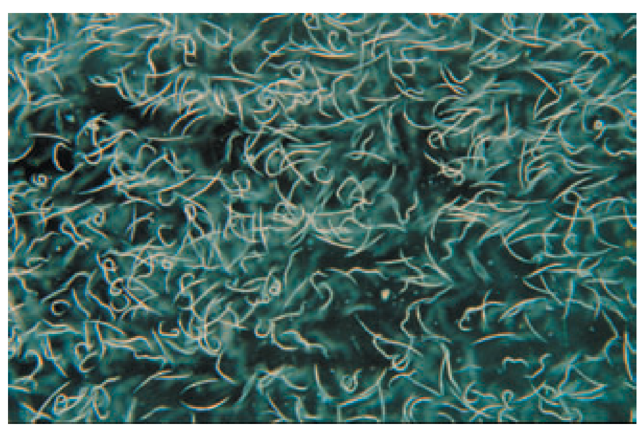


Figure 11. Infective juvenile stage of the nematode *Steinernema feltiae.*

Tips for using *Steinernema:*

- Do not store for extended periods.
- Soil temperatures should be above 55°F when applied.
- Apply in evening, directly to growing media.
- Use nozzle screens of at least 50 mesh or coarser during application.
- Water before and after application (nematodes require moisture for movement).
- Treat as soon as possible after sowing seed or inserting cuttings.
- For slow growing crops, reapply nematodes at 6-week intervals.
- If fungus gnat populations are already established, a noticeable reduction in adult fungus gnats may take 2 to 3 weeks.
- Do not apply within 7 days of a nematicide application.

Hypoaspis miles, a Predatory Mite of Fungus Gnat Larvae

Hypoaspis miles has shown good potential as a control for fungus gnat larvae, and may also feed on other soil insects such as springtails, thrips pupae, and shore fly larvae (Figure 12). *Hypoaspis* can be used in combination with insect parasitic nematodes. It should be used as a preventative treatment. Remember, the key for controlling fungus gnats is using good cultural control tactics.

Hypoaspis is shipped in shaker tubes with all stages of the predatory mites in a vermiculite/peat carrier. Always follow instructions supplied with the product. If instructions are not packed with the product, contact your supplier and request this information. Preventive rates are 35 to 70 mites per square yard; curative rates are 45 to 200 mites per square yard.

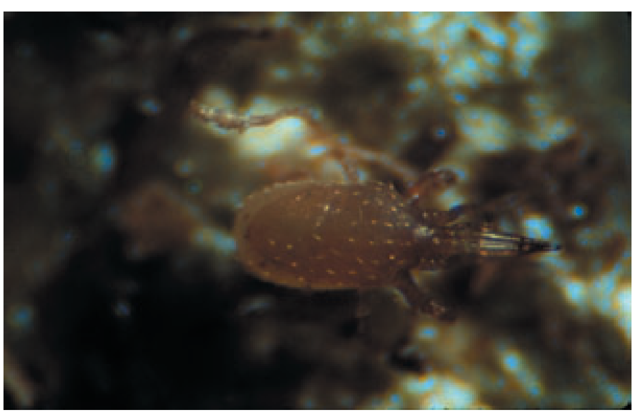


Figure 12. Brown predatory mite *Hypoaspsis miles.*

Tips for using *Hypoaspis:*

- Mites should be introduced as soon as possible after delivery.
- Minimum temperature for good activity is 60°F.
- Soil must be moist but not wet.
- Mites may be sprinkled over soil surface or mixed into growing media before planting; can be used preventatively.
- When introduced at planting time, control may last from 6 to 8 weeks.
- Should be compatible with Bt and beneficial nematodes.
- Several pesticides have a negative effect on *Hypoaspis miles*. When controlling diseases and other pests, check the compatibility table or consult with the supplier.

Cultural Control

- Avoid overwatering and fertilizer runoff; provide good drainage.
- Eliminate algae on benches, walls, mats, and soil under benches with a registered algaecide.
- Avoid using incompletely composted organic matter in potting media unless it is pasteurized first as it is often infested with fungus gnats.
- Eliminate freestanding water.
- Sanitation is critical for controlling fungus gnats; clean up algae spots and keep floors well drained (Figure 13).

Figure 13. Algae, a prime breeding site for fungus gnats and shore flies.

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Shore Flies: Diptera: Ephydridae

DESCRIPTION AND IDENTIFICATION OF PEST

Shore flies, which are about the same size (2 millimeters long) and shape as fruit flies, are sometimes confused with dark-winged fungus gnats. Both insects thrive in a moist greenhouse environment, have similar biology, and feed on algae. Shore fly larvae are not known to feed on live plant tissue, while fungus gnat larvae can cause economic damage to plant roots. In high numbers, the adults of both pests can be a nuisance to employees and to customers in retail greenhouses. Additionally, fungus gnat and shore fly adults and larvae can spread spores of fungal pathogens.

Identifying which fly is attacking your crops is important since the control strategy for each pest varies. Shore flies are very difficult to manage because chemical control options are limited on edible crops, and biocontrols that attack fungus gnats may not be effective for shore fly control. Adult shore flies are black with reddish eyes and gray wings and appear more robust than the delicate-looking fungus gnats. The dark shore flies have bristle-like antennae shorter than their heads (fungus gnats have antennae much longer than their heads). Each wing of the shore fly has five pale spots, while there is a Y-shaped vein on the tip of the fungus gnat's wing (Figure 14). These characteristics are easy to detect with a 16x hand lens.

Shore fly larvae are 2.5-millimeter-long, plump, brownish-yellow, legless maggots. They have no distinct head capsule, but their internal organs and dark mouthparts may be visible through their skin. The abdomen has distinct forked, dark-tipped breathing tubes. Pupae are brown to dark brown, curved, and tapered on both ends. They are about 2.6 millimeters long and 0.9 millimeters wide. A common species found in Pennsylvania greenhouses is *Scatella stagnalis* (Fallen).

The "Key to Most Common Fly Pests Found on Flowers and Foliage Plants," which includes shore flies, is available online at http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/flykey.htm (accessed 6/3/2004).

LIFE CYCLE

Female shore flies lay up to 300 oblong, white eggs on algal scum or in very wet areas with decomposing organic matter (potting mix, pots, floors, near water spigots). Eggs hatch in 2 to 3 days into tiny maggots. Larvae reach a mature length of 2.5 millimeters in 3 to 6 days. Pupae have a tough skin that provides protection from insecticides. All life stages are found within the crust of algae and in the top layer of potting mix. The life cycle from egg to adult takes approximately 3 to 4 weeks depending on temperature. Development time decreases as temperatures rise. Several generations may occur in a year.

Figure 14. Adult shore fly on a yellow sticky card.

DAMAGE TO PLANT

The primary damage caused by shore flies is "fly specks" or excrement left on foliage of seedlings or mature plants. Adult flies have been implicated in spreading fungus spores. Adults can also be a nuisance problem.

SCOUTING AND THRESHOLDS

Monitor weekly for shore fly development with yellow sticky cards, especially in propagation areas. Hang cards vertically for shore fly monitoring. Visual inspection for adults is usually adequate to determine if there is a problem. Inspect both plants and soil surface for adult shore flies.

MANAGEMENT

Biocontrol

Hypoaspis miles, a Predatory Mite

Hypoaspis miles provides some control over shore fly larvae if they are not in standing water. Shore fly larvae can survive in standing water, but *Hypoaspis* cannot. This soil mite is commercially available through most biological control suppliers.

Hypoaspis is shipped in shaker tubes with all stages of the predatory mites in a vermiculite/peat carrier. Always follow instructions that are supplied with the product. If instructions are not packed with the product, contact your supplier and request this information. Preventive release rate is 35 to 70 mites per square yard; curative release rate is 45 to 200 mites per square yard, depending on amount of infestation.

Tips for using *Hypoaspis*:

- The predatory mites should be introduced as soon as possible after delivery.
- Minimum temperature for good activity is 60°F.
- Soil must be moist but not wet; the mites live and breed in the top ½ inch of soil.
- Several pesticides have a negative effect on *Hypoaspis miles*. When controlling diseases and other pests, check the compatibility chart or consult the supplier for a list of side effects of pesticides on beneficial organisms.

A new biocontrol now available is *Atheta coriara*, a soil-dwelling staphylinid (rove) beetle that feeds on soil pests including fungus gnats, shore flies, and thrips pupae, as well as root mealybug crawlers, root aphids, and springtails. The beetle is about 3 to 4 millimeters long and can colonize an area. Both larvae and adults are predacious.

Two widely used biological products for fungus gnat control—*Steinernema feltiae* (beneficial nematode) and Gnatrol™ (*Bacillus thuringiensis*)—are not effective in controlling shore flies.

Cultural Control

Refer to cultural control for fungus gnats.

Other IPM Techniques

- Screening windows and doors can exclude fly pests.
- Do not bring plants with infested soil into the greenhouse.
- Use only pasteurized or treated container mix.

Drenches with Biorational Pesticides

Soil treatments can be used to control larval stages of shore flies. Treatments are mainly insect growth regulators used to prevent maturation of the insect to the adult stage. Many synthetic insect growth regulators are approved for control of shore flies on ornamental crops but are not approved for vegetable production. The following treatments are approved for greenhouse vegetables.

- Azadirachtin (Botanical)—When ingested or absorbed by insect larvae, the molting process is interrupted. Several products containing this active ingredient are commercially available.
- The mycoinsecticides containing *Beauveria bassiana* (BotaniGard™ and Naturalis T&O™) have been successful in controlling shore flies. The fungus works by invading the insect's body, causing it to stop feeding. It can be applied through drench or irrigation systems to the soil or media. Applications of fungicides to plant diseases must not be combined with the mycoinsecticide. Wait 48 hours after applying a fungicide before applying a mycoinsecticide.

Remember, these products are not "rescue treatments." Prevent outbreaks by applying when pest populations are at low levels.

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Symphylids: Symphyla

DESCRIPTION AND IDENTIFICATION OF PEST

Symphylans (sometimes called the garden centipede) are not insects but are closely related to centipedes and millipedes. The garden symphylan is a serious pest of many vegetable and field crops and can be found to infest crops worldwide. Recently the garden symphylan (*Scutigerella immaculata*) has become an important pest in high-tunnel production where high amounts of organic matter are used. Symphylans feed on sprouting seeds, plant roots, and root hairs, as well as on decaying organic matter.

Mature symphylans are translucent to milky white, slightly less than 6 millimeters long, have 12 pairs of legs, 14 body segments, and a pair of long, beaded antennae (Figure 15). Symphylans resemble tiny, white centipedes with 12 pairs of legs, while true centipedes and millipedes have at least 15 pairs of legs. Immature symphylans are smaller and start out with 6 pairs of legs, acquiring an additional pair at each molt.

For more pictures and further information, see http://www.pestspotter.co.uk/pests/63.htm (accessed 6/8/2004).

LIFE CYCLE

Symphylans spend their entire life cycles in soil, moving up and down in the soil profile with the moisture. They lay clusters of 4 to 25 eggs 9 to 12 inches below the soil surface. Eggs hatch in about 10 days into nymphs with 6 pairs of legs and 6 antennal segments. As they develop, nymphs become more similar to adults. The entire life cycle takes about 45 to 60 days. During hot, dry weather they move into the subsoil.

Symphylans are sensitive to light and move rapidly in soil, disappearing quickly when disturbed. Too fragile to burrow their own tunnels, they crawl through the soil in the trails of other soil dwellers or through loose organic material.

Figure 15. Mature symphylan.

DAMAGE TO PLANT

Symphylids feed on sprouting seeds, plant roots, and root hairs, as well as on decaying organic matter. The first indication of a symphylan infestation is a relatively small area of stunted, unhealthy plants. High rates of raw to partially decomposed organic matter additions are the main attraction to these pests. Soil dwellers rarely affect plants grown up off the ground, but they may enter pots on the ground through drainage holes.

SCOUTING AND THRESHOLDS

Look for symphylans by taking soil samples as deep as you can and drop each sample into a bucket of water. If symphylans are present, they will float to the water surface.

No well-established economic threshold is available for garden symphylans. Oregon State University Extension Service suggests that a definite problem exists if an average of five symphylans per shovelful of soil is found from 30 samples. Areas that have had symphylan damage in the past usually continue to have problems unless control measures are taken.

MANAGEMENT

Biocontrol

Natural enemies of symphylans include true centipedes, predatory mites, predacious ground beetles, and various fungi.

Cultural Control

Flooding infested areas for 2 or 3 weeks before planting can limit problems with symphylans.

REFERENCE

Flint, M. L. 1990. *Pests of the Garden and Small Farm*. Pest Notes Publication 3332. Division of Agriculture and Natural Resources, University of California.

Sucking Pests

Aphids: Homoptera: Aphididae

Aphids are pear-shaped insects ranging from 1.5 to 4 millimeters in length that form clusters, often on new plant growth, seedlings, and unfolding leaves. Usually wingless, they can produce winged forms that spread infestations rapidly to additional areas. Aphids have long, slender mouthparts called stylets that are used to pierce tender plant tissue and suck out plant fluids (Figure 16). Effective and timely control of aphid populations in greenhouse vegetable production is important due to aphids' ability to develop quickly into large populations. Many different aphid species can be found in Pennsylvania greenhouses including green peach aphid, potato aphid, and melon aphid. The species usually found infesting vegetable crops, especially tomatoes (solanaceous crops), is the potato aphid.

DESCRIPTION AND IDENTIFICATION OF PEST

The most distinguishing character for identifying aphids is the two cornicles ("tail pipes") on the rear of the abdomen. Colors vary among species and are not a reliable character for identification. As aphids grow and shed their exoskeletons, their white cast skins—often mistaken for adult whiteflies—can be found on leaves or stuck in honeydew secretions (Figure 17). A hand lens (at least 16x) is needed to identify distinguishing characters. Use the key on page 36 to help identify which species of aphid is present.

Figure 16. Aphid using its stylet to feed.

Figure 17. Shed aphid exoskeletons.

Green Peach Aphid *(Myzus persicae)*

Look for a rectangular indentation on the head between the antennae. Adult aphids are about 3 millimeters long, light to dark green, and have cornicles that are slightly darker than the rest of the body. They may also appear pink or orange depending on the host plant. Winged forms have a thorax darker than the abdomen and an irregular dark patch on the abdomen.

Potato Aphid *(Macrosiphum euphorbiae)*

Adults are 2.5 to 4 millimeters long. Their antennae are longer than their bodies and the cornicles are long and cylindrical. Color varies from green to pink. Winged forms have a green thorax and no abdominal markings.

Melon Aphid *(Aphis gossypii)*

These are small aphids, about 2 millimeters long, with antennae shorter than their body length. Color varies from yellow, green, blue-green, to black. Cornicles of adults are short and entirely black. Melon aphids have no head indentation. Winged forms have a darker thorax than abdomen.

If you cannot identify the aphid species attacking your crop, contact the cooperative extension service, the Pennsylvania Department of Agriculture, or check the following Web sites, which provide keys to the different aphid species encountered in greenhouses:

- http://res2.agr.ca/stjean/publication/web/aphidinae_e.pdf/ (accessed 6/3/2004)
- http://www.fcla.edu/FlaEnt/fe80p218.pdf/ (accessed 6/3/2004)
- http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/aphids.htm (accessed 6/3/2004)

Life Cycle

In greenhouse production, aphids are prolific. Reproduction occurs parthenogenically (without mating), and only females are produced. Females (stem mothers) give birth to live offspring (3 to 10 per day) that begin feeding immediately (Figure 18). Young aphids pass from nymph to reproducing adults in 7 to 8 days, thus producing many generations a year. In the fall, some aphids not living in greenhouses produce males, mate, and lay eggs, which provide them a more hardy stage to survive harsh weather. In some cases, these eggs are laid on an alternative host, usually a perennial plant, for winter survival (Flint, 2000). As colonies grow, aphids develop wings to migrate to less-populated areas in the crop (Figure 19).

Damage to Plant

Aphids feed on foliage and stems of plants. Damage can appear as leaf curling, yellowing, distortion, stunting, and/or killing of new growth (Figure 20). In addition to damage from direct feeding on plant sap, they excrete excess sugars in the form of honeydew. Honeydew serves as a growth medium for black sooty mold, which affects photosynthesis and may possibly reduce plant yields (Figure 21). Because of their feeding method, aphids can also act as vectors for plant viruses.

Scouting and Thresholds

Plant monitoring should begin at the seedling stage and continue through the duration of the crop cycle. Start plant inspection on lower leaves and continue up the plant to the growing tips. Aphid feeding on growing tips causes leaves to curl, sometimes resembling virus symptoms. Once leaves have begun to curl and distort, control becomes more difficult since the curled leaves may shelter aphids from biocontrols or insecticides.

Most aphid species prefer the undersides of leaves, so be sure to look there. Also check for evidence of natural enemies such as ladybird beetles, syrphid fly larvae, or lacewings, and look for the mummified skins of parasitized aphids. Watch for disease-killed aphids also—they may appear off-color, bloated, or flattened. Sufficient numbers of natural controls can mean the aphid population may be reduced rapidly without the need for further treatment where natural controls have access, such as in high-tunnel production areas.

Melon aphids have a more uniform vertical distribution on plants than do green peach aphids, which tend to be clustered around growing points. Infestations of melon aphids under lower leaves can easily go undetected if these areas are not inspected. Green peach aphids will produce winged individuals at lower densities than melon aphids on crops such as chrysanthemums (Robb, 2004).

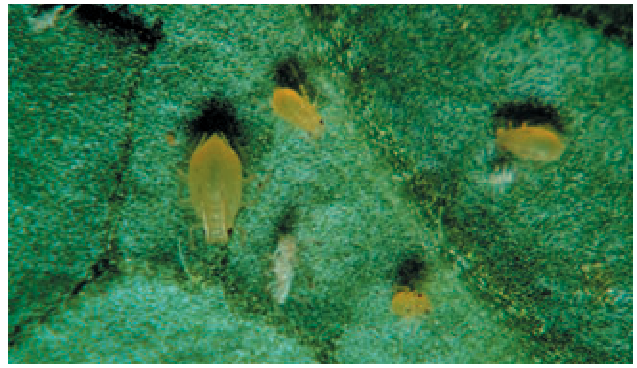

Figure 18. Potato aphids.

Figure 19. Aphid with wings.

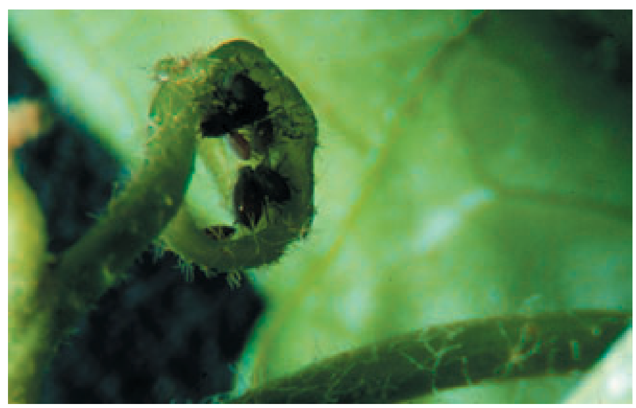

Figure 20. Aphid damage.

Figure 21. Honeydew and sooty mold damage on greenhouse tomato fruit increase handling time and reduce the quality of the fruit.

Yellow sticky cards are useful in detecting winged aphids. Hang sticky cards 4 to 6 inches from growing tips. Use the chart “Identifying Insects on Your Sticky Cards” on page 11 to identify the captured insects. Winged adults on sticky cards may indicate that clumped populations are already established in the crop and are migrating to less-populated areas.

The presence of ants in the greenhouse may also indicate aphid presence since the ants feed on the honeydew and thus protect the aphids. Control ants with baits or traps before introducing natural enemies.

Thresholds for aphids have not been determined. Through scouting and record keeping, growers should be able to set thresholds for their own specific crop situations.

MANAGEMENT

Biocontrol

Aphids have developed widespread resistance to many classes of traditional insecticides, so natural enemies offer an effective alternative method of control.

Several long-lasting and effective biocontrols are commercially available for aphids. In crop situations where a broad-spectrum insecticide is not being used, aphids can be controlled by naturally occurring predators such as lacewings, ladybird beetles, hover flies, and tiny parasitoids. Several biocontrols of aphids are sold commercially and can be used to augment a system of natural control.

Tips for using biocontrols effectively:

- Discontinue the use of residual pesticides 4 to 6 weeks prior to introducing biocontrols; see the table of pesticide compatibility on page 19.
- Identify the aphid species.
- Start introducing biocontrols when pest populations are low.
- Install traps for ants that feed on honeydew and thus protect aphid colonies from biocontrols.

Ladybird Beetles (*Hippodamia convergens* and Other Species), Predators

Ladybird beetles are sold as adults in pints, quarts, and gallons. As general predators, ladybird beetles are effective for cleaning up hot spots (Figure 22). They also feed on scales, thrips, and other soft-bodied insects. Larvae are black, alligator-like in appearance, and are also voracious predators. Release one to four adults per square yard biweekly for 2 to 4 weeks.

Tips for using ladybird beetles:

- Adults can be refrigerated until released.
- Release beetles in the evening to ensure more will remain; ladybird beetles can fly away.
- Release near an aphid hot spot.
- Mist the site before releasing the beetles.
- Flowering, pollen-producing plants will attract the beetles.

Figure 22. Ladybird beetle cleaning up aphid hot spots.

Lacewings *(Chrysoperla rufilabris)*, Predators

Lacewings are sold as eggs or larvae. Only the larvae are predatory and known as "aphid lions" (Figure 23). These voracious predators will also feed on mealybugs, scales, spider mites, and thrips.

Eggs are normally shipped loose in an inert medium of rice-hulls to facilitate distribution in the greenhouse. Eggs are more economical but slower to affect an aphid population. Larvae are cannibalistic and must be kept separate in transit—they are usually shipped in separate cells carried in a frame. Lacewing larvae are one of the fastest-acting predators available for aphids (Figure 24).

Lacewings may be shipped as eggs, immatures, or adults. Release rates are: one adult per every 5 to 30 aphids; 10 larvae per square yard as a curative release; or 1,000 eggs per 200 square feet. Apply every 1 to 3 weeks as needed.

Tips for using lacewings:

- Larvae need to be spread over an area because they are cannibalistic.
- Scouting is difficult; aphids hide by day. Clean, new growth is a sign of effective predation.
- Ants should be controlled—ants will eat lacewing eggs and defend aphids from predators.

Figure 23. Lacewing larva known as an "aphid lion."

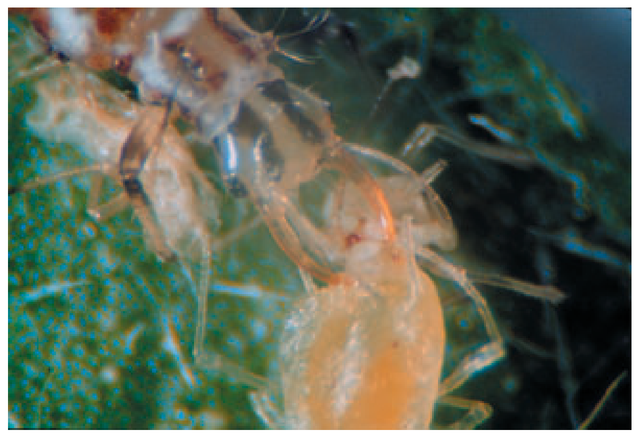

Figure 24. Lacewing larva attacking an aphid.

Aphelinus abdominalis, a Parasitoid Wasp

Aphelinus abdominalis is used to control larger aphid species such as the potato aphid (Figure 25). This wasp is about 3 millimeters long, and adults will feed directly on aphids as well as parasitize them. *Aphelinus* works more slowly for a longer time period (up to 8 weeks) than other parasitoid wasps. Hyperparasitism is rarely a problem with *Aphelinus*. *Aphelinus* is usually shipped as adults in units of 100 per tube or as pupae in mummies. Release one-half to two adults per square yard.

Tips for using *Aphelinus*:

- When aphids are first observed, introduce *Aphelinus* curatively for three introductions at 1-week intervals.
- Monitor weekly for the development of black, mummified aphids, which indicate parasitization by *Aphelinus* (Figure 26). When 80 percent of the aphids are parasitized, a parasitoid/prey balance has been achieved and no further introductions are needed. Augment with further introductions as required since aphid migration from outside may occur in warmer months.

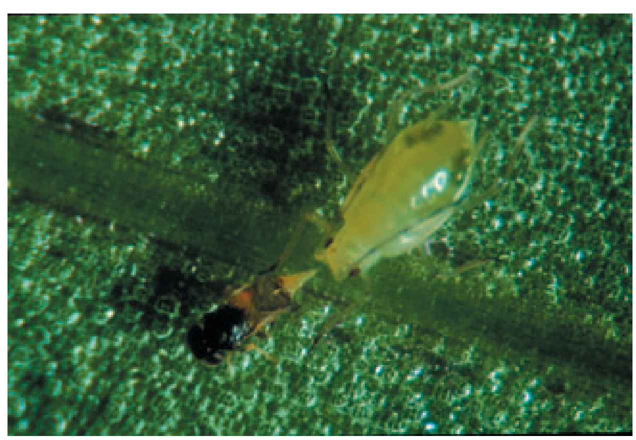

Figure 25. *Aphelinus abdominalis*, a parasitoid wasp, attacking an aphid.

Figure 26. Black, mummified aphid parasitized by *Aphelinus abdominalis.*

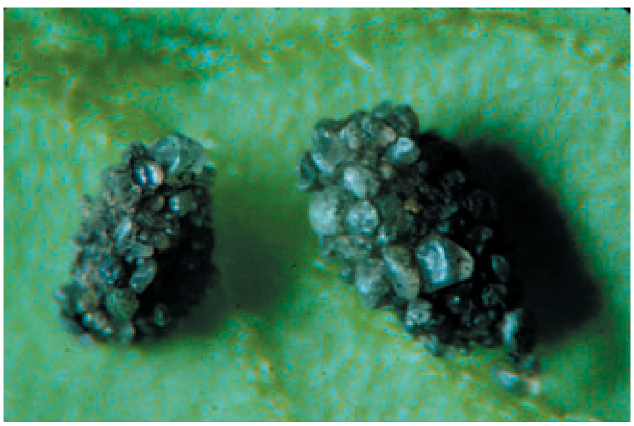

Figure 27. *Aphidoletes aphidimyza* pupae.

- When pruning leaves, check for parasitized aphids (black mummies). If mummies are present, keep these leaves in the greenhouse until new parasitoids hatch.
- Production of honeydew can interfere with the searching ability of the parasite. Heavy aphid populations can be reduced with soft, compatible compounds (see the table at the end of the "Pesticide Compatibility" section on page 19) or by using ladybird beetles.
- Tap wasps onto leaves (or near hot spots) of the infested plants in the morning or evening, not in direct sunlight. This wasp is not very mobile, so placing it close to infestations will increase its effectiveness.
- Parasitoid activity is reduced at temperatures above 86°F.
- *Aphelinus* can be stored up to 2 days at 47 to 50°F in the dark; however, distributing parasitoids immediately is best.

Aphidoletes aphidimyza, a Predatory Midge

These tiny (2.5-millimeter-long) midges are usually shipped in units of 1,000 pupae in a vermiculite carrier. Adults will emerge from pupae when placed in the warm greenhouse (Figure 27). Upon emerging, females lay their eggs near aphid colonies (Figure 28). After hatching, the orange midge larvae attack and feed on aphids (Figure 29). This predatory midge is a general aphid predator and will feed on many different aphid species. It can be used alone or in combination with a parasite for rapid knock-down of aphids. This predator is most effective on aphid hot spots (clumped populations). In soil cultures, midge larvae pupate in the ground and successive generations will occur, thus eliminating the need for continual

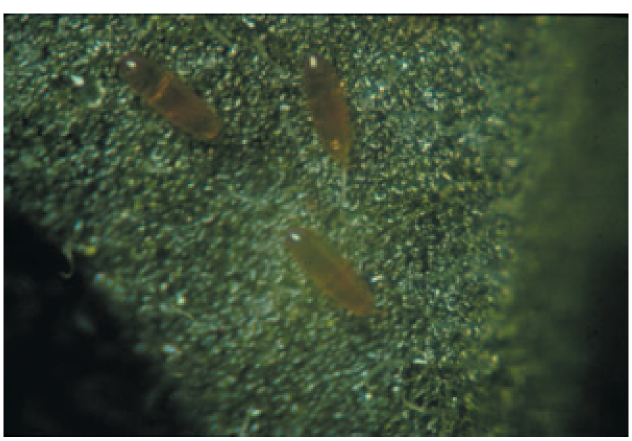

Figure 28. *Aphidoletes* eggs.

Figure 29. *Aphidoletes* midge larvae attacking and feeding on an aphid.

introductions. If soil is not available, successive generations will not occur and continued releases will be needed.

Note: Shorter day lengths in late September will trigger hibernation of midge larvae. If you are growing a fall crop, use a parasite such as *Aphidius ervi* or *Aphelinus abdominalis* unless your crop requires supplemental light. For preventative purposes, release one to three midge pupae per square yard when aphids are first detected or introduce at a higher rate of two to nine pupae per square yard (curative) when aphid colonies have become established. Three to four successive introductions are needed to build a sustained population of *Aphidoletes*. Augment with new introductions as needed throughout the season.

Tips for using *Aphidoletes*:

- If a short period of storage is necessary, keep them between 47 and 50°F.
- Introduce in the plant canopy away from direct sunlight, preferably in early morning or evening near aphid colonies; aphids are active at night and sensitive to day length.
- Temperatures should be 60 to 80°F; humidity should be 50 to 90 percent.
- When pruning, examine leaves for presence of midge larvae. Leaves with larvae should be left in the greenhouse so that they can complete their life cycles. Employees should be trained in recognizing this life stage.
- Monitor the effectiveness of this predator by looking for aphids that appear to be shriveled and will eventually turn brown and/or black and decay. Use at least a 10x hand lens when inspecting.
- Can be used preventatively in conjunction with *Aphidius* parasitoids.

Caution: The following biocontrols are very host specific. Identify the aphid species infesting your crop before ordering from your supplier. Start crop monitoring for pest and disease development at the seedling stage and continue weekly until the end of the crop cycle. Detect and treat hot spots on a timely basis to prevent rapid colonization of aphids. Always initiate biocontrols when pest populations are low. Biological control is not a rescue treatment.

Aphidius spp., Parasitoid Wasps

Aphidius colemani

Aphidius colemani is used to control green peach aphids and melon aphids (Figure 30). This tiny (2-millimeter-long) parasitoid wasp lays one egg in an aphid. This egg hatches into a larva, which feeds on the internal parts of the aphid (Figure 31). When mature, the larva will pupate and a new adult wasp will emerge from the shriveled aphid body (mummy). These are shipped in units of 500 mummies on sawdust. Units of 500 can be applied every 0.5 to 4 square yards for 3 consecutive weeks depending on the amount of infestation.

Figure 30. Parasitoids belonging to the genus *Aphidius*. The three species available for introduction are *A. colemani, A. marticariae,* and *A. ervi.*

Figure 31. Parasitoid egg hatching into a larva inside an aphid.

Aphidius ervi

Aphidius ervi is used to control potato aphids. This parasitoid wasp has a similar appearance and life cycle as *Aphidius colemani* but is about twice its size. Like *A. colemani*, the new adult wasp exits the aphid body, leaving behind a brown shell called an aphid mummy (Figures 32 and 33). Use about one-half the rate of *A. colemani*.

Figure 32. Brown and swollen "aphid mummy" parasitized by an *Aphidius* parasitoid.

Figure 33. Adult *Aphidius* parasitoid emerged from the mummified aphid through a round exit hole.

Figure 34. Release aphid parasitoids in the greenhouse as close as possible to aphid infestations.

Tips for using *Aphidius*:

- Order adult parasitoids because smaller wasps (hyperparasites) can parasitize the larvae, especially later in the season.
- Release as soon as aphids are found (Figures 34 and 35).
- Yellow sticky traps should be removed before releasing these parasitoids. If yellow sticky traps are needed for whiteflies, hang them only 2 days per week. For thrips, use blue sticky traps.
- Temperatures should be between 65 and 77°F and relative humidity between 70 and 85 percent.
- Effective in low light levels.
- Sensitive to pesticides.

Cultural Control

Spraying aphids off plants with water can provide some temporary relief.

Other IPM Techniques

Prevention

Other effective controls for aphids:

- Install screening vents.
- Remove weeds in the greenhouse and outside the greenhouse.
- Inspect incoming plant material.
- Remove plant debris from premise or destroy by burning.
- Avoid growing ornamentals in vegetable production areas to help prevent pathogen transmission.

Figure 35. Aphid parasitoids emerging from the bottle. Protect parasitoids from ants, which will kill them.

Biorational Pesticides

Strains of the fungus *Beauveria bassiana* (BotaniGard™ and Naturalis-O™) provide good aphid control. This fungus works by attaching to the outside of the pest, penetrating into its body, and killing it.

Horticultural oils, insecticidal soaps, and botanical insecticides such as neem or natural pyrethrums (which may have a negative effect on some biocontrols) are also used against aphids (Greer, 2000).

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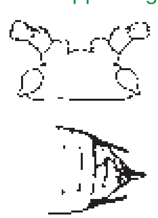
Identification of Green Peach, Melon, and Potato Aphids

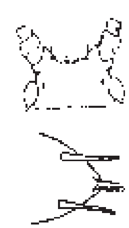
This key identifies the wingless and winged forms of the only three species of aphids in the manual—the green peach, melon, and potato aphids. To use the key, a 10x magnifying glass is needed.

WINGLESS APHIDS

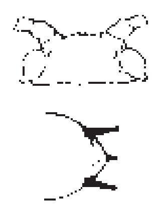
- Medium to large (≥ 3 mm); cornicles longer than cauda; antennal tubercules developed
  - Antennal tubercules swollen; body pear shaped; appendages light

    Myzus persicae
    green peach aphid
  - Antennal tubercules diverging; body long (4 mm), apple green; very mobile

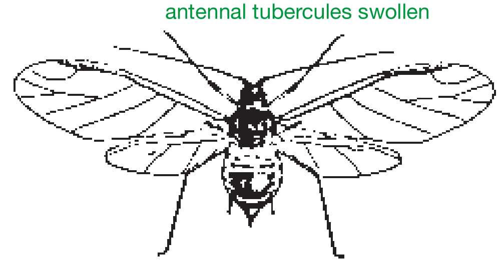
    Macrosiphum euphorbiae
    potato aphid
- Small, rounded (2 mm); cornicles short (= cauda); head flattened

  Aphis gossypii
  melon aphid

WINGED APHIDS

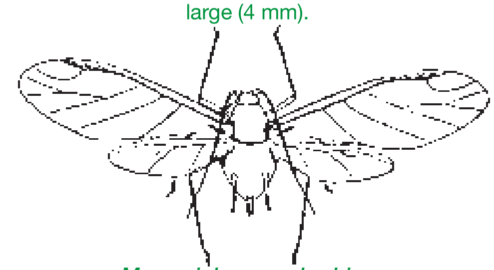
- Thorax darker than abdomen
  - Irregular patch on dorsal abdomen; medium to large (≥ 3 mm); antennal tubercules swollen

    Myzus persicae
    green peach aphid
  - No abdominal dorsal patch; small (< 2 mm); abdomen light to dark green

    Aphis gossypii
    melon aphid
- Thorax green; no abdominal dorsal markings; large (4 mm).

  Macrosiphum euphorbiae
  potato aphid

Modified from Godin, C. and G. Boivin. 2002. *Field Identification Guide to Aphids in Quebec Vegetable Crops*. For the Department of Agriculture and Agri-Food, Government of Canada, Minister of Public Works and Government Services Canada, 1999. http://res2.agr.ca/stjean/publication/web/aphidinae2_e.htm (accessed 5/6/2004).

Mealybugs: Homoptera: Pseudococcidae

Description and Identification of Pest

Mealybugs feed on a wide range of host plants. Foliage plants in greenhouses and interior plantscapes are very susceptible to mealybugs. Vegetables such as tomato, cucumber, and eggplant can serve as hosts for mealybugs as well.

Mealybugs are in the same superfamily as scale insects but are not covered with a hard shell like most scales. Mealybugs are covered with a white, waxy powder with threadlike projections around their perimeter (Figure 36). This waxy powder serves as protection from chemical pesticide applications. Clusters of mealybugs look like a cottony mass. The key to controlling this pest is to detect infestations before they become too dense. Biocontrols should be introduced when mealybugs are first spotted.

The most significant mealybug species attacking greenhouse crops are the citrus mealybug (*Planococcus citri*) and the longtailed mealybug (*Pseudococcus longispinus*).

Figure 36. Citrus mealybugs have piercing, sucking mouthparts and are covered with a white, waxy powder with threadlike projections.

A key to mealybugs can be found at http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/mealykey.htm (accessed 6/3/2004).

Life Cycle

Citrus mealybugs produce eggs in cottony structures called ovisacs (Figure 37). Eggs hatch into nymphs called crawlers in about 10 days. The crawlers move around the plant to find a suitable feeding site and then begin to feed on plant sap. Once they begin feeding, they are no longer mobile and begin to produce their waxy covering. They are only susceptible to chemical pesticides during their crawler stage. They have three nymphal stages in their life cycle, which takes approximately 30 days at 86°F.

Longtailed mealybugs produce fewer offspring than citrus mealybugs and do not produce the cottony ovisacs. Females produce live young or lay eggs that hatch almost immediately into crawlers.

Damage to Plant

Mealybugs have piercing, sucking mouthparts. Their feeding causes stunting of plants, and leaves turn yellow and appear distorted. Mealybugs, like aphids, excrete honeydew that serves a substrate for black sooty mold development, affecting the cosmetic value of the plant.

Scouting and Thresholds

Inspect carefully along the leaf midribs, at stem axils, and on undersides of leaves for white flecks or cottony residues. If larger plants are staked, mealybugs may hide beneath the tape on the stake used to secure the plant. Honeydew, sooty mold, and the presence of ants may also indicate a mealybug infestation.

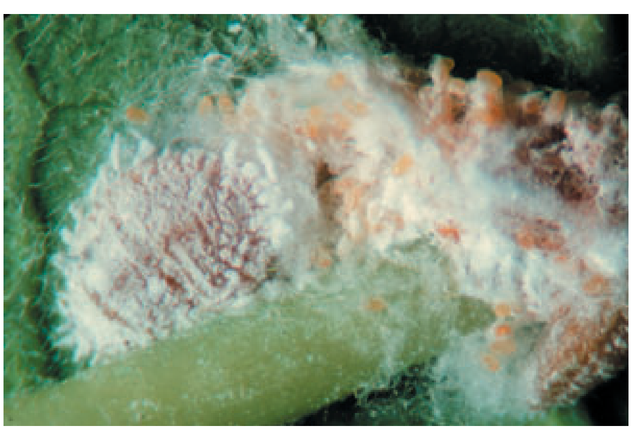


Figure 37. Citrus mealybug eggs in cottony structures called ovisacs.

Figure 38. *Cryptolaemus montrouzieri,* a small predatory ladybird beetle.

MANAGEMENT

Biocontrol

Cryptolaemus montrouzieri, Mealybug Destroyer

Cryptolaemus is a predatory ladybird beetle native to Australia (Figure 38). This predator is one of the most effective biocontrols for mealybug species producing cottony egg masses. Adults and young larvae eat every stage of the mealybug. The orange-brown adult beetle can reach a length of 4 millimeters. Female beetles live approximately 2 months and lay ten eggs a day in a mealybug colony or in a group of mealybug eggs. Eggs hatch into larvae that can grow to 13 millimeters and are recognized by the long, white, waxlike filaments. Because of this white secretion, the larvae and prey look very similar, and the biocontrol agent is sometimes mistaken for the pest (Figure 39). Young larvae are voracious predators of smaller stages of mealybugs, whereas the larger larvae will eat mealybugs of any size. *Cryptolaemus* is most active when the weather is sunny, with an optimal temperature of 68°F for a few hours each day and relative humidity between 70 and 80 percent.

Cryptolaemus is shipped as adults in plastic tubes. Introduce two to five adult beetles per infested plant; repeat as necessary for control.

Tips for using *Cryptolaemus*:

- Do not store adult beetles in containers for more than 18 hours.
- Since adults tend to disperse, keep windows and vents closed the day of release.
- Release the predators in the evening on day of receipt, if possible.
- Humidity should be 70 to 80 percent when released.
- *Cryptolaemus* won't fly at temperatures below 56°F.
- Mist the site with water before releasing.
- Gently tap beetles out of the container directly onto the foliage of infested plants.
- Don't wear white clothing when releasing the beetles because they are attracted to white.
- To assist beetles in locating the prey, place white 3 x 5 inch cards next to hot spots.
- Control ants if they are present—they protect the pests.

Leptomastix dactylopii, a Parasitoid Wasp

This tiny (3-millimeter-long) chalcid wasp is efficient in controlling citrus mealybugs but is not effective for other mealybug species (Figure 40). With heavy infestations, this parasite works well in conjunction with *Cryptolaemus*. Adult female wasps search the leaves for larger stages of mealybugs. Upon finding a suitable host, the wasp will lay an egg in the mealybug and a new parasite will emerge from its parasitized body. One wasp can parasitize 50 to 100 mealybugs. Its lifecycle takes approximately 3 weeks at 75°F.

Adults are shipped in small tubes with 100 adults per tube and can be released at a rate of one or two adults per square yard of infested area or five adults per infested plant. Repeat once or twice a year.

Tips for using *Leptomastix*:

- Discontinue the use of residual pesticides 4 to 6 weeks before introducing biocontrols.
- Identify the mealybug species before using this biocontrol; it is effective only against citrus mealybugs.
- Introduce *Leptomastix* when citrus mealybugs are first detected.

Figure 39. The larval stage of *Cryptolaemus,* which almost resembles a mealybug.

Figure 40. *Leptomastix dactylopii,* a tiny parasitoid wasp and natural enemy of mealybugs.

- Release immediately upon receipt.
- Release in mealybug hot spots; this wasp species mostly walks to search for its host.
- More than one release may be needed; scout weekly.

Cultural Control

- Inspect new plants carefully. Isolate any plants infested with mealybugs.
- Heavily infested plants should be discarded.
- Clean pots thoroughly and inspect used pots and edges of trays for egg masses and/or crawlers.
- Avoid overfertilizing with nitrogen.
- Flush mealybugs off leaves with water.

Other IPM Techniques

Biorational Pesticides

Beauveria bassiana (BotaniGard™ and Naturalis T&O™) is a fungus that secretes enzymes, which dissolve the insect's cuticle. After it enters the insect's body, the fungus produces a toxin that weakens the insect's immune system. Thorough coverage is needed so the fungal spores contact the insect. Repeated applications may be needed.

Other Pesticides

Insecticidal soaps and horticultural oils are most effective when applied underneath leaves, on pots, and on areas surrounding plants where crawlers could migrate.

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Mites: Arachnida: Acarina

DESCRIPTION AND IDENTIFICATION OF PEST

Mites are common pests in greenhouses. Being in the class Arachnida, they are not insects but are more closely related to spiders and ticks. Adults have eight legs (except the eriophyid mites with four legs) and no antennae or body segmentation. Mites feed by inserting their piercing mouthparts into plants and sucking up the liquid contents. They are tiny (most are less than 0.5 millimeters long) and often difficult to detect.

Four groups of mites are important in greenhouses: spider mites, false spider mites or flat mites, broad and cyclamen mites, and eriophyid mites (bud, gall, and rust mites).

Twospotted Spider Mites

Twospotted spider mites (*Tetranycus urticae*) are widely distributed and are common pests of many plant species. Adults, about 0.4 millimeters long, are straw yellow and can be identified by their characteristic two dark spots on their bodies. The "spider" part of the name derives from their ability to produce a fine webbing on plants. Damage includes stippling or bronzing of leaves. Round eggs are usually laid on the underside of leaves.

False Spider or Flat Mites

These mites, about 0.3 millimeters long, are reddish with occasional black patterns on their backs and produce no webbing. They are slow moving and commonly found feeding on the undersurface of leaves, usually near veins. Damage consists of chlorosis or stippling. Oval-shaped eggs are bright red and laid in clusters on both leaf surfaces.

Broad and Cyclamen Mites

These mites are so small they are difficult to see even with a hand lens. Broad mites produce eggs with rows of white tubercles. Nymphs remain hidden in cracks and crevices of the plants and become immobile after some development. Females are clear after hatching, soon turning straw colored with a prominent white stripe down their backs. A generation can be completed in 4 to 5 days. Damage appears on younger foliage and undersides of leaves, giving leaves a scalloped edge resembling physiological damage.

Cyclamen mites are not found on open leaf surfaces. Their oblong eggs are opaque, lack tubercles, and are found on the upper surface of young leaves. Bodies of nymphs are constricted behind their third pair of legs. Females hatch clear but turn amber with age. The first sign of damage is slightly curled or deformed new leaves on the crown. Damage also includes deformed buds.

Eriophyid Mites

Too small to be detected with the unaided eye, these cigar- or wedge-shaped mites have four very short legs near the front end. Most are light colored and live in protected areas on the host. Damage includes galls and deformed or discolored plant tissue. Generally eriophyid mites are host specific.

LIFE CYCLES

Twospotted Spider Mites

Twospotted spider mites have five life stages—egg, larva, two nymphal stages, and adult. Females can deposit hundreds of eggs during a lifetime. Usually laid underneath leaves, eggs hatch in 2 to 4 days into six-legged larvae that begin feeding immediately (Figure 41). Within another 2 to 4 days, the larvae will have passed through the next two stages and become adults (Figure 42). Total development time (egg to adult) at 86°F is 7 days. Nymphs and adults produce webs and, if populations are high, the plant can be completely covered with webbing (Figure 43). At this point, obtaining control is difficult and biological (or chemical) control may be ineffective.

False Spider or Flat Mites

Little is known of their life cycle. Adults overwinter on their hosts. Oval, bright-red eggs are deposited singly on the host in spring and several generations occur before fall. Populations generally are highest in spring and fall.

Broad and Cyclamen Mites

Females lay their eggs and feed on young, unfolding leaves at the crown of the plant. When leaves are fully unfolded, they appear stunted, crinkled, and malformed. A generation of mites may be completed in 2 weeks, so populations can grow rapidly.

Eriophyid Mites

Most eriophyid mite species go through four stages of development—egg, two nymphal instars, and adult. Females overwinter in protected areas on the host. The length of life cycle is variable depending on the species, but it is usually approximately 7 days. As the season progresses, populations tend to increase. Gall-forming eriophyids inject a growth-regulating substance into the host tissue as they feed. Only newly developing tissue is susceptible to the effects of this chemical, producing a characteristic tissue growth or gall.

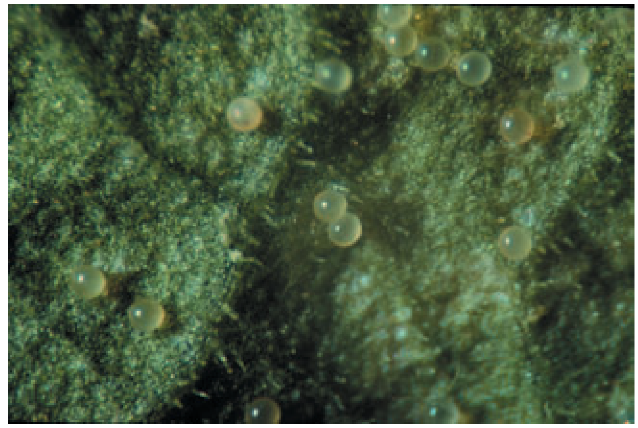

Figure 41. Twospotted spider mite eggs deposited on the underside of a leaf.

Figure 42. Twospotted spider mite nymphs.

Figure 43. Plant covered with webs—an indication of advanced spider mite damage.

DAMAGE TO PLANT

Plant damage is caused by larvae, nymphs, and adults piercing plant tissue and sucking out the liquids. Damaged areas appear as yellowish-white spots (stippling) from destroyed chlorophyll in the leaf surface (Figure 44). As populations increase, the whole leaf will eventually turn yellow. Other mites cause distortion or crinkling of new tissue. Eriophyid mites are often named by the damage caused: rust mite, gall mite, blister mite, bud mite, etc.

SCOUTING AND THRESHOLDS

Since there is no winged stage, sticky traps are ineffective. Plant inspection is the only reliable method to assess the presence of mites. Recognizing the early signs of mite feeding is important.

Spider mites cause stippling or bronzing of leaves as feeding destroys chlorophyll. Heavily infested plants will also have webbing present. To easily see the webbing, gently mist the plants to make the webbing visible. These mites like it dry and warm and are often found near vents, doors, and heaters in greenhouses, so monitor these areas carefully. A good technique for detecting mites is to tap the leaves over a sheet of white paper, dislodging mites and providing for easier identification. Using a good hand lens is essential to viewing mites in egg, nymph, and adult stages. Crop losses may occur when about 30 percent of the leaf surface is damaged. Flag hot spots for ease in locating release spots for biocontrols.

False spider mites produce no webbing but cause silvering of leaves. Look closely for the bright-red, oval-shaped eggs on leaves.

Figure 44. Twospotted spider mite feeding damage can be seen on the upper surface of the leaf as small yellow spots. This feeding reduces the photosynthetic area of the leaf affected, decreasing plant yields and reducing the aesthetic value of the plant.

Cyclamen and eriophyid mites are so tiny that, apart from symptoms listed above, actual observation of the mites may require a dissecting microscope.

MANAGEMENT

Biocontrol

Spider mites were the first greenhouse pests to be controlled by a commercial application of natural enemies. Several predators are commercially available from biocontrol suppliers, many of which will feed on the other groups of mites. Biocontrols are rarely effective on cyclamen or eriophyid mites. Probably the best way to manage these mites is to remove and destroy infested plants as soon as they are detected.

Phytoseiulus persimilis, a Predatory Mite

Phytoseiulus is the mainstay in spider mite control and can be used on many crops (Figure 45). They are active year-round and feed on spider mite eggs, larvae, nymphs, and adults. They reproduce faster than spider mites at temperatures above 82°F. When scouting, flag active spider mite colonies. Concentrate predator introductions at these hot spots as soon as possible after delivery. Monitor for effectiveness by inspecting plants for dead spider mites that appear as tiny black dots on plants while watching for the oval predator mite eggs and the adult predator mite. *Phytoseiulus* is orange red and much more mobile than spider mites. Introduce *Phytoseiulus* weekly for 3 weeks or until desired control is achieved.

Phytoseiulus is supplied in tubes of 1,000 to 2,000 adults mixed with vermiculite or corn cob grits. Application rate for a light infestation is one predator mite per square foot plus 10 predator mites per mite-infested leaf; heavy infestation rate is 10 to 100 mites per plant.

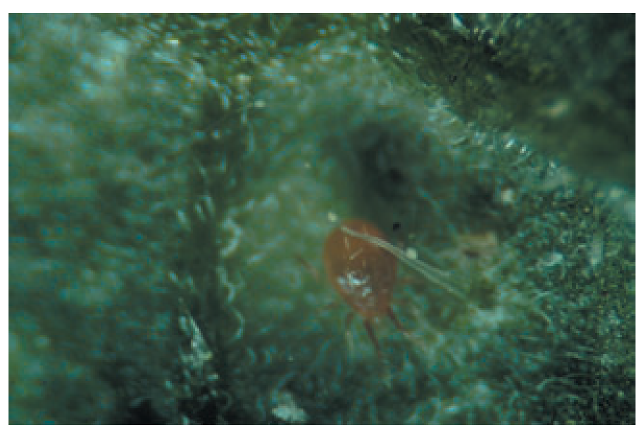

Figure 45. *Phytoseiulus persimilis,* an important predator for twospotted spider mites.

Tips for using *Phytoseiulus*:

- Start early to control spider mite populations.
- Gently roll the tube to mix the predatory mites equally in the carrier before application.
- Place predators directly onto infested leaves or pour into plant hangers.
- *Phytoseiulus* must have spider mite prey or they will disperse or starve.
- Spider mite colonies should be reduced within 2 to 3 weeks.
- Typically, *Phytoseiulus* will eventually exhaust its food supply and starve, so it must be reintroduced if the spider mite population increases again.
- If control is not achieved, increase the rate of predatory mites.

Neoseiulus (Amblyseius) californicus, a Predatory Mite

If the greenhouse humidity ranges below 60 percent, a long-term biocontrol option would be the predatory mite *Neoseiulus californicus* (Figure 46). In crops where detecting spider mite populations is difficult, this mite can be introduced on preventative basis since it can survive in the absence of prey.

Start early to control spider mite populations since spider mites reproduce quickly at high temperatures and low humidity. Once the spider mite population has built up, introduce both *Neoseiulus* with *Phytoseiulus* to clean up hot spots on a curative basis. Monitor weekly for predator activity by checking spider mite colonies for larval development and for shriveled pest mites that have been fed upon. *Neoseiulus* can be used as a biocontrol for broad mites (*Polyphagotarsonemus latus*) and cyclamen mites (*Tarsonemus pallidus*).

Figure 46. *Neoseiulus californicus,* a predatory mite for twospotted spider mites.

Neoseiulus is supplied in tubes of 1,000 to 2,000 adults mixed with vermiculite or corn cob grits. Release rates are similar to *Phytoseiulus*.

Tips for using *Neoseiulus*:

- Concentrate predator introductions at spider mite hot spots as soon as possible after delivery.
- Gently roll the tube to mix the predatory mites equally in the carrier before application.
- Place predators directly onto infested leaves or pour into plant hangers.
- Storage in refrigeration at 55°F is possible for up to 5 days.

Feltiella acarisuga, a Predatory Midge

A natural enemy that can be used in conjunction with predatory mites is the predatory midge *Feltiella acarisuga*, whose larvae feed on spider mite eggs. *Feltiella* may be especially effective when spider mites occur in colonies. *Feltiella* is good at finding hot spots and can be effective in combination with predatory mites. *Feltiella* can be an effective year-round predator, remaining active in cold and dark weather in spring and fall, and is particularly useful on hairy-leaved plants (such as tomatoes). This is a predator that can be found naturally in greenhouses (and gardens) if spider mite densities are high and pesticides are not used. The adults can fly and locate colonies of spider mites and work well in crops where scouting is difficult (e.g., in ornamentals).

Feltiella acarisuga is shipped as pupae on leaves or pieces of paper in units of 250.

Tips for using *Feltiella*:

- Introduce one to five adults per square yard each week for 4 weeks.
- Open the box containing predators in the greenhouse and place as close as possible to spider mite infestations. Let the box stand for at least one week until adults have emerged.
- Provides long-lasting protection with several introductions.

Cultural Control

Use clean, pest-free plants and cuttings. Knowledge of mite-prone plant varieties can help growers avoid them or monitor them closely. Drought-stressed plants are most prone to mite outbreaks, while overhead sprinkler systems are less favorable for mite outbreaks but lead to other problems.

Cyclamen mites are slow moving, and spread to other parts of the greenhouse probably occurs only when they are transferred mechanically on clothing, empty flats, splashing water, and so forth. Continual sanitation practices help prevent serious spread of this mite.

Gall-forming eriophyids can be somewhat controlled by sanitation (removal of galls). Chemical control of eriophyids is difficult to obtain because distorted leaf surfaces hinder thorough spray coverage.

Remember to maintain broadleaf weed control inside the greenhouse and for at least 20 feet around the outside. In many cases, spider mite infestations develop from weeds left in the greenhouse from the previous crop season. Remove and destroy the weeds.

Other IPM Techniques

Few chemical options are available for minor crops such as greenhouse vegetables and herbs. Ultra-fine horticultural oil and insecticidal soap are low residual toxicity pesticides that provide control when applied thoroughly to cover plants where mites are feeding. Oils have little or no impact on natural enemies and can be incorporated into a biocontrol program.

High-volume, high-pressure water sprays can dislodge many mites from foliage and temporarily suppress their populations.

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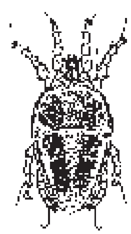
Identification of Mites

This key identifies only the main groups of mites in the manual. To use the key, a 10x magnifying glass or dissecting microscope is needed.

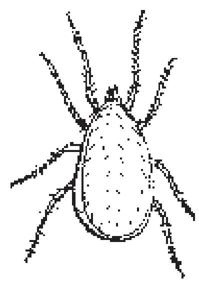
- Mites visible to naked eye. Infested plant may be discolored but usually not distorted by feeding.
  - Mite feeding on foliage, relatively slow moving.
    - Mites feeding on foliage, causing tiny chlorotic spots. Fine silk webbing may be present.

      Two spotted spider mite ***Tetranychus urticæ***
    - Mites feeding on foliage, no silk present.

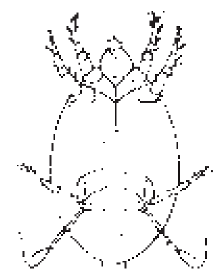
      Flat or false spider mite ***Brevipalpus* spp.**
  - Predatory mite, no spots, pear shaped, moves quickly.

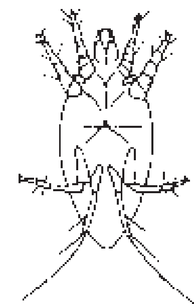
    Predatory mite *Phytoseuilus* spp.
- Mites not visible without at least 10x hand lens. Infested plant usually ceases blooming, has distorted leaves and stems, blasted buds.
  - Cigar- or wedge-shaped, extremely small.

    Rust, gall, or Eriophyid mite
  - Not cigar- or wedge-shaped.
    - Oval egg, 0.08 mm long, covered with minute, white bumps. Female translucent brown, about 0.2 mm long, shaped like fat football.

      Broad mite ***Polyphagotarsonemus latus***
    - Oval egg, 0.1 mm long, without bumps. Female translucent brown, about 0.3 mm long, shaped like skinny football.

      Cyclamen mite ***Steneotarsonemus pallidus***

Information from: North Carolina State University, *Insect and Related Pests of Flowers and Foliage Plants*. http://ipm.ncsu.edu/AG136/index.html (accessed 5/6/2004).

Soft Scales: Homoptera: Coccidae

DESCRIPTION OF PEST

Four families of scale insects can be found in Pennsylvania greenhouses. Most of them, however, are from one of three families, the Coccidae (soft scales), the Pseudococcidae (mealybugs, considered in the previous chapter), and the Diaspididae (armored scales, not discussed in this manual). The fourth family, the Eriococcidae, is represented in Pennsylvania greenhouses by only two species and is also not discussed in this manual.

The Coccidae are called soft scales because their bodies are soft, pliable, and usually naked. At maturity their skins often become somewhat hardened, or they may secrete various quantities of wax, but they never produce a shield as the armored scales do. Soft scales are large, reaching lengths up to 4 or 5 millimeters. They excrete a waste product, honeydew, which is a thick, sugary liquid. The honeydew falls on lower structures and leaves, coating them with a shiny, sticky film. Sooty mold thrives on honeydew, and blackened foliage may indicate the presence of a soft scale infestation (Stimmel, 1987). However, honeydew may also indicate some species of aphids, mealybugs, whiteflies, or Eriococcids.

Brown soft scale (*Coccus hesperidium* Linnaeus) is the most common scale found on indoor plants and is reported to feed on hundreds of plant species.

Adult female brown soft scales are pale yellowish green to yellowish brown with nerve-like brown markings on the dorsum. Older females appear brown. The male looks like a tiny two-winged wasp or fly. However, males are rarely produced. These scales cannot survive northern winters but thrive in greenhouses.

A key to scale insects often found in greenhouses is available online at http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/scalekey.htm (accessed 6/3/2004).

LIFE CYCLE

Brown soft scale crawlers are born alive, but before emerging they remain under the body of the female for a short time (Figure 47). After emergence they select a feeding site and settle, undergoing several molts before completing their development. Overlapping generations are found throughout the year in greenhouses and all stages can be found on the host at a given time, making control difficult. Adult scales are protected from insecticides by their hardened impenetrable skin, so pesticide applications must be repeated to target the overlapping generations of vulnerable crawlers.

DAMAGE TO PLANT

Feeding from brown soft scales can reduce the health of a plant, causing leaves to turn yellow and drop, and it may stunt new growth. As scales feed with their piercing-sucking mouthparts, they excrete sticky honeydew that serves as substrate for sooty mold development. This sooty mold reduces the photosynthetic surface of the leaf and also affects the aesthetic value of the plant. Female scales spend their adult life attached to the underside of leaves along veins and stems where sap flows. Infestations can become so heavy that the scales encrust stems and petioles. Such colonies remove large amounts of plant fluids and can cause wilting.

SCOUTING AND THRESHOLDS

Visual inspection will help locate infestations and may permit localized treatment of hot spots. Ants climbing on the plant can also indicate a problem with scales. Presence of honeydew and sooty mold may indicate the presence of soft scales.

Treatment is generally warranted when scales are present. Optimum treatment time is when crawlers are active, but often there are overlapping generations requiring multiple applications.

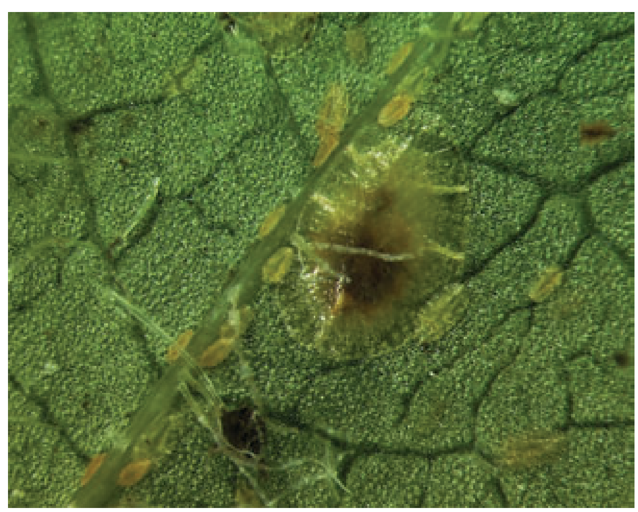


Figure 47. Adult female brown soft scale surrounded by crawlers.

MANAGEMENT

Biocontrol

Cryptolaemus montrouzieri, a Mealybug Destroyer

Cryptolaemus montrouzieri is a small (3- to 4-millimeter-long), predatory ladybird beetle used to control mealybugs and scales. They hide under leaves and in plant crevices where scales are usually feeding. Their eggs hatch into voracious larvae with long, white, waxy projections resembling those of a mealybug. *Cryptolaemus* prefers a temperature range of 72 to 77°F with a relative humidity of 70 to 80 percent.

Cryptolaemus is shipped as adults in plastic tubes. Depending on the infestation level, two to three adults per square yard or two to five adults per infested plant are introduced.

Tips for using *Cryptolaemus*:

- Do not store adult beetles in containers for more than 18 hours.
- Since adults tend to disperse, keep windows and vents closed the day of release.
- Release the predators in the evening on day of receipt if possible.
- Humidity should be 70 to 80 percent when released.
- *Cryptolaemus* won't fly at temperatures below 56°F.
- Mist the site with water before releasing.
- Gently tap beetles out of the container directly onto the foliage of infested plants.
- Don't wear white clothing when releasing the beetles, as they are attracted to white.
- To assist beetles in locating prey, place white 3 x 5 inch cards next to hot spots.
- Control ants if they are present—they protect the pests.

Metaphycus helvolus, a Soft Scale Parasitoid

Metaphycus helvolus is a tiny (1.5- to 2-millimeter-long) parasitoid wasp that is very effective when used as a preventive agent. *Metaphycus* is shipped as pupae. Due to their minute size, adult wasps may get caught in honeydew if it is heavy. If honeydew is excessive, plants should be rinsed before introducing the wasps, or predators may be used instead. The adult wasp places one egg inside each scale, which, upon hatching into a larva, consumes the scale from within. A new parasitoid emerges from the empty scale cadaver. The development time of this parasitoid is about 42 days. Adults live about 2 months. The optimum environmental conditions are 73 to 87°F with a relative humidity of around 50 percent. Release five to ten pupae per plant.

Tips for using *Metaphycus*:

- Use *Metaphycus* as a preventive treatment.
- Release biocontrols immediately upon delivery.
- Temperature should be 73 to 90°F; humidity 50 percent.
- Release biocontrols on a regular basis to prevent outbreaks and keep scale populations at manageable levels.
- Follow release recommendations from biocontrol suppliers.
- These parasitoids are attracted to yellow sticky traps. If the traps must be used, hang them only 2 or 3 days a week.
- Inspect stems and leaves of plants on a weekly basis to determine if biocontrols are effective in reducing populations.

Cultural Control against Brown Soft Scale

- Remove infested plant material immediately.
- Prune out heavily infested plant parts to prevent scales from spreading.
- Avoid overfertilizing.
- Gently spray plants with water to remove scales and honeydew (sooty mold) deposit.

Other IPM Techniques

- Inspect new or introduced plant material for scales looking for shiny spots of honeydew on tops of leaves.
- Insecticidal soaps and horticultural oils (when not phytotoxic) may be most effective against scales crawlers when applied underneath leaves.

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Thrips (WFT): Thysanoptera: Thripidae

DESCRIPTION AND IDENTIFICATION OF PEST

Many thrips species attack greenhouse and nursery crops, but the most economically important species is western flower thrips (WFT) (*Frankliniella occidentalis*) because it is a vector for the major tospoviruses, Impatiens Necrotic Spot Virus (INSV), and several strains of Tomato Spotted Wilt Virus (TSWV). Viruses are acquired by first instar nymphs feeding on infected plants but are not transmittable until the thrips reach the adult stage, when they can transmit the virus by feeding on susceptible hosts. WFT have a broad host range and may feed on impatiens, fuchsia, chrysanthemum, ivy geraniums, verbena, petunia, cyclamen, primula, and many other ornamentals.

Adult WFT are tiny (1- to 2-millimeter-long) insects with narrow bodies and fringed wings (Figure 48). Colors vary from straw yellow to brown. They feed with rasping-piercing-sucking mouthparts, resulting in deformed flowers and leaves. Even with a hand lens, identifying the species of thrips infesting a crop may not be possible.

Detecting and treating this pest early is critical to minimizing virus transmission. Brown- or black-edged lesions will develop on the edges of thrips feeding scars within 3 days if a tospovirus has been transmitted. Greenhouse vegetable seedlings and transplants should be isolated from ornamental plants.

A key to several kinds of thrips that may be found in greenhouses is available online at http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/thripkey.htm (accessed 6/4/2004).

Figure 48. Adult western flower thrips.

LIFE CYCLE

Female WFT insert eggs into leaves and buds, thus protecting them from insecticides. Eggs hatch in about 2.5 to 4 days into pale-yellow larvae. Two larval stages usually remain protected in flower buds or terminal foliage (Figure 49). At the end of the second larval stage, they stop feeding and move into the soil or leaf litter to pupate (Figure 50). The entire life cycle from egg to adult takes approximately 12 days at 86°F. Adults can survive 30 to 45 days and lay 150 to 300 eggs, depending on temperature and host plant, and feed in protected areas of the plant, such as flowers and terminals (Smith, et al., 2000).

Figure 49. One of the two stages of western flower thrips. Tap leaves and blossoms over a white sheet of paper to dislodge life stages.

Figure 50. Western flower thrips in the prepupal stage.

DAMAGE TO PLANT

WFT eat by rasping plant tissue and feeding on exuded juices on leaves, flowers, and buds of many plants. As damaged leaves and flowers grow, they appear deformed or streaked or have a silvery appearance. Black specks of excrement may also be evident where thrips have fed (Figures 51, 52, and 53).

WFT are vectors of INSV and TSWV. Virus symptoms may include ringspots, vein necrosis, mottling, or mosaic patterns (Figures 54 and 55). Vegetable plant yields are reduced, and fruit may be unmarketable. If you suspect that a plant has a virus, have it tested through a laboratory or use an onsite diagnostic kit. Once the plant is infected, no treatment for this virus is available. If INSV/TSWV is detected, rogue and remove infected plant material to prevent further spread of the virus.

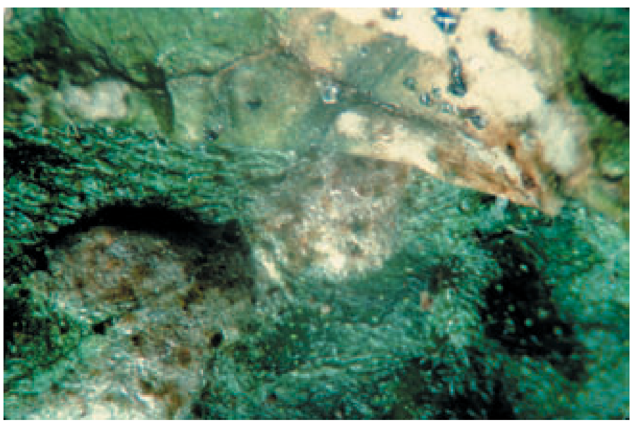

Figure 51. Tomato plant damage—silver-gray spots and dark-green fecal spots on the leaves—caused by thrips piercing and sucking out cells on the leaf surface.

Figure 52. Thrips feeding damage causes distortion on leaves of poinsettia cuttings.

Figure 53. Western flower thrips damage on greenhouse tomato leaves.

Figure 54. TWSV on tomato transplant. Greenhouse vegetable transplants should be isolated from ornamental plants.

Figure 55. INSV on garden impatiens. Rogue and destroy infected plant material.

SCOUTING AND THRESHOLDS

Early detection is critical for thrips control. Examine plants weekly for feeding damage and use blue or yellow sticky cards to detect winged adults. Blue sticky traps are more attractive to WFT. Place one trap per 1,000 square feet of growing space just above the crop canopy and hang traps near doors and vents. Before starting vegetable seedlings, monitor the growing area with sticky cards to detect lingering thrips from the previous season. Thrips are usually the smallest insects found on sticky cards. Their slender abdomen appears pointed at the rear and hairs line the edges of their wings. Female thrips are dark brown while males are yellow brown.

Adult thrips will most likely be found in blossoms and larvae on leaves or hidden deep in buds. If you have difficulty detecting thrips, tap the leaves and blossoms over a sheet of white paper (Figure 56). This technique may dislodge the dark-colored adults and the yellow larvae.

The economic threshold for thrips has not been determined for all greenhouse crops. A study in Switzerland determined that a threshold level of 20 WFT per trap per week was appropriate for chrysanthemums, while in New Mexico, a grower initiates control when just five thrips per trap per week are detected in chrysanthemums (Greer, 2000). When biocontrols are used, they should be released as soon as the first adult thrips have been trapped.

Indicator plants (susceptible varieties of plants) provide an early detection system for locating thrips. Certain petunia varieties (Carpet Blue, Blue Madness) are very effective in detecting thrips and INSV. Petunias attract thrips and may show symptoms of virus infection. However, the petunias do not become a reservoir for the virus. Virus symptoms appear as small, brown to black spots. Infected petunia leaves can be removed and the plant can be used for further detection throughout the season. Virus indicator plants should be used in vegetable production if the greenhouse range has a history of INSV. Extension greenhouse IPM specialists at the University of Connecticut give the following suggestions for using sticky cards and indicator plants (Pundt, 1992):

- Place sticky cards throughout the greenhouse to detect thrips activity and numbers.
- Place indicator plants among crops at bench or floor level every 20 to 30 feet.
- Place incoming plant material with indicator plants and isolate for at least 3 to 4 days to allow thrips scars to develop and show viral lesions.

MANAGEMENT

This pest is difficult to control with conventional pesticides because it has widespread resistance to many different classes of insecticides.

Biocontrol

WFT has many enemies, including green lacewings, but effective biocontrol of thrips often requires integration with compatible pesticides. Use of biological control methods should only be implemented as part of a well-planned IPM program. Biological control methods should not be used when either TSWV or INSV is already present in the greenhouse.

Neoseiulus (Amblyseius) cucumeris, a Predatory Mite

Neoseiulus cucumeris, a beige predatory mite smaller than 1 millimeter long, attacks thrips larvae and eggs on foliage and flowers. *Neoseiulus* pierces its prey and sucks fluids out of them (Figure 57). Mites are shipped in units of 25,000 or 50,000 in a carrier containing bran with flour mites added as food during shipment. They are applied directly to crops. Mites can also be purchased in sachets (small envelopes) containing bran, which serves as

Figure 56. Tap leaves and blossoms of plants over a sheet of white paper to dislodge western flower thrips adults and larvae.

Figure 57. The predatory mite *Neoseiulus cucumeris* attacking thrips larva.

food for flour mites; *Neoseiulus* then eats the flour mites (Figure 58). These breeder packets are hung on the plants and the predatory mites exit through the top of the sachet onto the plants. Most growers prefer the sachets because they serve as a breeding system, which provides new mites over a period of time. Release at a rate of 100 mites per square yard.

Tips for using *Neoseiulus*:

- Use when thrips populations are first detected.
- Reduce high thrips populations with a compatible insecticide. Consult biocontrol suppliers or this Web site: http://www.koppert.nl/e0110.html.
- Introduce predatory mites as soon as possible after delivery. Material may be stored for a day or two in a cool, dark place with at least 85 percent relative humidity.
- For release, temperatures should be 50 to 85°F; humidity 70 to 90 percent.
- Allow the mites to adjust to greenhouse temperature before distributing. Turn and shake the tube slightly in order to distribute the predatory mites evenly in the bran.
- The predatory mites should be sprinkled evenly throughout the plants. Sprinkle material (predatory mites mixed with bran) on leaves or in small piles on rockwool cubes.
- If using controlled-release sachets, hang them on plants near thrips infestations.
- The predatory mites develop well when relative humidity is above 65 percent.

Figure 58. Sachets (small envelopes) containing *Neoseiulus cucumeris* hung on plants.

Hypoaspis miles, a Predatory Mite

Hypoaspis miles is a predatory soil mite that feeds on thrips pupae. *Hypoaspis* can reduce thrips populations by as much as 30 to 60 percent (Figure 59). When introduced at planting time, control may last from 6 to 8 weeks. This mite should be used in conjunction with another natural enemy that will feed on thrips life stages that occur on the plants. *Hypoaspis* is also effective in reducing fungus gnat larvae. Release rate is 100 to 300 mites per square yard.

Tips for using *Hypoaspis*:

- The predatory mites should be introduced as soon as possible after delivery.
- Minimum temperature for good activity is 60°F.
- Soil must be moist but not wet.
- May be sprinkled over soil surface or mixed into growing media before planting; can be used preventively.
- When introduced at planting time, control may last from 6 to 8 weeks.
- Compatible with Bt and beneficial nematodes.
- Several pesticides have a negative effect on *Hypoaspis miles*. When controlling diseases and other pests, consult your supplier for a list of side effects of pesticides on beneficial organisms.

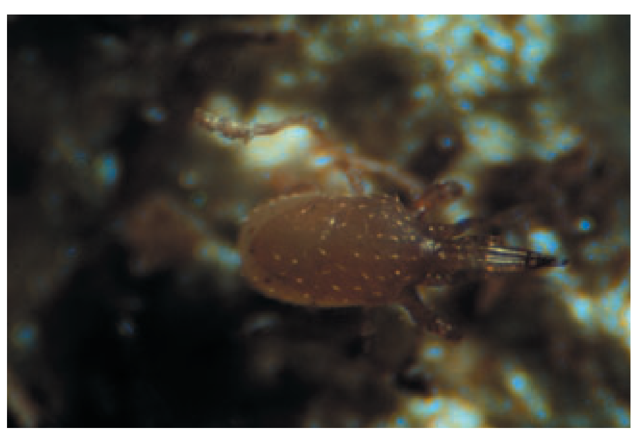

Figure 59. Brown predatory mite *Hypoaspis miles*. Use *Hypoaspis* as a preventative treatment.

Orius insidiosus, a Minute Pirate Bug

The minute pirate bug *Orius insidiosus* will attack both adult and immature thrips stages and will also feed on other prey such as aphids and spider mites (Figure 60). *Orius*, like most biocontrol agents, is not a rescue treatment and should not be used when thrips populations are high.

Orius is commercially available in the United States through biocontrol suppliers. Adults are sent in a buckwheat husk carrier, packed in a plastic bottle.

Turn the bottle and shake lightly before and during introduction to provide even distribution. Shake the material onto leaves in clusters to encourage mating and do not disturb for several days. Introduce *Orius* near thrips hot spots to increase their effectiveness. Do not introduce near sticky cards.

One adult per square yard or one every 2 square feet where pests are present. Reapply every 2 to 3 weeks if need is determined by scouting.

Tips for using *Orius*:

- Eliminate the use of toxic insecticides 2 months before introducing *Orius; Orius* is very susceptible to pesticides.
- Temperature should be 70 to 90°F.
- *Orius* can be used in combination with the predatory mite *Neoseiulus cucumeris.*
- Introduce *Orius* as soon as thrips are detected.
- Apply in the cool morning or early evening; avoid application in bright sunlight.
- *Orius* lays eggs largely in side shoots; introduce after pruning side shoots.

Figure 60. Minute pirate bug *Orius insidiosus.*

Cultural Control

WFT will fly readily and can be carried on wind currents or on clothing to nearby greenhouses. They can fly from a treated to untreated area and can move into and out of a greenhouse through doors or vents.

Sanitation is the key to controlling greenhouse pests. Eliminate sources of thrips by having good sanitation before and during the crop cycle. Remove weeds and all plant debris inside the production area and have at least a 20-foot vegetation-free zone around the greenhouse. Weeds can harbor both thrips (and other pests) and viruses. Ongoing problems with INSV are often the result of poor sanitation. Black plastic mulch covered with gravel can be used to maintain a weed-free zone around the greenhouse.

Plant debris from a previous crop can also harbor both immature and adult pests. Clean up all debris from previous crops and dispose of infested plants. Ideally, the greenhouse should be thoroughly cleaned and left empty for one week prior to beginning the next crop. This should remove all pest stages and starve any remaining adults. Closing up the greenhouse when it is empty in summer will increase the temperature and help eradicate pests. Researchers found that air temperatures of 104°F with a relative humidity of 10 percent were sufficient to kill WFT.

Examine incoming plants for thrips and reject any that are infested.

Research in California has shown that the use of 400-mesh screens as barriers over vents can help prevent the movement of thrips into a greenhouse (Smith, et al., 2000).

Greenhouse workers should avoid wearing yellow or blue to reduce the spread of thrips on their clothing.

Other IPM Techniques

Biorational Pesticides

Horticultural oils, neem oil, and other low-toxicity insecticides such as insecticidal soaps or pyrethrins can be somewhat effective for temporary reduction of thrips if applied when they first appear. These materials allow at least a portion of the natural enemy populations to survive because they don't leave toxic residues. Sprays must have thorough coverage on susceptible plant tissue such as new leaf growth and buds. Repeated applications may be needed. Protected eggs and pupae will not be killed (Dreistadt and Phillips, 2001).

Biorational Pesticide

Beauveria bassiana

This is a strain of fungus that is pathogenic to insects. To be lethal, fungal spores must directly contact the pest. Spores attach to the insect cuticle, where they germinate and the fungus infects the body cavity, killing it after 7 to 10 days. Two products commercially available are BotaniGard™ and Naturalis T&O™.

This fungus will not control heavy pest populations and therefore should be used as a preventive rather than a rescue treatment. Successive treatments may be required for control.

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Whiteflies: Homoptera: Aleyrodidae

DESCRIPTION AND IDENTIFICATION OF PEST

Whiteflies are tiny, sap-sucking insects usually smaller than 2 millimeters long that excrete honeydew and cause yellowing or death of leaves. Several species of whiteflies attack greenhouse crops, especially vegetables. The most common species infesting vegetables is the greenhouse whitefly. In a fall crop, the outdoor species, bandedwinged whitefly, may be observed on yellow sticky cards and occasionally feeds on plants in the greenhouse. A more serious pest species, the silverleaf whitefly (SLWF), is a common pest on poinsettias and is difficult to control due to its high reproductive rate and resistance to insecticides. Biocontrol is an effective alternative.

Whiteflies have sucking mouthparts and cause damage by feeding on plant sap. Both the adult and nymphal stages feed on sap and excrete waste in the form of honeydew, which serves as a medium for sooty mold development on foliage and fruit. Sooty mold can affect plant yields by reducing photosynthesis, and residue on fruit requires extra handling time. Whiteflies may also serve as vectors for several viral diseases.

Species identification is critical because different species respond differently to control strategies, both chemical and biological. Experienced growers may be able to identify species in the adult stage, but a more reliable method is to examine the pupal stage. Identification requires a 10x to 20x magnification.

Greenhouse Whitefly *(Trialeurodes vaporariorum)*

Greenhouse whitefly is the most common species on greenhouse vegetables. Adults hold their wings flat (horizontally) over their bodies (Figure 61). The pupal stage is white with straight, elevated sides and a fringe of wax filaments.

Figure 61. Greenhouse whitefly adult with its wings held horizontally (flat) over its body.

Bandedwinged Whitefly *(Trialeurodes abutilonia)*

Heavy populations of this species can be found outdoors on weeds and ornamentals in the fall. As their host plants decline, they begin to seek other plants and commonly make their way into greenhouses through vents and doors (Figure 62). This species may feed and lay a few eggs, but they usually do not cause damage or complete their life cycle in the greenhouse. High levels on sticky cards may alarm growers to make unnecessary pesticide applications. Adults hold their wings horizontally like greenhouse whiteflies, but they can be distinguished by two gray bands that form a zigzag pattern across each forewing. The pupal stage is distinguished from greenhouse whiteflies by a black band down the center of the pupal case (Figure 63).

Silverleaf Whitefly *(Bemisia argentifolii)*

Silverleaf whitefly is a common pest of poinsettias, foliage plants, and ornamentals. If ornamentals are grown in vegetable production houses—not a recommended practice—this pest will also colonize on vegetable plants. The SLWF has an enormous number of hosts. It is smaller than the greenhouse whitefly and holds its wings close to the body (Figure 64). The pupal stage is a bright yellow with a few waxy filaments. The pupa does not have a high profile like the greenhouse whitefly.

In addition to causing damage by sucking the leaf tissue and excreting honeydew, SLWF is an important carrier of damaging viruses, transmitting more than 25 viruses and many other virus-like diseases. Avoid colonization of this pest in vegetables by separating vegetable and ornamental crops. If you produce your own vegetable transplants and also grow ornamental crops, isolate a separate area for vegetable transplant production.

If you cannot identify the species attacking your crop, contact the cooperative extension service or the PDA for help or check the USDA's Whitefly Knowledgebase at http://whiteflies.ifas.ufl.edu/, or the University of Florida's information on silverleaf whitefly at http://www.imok.ufl.edu/entlab/projects/whitefly.htm.

Figure 62. Adult bandedwinged whitefly identifiable by two gray bands across each forewing.

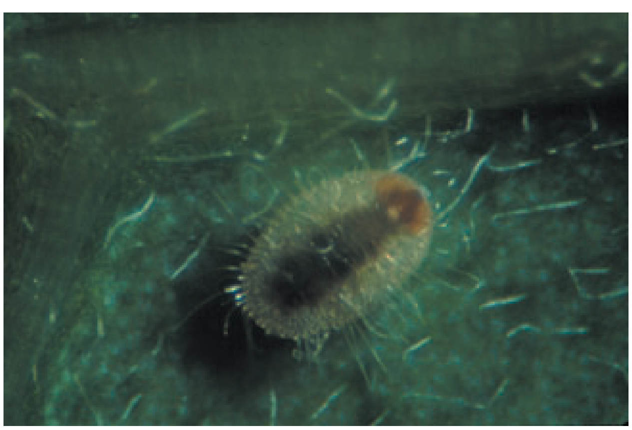

Figure 63. Pupal stage of bandedwinged whitefly.

Figure 64. Silverleaf whitefly with its wings held close to the body at a 45-degree angle.

LIFE CYCLE

Whitefly life stages include the adult, egg (Figures 65 and 66), three nymphal instars, and the fourth instar or pupa stage, all occurring on the underside of the leaves. The first nymph stage is referred to as the crawler stage, which moves around for several hours and then settles and remains there. Later nymphal stages are oval and flattened, resembling small scale insects with legs and greatly reduced antennae (Figure 67). During the pupal stage, you may see the red eyes of the developing adult (Figure 68). The final stage (pupa) develops a waxy fringe and appears elevated on the leaf surface. Empty pupal cases have a T-shaped opening after adult emergence (Figure 69). Development time varies with species, host plant, and temperature.

Figure 67. Eggs that have hatched into mobile larvae, which will eventually become immobile to complete the life cycle.

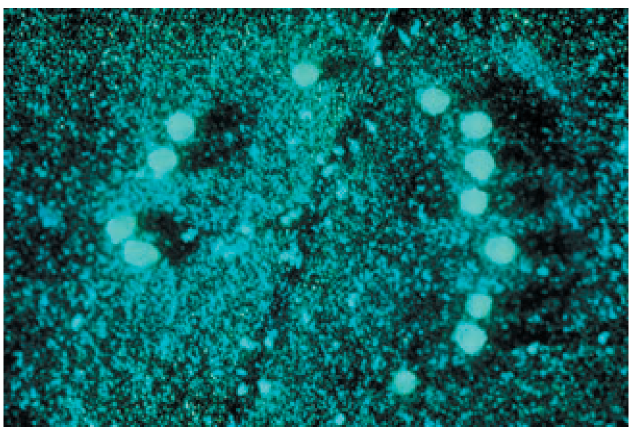

Figure 65. Eggs of greenhouse whitefly are laid on the underside of leaves, sometimes in a complete circle.

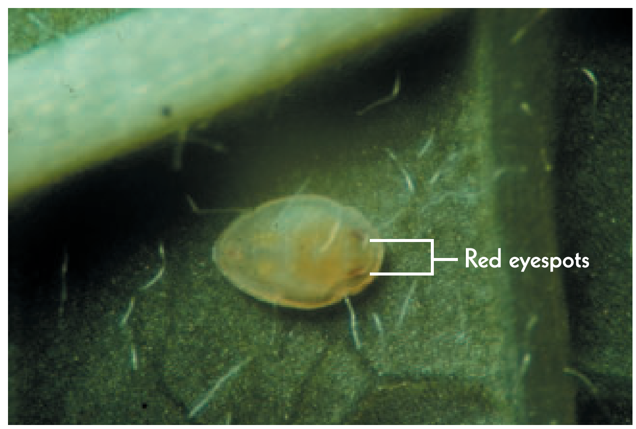

Figure 68. Red eyespots on this silverleaf whitefly pupa indicate that the adult will soon emerge.

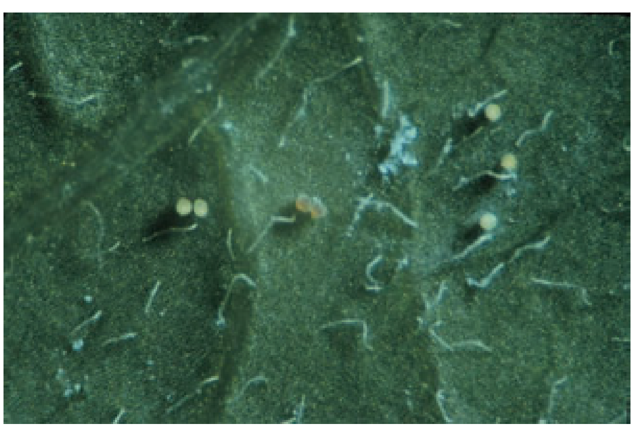

Figure 66. Silverleaf whitefly eggs on the underside of a leaf. The oval-shaped, yellow eggs eventually change to a light-brown color when ready to hatch.

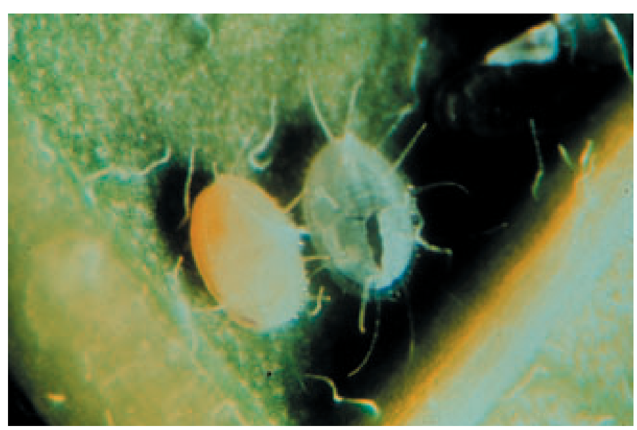

Figure 69. Silverleaf whitefly pupa and empty skin. A T-shaped opening on the exoskeleton is evidence that the adult whitefly has emerged.

DAMAGE TO PLANT

Large populations of whiteflies can cause leaves to turn yellow, appear dry, or fall off plants. Excreted honeydew may cause leaves to be covered with black sooty mold. Honeydew also attracts ants, which interfere with natural enemies that may control the whiteflies and other pests.

SCOUTING AND THRESHOLDS

Examine the undersides of leaves. Disturbed adults resemble flying white dandruff around the host plants. Larval and pupal stages are found on older leaves, while the adults are attracted to younger leaves, where they lay their eggs.

Trapping with yellow sticky cards is helpful in detecting and monitoring population levels. As a general rule, one to four cards spaced evenly throughout 1,000 square feet of greenhouse are sufficient. A generally accepted threshold for whiteflies is one-half per card per day when the crop is young, and two per card per day as the crop reaches maturity (Greer, 2000). Traps should be hung level with the tops of the plants since whitefly adults are attracted to young foliage. Monitor at vents and doors for migrating whiteflies. In the fall, bandedwinged whiteflies will appear on the cards as their outdoor host plants die. The white wings of greenhouse whiteflies appear gray after a few days on the sticky card, making distinguishing them from bandedwinged whiteflies difficult. Check sticky cards at frequent intervals to avoid identification problems. Again, a 10x to 20x hand lens will help with identification.

MANAGEMENT

Biocontrol

Whitefly populations can be controlled with several different natural enemies. Identifying the pest species attacking your crop before ordering a biocontrol is critical.

Encarsia formosa for Greenhouse and Bandedwinged Whiteflies

The parasitoid *Encarsia formosa* is a tiny (0.6-millimeter-long) wasp that parasitizes nymphal-stage whiteflies, eventually killing its host (Figure 70). The female adult wasp inserts an egg into a whitefly nymph (Figure 71). Upon hatching, the wasp larva feeds on its host, killing it in its pupal stage (Figure 72). The wasp completes its development inside the whitefly pupa, and a new adult wasp will emerge through a round hole that it chews in the whitefly pupal skin (Figure 73). Parasitized greenhouse and bandedwinged whitefly pupae are black (Figure 74) in contrast to silverleaf whitefly pupae, which turn brown when parasitized (Figure 75). Monitor leaves for this stage approximately 3 weeks after introducing *Encarsia*

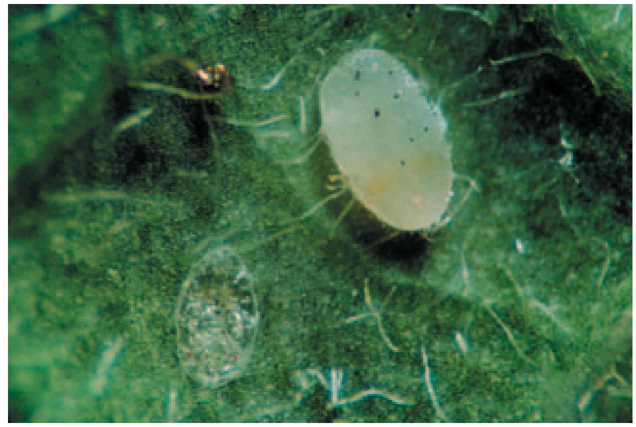

Figure 70. Black probe marks on whitefly nymphs indicate *Encarsia formosa* searching activity.

Figure 71. A female *Encarsia formosa* depositing her egg in the third and fourth whitefly instars. An adult parasitoid also feeds on first and second instars through puncture wounds.

Figure 72. The whitefly pupa turns gray when the parasitization process has begun.

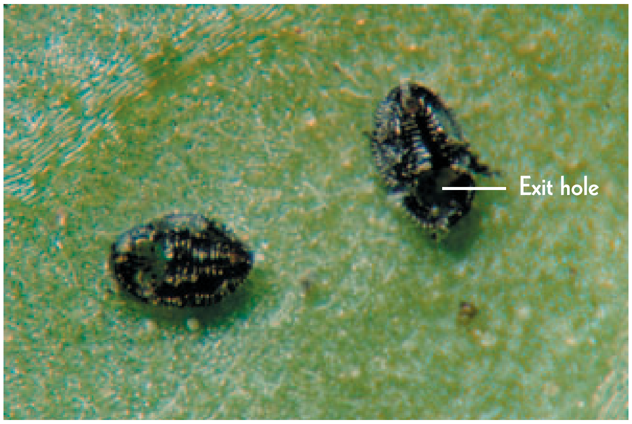

Figure 73. The adult wasp leaves the whitefly pupa through a round exit hole.

Figure 74. A totally blackened whitefly exoskeleton indicates that a new parasitoid has developed inside the whitefly body.

Figure 75. Silverleaf whitefly pupae appear brown when parasitized by *Encarsia formosa*.

formosa. *Encarsia* is very effective in controlling both greenhouse and bandedwinged whitefly populations but is not effective as a control for silverleaf whitefly. Another wasp, *Eretmocerus eremicus*, discussed later, is a more effective control for SLWF.

Encarsia should be introduced weekly at a rate of three to six adults per square yard when whitefly stages are first found and continued every 7 days until at least 80 percent of the whitefly pupae are parasitized. Continually monitoring the whitefly populations is important after introductions have stopped.

Encarsia formosa is supplied by two different methods—either as pupae glued on 2-inch by 2-inch cards (*Encarsia* cards) (Figure 76) or as loose pupae packed in tubes. Both systems have their own specific use in practice. Biocontrols should be introduced into the greenhouse immediately after they arrive. Most suppliers ship biocontrols via overnight delivery. Cards should be hung evenly among infested plants, while loose pupae are either left in the opened tube or placed in hanging pots for dispersal.

Figure 76. *Encarsia formosa* pupae glued to a piece of cardboard that is attached to the plant.

Figure 77. Tomato leaf with black parasitized whitefly pupae.

Tips for using *Encarsia*:

- Adult wasps rarely fly at temperatures below 64°F, seriously limiting their searching ability. At temperatures above 86°F, the adult life span is considerably shortened.
- Certain pesticides (e.g., pyrethroids) can have a long residual effect on *Encarsia*. Consult the chart on pesticide compatibility in the appendix.
- Introduce *Encarsia* at the first sign of whiteflies; accumulation of honeydew from an established whitefly population hampers ability of *Encarsia* to parasitize.
- By removing damaged lower leaves too early, parasitized pupae that have not yet emerged may be removed from the greenhouse (Figure 77).

Eretmocerus eremicus for Silverleaf Whitefly

Eretmocerus eremicus is a fairly new product for whitefly control and is more effective in controlling SLWF than *Encarsia* (Figure 78). Like *Encarsia*, it also attacks nymphal stages and kills its host in the pupal stage. The new adult wasp emerges through a round hole chewed in the whitefly pupal skin. When parasitized by *Eretmocerus*, greenhouse whitefly pupae turn yellow and silverleaf whitefly pupae turn yellow brown. Generally, *Eretmocerus* is more resistant to pesticides than *Encarsia*, and the adult is more active than *Encarsia* at high temperatures. This parasite is a good choice in the spring when greenhouse temperatures exceed 80°F.

Eretmocerus should be introduced weekly at curative levels (four to six adults per square yard), beginning when whitefly stages are first found and continuing until at least 80 percent of the whitefly pupae are parasitized. Continually monitoring the whitefly populations is important after introductions have stopped.

Figure 78. *Eretmocerus eremicus* female laying an egg in a greenhouse whitefly pupa.

Eretmocerus is supplied by two different methods. The parasitic wasps are supplied as pupae glued on cards or as loose pupae packed in tubes. Both systems have their own specific use in practice. Introduce biocontrols immediately into the greenhouse when they arrive. Place cards underneath the plant canopy, out of direct sunlight.

Tips for using *Eretmocerus*:

- At temperatures above 70°F, curatively introduce about six parasitic wasps per square meter for several weeks (whitefly nymphs need to be present for *Eretmocerus* introduction).
- When leaf pruning, examine leaves for the development of parasitism. Leaves with parasitized pupae should be left in the greenhouse so the new generation of parasitoids can emerge. All employees should be trained in recognizing parasitized whitefly pupae.

Delphastus catalinae for Whiteflies

This whitefly destroyer is a 1.3- to 1.4-millimeter-long ladybird beetle that attacks all stages of whiteflies but prefers eggs and nymphs (Figure 79). Adults can consume 160 eggs or 12 large nymphs per day. These predators can control all species of whiteflies and can be used with parasitic wasps. *Delphastus* beetles require high levels of whitefly life stages to reproduce. *Delphastus* is shipped in tubes of 100 adults. Often about 100 *Delphastus* per 10 plants are released in hot spots.

Tips for using *Delphastus*:

- Beetles may be refrigerated (for no more than 12 hours) before release.
- Release should be made in the early morning or evening.

Figure 79. *Delphastus catalinae,* a tiny ladybird beetle, feeding on a whitefly nymph.

- Lightly mist foliage with clear water prior to release.
- Release near high densities of whiteflies; they need to feed on whitefly eggs in order to reproduce.
- Release a minimum of 10 beetles per release point to ensure proper mating.
- Gently tap beetles out of the container directly onto infested plants.

Cultural Control

The best defense against whiteflies is sanitation. Start the crop cycle with a clean greenhouse, eliminate weeds within and outside the greenhouse, and grow disease- and insect-free transplants. If someone else is growing your transplants, inspect plants for insect development and treat appropriately. Use yellow sticky cards to monitor for adult whiteflies in the propagation and production houses. Inspect plants each week of the crop cycle for whitefly development and for proper timing of natural enemy introductions.

Controlled Atmosphere

Changing the composition of the atmosphere in the greenhouse by either reducing oxygen or increasing carbon dioxide appears to provide some control of greenhouse whitefly adults. Reduced-oxygen experiments at the University of Massachusetts resulted in 100 percent mortality after less than 2 hours of exposure, although 8-hour treatments were needed to control most of the eggs and pupae. Other experiments at North Carolina State University showed that daily 8-hour exposures of carbon dioxide lowered whitefly populations, probably due to lower concentrations of nitrogen in the plant tissues, which slowed whitefly growth and reproduction (Greer, 2000b).

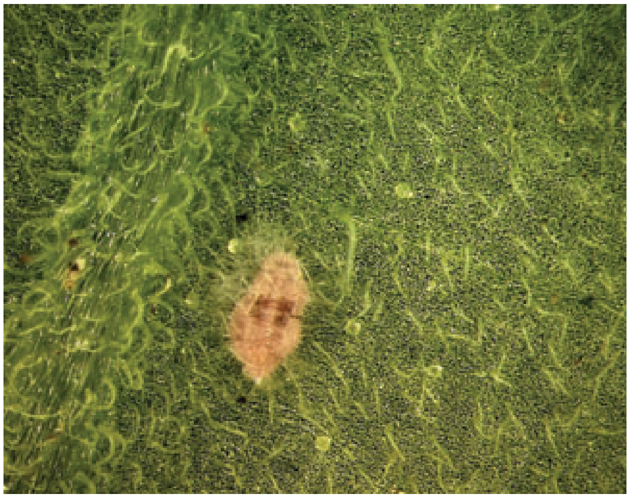

Figure 80. A greenhouse whitefly nymph infected with *Beauveria bassiana* may appear pinkish in color.

Other IPM Techniques

Biorational Pesticides

The fungus *Beauveria bassiana* (BotaniGard™ and Naturalis T&O™) is effective against eggs, immature whiteflies, and adult whiteflies (Figure 80). Best control is attained by thoroughly covering leaf undersides and correctly timing the applications.

Another fungus, *Paecilomyces fumosoroseus* (PFR-97™), is also available for control of whiteflies, aphids, and spider mites. Both fungi need high humidity for best results.

Other biorational pesticides for whiteflies include neem-based formulations, insecticidal soap, and horticultural oils. Thorough coverage is essential. Wider plant spacing and removal of dead lower leaves improve pesticide coverage and pest control.

Another least-toxic pesticide control option is insect growth regulators (IGRs). Depending on the choice, they can mimic juvenile hormones so insects never become adults; they can interfere with the production of chitin; or they can interfere with the molting process. IGRs usually work through ingestion, so good spray coverage is essential. They generally don't affect nontarget species, and most have minimal reentry restrictions. IGRs do not affect mature insects, so adult beneficials released after the application are not likely to be affected. However, IGRs are generally prohibited by organic certification organizations because the products are synthetic (Greer, 2000b).

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Leaf-Chewers

Caterpillars: Lepidoptera

DESCRIPTION AND IDENTIFICATION OF PEST

Caterpillars are not usually major pests in greenhouse vegetables. They can be a problem during the outdoor growing season when adult moths or butterflies migrate into the greenhouse to lay eggs. One of the most common species found on tomatoes is the tomato hornworm. Fruitworms, armyworms, and loopers can also infest tomatoes and peppers (Figure 81). If you are using biocontrols to control other pests, you must also use biocontrols or compatible pesticides to control caterpillars.

Many enemies of caterpillars occur in natural populations (Figure 82). Examples of these include predators such as assassin bugs, damsel bugs, minute pirate bugs, and parasitic flies and wasps. If caterpillar control is necessary, indigenous natural enemies may be supplemented with *Trichogramma* as discussed in the management section.

The following Web page is a key to most common caterpillars found on flowers and foliage plants: http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/caterkey.htm (accessed 6/3/2004).

LIFE CYCLE

Butterflies and moths have four life stages: egg, larva (caterpillar), pupa, and adult. Eggs are laid on leaves in groups. Larvae have well-developed chewing mouthparts, which if used almost continuously cause damage to foliage and fruit in a short period of time. Most caterpillars have several larval molts before spinning a cocoon where they pupate. Adults emerge from the cocoon to begin the egg-laying process again.

Figure 81. Two fruitworm eggs parasitized by *Trichogramma pretiosum.*

DAMAGE TO PLANT

Damage symptoms from caterpillar feeding are holes chewed in leaves and/or fruit. Copious amounts of pelletized excrement (frass) on the foliage or under plants may indicate caterpillar feeding. Cutworms may cause damage by cutting off seedlings at the soil level, killing the plants.

SCOUTING AND THRESHOLDS

Most damage done by caterpillars can be observed as holes in the leaves or deposits of frass (droppings) from caterpillars either on the leaves or the growing medium. Unless there is a major infestation, the few caterpillars found can be picked off by hand and dropped into a container of soapy water or smashed.

MANAGEMENT

Biocontrol

Trichogramma spp., Parasitoid Wasps

One of the most popular and effective controls for caterpillars is the egg parasitoid *Trichogramma*. These tiny wasps (0.9 millimeters) work by laying eggs in the eggs of many caterpillar pests. The wasp completes its life cycle in the parasitized egg and kills it. A new wasp will emerge from the parasitized egg. If you are going to use *Trichogramma* for biocontrol, inspect the crop for the presence of eggs since this is the only life stage that *Trichogramma* will attack. They are shipped as parasitized grain moth eggs glued to small cards or in capsules containing 500 pupae. Cards are placed throughout the crop where the wasps will emerge and search the plants for caterpillar eggs. Protect the cards from ants because

Figure 82. Tomato hornworm larva parasitized by the braconid wasp *Cotesia congregatus.* This parasitoid occurs naturally in greenhouses when insecticides are not used.

they will feed on the eggs. Capsules have small holes in the top for newly emerged wasps to leave. The capsule acts as an effective barrier to ants. Species available from most biocontrol suppliers include *T. brassicae, T. minutum*, and *T. pretiosum*. Release rate is one to four wasps per square foot.

Tips for using *Trichogramma*:

- Ants must be controlled—they will eat *Trichogramma* eggs.
- If ants are present and can't be controlled, keep the cards in the shipping bags and wait for adult emergence, checking daily. When the first adults appear, hang the cards and shake out the wasps in the bags.
- Timing is critical; only release these wasps if host eggs are available—it's the only stage they attack.

Cultural Control

Use screen vents and doors to exclude adults.

Other IPM Techniques

Biorational Pesticides

Various strains of *Bacillus thuringiensis* (Bt) are selective for caterpillars but do not harm biocontrols or other pests. The most widely used Bt insecticides are Dipel® and Javelin®. These products are toxic only to the larvae of butterflies and moths. For Bt to be lethal, the target pest must ingest it, so some feeding damage will occur. Mortality rate varies with larval size, target species, and dose consumed.

Azadirachtin (Azatin XL®, Neemix®) is a botanical insect growth regulator derived from seeds of the neem tree. As an insect growth regulator, azadirachtin blocks production of the insect's growth hormones, which interrupts the moulting process, preventing the insect from completing its life cycle. Azadirachtin may also serve as a feeding deterrent for some insects. This compound is compatible with beneficial insects, and in addition to controlling caterpillars, it will kill or repel a variety of greenhouse pests.

Pesticides are registered by the Environmental Protection Agency. Growers must read and follow the label to determine if the intended use has been approved. Always read the label before using.

Leafminer Flies: Diptera: Agromizidae

DESCRIPTION AND IDENTIFICATION OF PEST

Leafminers (*Liriomyza* spp.) are flies that attack a wide range of vegetable and ornamental crops in the greenhouse and in the field. The most common species found to infest greenhouse crops is *Liriomyza trifolii*, American serpentine leafminer. Adult female American serpentine leafminers are about 2 to 3 millimeters long with a wing length of less than 2 millimeters. They are black with a yellow spot on their backs and are about the same size and shape as fruit flies. The larvae feed between the upper and lower surfaces of leaves, creating wavy lines that are visible on the top of the leaf. This feeding damage affects the aesthetic value of ornamental plants and reduces photosynthesis, causing the leaves to wither or the plants to prematurely drop their leaves. Biocontrol of leafminers can be very effective and should be part of an IPM program.

The "Key to Most Common Fly Pests Found on Flowers and Foliage Plants," which includes leafminers, is available online at http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/flykey.htm (accessed 6/3/2004).

LIFE CYCLE

Female leafminers have a very sharp ovipositor or egg-laying tube used to pierce holes in the upper surface of the leaf to extract plant sap for feeding and to lay eggs in the puncture marks. Eggs hatch into maggots that start eating their way through the leaf. The legless, whitish to yellow larva grows to about 2 millimeters long with a dark mouth-hook structure that can be retracted into its body. Mature larvae cut sickle-shaped holes in the leaf cuticle through which they crawl out. The yellowish-brown pupa, formed within the skin of the last larval stage, usually falls off the leaf into the soil but sometimes may remain hanging on the leaf. Development time from egg to adult is dependent upon temperature. At 86°F, the life cycle is completed in 12 to 14 days.

DAMAGE TO PLANT

Larval mines detract from the aesthetic value of the crop. When fly populations are high, stippling—caused by females puncturing the leaves with their ovipositors to feed and lay eggs—can be serious, resulting in reduced photosynthetic capacity and retarded plant growth.

SCOUTING AND THRESHOLDS

Yellow sticky cards will capture adults. Place one trap per 10,000 square feet and monitor weekly. Research has shown that more leafminers are caught if the cards are placed horizontally, close to the ground level. Watch for mined or stippled leaves.

MANAGEMENT

Biocontrol

Dacnusa sibirica, a Parasitoid Wasp

Dacnusa sibirica (Hymenoptera: Braconidae) is a parasitic wasp that deposits an egg in a young leafminer larva. The wasp completes its life cycle within the body of its host, killing it. A new parasite will emerge from the body of the leafminer in about 17 to 19 days at 68°F.

They are shipped in tubes of 250 adults. Preventive release rate is one to three adults per square yard biweekly; curative release rate is two to five adults per square yard biweekly, making two to three releases.

Tips for using *Dacnusa*:

- Introduce when leafminers are first detected.
- Temperature at release should be 60 to 85°F; humidity 50 to 90 percent.
- Tubes of adults may be stored vertically for a short time at 43 to 50°F.
- Spread equally throughout greenhouse by carrying the open tube around until most have flown out. Then place tube in greenhouse until all have left.
- Monitor leaves every 2 to 3 weeks to check for parasitism. (Place some leafminer pupae samples in a glass jar or bottle and wait to see if a leafminer or wasp comes out. By counting the number of emerged wasps and leafminers, the percentage of parasitism can be determined.)

Diglyphus isaea, a Parasitoid Wasp

Diglyphus isaea (Hymenoptera: Eulophidae) is a parasitic wasp that stings small leafminer larvae to paralyze and then lay oval eggs next to them. Upon hatching, the wasp larvae feed on the leafminer larvae. *Dacnusa sibirica* is more efficient than *Diglyphus* in locating prey at lower leafminer densities.

Diglyphus is shipped in tubes of 250 adults. Preventative release rate is one to two adults per square yard triweekly; curative release rate is two to four adults per square yard biweekly, two to three times.

Tips for using *Diglyphus*:

- Distribute equally in vegetation by carrying the open tube around the greenhouse. When most have left the tube, let it remain in greenhouse to make sure all have left.
- Temperature should be 75 to 90°F; humidity around 80 percent.
- Monitor leaves every 2 to 3 weeks to check for parasitism in the same manner as for *Dacnusa*.
- Use a mix of *Diglyphus* and *Dacnusa* if leafminer populations are low.

Cultural Control

Sanitation is critical in the control of this pest. Remove infested leaves and destroy all plant debris. Broadleaf weeds may serve as leafminer hosts. Practice good weed control both inside and outside the greenhouse. Yellow sticky traps can be used to trap adult leafminers.

Other IPM Techniques

- Avoid plant varieties highly susceptible to leafminer infestations, or grow susceptible varieties in isolation.
- Crop rotation is an effective pest management tool. Alternating leafminer-susceptible crops with leafminer-resistant crops reduces the population.
- Leaving greenhouses empty during the winter reduces leafminer populations.
- Insect screens can keep out adult flies.
- Insecticide resistance is widespread. If insecticides are used, rotate to a new class of insecticides every 1 to 2 months.

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Slugs and Snails: Mollusca

DESCRIPTION AND IDENTIFICATION OF PEST

Snails and slugs can both damage plants. Slugs are simply snails without shells. They leave a slimy (mucus) trail as they crawl on their muscular "foot." Their mouthparts are composed of a rasping tongue used to scrape plant material. Because they need moisture, snails and slugs are frequently found in greenhouses, where they damage plants.

A key to some of the slugs and snails potentially found in greenhouses is available online at http://mrec.ifas.ufl.edu/Foliage/entomol/ncstate/slugkey.htm (accessed 6/3/2004).

LIFE CYCLE

Slugs and snails lay eggs that appear as perfectly round, gelatinous spheres ranging from $^1/_8$ inch to ¼ inch in diameter. Different species lay different numbers of eggs (from less than 20 up to 100) and require different development times. As soon as the eggs hatch, they are active and begin to crawl or feed if the temperature and humidity are right. They are nocturnal and remain concealed during the day. Most species overwinter as adults or nearly mature young. In greenhouses, many species may live for more than a year.

DAMAGE TO PLANT

Slugs and snails make ragged holes in leaves, beginning with lower leaves. Leaves may appear shredded.

SCOUTING AND THRESHOLDS

Look for slime trails, which become silvery when dry. Watch for eggs, which are usually on or near the soil surface but often hidden under mulch, dead leaves, flower pots, and so forth.

MANAGEMENT

Biocontrol

No biocontrols for slugs or snails are currently registered in Pennsylvania. *Phasmarhabditis hermaphrodita* is a strain of nematode used in Europe for biocontrol, but it is not available in the United States at this time.

Cultural Control

Sanitation under the benches will reduce hiding places for snails and slugs. Do not let compost pile up in the greenhouse.

Other IPM Techniques

Handpicking can be effective if done thoroughly on a regular basis. Water the infested area in the late afternoon; after dark, search out the snails and slugs using a flashlight. Collected snails and slugs can be placed in a plastic bag and disposed of in the trash, or put in a bucket of soapy water and disposed of. Alternatively, they can be crushed and discarded outside.

Trapping is an effective way to control slugs and snails. Inverted flowerpots or inverted melon rinds make good traps. A trap constructed of a 1 foot by 1 foot board with 1-inch strips on two opposite sides to hold it up off the ground will serve as a hiding place for the mollusks during the day, where they can be collected and destroyed by crushing. Do not use salt to destroy them—it will increase soil salinity.

Barriers of copper flashing and screens are effective in keeping snails and slugs out of planting beds. The copper screens should be 6 inches high and buried several inches below the surface to prevent slugs from crawling through the soil beneath the barrier. Copper foil can be wrapped around planting boxes to keep snails out.

Barriers of dry ashes or diatomaceous earth in a band 1 inch high and 3 inches wide have been shown to be effective in dry environments but may not be useful in the damp greenhouse environment.

Pesticide formulations containing iron phosphate (Sluggo®, a molluscide) are available to control snails and slugs. It may be applied wherever slugs and snails are seen. There is no reentry interval. Reapply as it is eaten. Ingesting even small amounts will cause snails and slugs to cease feeding, causing them to eventually die.

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Plant Pathogens

Bacterial Diseases of Plants

Bacteria are microscopic, single-celled organisms that have a cell wall. Their genetic material—a circular strand of DNA—floats inside the cell and is not surrounded by a nuclear membrane. Therefore, bacteria do not have a true nucleus, as do plants, animals, and fungi. Bacteria contain other small gene-carrying structures called plasmids. The plasmid genes control some of the characteristics exhibited by bacteria, such as resistance to streptomycin, copper, and other antibiotics. While most bacteria in the environment are beneficial, several are able to cause leaf spots, stem rots, root rots, galls wilts, blights, and cankers.

Plant pathogenic bacteria generally survive in infected plants, in debris from infected plants, and, in a few cases, in infested soil. Most require a wound or natural opening in the plant to gain entry and require warm, moist conditions in order to cause disease. Bacteria grow between plant cells on the nutrients that leak into that space or within the vascular tissue of the plant. Depending on the species of bacteria involved and the tissue infected, they release enzymes that degrade cell walls, toxins that damage cell membranes, growth regulators that disrupt normal plant growth, and complex sugars that plug water-conducting vessels. In most bacterial diseases, photosynthesis and respiration are severely altered to the detriment of the plant.

Bacteria reproduce very rapidly. They are splashed easily from the soil to the leaves and from leaf to leaf by overhead irrigation. They are also easily moved from soil or debris when a worker handles such material and then handles the live plant. The most important means of avoiding ornamental crop losses caused by bacteria is to purchase plants that have been shown to be free of such pathogens by the process of culture indexing. In this procedure, pieces of plant tissue are incubated in a nutrient broth that will encourage the growth of plant pathogenic bacteria. If the test is repeated two to three times and no pathogenic bacteria are detected, the plant is said to have been indexed and is free of bacterial pathogens. Plants are usually indexed at the same time for fungi that grow within the vascular tissue of the plant. In different procedures, elite propagators also index plants for viruses. Plants found to be free of the organisms for which they are tested are said to be culture/virus indexed.

The strict sanitation practices required to control bacterial diseases include destroying infected plants as well as cleaning and disinfesting tools, benches, flats, and pots that are used repeatedly. Soil used in potting should be treated to kill all pathogens. Soil in which infected plants were grown or rooted should be discarded or thoroughly treated. Workers should be trained to not handle soil or debris and then the living plant tissue unless they stop work immediately and wash their hands. Plant-handling procedures and debris/soil-handling operations should be kept completely separate.

The most important cultural practice to prevent bacterial infection is irrigating in a manner that keeps foliage surfaces dry and avoids splashing. Overhead irrigation should not be used in crops particularly susceptible to bacterial diseases. When overhead watering is employed, watering should be done early in the day so that free moisture evaporates quickly. Provide good air circulation within the crop canopy. Forcing air under benches and up through the canopy is best. Horizontal airflow, with rows of plants oriented parallel to the air movement, can greatly reduce relative humidity within the canopy. Various types of trickle irrigation and capillary mat watering are techniques that avoid providing the conditions required for bacterial spread and infection. Some bacteria have been shown to spread in ebb and flow systems. If using this type of system, take steps to filter crop debris out of and chemically treat the water.

Once disease begins on the plants, chemical control is not effective. Although research reports may indicate 80 to 90 percent control with chemicals under experimental conditions, often less than 50 percent control is achieved under commercial conditions with chemicals.

Erwinia chrysanthemi and *Erwinia carotovora* survive in plant debris that is not completely decomposed, on or in infected plants, on other greenhouse plants without causing disease, and, under some conditions, in soil (Figure 83). Both species infect a wide range of plants

Figure 83. Bacterial soft rot of a poinsettia cutting caused by *Erwinia carotovora.* Stems will have a wet, greasy feel when handled and will have a foul odor.

in the greenhouse. They can cause a stem rot or mushy, brown, smelly, soft rot. *E. chrysanthemi* has been shown to survive on plants that it does not actually infect.

Pseudomonas cichorii can cause leaf spots and blights on chrysanthemum, geranium, impatiens, and many other ornamental plants. The spots are generally water soaked (wet looking) and dark brown to black. Depending on the plant infected, the leaf spots may have a yellow halo.

Xanthomonas is another genus of bacteria containing important plant pathogenic species. *Xanthomonas campestris* pv. *pelargonii* causes bacterial blight or wilt of geranium (Figures 84 and 85). Other species of *Xanthomonas* attack *Dieffenbachia*, *Philodendron*, *Syngonium*, *Aglaonema*, and other foliage plants.

Figure 84. Bacterial blight of fancy leaf geranium caused by *Xanthomonas campestris* pv. *pelargonii.* Initial symptom of systemic infection may be only one wilted leaf.

Figure 85. Bacterial blight of zonal geranium caused by *Xanthomonas campestris* pv. *pelargonii* exhibiting advanced stages of systemic infection of stem rot, which will eventually lead to plant death.

Rhodococcus fascians (formerly *Corynebacterium fascians*) causes abnormal branching and stem development near the base of infected plants such as geranium. The bacterium is carried on infected cuttings and may enter the propagation medium (Figure 86).

Ralstonia solanacearum (formerly *Pseudomonas solanacearum*) causes vascular wilting of many herbaceous ornamentals, including geraniums. Gross symptoms in geraniums mimic those caused by *Xanthomonas campestris* pv. *pelargonii*. Unlike most other bacteria, *Ralstonia solanacearum* survives well in the soil. Once a greenhouse is contaminated with this organism, it is difficult to eliminate and poses a threat to many different crops. Symptoms include wilting, discoloration of the vascular tissue, leaf yellowing, and death of the plant.

MANAGEMENT

- Purchase culture-indexed plants known to be free of the most important bacterial pathogens.
- Destroy infected plants.
- Do not use overhead irrigation.
- Pasteurize the propagation bed and medium between crops.
- Do not handle soil or debris on the potting soil surface and then the plant.

REFERENCE

Moorman, G. W. No date. *Bacterial Diseases of Ornamental Plants*. The Pennsylvania State University. http://www.ppath.cas.psu.edu/EXTENSION/PLANT_DISEASE/bact_dis.html (accessed 9/27/2004).

Figure 86. Bacterial fasciation of geranium showing proliferation of shoots at the base caused by *Rhodococcus fascians.*

Fungal Root Rots

Root rots of floricultural and woody ornamental crops are one of the most important causes of crop loss. In addition to killing plants and thereby reducing the quantity of saleable crop, root rots can also slow or stop plant growth and thus suppress plant quality (Figure 87). Root-rotted plants are usually smaller, less vigorous, and produce fewer and/or smaller leaves, flowers, and fruit than healthy plants of equal age. Flowering may be delayed when the plant's roots are rotted. As a result, the crop quality is very uneven. Root rots must be managed early in the disease if serious crop losses are to be avoided.

Management in established plants is based on:

- Proper diagnosis of the cause of the root rot.
- Proper use of fungicides.

Symptoms of root rot:

- Growth of infected plants slows as compared to healthy plants (Figures 88 and 89).
- Older leaves yellow and fall (Figures 90 and 91).
- Margins of leaves die.
- Roots appear dark brown or black, and few or no white roots or root tips can be found when the root ball is washed free of soil. Note that although some plants naturally have brown, dark-colored roots (azaleas, rhododendrons), the next two symptoms below are not characteristic of those plants if their roots are healthy.
- Roots are limp and not brittle and crisp as those of healthy plants of all types.
- When plants are pulled from the potting mix, the outer layer of cells strips off the roots, leaving only the central strand of water-conducting tissue.

Figure 87. Pythium root rot of poinsettia exhibiting yellowing, stunting, and wilting of plant.

Figure 88. Black root rot of petunia seedlings caused by *Thielaviopsis basicola.* Although some plants are yellowing and stunted, healthy-looking plants in the same pack are also infected.

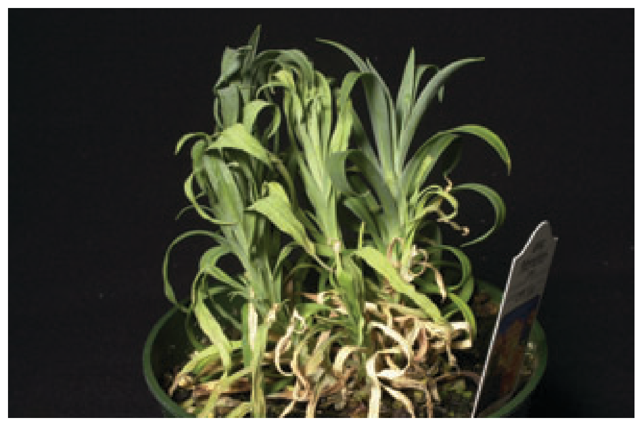

Figure 89. Fusarium wilt of carnation caused by *Fusarium oxysporum.* Yellowing and wilted foliage will result in plant death.

Figure 90. Black root rot of annual vinca caused by *Thielaviopsis basicola* exhibiting yellowing and defoliation of older leaves.

Figure 91. Pythium root rot of regal geranium. Advanced stages of root rot may lead to discoloration and rot of crown.

Figure 92. Pythium root rot of poinsettia. Roots are discolored and epidermis strips easily from vascular tissues.

The above symptoms can be caused by:

- root-rotting fungi
- overfertilization
- too much or too little water
- root exposure to chilling or freezing temperatures
- phytotoxicity due to the mishandling of pesticides when used as soil drenches
- damage as a result of a plant becoming potbound (primarily to roots next to pot)

Before any action is taken, a diagnosis must be made of the actual cause of the symptoms. If the damage is due to the activity of fungi, chemicals are sometimes available that can check the fungus and allow the plant to grow. The dead roots do not recover; new roots must grow. The fungus is usually not completely eradicated (killed) by chemicals. Some fungus usually remains alive, although its growth is greatly slowed as long as the fungicide is high enough in concentration. Therefore, repeated applications of fungicides are necessary (Figure 92).

DIAGNOSIS

Many fungi can cause root rots. Often, identifying the responsible fungus is possible either by observing the structure of the fungus in the roots using a microscope or by placing infected roots on artificial media or baits (apple, carrot, or potato pieces) and allowing the fungus to grow out where it can be detected and then identified. This is done at the Plant Disease Clinic of The Pennsylvania State University.

MANAGEMENT USING FUNGICIDES

No single fungicide will kill or inhibit the growth of all fungi. In fact, some chemicals will allow certain fungi to cause more damage than usual because the chemical eliminates fungi that compete with the disease-causing fungus. However, fungicides are effective against “groups” of fungi, and therefore a different chemical is not needed for each fungus.

- Obtain a diagnosis of which fungus or fungal group is the cause of the root rot.
- Obtain a recommendation of which fungicide is effective in managing that particular fungus or fungal group. The chemical label of each fungicide notes the fungi against which the chemical is effective.
- Be certain the name of the crop to be treated is on the label of the fungicide to be used.
- Note the rate at which the chemical is to be used when applied as a soil drench. Read the label.
- Wear goggles, waterproof gloves, boots, coveralls (water resistant or waterproof), a respirator, and other recommended safety equipment when mixing and applying the chemical.
- If two different fungicides are to be applied, check the chemical labels of each and any available compatibility charts, or check with your extension educator before mixing them together. Otherwise, apply each separately.
- Prepare and apply the proper concentration rather than using a proportioner to dilute the chemical from a bucket of chemical concentrate because (a) the wettable powder fungicides must be agitated constantly to prevent settling out; (b) proportioners are not

designed to dispense suspensions; and (c) fluctuations in water pressure and hose length or obstructions to water flow in the hose results in inaccurate dilution of the chemical. If too much chemical is injected, phytotoxicity may result. If too little chemical is injected, the concentration of fungicide needed to stop fungus development will not be delivered.

- Repeat the application of the chemical at the time interval recommended on the label. Additional treatments are often needed because the fungi are seldom totally eliminated by a fungicide. Check the label for the proper dose to use on repeat applications.

For control of fungus diseases, refer to biofungicides in the pesticide compatibility section on pages 16 and 17.

REFERENCE

Moorman, G. W. No date. *Fungal Root Rots and Fungicide Use.* The Pennsylvania State University. http://www.ppath.cas.psu.edu/EXTENSION/PLANT_DISEASE/rootrots.html (accessed 9/27/2004).

Virus Diseases

Viruses are submicroscopic entities capable of causing disease. They are a piece of nucleic acid (genetic material) surrounded by a protein coat. Once inside the plant cell, the nucleic acid portion directs the plant cell to produce more virus nucleic acid and virus protein, disrupting the normal activity of the cell. Viruses can multiply only inside a living cell. While some viruses such as cucumber mosaic die quickly if outside a cell or if the cell dies, other viruses such as tobacco mosaic retain their ability to infect for years after the infected plant part dies. Many different viruses can infect plants.

Depending on which virus is involved, the disease may be spread from infected plants to healthy plants:

- mechanically on workers' hands or tools
- by aphid, thrips, whitefly, leafhopper, mite, or nematode feeding
- through dodder
- through grafting

Vegetative propagation perpetuates virus diseases. Cuttings taken from an infected plant usually are infected even if no symptoms are immediately exhibited by the cutting. The virus particles are found in all parts of the plant except the few cells at the tips of the growing points, which are removed and grown into a healthy plant free of virus by the process called meristem tip culturing.

Symptoms vary with the virus involved, the species of plant infected, and the environmental conditions. In some cases, such as virus disease of geraniums, certain environmental conditions bring out symptoms while other conditions mask or hide symptoms. Symptoms associated with virus infections include:

- reduced growth that results in stunting
- light- and dark-green (or yellow and green) mosaic pattern on the leaves (Figure 93)
- malformation of leaves or growing points
- yellow streaking of leaves (especially monocots)
- yellow spotting or rings on leaves
- ring-spots or line patterns on leaves (Figure 94)
- cup-shaped leaves
- uniform yellowing, bronzing, or reddening of foliage
- flower color breaking
- distinct yellowing only of veins
- crinkling or curling leaf margins

Figure 93. Mosaic pattern on leaves of a begonia infected with INSV.

Figure 94. Ring-spots on foliage of New Guinea impatiens infected with INSV.

Some of the above symptoms can also be caused by high temperature, insect feeding, growth regulators, herbicides, mineral deficiencies, and mineral excesses. Virus diseases cannot be diagnosed on the basis of symptoms alone.

Certain crops including geraniums, roses, Easter lilies, dahlias, gladiolus, and tulips are well known for being infected by virus diseases.

MANAGEMENT

No chemicals cure a virus-infected plant nor do any protect plants from becoming infected.

- Purchase virus-free plants.
- Maintain strict insect and mite control.
- Remove all weeds because they may harbor both viruses and insects.
- Remove all crop debris from benches and the greenhouse structure.
- Immediately set aside plants with the above symptoms and obtain a diagnosis from your Plant Disease Clinic.
- Discard virus-infected plants.
- Frequently disinfect tools used for vegetative propagation.
- Propagate plants via seed rather than vegetatively. (Note that certain viruses of certain crops can be carried in or on the seed.)

REFERENCE

Moorman, G. W. No date. *Virus Diseases*. The Pennsylvania State University. http://www.ppath.cas.psu.edu/EXTENSION/PLANT_DISEASE/virus.html (accessed 9/27/2004).

Foliar Nematodes

Foliar nematodes include several species of the genus *Aphelenchoides* that commonly feed inside tender leaves of higher plants. They are very slender, small (about 0.5 millimeter to 1.0 millimeter long), and colorless, so they are hard to see.

SYMPTOMS

The most distinctive field symptom of foliar nematodes is lesions that are bounded by the major veins in leaves. Leaves with parallel veins display stripes of affected tissue. Those with a netlike pattern of veins have small blocks of affected tissue.

Cells on which foliar nematodes feed gradually lose color, turn brown, and die. Those areas become visible in the leaf blades, turning chlorotic, then darker brown, then almost black. The darkest lesions usually are dry.

Symptoms develop locally because these nematodes are so delicate they cannot move easily through tough leaf tissues such as major veins. After exploiting most of the cells between major veins, they return to the outside of the leaf to enter new areas of the leaf in which to feed. They enter and leave by natural openings (stomates) and must have free moisture on the leaf surfaces to move about. They are most easily spread from plant to plant when foliage of two plants comes into direct contact.

HOSTS

Foliar nematodes infect hundreds of plants. *A. ritzemabosi,* chrysanthemum foliar nematode, parasitizes more than 200 species, a third of which are in the family Compositae. *A. fragariae,* strawberry nematode, is reported from more than 250 species including ferns and members of Liliaceae, Primulaceae, and Ranunculaceae. *A. besseyi,* the rice white tip nematode, infects many grasses, vegetable and agronomic crops, and ornamentals including ferns. Foliar nematodes often damage some varieties of a plant species while not affecting other varieties in direct contact with the affected plants.

Not all distinctly vein-bounded foliar lesions are caused by nematodes. Several bacterial and fungal diseases are similarly confined by vein patterns, so simple laboratory tests should be done to confirm visual diagnoses. If small pieces of suspect leaf tissues are floated on clean tap water, live foliar nematodes will emerge within a few minutes to 24 hours. A low-power microscope makes seeing them moving in the water near the leaf pieces easier (Dunn, 1997).

TREATMENT

Since July 2002, Olympic Pylon Miticide (EPA Reg. Number 241-374-59807) containing chlorfenapyr as the active ingredient has been registered for use against foliar nematodes. Two applications are allowed at 7- to 14-day intervals, and a third application can be made if fresh plant damage or nematodes are detected. Restrictions on the label allow no more than three applications per season or crop cycle, and it is labeled only for nonedible ornamental crops grown in commercial greenhouses. For Pylon to be most effective, growers should practice strict sanitation; space plants to achieve good coverage; keep the plants off the ground; remove infested leaves and cut back plants; and apply the Pylon at the first sign of plant damage or nematode detection (Nadja, 2002).

REFERENCES

Dunn, R. A. 1997. *Foliar Nematodes as Pests of Ornamental Plants*. Department of Entomology and Nematology Publication SP 221, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. http://edis.ifas.ufl.edu/BODY_IN036/ (accessed 9/27/2004).

Najda, K. 2002. "New Treatment for Foliar Nematode." *Regulatory Horticulture* 28: 15–16. Bureau of Plant Industry, Pennsylvania Department of Agriculture.

Phytoplasmas

Until recently, plant diseases known as the "yellows diseases" were thought to be caused by viruses. This was because the yellows disease agents had certain characteristics in common with virus agents. They couldn't be grown on culture media like most fungal or bacterial pathogens. In addition, while a yellows disease had characteristic symptoms, infected plants never had signs—obvious structures of a disease organism. Then, in 1967, using an electron microscope, researchers in Japan found wall-less microorganisms in yellows-diseased plants. This new class of plant disease agent was eventually called phytoplasmas.

HOSTS AND DISTRIBUTION

Diseases caused by phytoplasmas occur worldwide in many crops, although individual phytoplasmas may be limited in their host range or distribution. More than 300 distinct plant diseases are attributed to phytoplasmas, affecting hundreds of plant genera. Many of the economically important diseases are those of tree crops, including coconut lethal yellowing, peach X-disease, and apple proliferation. There are also major diseases of vegetables, such as aster yellows in carrot and onion and tomato big bud. Hosts for aster yellows phytoplasma include aster, chrysanthemum, gloxinia, monarda, and many other perennials and flowering plants.

DISEASE AGENT AND DETECTION METHODS

Phytoplasmas are single-celled organisms that are similar to bacteria but lack a rigid cell wall. Phytoplasmas are obligate parasites—they cannot survive apart from a host. They grow and reproduce in the cytoplasm of host cells, both in insect vectors and in plants.

Phytoplasmas are very small—submicroscopic—requiring an electron microscope to be seen. They reproduce asexually by budding. Phytoplasmas look like amorphous sacks or blobs, ranging from 70 to 1,000 nanometers in diameter, or roughly the size of a plant cell's chloroplasts.

Although phytoplasmas were first detected with electron microscopy, staining, serological, and DNA-based techniques have been developed that make detection more rapid and practical for diagnostic labs. Serological and DNA-based techniques provide the ability to distinguish among different phytoplasmas and permit specific identification and classification.

TRANSMISSION

Phytoplasmas reside in conducting tissue of the plants they infect and are transmitted by sap-feeding insect vectors, most commonly leafhoppers but also some psyllids and planthoppers.

An insect vector acquires the phytoplasma after feeding on an infected plant for several hours or days. For 10 to 45 days, the phytoplasma moves through the insect and multiplies within specific organs. After that incubation period, the insect is able to transmit the phytoplasma to uninfected plants when it feeds. The incubation time within the insect depends on several factors, including temperature. An infected insect will be able to spread disease for the rest of its life. It was generally believed that phytoplasmas could not be passed from adults into eggs, but that each insect generation must reacquire the phytoplasma from infected plants. A recent report brings this belief into question again, and more study is needed to make certain that the lack of transmission from adult to egg is always true.

Plant host range for a phytoplasma is dependent on vector specificity and feeding habits. Some leafhoppers only feed on one or a few host species. If a phytoplasma is dependent on natural spread by this vector, then it will only be spread to those species of plants fed upon by the leafhopper.

Phytoplasmas cannot be transmitted mechanically by rubbing sap from an infected plant onto a healthy plant or by using contaminated tools. But they can infect healthy plants if infected stock is budded or grafted directly onto it. Plants growing close together can be infected through naturally formed root grafts. Phytoplasmas are not known to be transmitted through seed or pollen.

SYMPTOMS

Symptoms of the group include a general yellowing or reddening of leaves, reduced leaf size, shortening of internodes, and loss of apical dominance. These effects lead to stunting of the plant, proliferation of shoots or roots, witches-brooming, reduced yields, general decline, and sometimes death of the plant. Several symptoms fairly unique to phytoplasma diseases involve flowers: virescence (greening of the flowers), phyllody (conversion of petals and sepals to more leaf-like structures), and sterility of flowers. Obviously, these types of symptoms are disastrous for seed or ornamental crops.

PHYTOPLASMA DISEASE FOUND IN PENNSYLVANIA GREENHOUSES

Aster Yellows

Originally described in aster, this phytoplasma infects herbaceous plants in more than 40 families including vegetables, ornamentals, and weeds. The phytoplasma overwinters in perennial and biennial plants. Some important weed species in which it can overwinter are dandelion, wide-leafed plantain, thistle, and wild carrot. Aster yellows is transmitted by *Macrosteles fascifrons* and several other leafhoppers. This leafhopper feeds on many different plant species, maximizing the spread of the phytoplasma within its own wide host range. The vectoring leafhoppers may overwinter in Pennsylvania or migrate into the state from the south. Phytoplasma diseases tend to occur more often in outdoor plantings than in greenhouses, where leafhopper detection and control is easier. When found in greenhouses, the disease is most often seen on plants that were moved outside during the summer months. Diseased plants may also be propagated vegetatively from infected stock.

Management and Control

Although phytoplasma disease symptoms may be delayed or alleviated by treatment with certain classes of antibiotics, this approach is not usually practical. Plants are not really cured, and symptoms reappear when treatments cease. Foliar applications or soil drenches of antibiotics are not effective. Infected plants or dormant propagative tissue can be freed of phytoplasma by heat treatment. This technique is used at quarantine facilities when phytoplasma infection is suspected in fruit tree nursery stock being imported.

The most promising strategy for avoiding phytoplasma disease is the identification or development of resistant plant varieties. Management and control center around clean stock programs, eliminating sources of the phytoplasma and controlling leafhopper vectors:

- Propagate from seed or from phytoplasma-free plants.
- Eliminate perennial and biennial weed hosts.
- Rogue out and destroy symptomatic plants.
- Avoid planting susceptible crops next to crops harboring the phytoplasma.
- Control the leafhopper vector in the crop and nearby weeds early in the season.
- Plant varieties more resistant to the disease, if available.

REFERENCE

Welliver, R. 1999. "Diseases Caused by Phytoplasmas." Plant Pathology Circular No. 82. *Regulatory Horticulture* 25(1): 17–22. Pennsylvania Department of Agriculture, Bureau of Plant Industry.

Sources of Plant Disease

Where do diseases begin? The greenhouse manager who can answer this question is in an excellent position to prevent losses due to plant pathogens by reducing or eliminating the numbers of pathogens at their source. The major sources of living things that commonly plague greenhouse crops are noted here. Make an inventory of the practices you employ in your operation and note which make your crops vulnerable to a disease problem and which help avoid diseases.

INFESTED SOIL

Many plant pathogens can be found in soil. Fungi such as *Pythium*, *Phytophthora*, *Fusarium*, *Rhizoctonia*, and *Thielaviopsis*, crown gall bacteria (*Agrobacterium*), and most nematodes reside in the soil. *Pythium* species are found in sand and peat as well. When greenhouse crops are potted in a mix containing these pathogens, the pathogens are stimulated into activity by nutrients that leak from the plant's roots, and disease may begin. Therefore, the potting mix must be free of pathogens before planting. A potting mix that has been treated to kill plant pathogens or a soilless mix purchased with the assurance of being free of pathogens should be handled as if it were food and kept free of unwanted organisms. It should be stored on a clean surface, moved with clean implements to a clean potting bench, and placed in clean pots or flats.

No matter how careful a grower is, disease caused by soilborne pathogens can still occur. Soil is found many other places in the greenhouse besides the potting mix. Soil is usually under benches, in aisles, and in the benches in older greenhouses. Soil is brought into the greenhouse on workers' and pets' feet, on machinery used to move materials into the greenhouse, and on crates, flats, and boxes stored unprotected on the ground outdoors. Care must be taken to avoid getting this potentially contaminated soil into the potting mix. Tools, hose ends, and other things that have the potential of moving pathogen-containing soil into a pathogen-free potting mix must be thoroughly cleaned and disinfested. If old benches are full of soil, the soil should be sterilized or covered with clean plastic sheets to separate it from the potted plants placed on the bench.

DEBRIS FROM PREVIOUS CROPS

Most plant pathogens have a stage in their life histories that can rest in a dormant state and survive periods of time when temperatures are extreme or moisture is not sufficient for growth. Some pathogens become dormant in the dead leaves, stems, and roots where they previously caused disease. Inside those tissues they are protected from the hostile environments of the soil and air and are away from competition with other organisms in the soil and air. They have at hand a ready supply of nutrients when conditions become favorable again. Bacteria such as *Erwinia chrysanthemi*, fungi such as *Botrytis* and *Pythium*, foliar nematodes (*Aphelenchoides*), and tobacco mosaic virus survive for months in plant debris. A disease may recur if infested debris is left in the greenhouse where it may come in contact with the next crop.

PLANTS KEPT ALL YEAR

Some pathogens must have living plant tissues in order to grow, reproduce, and survive. Viruses such as tomato spotted wilt and cucumber mosaic only survive in living plant cells. Rusts such as geranium or fuchsia rust must pass from living plants to other living plants or they die within weeks. Powdery mildew fungi may be on grape ivies, begonias, roses, and African violets unnoticed or at a level of severity thought insignificant until they later explode into activity. Similarly, *Botrytis* on geraniums can usually be found on branch stubs, fading leaves, and flowers most of the year. When light, humidity, and temperature conditions become favorable for these pathogens, disease seems to appear and spread rapidly when, in fact, the problem had been building for some time. Thus, plants kept in the greenhouse all year act as reservoirs for pathogens and should be under strict disease control.

Weeds—especially bittercress and oxalis—fall under this heading as do plants such as *Tradescantia* and English ivy that are also allowed to escape and grow under benches. Plants found all year in the greenhouse not only harbor pathogens, they are also excellent havens for the thrips, whiteflies, and aphids that can spread diseases.

VEGETATIVELY PROPAGATED CROPS

Cuttings purchased each year may be new to your greenhouse, but someone somewhere had them and the stock plants in the greenhouse all year. Thus, the problems mentioned in the above section apply to vegetatively propagated plants. Any disease affecting stock plants is likely to be found on cuttings taken from those plants, particularly if the pathogens reside inside the plant. Vascular wilt diseases such as bacterial blight of geraniums, *Fusarium* wilt of chrysanthemums and *Verticillium* wilt of impatiens; virus diseases caused by dasheen mosaic, tomato spotted wilt, and tomato ringspot viruses; foliar nematodes in chrysanthemums, begonias, and African violets all will accompany cuttings if stock plants are infected. The propagator must assume responsibility for strictly controlling diseases and insects on stock plants so that these pests are not sold to the customer on the cutting. The customer must inspect purchased material carefully as soon after arrival as possible. If inspection is put off until the plants have been in the greenhouse many days, being certain whether the pathogens accompanied the cuttings or moved to the cuttings from sources within the greenhouse is not possible.

Culture indexing systems have been devised to determine that plants are free of major fungi, bacteria, and nematodes affecting the crop; virus indexing was developed to be certain those plants do not harbor the most important viruses that threaten the crop. Once indexed plants are purchased and placed in a producer's greenhouse, it may only be a matter of time before the plants again become infected with the pathogens for which they had been indexed. Indexing does not guarantee the future health of the plant. As the time during which indexed plants are kept in the greenhouse passes, the likelihood increases that disease will occur.

Realizing that indexed plants are only examined for some disease-causing organisms is important. Culture and virus indexed plants are not necessarily "disease free." That is, disease-causing organisms other than those for which indexing was done may be present. For example, no company indexes for *Botrytis*. However, in crops where culture and virus indexing is done, the probability of serious losses due to organisms carried on or in the cuttings is greatly reduced.

WATER

The fungus *Pythium*, which can cause damping-off, root and stem rots, and cutting rots, is probably the main pathogen that can be brought into the greenhouse in water. Surface water such as lakes, ponds, rivers, and streams contain *Pythium* primarily in the bottom sediment. Runoff can carry the fungus from the soil into wells. Care should be taken to avoid pumping bottom sediment from water supplies into the greenhouse irrigation system. *Pythium* is a major problem in hydroponic systems. It becomes an important problem in ebb and flow systems when the system is heavily contaminated.

AIR

The spores of powdery mildew fungi, *Botrytis*, rust fungi, *Alternaria*, and others can be carried by air currents from outdoor plants into the greenhouse. Infected plants in nearby gardens and weeds close to the greenhouse can supply enormous numbers of spores. Thus, even if great care is taken to eliminate other sources of pathogens, the air we breathe may carry certain disease-causing organisms. During the warm months, maintaining greenhouse conditions that inhibit pathogen activity and eliminating noncrop sources of pathogens around the greenhouse are critical. However, cautious use of herbicides near the greenhouse is necessary since many crops have been ruined when herbicide vapors have been drawn in by fans or natural air currents. Since most greenhouse crops are dicotyledonous plants and very few pathogens attack both monocots and dicots, consider establishing a grassy lawn around the greenhouse.

CONCLUSION

The sources of living things that cause diseases in greenhouse crops listed in this section are not the only sources of disease, but they are the first to suspect when trying to answer the question “where did the disease begin?” Every greenhouse manager should be aware of the sources of pathogens for each crop grown in their particular operation and should plan to eliminate those sources of disease. Money can be saved by not losing plants during production and by minimizing the expense of purchasing and applying disease-control chemicals.

REFERENCE

Moorman, G. W. No date. *Sources of Plant Disease*. The Pennsylvania State University. http://www.ppath.cas.psu.edu/EXTENSION/PLANT_DISEASE/sourcedi.html (accessed 9/27/2004).

Biocontrol Organisms

Most of the biocontrol organisms used in greenhouses can be classified as predators, parasitoids, or pathogens. This section includes short descriptions of biocontrols, their life cycles, and other useful information about them.

Predators

Beetles

Cryptolaemus montrouzieri, a Mealybug Destroyer (a Ladybird Beetle)

Native to Australia, this predator is one of the most effective biocontrols for citrus mealybug or other mealybug species producing cottony egg masses. Adults and young larvae eat all stages of mealybugs. The adult beetle is 4 millimeters long with an orange-brown head and thorax and a darker brown abdomen. Females live approximately 2 months and lay up to 10 eggs a day in mealybug colonies or in groups of mealybug eggs. Eggs hatch into larvae that grow to 13 millimeters and are distinguished by white waxlike filaments. Because of this white secretion, the beetle larvae are sometimes mistaken for mealybugs. Young larvae are voracious predators of early stage mealybugs, whereas the larger larvae will eat mealybugs of any size. *Cryptolaemus* is most active when the weather is sunny, with optimal temperatures above 72°F and relative humidity of 70 to 80 percent. Because of the beetles' flying ability, windows and vents should be kept closed on the day of release. *Cryptolaemus* is supplied in units of 25, 100, 250, 500, or 1,000 adults in tubes with a honey-drenched paper strip.

Delphastus pusillus (= *catalinae*), a Whitefly Destroyer (a Ladybird Beetle)

This black ladybird beetle is less than 2 millimeters long and attacks all stages of whiteflies but prefers eggs and nymphs. Adults can consume 160 eggs or 12 large nymphs per day. These predators can control all species of whiteflies and can be used in conjunction with parasitoid wasps. *Delphastus* beetles require an abundant supply of whiteflies to provide enough food for reproduction. For that reason, releases of at least 25 beetles per release site should be made near areas of high whitefly populations. *Delphastus* is shipped in tubes of 100, 250, 500, or 1,000 adult beetles.

Hippodamia convergens, a General Insect Predator (a Ladybird Beetle)

These field-collected ladybird beetles are shipped as adults and are sold by volume. A general predator, *Hippodamia* beetles are effective for cleaning up hot spots. They feed on aphids, scales, thrips, and other soft-bodied insects. Beetles collected in the dormant state generally migrate prior to feeding and laying eggs. Beetles may be preconditioned by feeding them a special diet to minimize their migration behavior. Only such preconditioned adult beetles should be purchased.

Lacewings

Chrysoperla spp., Green Lacewing Predator on Soft-Bodied Insects

These native, delicate, green insects lay eggs on silken stalks attached to leaves or stems. Eggs hatch into voracious larvae (aphid lions) that feed on aphids, mealybugs, scales, spider mites, thrips, and insect eggs. They may have difficulty finding prey in crops with hairy or sticky leaves. Larvae feed about 3 weeks before pupating inside cocoons attached to the undersides of leaves. Lacewings can be purchased as eggs or as larvae packed in individual cells because they are cannibalistic.

Flies

Aphidoletes aphidimyza, a Predatory Midge for Aphids

Aphidoletes is a predatory midge that attacks over 70 different aphid species. The adult midge is about 2.5 millimeters long with long legs and a slender body. They are mainly active at night, live for about 7 to 10 days, and commonly feed on honeydew.

Females deposit eggs in aphid colonies, which they locate by the smell of honeydew. Upon finding an aphid, the midge larvae inject a paralyzing toxin that also dissolves the body contents of the prey. The midge larvae attach their mouthparts to the aphid and feed on the dissolved contents. Each larva must feed on about five aphids to complete its development, but they may kill up to 65 aphids if available. Initially, larvae are transparent orange but become solid orange, red, brown, or gray, depending on the food source. When mature (in about 7 to 14 days) the 2- to 3-millimeter-long midge larvae fall from the plant into the soil and use soil particles to make cocoons. Within 7 to 10 days, adult midges emerge from the cocoons.

Larvae enter hibernation starting in late September (lower temperatures, shorter days), unless supplemental light (60-watt bulbs spaced 30 feet apart, or 100-watt bulbs spaced 65 feet apart) is used. Because of their natural tendency to hibernate in the fall, *Aphidius* spp. or *Aphelinus abdominalis* are a better biocontrol choice for a fall crop.

Aphidoletes is shipped as pupae mixed with vermiculite for release in greenhouses. It is a general aphid predator and can be used alone or in combination with a parasitoid for rapid knockdown of aphids. This predator is most effective in aphid hot spots. The main benefit to using *Aphidoletes* is its applicability on several crops (tomatoes, peppers, eggplants, cucumbers, etc.) and varied aphid species.

Feltiella acarisuga, a Predatory Midge for Spider Mites

The predatory midge *Feltiella acarisuga* can be effective in controlling spider mites, especially when used in conjunction with predatory mites. *Feltiella* larvae feed on spider mite eggs and are especially effective when mites occur in colonies. *Feltiella* is good at finding hot spots, and therefore is complementary to predatory mites, which are better searchers. *Feltiella* can be an effective year-round predator and is particularly useful on hairy-leaved plants (such as tomatoes). This predator might occur naturally in greenhouses (and gardens) if spider mite densities are high and pesticides are not used.

The adult *Feltiella* is a delicate, pink-brown midge about 1 millimeter long with relatively long legs. Adults do not feed and live only 3 to 4 days. Optimal conditions for *Feltiella* are temperatures 68 to 81°F and relative humidity greater than 60 percent. Larvae can tolerate a wider range of conditions than adults. Females actively seek mite colonies where they lay an average of 30 shiny, yellow eggs, usually where mite webbing occurs. Eggs hatch in 5 to 7 days. Brownish-yellow larvae, which grow to about 2 millimeters long, feed on eggs, nymphs, and adults of twospotted spider mites. Larvae feed by inserting their mandibles into their prey and sucking out the contents. They can consume over 300 mite eggs during their larval development, which takes about a week under greenhouse conditions. Mature larvae spin fluffy, white cocoons on the underside of leaves, usually along a vein. The pupal stage lasts approximately 1 week in the greenhouse and longer under cooler conditions.

Pupae are shipped on leaves or paper in various containers, which should be placed on the ground near concentrations of spider mites with their lids removed to release adult midges as they emerge.

Predatory Mites

Hypoaspis miles, a Predatory Soil Mite for Thrips and Fungus Gnat Larvae

Hypoaspis miles is a brown-colored, soil-dwelling predator about 1 millimeter long that feeds on thrips pupae in growing media. Studies have shown that *Hypoaspis* can reduce thrips populations by 30 to 60 percent. For biocontrol of thrips, this mite should be used in conjunction with another natural enemy that attacks thrips life stages, which occur on host plants. *Hypoaspis* is also effective in reducing fungus gnat larvae and may provide some control of shore fly larvae. *Hypoaspis* is commercially available through most biological control suppliers.

All life stages of *Hypoaspis* inhabit the top layer (2.5 to 4 centimeters) of the soil. At 75°F, its complete life cycle from egg to adult takes 10 to 13 days. *Hypoaspis* prefers moist potting compost and can live for up to 7 weeks in the absence of food. Soil must be moist but not wet. The minimum temperature for good activity is 60°F. *Hypoaspis* is shipped in shaker tubes with all stages of the mites in a vermiculite/peat carrier.

Neoseiulus (Amblyseius) barkeri, a Predatory Mite on Broad Mites

The predatory mite *Neoseiulus barkeri* is effective for controlling broad mites (*Polyphagotarsonemus latus*). It also feeds on western flower thrips.

Neoseiulus (Amblyseius) californicus, a Predatory Mite on Spider Mites and Broad Mites

This predatory mite is used to manage spider mites and is particularly useful if the environment reaches temperatures up to 100°F and humidity stays above 50 percent. *Neoseiulus* can survive in the absence of prey and therefore can be introduced on a preventative basis.

This mite has five life stages—egg, larva, protonymph, deutonymph, and adult—and completes its life cycle in 1 to 2 weeks depending on temperatures. Adults live about 20 days and can lay up to three eggs a day. They can consume five adult spider mites daily and may also feed on eggs and larvae.

N. californicus is shipped as units of 1,000, 2,000, or 5,000 in a shaker tube.

Neoseiulus (Amblyseius) cucumeris, a Predatory Mite on Thrips

N. cucumeris is a beige-colored predatory mite less than 1 millimeter long. After mating, the female mite deposits eggs on leaf hairs close to the veins on the underside of the leaf. This mite passes through one larval stage and two nymphal stages before becoming an adult. Both the nymphal and adult stages feed on thrips larvae. Total development time from egg to adult is about 6 to 9 days at 77°F.

These mites kill their prey by piercing the thrips larvae and sucking out the body contents. They attack thrips larvae and eggs on foliage and flowers. High numbers are needed for effective control. Second instar and adult thrips will defend themselves against the mites by striking out with their abdomens. Therefore, timing predatory mite introductions with the presence of first instar larva increases their effectiveness. *Neoseiulus* may also prey on spider mites or their eggs.

N. cucumeris has been used successfully to control thrips on greenhouse tomatoes, peppers, and eggplants. *N. cucumeris* is shipped as units of 10,000 to 50,000 in a shaker tube with bran and flour mites to serve as food during shipping, or as breeding sachets with 200 or more mites in different stages of growth. These sachets may provide several generations of reproducing predatory mites over a 6-week period.

N. cucumeris should be introduced when thrips populations are at low levels or as a preventative treatment. They are not effective as a rescue treatment. Virus indicator plants should be used in vegetable production houses where there is a history of Impatiens Necrotic Spot Virus (INSV). Indicator plants (highly susceptible to INSV) provide an early warning detection for thrips. Certain petunia varieties are very effective as indicators for plants (Carpet Blue, Blue Madness). Although petunias readily show virus symptoms (small, brown to black spots), they do not act as a virus reservoir and therefore may be used throughout the season by removing infected leaves. For more information on indicator plants, consult the University of Connecticut Web site at http://www.hort.uconn.edu/ipm/greenhs/htms/tospov.htm (accessed 6/9/2004).

Phytoseiulus persimilis, a Predatory Mite for Spider Mites

Phytoseiulus persimilis, the mainstay in spider mite control, can be used on many crops including tomato, pepper, cucumber, squash, beans, and flowers.

The adult mite is pear shaped and shiny orange, while nymphal stages are pale salmon. Predatory mites have a more slender body and longer legs than phytophagous mites. *Phytoseiulus* adults deposit eggs (oval shaped compared to round spider mite eggs) near spider mite colonies. Development time from egg to adult is 5 days at 86°F. Usually *Phytoseiulus* will develop faster than spider mites if the temperature is below 86°F and humidity is above 60 percent. Low humidity causes *Phytoseiulus* eggs to desiccate. Creating high humidity by spraying water through a fine nozzle with high pressure can extend their activity.

Phytoseiulus adults feed on all stages of spider mites, while the nymphs feed only on eggs, larvae, or protonymphs. Upon finding their prey, *Phytoseiulus* will kill the mite and consume the body contents. If webbing is evident—indicating a high population of spider mites—reduce their populations with compatible soft pesticides before introducing predatory mites. If new infestations occur, repeated applications of *Phytoseiulus* are necessary since these predators will starve without prey.

True Bugs

Orius insidiosus, a Minute Pirate Bug, Predator of Small Soft-Bodied Insects and Mites

The minute pirate bug *Orius insidiosus* is effective in attacking both adult and immature thrips and will also feed on other prey such as aphids, spider mites, and even small caterpillars.

Orius is a small (2-millimeter-long) bug, somewhat oval shaped, and black with white wing patches. Wings extend beyond the tip of the body. Nymphs are small, teardrop-shaped, and fast-moving wingless insects, yellow-orange to brown with conspicuous red eyes. Both adults and nymphs have a long feeding tube called a rostrum that folds under the body.

Females lay one to three eggs per day embedded in petioles or in veins on the underside of the leaf. They reproduce best at high humidity and during long days. Total development time from egg to adult is approximately 3 weeks at 77°F. Adult bugs live for 3 to 4 weeks and feed on all stages of thrips, while the nymphs eat only thrips larvae. Upon finding prey, the bugs insert their beaks and drain the prey of its body fluids. *Orius* will also eat pollen in the absence of thrips.

Orius is commercially available in the United States through biocontrol suppliers and is shipped as adults in a buckwheat husk carrier, packed in a plastic bottle. *Orius* is most effective when used as a preventive control.

Parasitoids

Parasitoid Wasps

Aphidius colemani, a Parasitoid Wasp of Aphids

Aphidius colemani is a slender, black wasp with brown legs, long antennae, and conspicuous wing venation, and is about 2 millimeters long. The female's abdomen is pointed while the male's is rounded. This tiny parasitoid attacks green peach and melon aphids. Females lay an egg in each aphid host. Larval and pupal development take place within the host, killing it in the process. The new adult wasp exits the aphid body, leaving behind a brown shell called an aphid mummy. Complete development takes 14 days at 70°F. Adults can live 2 to 3 weeks.

Aphidius colemani is shipped as parasitized aphids (mummies) in units of 500 per tube, mixed with sawdust. The contents of the tube should be shaken onto plants throughout the greenhouse.

Aphidius ervi, a Parasitoid Wasp of Potato Aphids

This parasitoid wasp is similar in appearance and life cycle as *Aphidius colemani* but about twice its size. It is used to control potato aphids and, like *A. colemani*, leaves behind a brown aphid mummy.

Aphelinus abdominalis, a Parasitoid Wasp of Aphids

This parasitoid wasp is about 3 millimeters long with short legs and short antennae. The female has a black thorax and yellow abdomen. Males are smaller and have darker abdomens. These are used to control larger aphid species such as potato aphid and glasshouse potato aphid. Upon finding prey, the female wasp inserts an egg into the aphid. *Aphelinus* can parasitize an aphid in any stage including winged adults. The wasp larva develops inside the aphid body, transforming it into a black mummy. A new adult wasp will emerge through a hole chewed in the aphid exoskeleton. *Aphelinus* adults will also feed on aphids that have not been parasitized. Adult females are active for up to 8 weeks and will continue to parasitize aphids over that time, as well as directly feed on them. *Aphelinus abdominalis* should be introduced as soon as aphids appear. They work more slowly than *Aphidius* but have the advantage of staying active for up to 2 months. *Aphelinus* is shipped in tubes containing 100 adults and are released into the crop by tapping softly on the open tube.

Dacnusa sibirica, a Parasitoid Wasp for Leafminers

This parasitoid wasp occurs naturally in North America and Europe. Adults are dark brown, 2 to 3 millimeters long, and have very long antennae. This wasp is able to locate leafminer mines at very low densities, searching mainly in the lower crop canopy. Females deposit an egg in a leafminer larva, preferably of the first or second instar. Upon hatching, the new wasp completes its life cycle within the body of the leafminer, killing it in the process. Development time for the wasp is 17 to 19 days at 68°F. *Dacnusa* can hibernate in leafminer pupae. These wasps are shipped in units of 250 adults in 100-milliliter bottles.

Diglyphus isaea, a Parasitoid Wasp for Leafminers

This black parasitoid wasp is 2 to 3 millimeters long and also occurs naturally in North America. Females sting second or third instar leafminer larvae to paralyze them. They then deposit an oval egg in the mine, next to the leafminer larva. Upon hatching, the wasp larva feeds on the leafminer. *Diglyphus* populations build up rapidly, controlling heavy leafminer infestations in a short time. At lower leafminer densities, *Dacnusa sibirica* is more efficient in locating prey.

These parasitoids are also shipped in units of 250 adults in 100-milliliter bottles. Because of the different searching actions of *Diglyphus* and *Dacnusa*, they can be shipped as a mixture of 225 *Dacnusa* and 25 *Diglyphus* adults in 100-milliliter bottles.

Encarsia formosa, a Parasitoid Wasp for Whiteflies

Adult female wasps are about 0.6 millimeters long and live 15 to 30 days at a temperature range of 61 to 83°F. Higher temperatures decrease longevity. They have black heads and thoraxes and yellow abdomens. Males are darker than females but rarely occur; females reproduce parthenogenetically (without mating). Adults obtain energy by consuming honeydew produced by whiteflies and by feeding on whitefly larvae. *Encarsia* females search the plant canopy for whitefly larvae. Upon finding the correct size to parasitize (third or early fourth instar larva), the female inserts an egg into the larva. *Encarsia* completes its development from egg to adult within the parasitized whitefly. Each adult female *Encarsia* can lay about five eggs per day with a total of about 59 in a lifetime.

On the eighth day after being parasitized, whitefly pupae begin to turn gray. Healthy whitefly pupae are creamy white. As the *Encarsia* larva continues to grow, the whitefly pupal case changes color from gray to black and can be easily recognized as parasitized. This totally blackened appearance indicates that the *Encarsia* larva has pupated, and within 7 days a mature wasp will emerge through a round hole chewed in the head portion of the top surface of the pupa. The complete life cycle for *Encarsia* takes approximately 19 to 21 days at 73°F.

Four methods of releasing *Encarsia* to control greenhouse whiteflies have been developed in Europe and are used by commercial vegetable producers. The four methods are: Dribble, Banker Plants, Inundative, and Pest in First. The effectiveness and success of these programs are based on the level of honeydew and sooty mold development on foliage and fruit. If sooty mold levels are acceptable for a marketable product, control of greenhouse whitefly has been achieved.

1. **Dribble:** Weekly parasitoid introductions begin at planting in anticipation of naturally developing whitefly populations, or introductions *of Encarsia* are made when whiteflies are first observed. After observing whitefly stages, parasitoids are introduced every 2 weeks until there is a high level of parasitized whitefly pupae in the crop. The introductions can then be stopped. This is usually more cost effective than introducing *Encarsia* every week of the crop cycle. The dribble method is the most common introduction method used in Pennsylvania greenhouses.
2. **Banker Plants:** This system uses established colonies of parasitoids reared on whitefly-infested plants that are introduced into the crop. Mesh screens can be used to cage banker plants to contain whiteflies, allowing only the tiny parasitoids to disperse into the production area. Using this method may require other facilities (greenhouses or growth chambers) to establish the pest and biocontrol on the banker plant. However, an advantage is having a sustainable, onsite supply of parasitoids.
3. **Inundative:** High numbers of *Encarsia* are introduced on a regular basis. This method might be used when establishment and reproduction of the biocontrols are not expected. Inundative releases are commonly used in ornamental crops or short-term crops. Inundative introductions of biocontrols may not be cost effective.
4. **Pest in First:** Adult whiteflies are introduced into the crop at a fixed rate when transplants are installed in production houses. *Encarsia* is then introduced at regular intervals when whitefly nymphs develop. This method has not been widely adopted because of the concern of releasing pests into the crop.

These introduction methods should be discussed with the supplier, who can also give advice on the number of *Encarsia* needed for the crop. This amount will be based on whitefly populations, hence the need for careful crop observation and scouting. The methods discussed here can be used for other parasitoids and predators.

Eretmocerus eremicus, a Parasitoid Wasp for Whiteflies

Identifying the species of whitefly to be controlled is important because both *Encarsia* and *Eretmocerus* are parasitoids of all whitefly species, but *Encarsia* is more effective in controlling greenhouse whitefly while *Eretmocerus* is more effective on silverleaf whitefly.

Like *Encarsia*, adults will feed on whitefly nymphs as well as lay eggs in or under them. Generally, *Eretmocerus* is more resistant to pesticides than *Encarsia*, and adults are more active than *Encarsia* at higher temperatures. This parasitoid is a good choice in the spring when greenhouse temperatures exceed 80°F.

The adult female *Eretmocerus*, about 1 millimeter long, is pale lemon yellow with green eyes and thick antennae. Males have longer, elbowed antennae and are yellowish brown. They can develop in any instar of the whitefly nymph but prefer the second and early third instar. Adult wasps will also feed on whitefly nymphs. *Eretmocerus* lays its eggs under its host. The newly emerged larva attaches its hooklike mouthparts to the underside of the whitefly nymph and chews a small hole into it. After 3 to 4 days, the parasitoid larva enters the whitefly nymph where it remains dormant until the whitefly pupates. Once that stage is reached, the *Eretmocerus* larva releases digestive enzymes and begins ingesting the semiliquid body parts of the pupa.

Two weeks after being parasitized, whitefly pupae turn yellow rather than black as when parasitized by *Encarsia*. In order to exit its host, *Eretmocerus* makes a small, round hole in the top of the whitefly pupa. Its complete life cycle takes 17 to 20 days, depending on temperature and which instar of the whitefly was parasitized.

Eretmocerus should be introduced at curative levels when whitefly stages are first found and continue weekly until 80 percent of the whitefly pupae are parasitized. A 16x to 20x hand lens is required for monitoring. Continuing to monitor whitefly populations after introductions are stopped is important. These parasitoids are usually shipped as parasitized whitefly pupae in units of 3,000 attached to cardboard strips or loose in bottles of 3,000 or 10,000.

Leptomastix dactylopii, a Parasitoid Wasp of Citrus Mealybugs

This 3-millimeter-long parasitoid wasp moves around by short, hopping flights. Females are generally longer than males and have nonhairy, long, straight antennae. Males have hairy, slightly bent antennae. Females live about 27 days and can lay 50 to 100 eggs. *Leptomastix* is very efficient in controlling citrus mealybugs and is attracted to the odor of unparasitized mealybugs. *Leptomastix* females search leaves for larger stages of mealybugs. Upon finding a suitable host, the wasp will lay an egg in the mealybug body. The developing larva turns the mealybug into a legless, brown, barrel-shaped mummy in which it completes its life cycle. After emerging from the parasitized body of the mealybug, the adult wasp feeds on honeydew produced by mealybugs before starting the next generation. Its lifecycle takes approximately 3 weeks at 75°F. If mealybug populations are heavy, this parasite works well when introduced in conjunction with *Cryptolaemus*. Mealybug identification is important because *Leptomastix* only parasitizes citrus mealybugs. *Leptomastix* is shipped in tubes of 100 adults.

Metaphycus helvolus, a Parasitoid Wasp of Soft Scales

Metaphycus helvolus is a 1.5- to 2-millimeter-long parasitoid wasp best used as a preventive agent and, when introduced at the proper time, is very effective. *Metaphycus* is shipped as adults. Due to their minute size, adult wasps may get caught in honeydew if amounts are excessive. Plants may need to be rinsed before introducing the wasps, or predators that don't get caught in the honeydew may be used instead. The adult wasp places one egg under each scale, which, upon hatching into a larva, consumes the scale from within. After completing its development, a new parasitoid emerges from the empty scale cadaver. Development time of this parasitoid is about 42 days. Adults live about 2 months. The optimum environmental conditions are temperatures of 73 to 87°F with a relative humidity around 50 percent.

Trichogramma spp., a Parasitoid Wasp of Caterpillars

One of the most popular and effective controls for caterpillars is the egg parasitoid *Trichogramma*. These 0.9-millimeter-wasps have a relatively compact body and short antennae. Females lay their eggs in the eggs of many destructive caterpillar pests. The wasp completes its life cycle within the parasitized caterpillar egg. *Trichogramma* will only parasitize caterpillar eggs, so using pheromone traps to predict the presence of egg-laying females before introducing them is important.

Trichogramma is shipped in parasitized grain moth eggs glued to small cards. These cards are placed throughout the crop where the wasps will emerge and begin searching plants for host eggs. Protect the cards from ants since they will feed on the eggs. Species available from most biocontrol suppliers include *T. brassicae, T. minutum*, and *T. pretiosum*.

Parasites

Entomopathogenic Nematodes

These nematodes are microscopic, simple roundworms lacking segments or appendages and may be parasitic, free-living, or predaceous. An entomopathogenic (insect-parasitic) nematode has a symbiotic association with bacteria that are lethal to many soil-dwelling insects but have no effect on vertebrate animals and plants. The two genera of insect-parasitic nematodes used for biocontrol are *Steinernema* and *Heterorhabditis*. Nematodes are host specific. Therefore, purchasing the correct nematode for your pest situation is important. Insect-parasitic nematodes have been used successfully to control soil-dwelling pests in greenhouse, nursery, strawberry, mushroom, and turf industries. Because of their high degree of safety, nematode applications are exempt from reentry intervals and worker protection standards and do not require a mask or other safety equipment. Nematodes can be applied like most conventional pesticides using a pull-behind sprayer, fertigation system, or backpack sprayer.

Steinernematid nematodes are shipped in the infective juvenile stage. When applied to soil, the infective juveniles surround the pest insect and enter it through natural body openings. Once inside the body, symbiotic bacteria are released from the nematode gut, which multiply rapidly and cause insect death within 24 to 48 hours. The nematodes then feed on broken-down tissue in the insect cadaver and develop into adults. A new generation of nematodes is produced within 2 weeks. Thousands of infective juveniles emerge from the insect cadaver in search of fresh hosts. Insects killed by steinernematid nematodes appear brownish yellow, while insects killed by heterorhabditids become red with gummy-like tissue.

Heterorhabditis bacteriophora, an Entomopathogenic Nematode

This entomopathogenic nematode attacks caterpillars, grubs, and fungus gnats, among other soil-dwelling hosts. This is the most widely used nematode for controlling root weevils, especially black vine weevil in warm, containerized soil. It is used in home gardens, lawns, strawberries, ornamentals, tree nurseries, and greenhouses. *Heterorhabditis* is shipped as a clay formulation containing a minimum of 50 million infective juvenile nematodes.

Steinernema carpocapsae, an Entomopathogenic Nematode

Easily mass produced, these were the most studied of all entomopathogenic nematodes. They are formulated into a partially desiccated state or on a moist sponge. They are especially effective against soil/surface-feeding insects such as cutworms, armyworms, billbugs, stem borers, fleas, and webworms. This species is an “ambusher,” standing on its tail in an upright position near the soil surface and attaching to passing hosts. It is sold under the trade names Exhibit SCO® and EcoMask®, and is used for vegetables, small fruits, turf, ornamentals, and greenhouse crops. *S. carpocapsae* does not function well below 60°F.

Steinernema feltiae, an Entomopathogenic Nematode

Steinernema feltiae is used to control dipterous insects (flies), including fungus gnats and mushroom flies. Infected fungus gnat larvae appear brownish yellow rather than their healthy white color. This nematode is more effective than *S. carpocapsae* at lower soil temperatures because it is active at temperatures from 50 to 86°F. Trade names include Scanmask®, Exhibit SF®, and Entonem®. *Steinernema* nematodes are shipped as either a clay formulation on a moist sponge or liquid suspension. Follow label directions for application. Once in suspension, apply nematodes to the compost/soil surface as a drench. Water well before and after application.

Pathogens

Fungus

Beauveria bassiana, Mycoinsecticide

Beauveria bassiana is a fungus that is pathogenic to insects. To be infective, fungal spores must have direct contact with insects. As spores attach to the insect cuticle, they germinate and the fungus grows into the body cavity. Two products commercially available are and Botani-Gard™ and Naturalis T&O™. This fungus should be used as a preventive and not as a "rescue treatment." Successive treatments may be required to achieve desired control. Killing insects takes 7 to 10 days. Therefore, *Beauveria bassiana* should not be used to control heavy pest populations.

Paecilomyces fumosoroseus, Mycoinsecticide

Paecilomyces fumosoroseus is a fungal insect pathogen effective against whitefly. It acts very similarly to *Beauveria bassiana*. A formulation, PFR-97™ 20 percent WDG, for use in greenhouses and interiorscapes is produced. While this formulation is registered in many states, it is currently not registered for use in Pennsylvania.

Glossary

Action threshold—the pest density at which a control tactic must be implemented to avoid an economic loss. *See economic threshold*.

Active ingredient (AI)—the component of a pesticide formulation responsible for the toxic effect.

Antenna, Antennae (pl.)—a pair of sensory organs located on the head of an insect, above the mouthparts.

Arthropod—any of the invertebrate animals (such as insects, spiders, or crustaceans) having an exoskeleton, a segmented body, and jointed limbs.

Augmentation—biological control practices intended to increase the number or effectiveness of existing natural enemies when too few are present to control a pest effectively.

Bacterium—a single-celled microscopic plant-like organism that does not produce chlorophyll.

Biofungicides—substances of biological origin that kill or inhibit the growth of plant pathogenic fungi.

Biological control—the use of living organisms such as predators, parasitoids, and pathogens to control pest arthropods, weeds, or diseases. Typically involves some human activity, which can include introducing predators, parasites, and disease organisms, or releasing sterilized individuals. Biocontrol methods may be an alternative or complement to chemical pest control methods.

Biological pesticide/Biopesticide/Biorational pesticide—a pesticide that is biological in origin in contrast to synthetic chemicals (e.g., viruses, bacteria, pheromones, natural plant compounds); Bt is a biopesticide.

Botanical/Botanical pesticide—a pesticide whose active ingredient is a plant-produced chemical such as nicotine or strychnine; also called a plant-derived pesticide. Being "natural" pesticides, as distinct from synthetic ones, they are typically acceptable to organic farmers.

Bt—the bacterium *Bacillus thuringiensis*. Bt is a biological pesticide (biopesticide) that degrades rapidly to non-toxic compounds, does not present any human or animal hazards, and does not harm biocontrols.

Caterpillar—the immature stage (larva) of a butterfly, moth, sawfly, or scorpionfly.

Chemical control—pest management practices that rely upon the application of synthetic or naturally derived pesticides.

Complete metamorphosis—type of insect development characterized by four distinct stages—egg, larva, pupa, and adult.

Contact poison—a pesticide that is absorbed through the body wall, as opposed to one that must be ingested.

Conventional pesticide—*see pesticide*.

Cornicle—dorsal tubular structure on the posterior part of the abdomen of aphids from which various alarm pheromones are released.

Crawler—the active first instar in whiteflies and scales. This instar moves to find a suitable feeding site and then embeds its piercing-sucking mouthparts into a plant. Later instars usually do not move from this site so the term crawler is often used in place of "first instar."

Cultural control—pest management practices that rely upon manipulation of the cropping environment (e.g., cultivation of weeds harboring insect pests).

Curative introduction—adding the biocontrol organisms after detecting the pest.

Deutonymph—second nymphal stage of mites.

Economic threshold—level of pest populations at which damage from pests is more costly than controlling them. *See action threshold.*

Entomopathogenic—insect-attacking organism.

Fumigant—a substance that produces a gas, vapor, fume, or smoke intended to kill a pest.

Fungicide—any substance that kills or inhibits the growth of a fungus.

Fungus, Fungi (pl.)—any of numerous plants lacking chlorophyll, ranging in form from a single cell to a body of branched filaments; includes the yeasts, molds, smuts, and mushrooms.

Gradual metamorphosis—a type of insect development in which there is no prolonged resting stage (pupa); the three stages are egg, nymph, and adult.

Herbicide—a substance used to kill or control weeds.

Honeydew—the sugary liquid discharge from the anus of certain insects (Homoptera) such as aphids and scales.

Host—the organism in or on which a parasite or parasitoid lives; a plant on which an insect feeds.

Hyperparasite—a parasite of a parasite.

Indicator plant—varieties of virus-susceptible plants that provide an early detection system for locating thrips. Certain petunia varieties are very effective because they attract thrips and may show symptoms of virus infection; however, the petunias do not become a reservoir for the virus.

Inoculative release—the release of relatively small numbers of natural enemies that are expected to colonize, reproduce, and spread naturally throughout an area. *See inundative release*.

Insect growth regulator (IGR)—a pesticide constructed to mimic insect hormones that control molting and the development of some insect systems, affecting the change from immature to adult. In most cases this pesticide prevents the insect from becoming a sexually mature adult, and perhaps even causes its death.

Insecticide resistance—genetically inherited ability to withstand doses of pesticide that would kill individuals from strains whose ancestors had not been exposed to the pesticide.

Instar—the stage of an insect's life between successive molts; for example, the first instar is between hatching from the egg and the first molt.

Integrated Pest Management (IPM)—an approach to the management of pests in which all available control options, including physical, chemical, cultural, and biological controls, are evaluated and integrated into a unified program. Pesticide applications are used only when preventive practices fail to keep pests under control.

Inundative release—the release of relatively large numbers of natural enemies to suppress pest populations without the expectation that the natural enemies will colonize and spread throughout the area. *See inoculative release*.

Larva, Larvae (pl.)—the immature stage between the egg and pupa of insects having complete metamorphosis where the immature differs radically from the adult (e.g., caterpillars, grubs).

Least toxic—having a minimal toxic effect on nontarget organisms.

Life cycle—the sequence of events that occurs during the lifetime of an individual organism.

Mechanical control—management of pests by physical means such as the use of screens or row covers.

Metamorphosis—a change in body form during development of an insect.

Microbial insecticide—a preparation of microorganisms (e.g., viruses or bacteria) or their products used to suppress insect pest populations.

Mite—any of several minute invertebrates belonging to the phylum Arthropoda, class Arachnida.

Monitoring—using sticky traps, pheromone traps, or other devices to determine the presence or abundance of pest populations. *See scouting*.

Multivoltine—having more than generation per season.

Mycoinsecticide—a biological pesticide based on a naturally occurring fungal disease (e.g., *Beauveria*) that is specific to the target pest.

Nanometer—unit of length that is one-billionth of a meter.

Natural enemies—living organisms found in nature that kill, weaken, or reduce the reproductive potential of other organisms.

Nematode—an elongated, cylindrical worm parasitic in animals, insects, or plants, or free-living in soil or water.

Nymph—the immature stage, following hatching from the egg, of an insect that does not have a pupal stage.

Oviposition—the laying or depositing of eggs.

Parasite—an organism that lives in or on another organism (the host) during some portion of its life cycle, usually without killing the host. The entomopathogenic nematodes are parasitic but in the manual are considered biorational pesticides.

Parasitize—the act of a parasitoid or parasite entering its host.

Parasitoid—an animal that feeds in or on another living animal for a relatively long time, consuming all or most of its tissues, and eventually killing it.

Parthenogenesis—reproducing by eggs that develop without being fertilized by a male.

Pathogen—a disease-causing organism.

Pest—an organism (e.g., weeds, termites, rats, and mildew) that interferes with human activities, property, or health, or is objectionable.

Pesticide—any substance or mixture of substances used to kill, control, repel, or mitigate any pest and any substance or mixture of substances used as a plant regulator, defoliant, or desiccant. Insecticides, fungicides, rodenticides, herbicides, and germicides are all pesticides.

Pheromone—a substance emitted by an animal to influence the behavior of others of the same species. Some are synthetically produced for use in insect traps.

Phyllody—conversion of petals and sepals to more leaf-like structures; a symptom produced by some phytoplasmas.

Physical control—management of pests by physical means such as heat, cold, sound waves, etc.

Phytophagous—feeding on plants.

Phytotoxic—substance that is poisonous to plants.

Predator—any animal (including insects and mites) that kills other animals (prey) and feeds on them. Each predator eats many prey individuals.

Prepupa—the nonfeeding stage between the larval period and the pupal period. Occurs in thrips and female scales.

Preventative introduction—introducing biocontrol organisms before detecting the presence pests.

Protonymph—first nymphal stage of mites.

Pupa, Pupae (pl.)—the nonfeeding stage between the larva and adult in insects with complete metamorphosis

Pyrethroids—synthetic compounds produced to duplicate or improve on the biological activity of the active principles of the pyrethrum plant.

Pyrethrum—a natural botanical insecticide, the active principles of which are extracted from the flowers of the pyrethrum plant, and are know collectively as "pyrethrins."

Residual—refers to the property of a substance (pesticides are one example) that allows it to remain in an area for an extended period.

Sampling—estimating the density of organisms (pests or natural enemies) or damage by examining a defined portion of the crop. *See scouting*.

Sanitation—any activity that reduces the spread of pathogen inoculum, such as removing and destroying infected plant parts and cleaning tools and field equipment.

Scouting—inspecting for pests, including insects, weeds, and pathogens. Pest scouting is a basic component of integrated pest management programs used to determine whether pest populations are at levels that warrant control intervention and also may help to determine the most appropriate method of control. *See monitoring*.

Species—a group of individuals similar in structure and capable of interbreeding and producing fertile offspring. They are different in structure from other such groups and do not interbreed with them.

Symbiotic—a close biological relationship between two or more kinds of organisms. An entomopathogenic nematode has a symbiotic relationship with bacteria that are deadly to some insects.

Systemic insecticide—an insecticide that is absorbed into plant sap and is lethal to insects feeding on or within the treated plant.

Threshold/control action threshold—*see action threshold*.

Vector—an organism capable of carrying and transmitting a disease-causing agent from one host to another.

Virescence—greening of the flowers; a symptom produced by some phytoplasmas.

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Appendixes

A. Monitoring and Scouting Techniques for Greenhouse Plants

B. Greenhouse IPM Crop Information Reporting Form

C. Beneficial Organisms

D. Quick Methods for Evaluating Biocontrol Shipments

E. Biocontrol Suppliers

F. Biorational Pesticides

Appendix A. Monitoring and Scouting Techniques for Greenhouse Plants

	Aphids	Plant Bugs	Shore Flies	Fungus Gnats	Leaf-miners	Mealy-bugs	Broad Mites	Spider Mites	Soft Scales	Armored Scales	Slugs	Thrips	White-flies	Cater-pillars
MONITORING														
Sticky cards at top of pot	X	X	X	X	X							X	X	
Horizontal sticky trap at top of pot	X		X	X	X									
Trap/Indicator plants		X			X							X	X	
Place piece of potato on media			X	X										
SCOUTING														
Inspect underside of leaf	X					X	X	X	X	X		X	X	X
Inspect upper surface for stippling/small white spots								X				X		
Inspect leaves for mines within tissue					X									
Inspect new growth or terminal for feeding	X	X					X					X		
Lightly blow into flowers and look for movement												X		
Tap flowers over white surface and look for movement	X							X				X		
Press lower leaf on white card and look for spots on card								X						
White or brown spots on flowers												X		
Dark area on buds that are just opening												X		
Check leaves on media for feeding and larvae beneath			X	X										
OBSERVE FOR														
Honeydew or sooty mold on leaves	X					X			X	X			X	
Brown, callus-like spots on stems/leaves									X	X				
White, cottony mass on stems/leaves						X								
Holes in leaves											X			X
Small, clear, skeletonized spot on leaf											X			X
Cut edges of leaves											X			X
Frass on leaves														X
Small, black spots on leaves (fecal drops)			X									X		
Chlorotic (yellow) spots on upper leaf surface	X							X	X	X		X	X	
Wilting of new growth		X												
Cast skins on leaf from molting insect	X													
Curling of leaves	X						X							
Distortion of new growth	X	X				X	X						X	
Main stems of plants	X	X				X			X	X				
Slime trail on leaf											X			
Buds fail to open or uneven opening of flowers												X		
Webbing on leaves or flowers								X						
Gnat-like insects flying among plants			X	X										

Source: Adapted from Oetting, Ronald D. 1997. "Table: Ornamentals-Greenhouse Plants." In: *1997 Insect Control Guide*. Willoughby: Meister Publishing.

Appendix B. Greenhouse IPM Crop Information Reporting Form

LOCATION: Greenhouse Management Unit (GMU) identification (indicate section if greenhouse has multiple areas)
EXAMPLES: Greenhouse area 1 (left side) or Greenhouse area 2 (back) or Greenhouse area 3 (front)

Crop Information:

PLANT SPECIES	NUMBER OF PLANTS OR CONTAINERS	PLANTING DATE	EXPECTED HARVEST DATE

Insect Control Information:

DATE APPLIED	LOCATION	PRODUCT APPLIED FOR INSECT CONTROL	PEST TREATED	BIOLOGICAL OR CHEMICAL? (B OR C)	APPLICATOR	APPLICATION RATE	WAS APPLICATION EFFECTIVE?	EVALUATION METHOD USED

Disease Control Information:

DATE APPLIED	LOCATION	PRODUCT APPLIED FOR DISEASE CONTROL	DISEASE TREATED	BIOLOGICAL OR CHEMICAL? (B OR C)	APPLICATOR	APPLICATION RATE	WAS APPLICATION EFFECTIVE?	EVALUATION METHOD USED

APPENDIX B *(continued)*

Sticky Card Counts:

DATE	LOCATION	CARD NUMBER	WHITEFLY COUNT PER CARD	THRIPS COUNT PER CARD	FUNGUS GNAT COUNT PER CARD	SHORE FLY COUNT PER CARD	WINGED APHID COUNT PER CARD

Insect and Mite Activity Whole Plant Count:

DATE	LOCATION	PLANT	PEST FOUND	NUMBER OF PLANTS SAMPLED	NUMBER OF PESTS FOUND PER PLANT	AVERAGE NUMBER OF PESTS FOUND	INCREASE OR DECREASE FROM LAST COUNT?	PLANT DAMAGE NOTED

Disease Activity:

DATE	LOCATION	PLANT	DISEASE ACTIVE ON PLANTS	% OF PLANTS INFECTED	INCREASING OR DECREASING IN SEVERITY?

APPENDIX B *(continued)*

Root Health:

DATE	LOCATION	PLANT	RATING (GOOD, FAIR, POOR)	COMMENTS

Comments:

Map of Greenhouse:

Source: Adapted from Gill, S. et al. 2003. *Integrated Pest Management for School Greenhouse Operations*. Maryland Cooperative Extension, University of Maryland.

Appendix C. Beneficial Organisms

The numbers under "Suppliers" refer to those listed in Appendix E.

BENEFICIAL ORGANISM	PESTS CONTROLLED	APPLICATION/COMMENTS (Follow current recommendations from supplier for your particular crop.)	SUPPLIERS
Aphelinus abdominalis (parasitoid, wasp)	aphids	Release 0.5–2 adults/sq yd; release at first sign of pests	1, 2, 3, 4, 5
Aphidius colemani (parasitoid, wasp)	aphids	Release 0.5–2 pupae/sq yd; release at first sign of pests and for 3 consecutive weeks thereafter; humidity should be 70–85%, temp. 65–77°F; sensitive to pesticides	1, 2, 3, 4, 5
Aphidius ervi (parasitoid, wasp)	potato aphids	Use about 1/2 the rate of *A. colemani*	1, 2, 3, 4, 5
Aphidoletes aphidimyza (predator, midge)	aphids	Preventative: 1–3 pupae/sq yd monthly; humidity should be 50–90%, temp. 60–80°F; release when aphids are first observed; active at night; sensitive to day length Curative: 2–9 pupae/sq yd weekly, depending on amount of infestation	1, 2, 3, 4, 5
Chrysopa carnea (predator, lacewing)	aphids, caterpillars, mealybugs, scales, spider mites, thrips, whiteflies	May arrive as eggs, immatures, or adults. Adults: 1 adult/5–30 aphids. Larvae: 10 larvae/sq yd as curative release. Eggs: 1,000 eggs/200 sq ft. Apply every 1–3 weeks as needed	2, 3
Chrysoperla rufilabris (predator, lacewing)	See above	See above	1, 3, 4, 5
Cryptolaemus montrouzieri (predator, ladybird beetle)	aphids, mealybugs, soft scales	2–5 adults/infested plant; humidity should be 70–80%, temp. 70–80°F; larvae are cannibalistic; repeat as necessary for control; do not wear white while distributing	1, 2, 3, 4, 5
Dacnusa siberica (parasitoid, wasp)	leafminers	Preventive: 1–3 adults/sq yd, biweekly; Curative: 2–5 adults/sq yd biweekly, 2–3 times. Apply at first appearance of pests. Humidity should be 50-90%; temp. 60-85°F.	1, 2, 3, 4, 5
Delphastus pusillus (=*catalinae*) (predator, beetle)	greenhouse whitefly, sweetpotato whitefly	100 adults/10 plants; will feed on spider mites if no whiteflies are available; should be used along with *Encarsia formosa* and traps; temp. should be 60–85°F	1, 2, 3, 5
Diglyphus isaea (parasitoid, wasp)	leafminers	Preventative: 1–2 adults/sq yd triweekly. Curative: 2–4 adults/sq yd biweekly, 2–3 times. Temps. should be 75–90°F and humidity around 80%	1, 2, 3, 4, 5
Encarsia formosa (parasitoid, wasp)	greenhouse whitefly, sweetpotato whitefly, silverleaf whitefly	3–6 pupae/sq yd weekly for 3 weeks; apply when pests are first observed; should be used in conjunction with traps, may be used along with other beneficials; *E. formosa* is very susceptible to chemicals; temp. should be at least 64°F	1, 2, 3, 4, 5
Eretmocerus californicus or *E. eremicus* (parasitoid, wasp)	greenhouse whitefly, sweetpotato whitefly, silverleaf whitefly	4–6 adults/sq yd; introduce when whiteflies are first observed; may be used in combination with other beneficials such as green lacewings; *Eretmocerus* is more tolerant of pesticides and hot, dry temperatures than *Encarsia formosa*	1, 2, 3, 4, 5
Feltiella acarisuga (predator, midge)	mites	1–5 adults/sq yd/week for 4 weeks	1, 2, 3, 4, 5
Hippodamia convergens (predator, ladybird beetle)	aphids, mites, whiteflies	1–4 beetles/sq yd biweekly, 2–4 times; release at dusk near an immediate food source; spray plants with water prior to release	1, 2, 3
Hypoaspis miles (predator, mite)	fungus gnats, shore flies, mites, springtails	Preventive: 35–70 mites/sq yd. Curative: 45–200 mites/sq yd, depending on amount of infestation; live and breed in the top 0.5 inch of soil	1, 2, 3, 4, 5
Hypoaspis miles (predator, mite)	thrips	100–300 mites/sq yd	1, 2, 3, 4, 5
Leptomastix dactylopii (parasitoid, wasp)	mealybug	2 adults/sq yd or 5 adults/infested plant; repeat 1 or 2 times/year	2, 3, 4, 5
Metaphycus helvolus (parasitoid, wasp)	scales	5–10 pupae/plant; temp. should be 73–90°F; humidity 50%; do not overwinter in cold climates; attracted to lights and sticky traps	1, 3
Neoseiulus (Amblyseius) barkeri (predator, mite)	broad mites, thrips	10–30 mites/plant per week	

APPENDIX C *(continued)*

The numbers under “Suppliers” refer to those listed in Appendix E.

BENEFICIAL ORGANISM	PESTS CONTROLLED	APPLICATION/COMMENTS (Follow current recommendations from supplier for your particular crop.)	SUPPLIERS
Neoseiulus (Amblyseius) californicus (predator, mite)	spider mites	6 mites/sq yd; introduce at first sign of spider mites; can tolerate hot conditions (temp. 70–90°F; humidity 60%); can survive absence of prey longer than other predator mites	1, 2, 3, 4, 5
Neoseiulus (Amblyseius) cucumeris (predator, mite)	thrips, mites	100 mites/sq yd; introduce at first sign of pests; temp. should be 50–85°F; humidity 70–90%	1, 2, 3, 4, 5
Orius insidiosus (predator, minute pirate bug)	aphids, caterpillars, thrips, whiteflies, mites	1 adult/sq yd, 1 adult every 2 sq ft when pests are present; temp. should be 70–90°F; *Orius* are dormant September–April; reapply every 2–3 weeks; very susceptible to pesticides; works well in conjunction with *Neoseiulus cucumeris*	1, 2, 3, 4, 5
Phytoseiulus persimilis (predator, mite)	spider mites	1 mite/sq ft plus 10 mites/mite-infested leaf; apply at first sign of spider mites; if pests persist, reapply every 3–5 weeks; can be used in conjunction with *Neoseiulus californicus*; may be used in combination with *Bt* or Enstar II; temp. should be 65–80°F; humidity 60–90%	1, 2, 3, 4, 5
Steinernema feltiae (beneficial nematode)	fungus gnats	100,000–350,000/sq yd; apply when media temps. are 55–90°F; apply in evening, directly to growing media; water in after application; needs moist environment to thrive	1, 2, 3, 4, 5
Trichogramma spp. (parasitoid, wasps)	caterpillars	1–4 wasps/sq ft	1, 2, 3, 4

Sources: Greer, L., and S. Diver. 1999. *Integrated Pest Management for Greenhouse Crops: Pest Management Systems Guide.* Appropriate Technology Transfer for Rural Areas. 34 pp. http://attra.ncat.org/attra-pub/gh-ipm.html#general (accessed November 20, 2003); Orr, D. B., and J. R. Baker. No date. *Biocontrol in Greenhouses.* Biological Control Virtual Information Center, North Carolina State University. 7 pp http://cipm.ncsu.edu/ent/biocontrol/2a.htm (accessed 6/2/2004).

Appendix D. Quick Methods for Evaluating Biocontrol Shipments

Biocontrol Agent	Stage shipped	Packaging method	How to determine viability	How to estimate quantity	How to determine establishment and reproductive success
Aphelinus abdominalis	Adults	In tube	Movement, adults will fly	Visual count	Parasitized aphid mummies after about 8 days
Aphidius spp.	Adults, parasitized mummies	Loose in container	Movement, released adults will fly immediately	Visual count	Parasitized aphid mummies after 2 weeks
Aphidoletes aphidimyza	Pupae	Loose in container of vermiculite	Hold container in warm place until hatch		Look for tiny, orange larvae in aphid colonies
Chrysopa, Chrysoperla spp.	Eggs	Loose in vial or stuck to card	Hatching larvae within 3 days of receipt, if held at 75–80°F	Visual count	Look for pest reduction within 10 days; lacewings normally do not reproduce in most greenhouses
	Larvae	Cold bottle of rice hulls or vermiculite or in cardboard frame	Movement	Visual count	See above
	Adults		Movement, interest in flight	Visual count	Eggs laid on foliage
Cryptolaemus montrouzieri	Adults	In tube or bottle with paper or wood strips	Movement, less than 10% mortality	Count active adults	Reduction in pest numbers, mobile, large, mealybug-like larvae after 4 weeks
Dacnusa siberica	Adults	Loose in tube	Movement, released adults will fly immediately	Visual count	Place leafminer pupae in glass container; count wasps and leafminers that emerge
Delphastus pusillus (=*catalinae*)	Adults	Loose in container	Movement, less than 10% mortality	Count active adults	Mobile larval stage, after 4 weeks, active adults
Diglyphus isaea	Adults	Tube with screw cap	Movement	Count active adults	Put leaf samples in container; see if wasps or flies emerge
Encarsia formosa	Parasite pupae inside of whitefly scales	Glued to card	7–10 days after release, look for emergence holes in pupae using microscope or high-powered hand lens	Keep 1 card in small jar to observe number of adults that emerge over 2 week period; smear of Vaseline on lid will capture new adults to make counting easier	Black parasitized scale after 5 weeks, or golden parasitized scale if silverleaf whitefly was attacked; wasp body is visible inside parasitized scale observed under microscope
	Parasite pupae inside of whitefly scales	Loose in vial	Low number of emerged adults, few should emerge during shipment	Measure portion into clear vial and proceed as above	See above
Eretmocerus spp.	Pupae, adults	Loose or in sawdust or glued to cards	See *Encarsia*	See *Encarsia* entry for cards	Parasitized whitefly pupa turns yellow
Feltiella acarisuga	Pupae	On paper pieces	Look for "emergence tubes" on pupae	Visual count of pupae with "emergence tubes"	Look for tiny white larvae in spider mite colonies
Hippodamia convergens	Adults	In bag or container with packing materials	Movement, less than 10% mortality	Visual count	Only establish on enormous aphid populations; eggs and larvae will be seen if abundant
Hypoaspis miles	Adults	In peat mix in tube or bottle	Movement	See predator mites	Mobile mites on substrate after 5 weeks
Leptomastix dactylopii	Adults	In bottle or deli container, no carrier	Movement, less than 10% mortality	Count active adults	Parasitized mealybug is an empty shell with emergence hole that can be seen with hand lens

APPENDIX D. *(continued)*

Biocontrol Agent	Stage shipped	Packaging method	How to determine viability	How to estimate quantity	How to determine establishment and reproductive success
Metaphycus helvolus	Adults	In deli container, no carrier	Movement, less than 10% mortality	Count active adults	Parasitized scale after 4 weeks; are identified by emergence holes
Orius spp.	Adults and nymphs	In buckwheat hulls	Mix well, pour measured sample into dish under light source and watch for activity	Mix well, measure sample and count individuals	*Orius* nymphs in flowers after 2 weeks
Beneficial nematodes (*Steinernema* spp.)	Infective stage (juvenile stage)	On sponge or some other carrier in plastic container	Push pin point into nematode mass, withdraw and place in drop of water with a few grains of salt and wait 5 minutes; inactive or dead nematodes are straight; living nematodes are curved or curled	Small microscope necessary, 30x is acceptable	Decline in pest population; dead host larvae
Predatory mites (*Hypoaspis* spp., *Neoseiulus* spp., *Phytoseiulus* spp.)	Adults	In vermiculite, corn cob grits, or wheat bran	Active, mobile stages	Empty container into small bucket and mix well; sample a given volume and spread on flat surface, shine bright light on carrier, count mites as they try to escape heat and light	Various predatory mite stages, including eggs, after 2 weeks
	All stages	On leaves	Movement on leaf	Count sample of 10 leaves	See above
	All stages	Slow-release bag	Movement	Pour entire bag onto flat surface, look for dark-colored, rapid-moving adults	Mobile predators on plant after 1 week
Trichogramma spp.	Parasitized eggs	Glued to card, or loose in container	Tiny wasps hatch within 3-5 days of receipt, look for emergence holes under microscope		Caterpillar eggs darker than normal

Source: Spencer, B., and C. Glenister. In production. "Quick Methods for Evaluating Biocontrol Shipments." In Moorman, G. W., and R. Berghage, eds. In production. *Total Crop Management in Greenhouses: A Guide to Greenhouse Crop Production.* Penn State Cooperative Extension. Funded by the PA IPM Program and Pennsylvania Department of Agriculture.

Appendix E. Biocontrol Suppliers

The Association of Natural Biocontrol Producers has a listing of members' products at http://www.anbp.org/a-websites.htm. This manual lists only a few of the members' contact information. The numbers associated with the supplier are the numbers listed in Appendix C. Other sources for biocontrols are available.

1. The Green Spot, Ltd.

93 Priest Rd
Nottingham, NH 03290-6204
Phone: 603-942-8925
Fax: 603-942-8932
Voicemail: 603-942-5027
E-mail: GrnSpt@internetMCI.com
Web site: http://www.anbp.org/Green%20Spot.htm

2. International Technology Services, Inc.

(Distributor for BioBest)
PO Box 19227
Boulder, CO 80308-2227
Phone: 303-473-9141
Fax: 303-473-9143
E-mail: intertechserv@worldnet.att.net
Web site: http://www.biobest.be/

3. IPM Laboratories

PO Box 300
Locke, NY 13092-0099
Phone: 315-497-2063
Fax: 315-497-3129
Web site: http://www.anbp.org/IPM%20Labs.htm

4. Koppert Biological Systems

2856 Main St South
Ann Arbor, MI 48103
Phone: 313-998-5589
Fax: 313-998-5557
Web site: http://www.koppert.nl/

5. Syngenta Bioline

Oxnard, CA
Phone: 805-986-8265
Fax: 805-986-8267
E-mail: info@syngentabioline.com
Web site: http://www.anbp.org/b-novartis.htm

Appendix F. Biorational Pesticides

Product	Brand Name	Pests Controlled	Reentry Interval (REI)	Application/Comments
Abamectin—produced by the soil organism *Streptomyces avermitilis*				
	Avid	spider mites, leafminers	12 hours	Many beneficials can be released 1 week after use
***Ampelomyces quisqualis*—fungus that parasitizes powdery mildew**				
	AQ10	powdery mildew	4 hours	Begin application as soon as host tissue emerges; apply at least 2 sequential sprays 7–14 days apart; works best under conditions of high humidity
Azadiractin—extract of neem seed; IGR that works through contact or ingestion				
	Azatin-XL+	aphids, caterpillars, fungus gnats, leafhoppers, leafminers, western flower thrips, whiteflies, psyllids	4 hours	Apply when pests first appear
	Neemix 4.5	aphids, caterpillars, thrips, greenhouse whitefly, sweetpotato whitefly, psyllids, leafhoppers	12 hours	Cannot be applied through irrigation; low rate can be used as a preventative
***Beauveria bassiana*—fungus that works through contact; exposure to non-target insects should be avoided**				
	BotaniGard	giant whitefly, green peach aphid, black vine weevil, other aphids and whiteflies, thrips, leafhoppers, psyllids, white grubs	12 hours	See above
	Naturalis T&O	aphids, caterpillars, mites, psyllids, thrips, whiteflies	4 hours	Apply when pests first appear and repeat every 7–10 days; need good spray coverage; not compatible with other fungicides
Burkholderia cepacia*—see *Pseudomonas (Burkholderisa) cepacia				
ClandoSan—dried material isolated from crustacean exoskeletons; product acts in soils to stimulate growth of soil microorganisms and destroy nematodes				
	ClandoSan 618	plant-pathogenic nematodes	12 hours	Single annual application
Garlic extracts				
	Garlic Gard	repels many insects		
	Garlic Barrier	repels many insects	4 hours	Use late in the day; can be mixed with fish oil or horticultural oil; do not use in combination with bumblebees or honeybees
***Gliocladium virens*—naturally occurring soilborne fungus that attacks soilborne, plant pathogenic fungi**				
	SoilGard	*Rhizoctonia, Fusarium, Pythium, Phytophthora, Thielaviopsis*	4 hours	Incorporate into soil before planting
Herbicides—sustainable herbicides labeled for greenhouse use				
	DeMoss	mosses, liverworts		Contains potassium salts of fatty acids; avoid contact with desirable foliage; apparently nonvolatile
	Scythe	nonselective		Contains pelargonic acid and related fatty acids; nonselective postemergence weed control in noncrop areas; reportedly nonvolatile; avoid contact with desirable foliage and green stems
Horticultural oil—includes dormant and summer superior oils				
	All Seasons	aphids, mealybugs, scales, thrips, whiteflies, spider mites	4 hours	Use on sunny days to promote rapid drying and decrease chance of phytotoxicity; not compatible with beneficials
Hot pepper wax—contains capsaicin, paraffin, and mineral oil				
	Hot Pepper Wax	aphids, loopers, beet armyworms, mites, whiteflies, thrips, mealybugs, etc.	4 hours	Also contains herbal essential oils; not compatible with beneficials
	Hot Pepper Wax		See above	

APPENDIX F. *(continued)*

Product	Brand Name	Pests Controlled	REI	Application/Comments
Insecticidal soap—contains potassium salts of fatty acids				
	M-Pede	aphids, mealybugs, scales, thrips, whiteflies, spider mites	12 hours	Phytotoxicity is often a concern, especially after repeated applications
	Safer	See above	4 hours	See above
	Insecticidal soap	See above		
***Myrothecium verrucaria*—biological nematode**				
	DiTera	plant-pathogenic nematodes	4 hours	Can be used before or after planting
Neem oil—multipurpose organic insecticide/fungicide/miticide; kills eggs, larval, and adult stages of insects				
	Trilogy 90EC	whiteflies, thrips, leafminers, aphids, mites, psyllids, scales, spider mites, downy mildew, powdery mildew, *Alternaria*, *Botrytis*, etc.	4 hours	Apply at first signs of damage; repeat every 7–10 days as needed
	Triact 90EC	See above	4 hours	For ornamental crops only
Prosper Nema—pathogenic fungi				
	Prosper Nema	nematodes	0 hours	Apply as needed to maintain control
***Pseudomonas (Burkholderia) cepacia*—bacterium to control root-rot diseases**				
	Deny	*Rhizoctonia, Fusarium, Pythium*		
	Intercept	*Rhizoctonia*, *Fusarium*, *Pythium*, nematodes		
***Saccharopolyspora spinosa*—soil-inhabiting actinomycete**				
	Conserve	caterpillars, leafminers, thrips		
Soybean oil				
	Golden Natur'l Spray Oil	aphids, fungus gnats, lace bugs, leafminers, scales, mealybugs, spider mites, whiteflies	12 hours	
***Streptomyces griseoviridis*—naturally occurring, soilborne bacterium**				
	Mycostop	*Fusarium*, *Alternaria*, *Phomopsis*		Can be incorporated into medium or applied to seed
***Streptomyces lydicus*—naturally occurring, soilborne actinomycete**				
	Actinovate	*Pythium*, *Fusarium*, *Phytophthora*, *Sclerotinia*		Can be incorporated into medium or applied to seed
***Trichoderma harzianum*—fungus**				
	Bio-Trek HB	*Fusarium*, *Pythium*, *Rhizoctonia*	12 hours	Apply to seed
	Bio-Trek Nursery Drench	*Fusarium*, *Pythium*, *Rhizoctonia*	12 hours	
	RootShield	*Fusarium, Pythium, Rhizoctonia, Sclerotinia*		
	Trichodex	*Botrytis*		
	TopShield	*Botrytis*, powdery mildew		

Source: Greer, L., and S. Diver. 1999. *Integrated Pest Management for Greenhouse Crops*. Appropriate Technology Transfer for Rural Areas.

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Encarsia formosa adult

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