High Tunnel Integrated Pest Management (IPM): Insects and Mites

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During the six years of high tunnel production and research in Minnesota insects have not generally been a serious problem in our high tunnels. From time to time we would have some problem with slugs; however this usually happened with high tunnels that were located on heavier type soils or those that were not ventilated properly. There has been no problem with slugs where high tunnels have been located on sandy type soils.

The other problem that we encountered for the first time in late 2004 was white flies at the Grand Rapids research site. This was the only site that we had white fly problems. While other states have had problems with aphids we did not encounter aphids in our high tunnel research projects. There have been times that we have had aphid problems with our low plastic production research with peppers and like crops.

It is extremely important that high tunnel vegetable and fruit producers in Minnesota be aware that we might encounter new and different insect problems in high tunnel production as this new technology develops in Minnesota. Minnesota high tunnel producers must monitor daily and be on the alert for new and unexpected insects in their high tunnels. Producers should contact their extension personnel if insects appear in high numbers or insects need identification. Remember that in the ideal environment of high tunnels, insects can multiply at very fast rates and waiting too long for control measures could cost you the crop.

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Integrated pest management (IPM) is an approach to dealing with pest problems that relies upon a variety of tactics to maintain pest numbers below economic levels. Any good IPM program begins with prevention, but may progress to use of pesticides or introduced biological controls as circumstances warrant.

Research being conducted at The Penn State High Tunnel Research and Education Facility has continued to note that pest and disease problems common to greenhouse production also predominate in high tunnel systems. An important difference, however, is that economically significant pest problems in high tunnels during the winter cropping

months (November-March) are generally uncommon. This feature makes winter cropping an attractive option for market farmers with year-round outlets. It also makes pest control less overwhelming since there are only certain times of the year when one would expect to find severe infestations.

As with greenhouse production, a combination of biological control with other tactics should prove to be successful in managing insects within high tunnels. The present challenge for researchers and growers is to determine which of the integrated pest management (IPM) tactics developed for greenhouse production are effective and economical for high tunnel systems. Until there are more thorough studies of biological control in high tunnels, recommendations can only be cautiously generated and adopted. Nevertheless, the application of biological control to tunnel cropping has great potential and should be strongly considered by growers.

The Use of Pesticides in High Tunnels

There may be circumstances in which it is necessary to control insect pests through pesticide applications. Growers should begin by selecting materials that are least toxic to both humans and beneficial insects, including pollinators. Pesticides that are low in acute toxicity and also display a low residual activity are often referred to as "soft" pesticides. These materials should be strongly considered in high tunnel cropping because of the "closed" nature of the system, which may prolong any residual activity of applied pesticides.

Common examples of "soft pesticides" include insecticidal soap, horticultural oils, and biological pathogens such as *Bacillus thuringiensis* (Bt) and *Beauveria bassiana*. In addition, many of the botanical pesticides available to growers are also regarded as "soft," including neem (azadirachtin) and ryania. These materials usually provide adequate control of pests and are compatible with biological control programs. However, the toxicity of each material to humans can vary greatly and so caution must always be exercised.

Pesticide applications should be timed to avoid beneficial insect and pollinator activity. Generally, this means that applications should be made in early morning or late evening. If possible, applications should also be strategically localized. This will require scouting to determine where pest "hot spots" occur. If pest problems are restricted to a small area or several small areas in high tunnels, then applications should be limited to these "hot spots." This simple practice will save money, labor, and time but will also allow beneficial insects or biological control agents to "retreat" to safe (untreated) spots. In this manner, one can effectively conserve introduced and/or background beneficial insects and pollinators, while simultaneously using multiple pest control tactics.

The Use of Biological Control in High Tunnels

The three insect pests most frequently encountered in high tunnels at Rock Springs, PA are whiteflies, aphids, and mites. Fortunately, all of these pests are manageable by

combining tactics such as biological control (bio-control), with judicious use of "soft" pesticides like insecticidal soap. Table 7A lists a number of biological control agents that can be used by growers against these three major pests of high tunnel crops. To date, there has been limited research into the performance of these bio-control agents in high tunnel cropping systems and so growers should begin cautiously.

There is much to gain by adapting greenhouse biological control to high tunnel systems. If done correctly, the use of bio-control can reduce pesticide applications dramatically. This, in turn, limits or eliminates pesticide residues on product and can be a strong selling point to customers. In addition, fewer pesticide applications make the tunnel environment safer and allow work to proceed uninterrupted without the need to be concerned about reentry intervals.

The transition from relying on pesticides to biological control may seem like a daunting challenge, however. It requires that a grower become more knowledgeable about both pest and potential bio-control options. It will also probably require a few shifts in management style. Managing pests with biological controls requires thoughtful, careful planning and the realization that every crop cycle may present a unique situation. Results are not instantaneous and so patience and diligence is absolutely necessary. The results, nevertheless, can be highly rewarding---both personally and financially.

How to Get Started With a Biological Control Program

1. Start small

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

2. Eliminate pesticide residues

Discontinue using insecticides with residual activity at least one to two months prior to introducing bio-controls. Pesticide residues on plants and high tunnel coverings can be deadly to bio-control agents. Consult bio-control suppliers for information on specific products if you want to be certain about the compatibility of a compound that has been applied.

3. Use "soft" pesticides

Consider the use of "soft" or "reduced risk" compounds for treating "hot spots" or pests that are not being controlled biologically. Have products on hand before outbreaks occur. Some bio-control suppliers sell these products, and can provide compatibility information. If there is uncertainty about the compound, consult a bio-control supplier before spraying. Some growers find it beneficial to have a sprayer designated for soft pesticides only, avoiding contamination with more toxic insecticides.

4. Practice strict sanitation

Weed management is critical to the success of a bio-control program both before and during crop production. Weeds serve as reservoirs for pests and diseases and may upset the predator-prey balance that is trying to be established in the crop. It is also critical to maintain a weed free zone around the outside perimeter of the high tunnel 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 a crop. Remove weeds and destroy on a continuing basis.

5. Use clean transplants

In many cases, serious pest and disease problems that plague growers throughout the growing season result from purchasing infested transplants. Selection of a reputable grower ensures a quality transplant. Inspect purchased plant material carefully. If producing transplants, follow strict sanitation procedures and inspect seedlings weekly for pest and disease development. Preventing a problem from becoming established can save a lot of time, effort and expense.

6. Start early

Begin introductions of bio-control agents when pest populations are at low levels so that the bio-control species is not overwhelmed. This can be determined by weekly crop inspection. For example, even though *Encarsia formosa*, a tiny parasitic wasp, is an excellent control for whiteflies, the wasp will not be as effective if it is released too late. This is because high populations of whiteflies produce sticky honeydew that will interfere with the parasitoid's walking and searching speed and may even cause them to become trapped and die.

Production, Distribution and Quality Control of Biological Control Organisms

Most of the successes in greenhouse biological control have occurred in the Netherlands and the United Kingdom, mainly because these countries together contain more than half of the world's greenhouse acreage. An important event occurred when Koppert entered the natural enemy business in 1967; Koppert is currently the international market leader in the field of biological crop protection. Large scale production of natural enemies such as *Encarsia formosa* and *Aphidius colemani* takes place in their main facility located in the Netherlands.

In addition to Koppert, there are several other large producers such as Biobest (Belgium) – a leader in bumblebee pollination, Syngenta (England and California), and Applied Bio-Nomics Ltd. – Canada's largest producer of biological controls. here are also some small companies in the United States that specialize in the production of predatory mites, lacewings and parasitoids.

Regional distributors for these large bio-control producers are found throughout the United States and Canada. For example, International Technology Services (ITS), Lafayette, CO is the U.S. distributor for Biobest Biologicals. Together with the technical support staff at Biobest, they have a full-time entomologist to answer pest control and pollination questions.

A list of distributors in the United States can be found on the internet (see Appendix C). A list is maintained by the Association of Natural Bio-control Producers. Most distributors require orders to be placed by Thursday (since they must be shipped from Europe or Canada) for delivery the following Wednesday. Products are delivered directly to farm or greenhouse via UPS, Airborne or FedEx. Growers should insist on guaranteed live delivery and overnight express only. The large natural enemy producers screen for quality and use expiration dates. Check bio-control shipments for this date and be cautious of suppliers who do not put dates on the material. A non-reputable supplier could have material that is weeks old and not viable.

When bio-control orders arrive at the farm, growers should immediately check for viability. Predatory mites can be examined by shaking material onto a white sheet of paper and looking for movement. Parasitoids such as *Aphidius colemani* are shipped in bottles. Within 24 hours after placement in the greenhouse check bottles for parasitoid emergence. If high mortality of parasitoids is observed, call the distributor immediately. During warm weather months, bio-control insects should be shipped with cooling material. Employees should be informed that bio-controls are expected so that they can be stored in a cool area if they cannot be released or distributed right away.

Biological Control of Whiteflies in High Tunnels

Whitefly development can be controlled with several different natural enemies. It is important to identify the species attacking your crop before ordering a bio-control.

Identification of Whitefly Species

There are several species of whiteflies that attack greenhouse crops, especially greenhouse vegetables. The most common whitefly found to infest greenhouse vegetables is Greenhouse Whitefly (*Trialeurodes vaporariorum*). In a fall crop, the outdoor species, Banded-wing Whitefly (*Trialeurodes abutilonia*), is observed on yellow sticky cards and occasionally feeds on plants. Another more serious whitefly is the Silverleaf whitefly (*Bemisia argentifolii*), a common pest on Poinsettias that is difficult to control due to its high reproductive rate and resistance to insecticides.

Whiteflies have sucking mouthparts and cause direct plant damage by feeding on plant sap. Both the adult and nymphal stages feed on plant sap and secret the excess in the form of a sticky, sweet substance known as honeydew. Honeydew serves as a substrate for sooty mold development, which can occur on foliage and fruit covered by

honeydew. Sooty mold can reduce plant yields by interfering with photosynthesis. The mold that develops on fruit creates extra handling time and can impact market value. Indirect damage by whiteflies is caused by transmission of several viral diseases.

Whiteflies in general have six life stages: adult, egg, three nymphal instars and the fourth instar or pupa. All occur on the underside of the leaves. During the pupal stage the red eyes of the developing adult are often visible. After the adults emerge from the pupal case, a t-shaped opening can be observed. Development time varies with species, host plant, and environmental conditions. Identification of these species is critical since they respond differently to control strategies, both chemical and biological. Experienced growers may be able to identify species in the adult stage; however, a more reliable method is to examine the pupal stage. Identification requires a hand-lens capable of 10 – 20x magnification.

Greenhouse whitefly (*Trialeurodes vaporariorum*)

Greenhouse whitefly is the most common species to infest greenhouse vegetables. Widespread resistance to many different classes of insecticides has created the need for integrated approaches to management that include bio-control.

The adults have wings that are held flat (horizontal) over their body. The pupal stage is white, with straight elevated sides and a fringe of wax filaments around the edge.

Banded-wing whitefly (*Trialeurodes abutilonia*)

Banded-wing whitefly is a species found outside in high populations in the fall on weeds and ornamental plants. As their host plants decline, they begin to seek plants and commonly make their way into the greenhouse through vents and doors. This species may feed on plants and lay eggs at a low rate although they usually do not complete their life cycle. High levels on sticky cards may alarm growers resulting in needless pesticide applications.

The adult looks much like a greenhouse whitefly adult with the horizontal wing span; however, they can be distinguished by the two gray bands that form a zigzag pattern across each forewing. The pupal stage is similar as well except for a black band down the center of the pupal case.

Silverleaf Whitefly (*Bemisia argentifolii*)

Silverleaf whitefly (SLWF) can be found on a wide range of host plants. In Pennsylvania greenhouses, this species is most commonly found as a pest of poinsettias. In addition to causing damage by sucking the leaf tissue and secreting 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.

The silverleaf adult is smaller than greenhouse whitefly and holds its wings close to the body. The pupal stage is a bright yellow with a few waxy filaments. The pupa does not have a high profile like the greenhouse whitefly.

Biological Control of Whiteflies: Parasitoid wasp *(Encarsia formosa)*

The parasitoid (*Encarsia formosa*) is tiny wasp (0.6 mm) that consumes and eventually kills its host the Greenhouse whitefly. In Pennsylvania, *E. formosa* is used successfully in greenhouse vegetable production to control whiteflies. It is important to accurately identify the pest you are trying to control with a parasitoid. Inform the bio-control supplier of the pest species in your crop so they can recommend the most effective parasitoid for the pest and crop situation.

Biology

The adult female wasp lives for about 15 – 30 days. Longevity of a female parasitoid diminishes rapidly with increasing temperatures. Adults obtain energy and nutrients by consuming honeydew produced by the whiteflies and by feeding on whitefly larvae. A population of *E. formosa* consists mainly of females.

E. formosa searches the plant canopy for whitefly larvae. Upon finding the correct size to parasitize (third or early fourth instar larva) she inserts an egg into the whitefly larva with her ovipositor. All stages (egg, larva, pupa, adult) of *Encarsia formosa* develop in the whitefly larva or pupa. One female adult *Encarsia* can lay about 3 – 70 eggs.

Introduction interval and duration

Encarsia is introduced weekly at a curative level when whitefly stages are found until sufficient parasitization is reached. If at least 80% of the whitefly pupae are parasitized (black in case of the greenhouse whitefly), parasitism levels are high enough to cease introductions. It is important to continue to monitor the whitefly populations after introductions are stopped.

Methods of dispersal

Encarsia formosa is supplied in two different manners. The parasitic wasps are supplied either as pupae glued on cards (*Encarsia* cards) or as loose pupae packed in tubes. Both systems have their own specific use in practice. Introduce bio-controls immediately into the greenhouse when they arrive. Most suppliers ship bio-controls via overnight delivery.

How to determine if E. formosa releases are reducing whitefly numbers

A healthy whitefly pupa is creamy white in color. On the eighth day following parasitization, the effected whitefly pupa will begin to turn grey. As the parasitoid larva

grows, the pupal case changes in color from grey to black. It is at this point that a parasitized pupa can be easily recognized. The entirely blackened appearance indicates that the *E. formosa* larva has developed to the pupa and maturation of the adult wasp begins. Within seven days, a mature wasp emerges through a round hole chewed in the head portion of the top surface of the pupa. The duration of this life cycle at 73.4 °F is approximately 19 – 21 days. The life cycle duration is completely dependent upon temperature.

Considerations

- At a temperature below 64.4°F, the parasitic wasps will not frequently fly, and their searching ability is limited. At temperatures above 86°F, the adult life span is considerably reduced.
- Certain pesticides (e.g. pyrethroids) can have a long residual effect on *Encarsia*.
- Consult a bio-control supplier for information on pesticide residues.
- If *Encarsia* is introduced too late, honeydew excreted by the whitefly on the leaf hampers the mobility of *Encarsia* and consequently parasitism.
- By removing lower leaves too early, parasitized pupae that have not yet emerged, may be removed from the greenhouse.
- Consult the supplier about introduction rates. This will require crop inspection (scouting) to determine whitefly population levels.

Benefits

- Applicable in a wide range of crops
- Efficient searching ability
- Parasitized (black) pupae are easily recognized
- Adults feed on small whitefly instars
- Easy to introduce
- Reliable results
- Economical

Biological Control of Whiteflies: Parasitoid wasp *(Eretmocerus eremicus)*

Eretmocerus eremicus is a fairly new agent for whitefly control and is more effective in controlling SLWF than *Encarsia formosa*. It will also parasitize greenhouse whitefly. Generally, *Eretmocerus* is more resistant to pesticides than *Encarsia formosa*. The primary supplier, Biobest, is currently carrying out numerous experiments to determine the side effects of pesticides on this parasitoid.

Biology

The adult female wasp is lemon-colored with thick antennae. *Eretmocerus* can develop in any larval stage of the whitefly, but it prefers the second and early third stage. This

wasp will also feed on whitefly larva. *Eretmocerus eremicus* lays its eggs under the whitefly larva.

Introduction interval and duration

Eretmocerus is introduced weekly at curative levels when whitefly stages are found until sufficient parasitism is observed. If at least 80% of the whitefly pupae are parasitized (brown in color for greenhouse and silverleaf whitefly), parasitism levels are high enough to cease introductions. It is important to continue to monitor whitefly populations after introductions are stopped.

Methods of dispersal

Eretmocerus eremicus is supplied in two different forms. 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 bio-controls immediately into the greenhouse when they arrive. Place cards underneath plant canopy, out of direct sunlight. Most suppliers ship bio-controls via overnight delivery.

How to determine if E. eremicus is reducing whitefly numbers

Two weeks after the egg is laid in the whitefly larva, the pupa stage of the whitefly will turn yellow instead of black as with *Encarsia*. In order to exit the host, *Eretmocerus* will make a small round hole in the top of the whitefly pupa and emerge. The complete life cycle takes 17 to 20 days, depending on temperature and the larval stage of the whitefly. Whitefly levels must be monitored each week of the crop cycle by inspecting the larvae on the foliage to determine if it has been parasitized. A 16 – 20x hand lens is necessary for examining foliage for signs of parasitism.

Considerations

- At temperatures above 70°F, it is recommended to introduce about six parasitic wasps per square meter for several weeks (whitefly larva needs to be present to introduce *Eretmocerus eremicus*).
- In some crops, introduction can begin at first signs of infestation (e.g. eggplant). In other crops (e.g. tomato), introductions should occur when daytime tunnel temperatures are at least 70°F. Introduce one *Eretmocerus eremicus* per square meter weekly, until sufficient parasitism is noted.
- When pruning leaves, a few should be examined for signs of parasitism. Leaves on which parasitized whiteflies are found should be left in the high tunnel in order for a new generation of parasitoids to emerge. Employees should be trained in recognizing parasitized whitefly pupae.

Benefits

- *Eretmocerus eremicus* is more tolerant to pesticides than *Encarsia formosa*.

- *Eretmocerus eremicus* can tolerate high temperatures.
- Both greenhouse whitefly and silverleaf whitefly can be parasitized by *Eretmocerus*.
- Parasitized pupae are very easy to recognize due to their yellow color.

Biological Control of Aphids in High Tunnels

Effective and timely control of aphid populations in high tunnel production is important due to their ability to develop into large populations quickly. Identification of aphid species is integral to selecting an appropriate bio-control agent. Aphid parasites in particular are host specific and the correct parasite must be applied for timely aphid control. Aphid parasites are effective in searching for isolated aphids, winged aphids and aphid colonies. If identification is uncertain for the aphid species attacking a crop, consider using a general predator rather than a parasite.

Feeding aphids secrete excess sugars from their abdomen in the form of sticky 'honeydew'. Honeydew supports the growth of black sooty mold, reducing plant photosynthesis and often plant yields. Removing sooty mold from fruit increases handling time and can render fruit less marketable. In addition to the direct damage caused by honeydew excretion, aphids are vectors of a wide range of viruses and so can cause indirect damage as well.

Identification of Aphid Species

There are many different aphid species that are reported in Pennsylvania greenhouse production including the green peach aphid, potato aphid, and melon aphid. The aphid that is usually found to infest vegetable crops, especially tomatoes and other Solanaceous crops (peppers, eggplant), is the potato aphid (*Macrosiphum euphorbia*).

The most outstanding characteristic for identifying aphids is by the two cornicles ("tail pipes") on the rear of their abdomen. Color is variable among species and is not accurate for identification. As aphids increase in size, they shed their exoskeletons (cast skins). These white cast skins, often mistaken for adult whiteflies, can be found on leaves or stuck in honeydew excretions

Biology

In protected environments such as greenhouses and high tunnels, aphids are very prolific. Instead of reproducing by eggs, female aphids (stem mother) give birth to live offspring (3-10 per day) that start to feed immediately. Within a week, this offspring will be ready to reproduce. Aphids can have two forms: winged or wingless. As colonies enlarge, aphids develop wings to migrate to less populated areas in the crop.

Monitoring

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. As aphids feed on growing tips, the leaves curl, sometimes looking like virus symptoms.

Yellow sticky cards are useful in detecting winged aphids. Hang sticky cards 4 to 6 inches from growing tips. The presence of ants in the greenhouse may indicate aphid development, since the ants feed on the excreted honeydew and thus protect the aphids. When introducing natural enemies, place them in an area protected from ants and control ants with baits or traps.

Biological Control of Aphids: Lady beetles *(Hippodamia convergens)*

Lady beetles (or Ladybugs) are general predators that feed on a number of soft-bodied insects including aphids, whiteflies (immature stages), scale, and thrips. Because they are excellent at seeking out prey, they are effective for cleaning up "hot spots." This feature, combined with their propensity to establish under the appropriate conditions, makes them good candidates for high tunnel bio-control agents.

Biology

There are 500 species of lady beetles reported to occur throughout North America. The most commonly recognized of the species are those that have an orange to orange-reddish body with black spots; these are recognizable even to children who learn them as "ladybugs."

Most lady beetles consume mites and soft-bodied insects, while a few feed on fungi. A small number feed on plants and these are notable pests such as the Mexican bean beetle and Squash beetle. When the insect feeding species lack prey items, they often survive on nectar, honeydew, and/or pollen. Under such conditions, however, they typically do not reproduce.

The Convergent lady beetle (*Hippodamia convergens*) is the most commonly used species for biological control, although many other species are effective background predators if allowed to establish naturally. The life cycle of the Convergent lady beetle consists of four distinct stages: an egg stage; a larval stage (with numerous sub-stages of development); a pupal stage; and an adult stage. The larval and adult stages are the two stages when predatory feeding occurs.

Many species of lady beetle including the Convergent lady beetle aggregate during certain times of the year. This feature permits easy collection/rearing and release, but it also presents difficulties. For example, without proper enticement or containment, lady beetles will often leave the area where they were released. For this reason, it is critical

that growers follow a few simple guidelines for release (outlined in the next section) as well as provide adequate enticement in the form of prey (for eating) and moisture (for drinking). If lady beetles establish within the high tunnels, satisfactory control of pests such as aphids can be expected.

If well-timed, female Convergent lady beetles will seek out aphid groups and lay eggs in the vicinity. The eggs will hatch in about a week a give rise to alligator-shaped larvae that will begin to feed voraciously on adjacent aphids. Each lady beetle adult and larvae can eat anywhere from several dozen to several hundred aphids. Pupation follows several stages of larval development.

Method(s) of dispersal

Ladybeetles are sold as adults in pints, quarts and gallons. They are dispersed by placing the shipping medium (typically fibrous) plus loose beetles throughout the high tunnel structure.

Introduction interval and duration

Releases can be made from late spring/ early summer onwards on a prophylactic basis, but are most economical when timed to synchronize with aphid population development.

Releases within high tunnels should occur in the evening, and should be done while the structure is completely closed (i.e. not ventilated). This will encourage the beetles to investigate conditions within the tunnel(s), rather than to fly away. A hand-full or so of beetles should be placed at each "hot spot" in the tunnel to assure that the beetles find food easily and quickly. Some growers use sugar water to coat the beetles at release so that they find it difficult to fly. This will further encourage investigation and, hopefully, establishment.

The next day following release(s), high tunnels must be ventilated before temperatures become too great. In the summer months, this should occur no later than 9:00 to10:00 AM, unless the weather is unseasonable cool or cloudy. The objective is to contain the beetles for as long as possible without causing detriment. Experience at the Penn State High Tunnel Research and Education Facility suggests that effective numbers of adult beetles will remain in tunnels, on average, for two to four weeks following release. However, if the adults have laid eggs, one can expect a permanent presence for as long as food and water are available.

Considerations

- Make sure favorable (temperature) conditions for containment exist before releasing beetles into high tunnels.
- Place beetles near "hot spots" for rapid feeding and control.
- Monitor beetle establishment by scouting for eggs and larvae in the weeks following release(s).

Benefits

- Effective against a variety of soft-bodied pests
- Economical
- Can be readily encouraged to establish in high tunnels

Biological Control of Aphids: Lacewings *(Chrysoperla spp.)*

Lacewings are sold as eggs and larvae. The larvae are voracious predators known as "aphid lions". They will also feed on mealybugs, scales, spider mites and thrips.

Biological Control of Aphids: Predatory Midge *(Aphidoletes aphidimyza)*

The predatory midge, *Aphidoletes aphidimyza*, is a general aphid predator that attacks many different species of aphids. It can be used alone or combination with a parasite for rapid control. This predator is most effective where aphid "hot spots" (clumped populations) are found to occur. The main advantage to using *Aphidoletes* is its usefulness in a variety of crops (peppers, eggplants, cucumbers, etc.) on which different species of aphid occur.

Biology

Aphidoletes is a predatory gall midge that attacks over 70 different aphid species. The adult midge is about 2.5 mm long, with long legs and a slender body. It is mainly active at night, lives for 7 to 10 days on average, and commonly feeds on honeydew.

After dusk, the female midge deposits her eggs in aphid colonies. She is attracted to aphid colonies by the smell of honeydew. The eggs hatch into tiny larvae (0.3 – 3.0 mm) that search the leaf for suitable prey. Upon finding an aphid, a larva injects a paralyzing toxin which dissolves the body contents. It then attaches it's mouthparts to the aphid and feeds on the dissolved contents.

Each larva needs to feed on about five aphids to complete its development; however, it will devour more if they are available (up to 65 aphids). Initially, the larva is transparent orange but becomes orange, red, brown or grey---depending on the food source. In 7 to 14 days, the larva falls from the plant into the soil, using the soil particles to make a cocoon. Within 7 to 10 days after forming a cocoon in the soil, a new adult gall midge will emerge.

Method(s) of dispersal

Aphidoletes aphidimyza is usually shipped as pupae in a vermiculite carrier. Adults will emerge from pupa when placed in a warm greenhouse or high tunnel. Introductions

should be made throughout the plant canopy, away from direct sunlight. They should also be made in early morning or evening near aphid colonies. *Aphidoletes* can be obtained through most biological control distributors.

Introduction interval and duration

Reduce or eliminate the use of toxic or residual pesticides before introducing *Aphidoletes* or any other natural enemy; this predator is very sensitive to pesticides. Release on a preventative basis or introduce at a higher rate (curative) when aphid colonies are first found. Consult the supplier for exact rates.

Considerations

- Three to four successive introductions are needed to build a sustaining population of *Aphidoletes*. Augment with new introductions throughout the season on an as needed basis.
- When pruning, examine leaves for orange larvae. These leaves should be left in the greenhouse so that the larva can complete the life cycle. All employees should be trained in recognizing this life stage.
- When introducing into the greenhouse, protect predators from ants. Ants feed on honeydew and thus protect the aphid colonies from natural enemies. Install traps for ants.
- Monitor the effectiveness of this predator by looking for aphids that appear to be shriveled and eventually turn brown and/or black and decay. Use at least a 10x hand lens when inspecting.
- In soil cultures, larvae can pupate in the ground and successive generations will occur. This eliminates the need for continual introductions.
- If soil is covered by plastic, there are no appropriate sites for pupation and many will die. Successive generations do not occur and continued releases are required.
- The larva enters hibernation (lower temperatures, shorter days), starting in late September unless you add supplemental light (one 60 watt bulb per 30 feet, or 100 watt bulb per 65 feet). If you are growing a fall crop, a better strategy would be the application of a parasite such as *Aphidius ervi* or *Aphelinus abdominalis*.

Benefits

- Control all aphid species
- Can be applied in several crops
- Excellent searching ability
- Curative control of aphid colonies
- Long lasting effect in soil

Biological Control of Aphids: Parasitoid wasp *(Aphidius colemani)*

This organism is used to control green peach and melon aphids. It is a tiny parasitic wasp that lays an egg in the aphid. The egg hatches into a larva which spins a cocoon, producing a new wasp. The wasp exits the aphid body, leaving behind a brown shell called an aphid "mummy."

Biological Control of Aphids: Parasitoid wasp *(Aphidius ervi)*

This insect is used to control potato aphids. It is a parasite that is similar appearance and biology to *Aphidius colemani* but is about twice the size.

Biological Control of Aphids: Parasitoid wasp *(Aphelinus abdominalis)*

Aphelinus abdominalis can be introduced as preventative method when a crop is first seeded or transplanted. Otherwise, begin introducing as soon as aphids appear. *Aphelinus* is slower to become active, when compared to *Aphidius ervi* which goes to work immediately; however, *Aphelinus* adults may be continuously active for up to eight weeks after they are introduced, making them better long-term candidates for bio-control.

Biology

Aphelinus is a very tiny wasp, about 3.0 mm long, with short legs and antennae. The female has a black thorax and a yellow abdomen. The female can parasitize any aphid stage including winged aphids. When the female wasp finds an aphid, she injects her ovipositor and deposits an egg. The parasite larva develops inside the aphid body transforming it into a black mummy. The new wasp will emerge through a hole chewed in the aphid exoskeleton. *A. abdominalis* will also feed on aphids that she does not parasitize.

Method(s) of dispersal

Aphelinus abdominalis is usually shipped as adults or mummies. These can be stored in darkness for up to two days at 47 - 50° F; however, it is best to distribute parasites immediately. Release wasps by tapping them onto leaves of infested plants (hot spots) in the morning or evening, avoiding direct sunlight. These wasps are not very mobile so placing them close to infestations will increase effectiveness.

Introduction interval and duration

Reduce or eliminate the use of toxic or residual pesticides before introducing *Aphelinus*. Consult a bio-control supplier for specific information regarding pesticide use.

Release *A. abdominalis* on a preventative basis or introduce at a higher rate (curative) when aphids are first noted. When aphids are first observed, introduce *Aphelinus* at a curative rate for 3 introductions at 1 week intervals. Monitor weekly for the development of black, mummifed aphids. When 80% of the aphids are parasitized a parasite to 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.

Considerations

- When pruning leaves, check for parasitized aphids (black mummies). If mummies are present keep these leaves in the greenhouse until new parasites hatch.
- When aphid populations are heavy, the production of honeydew can interfere with the searching ability of the parasite. Heavy aphid populations can be reduced with soft, compatible compounds or by using ladybeetles.
- Protect parasites from ants. Ants feed on honeydew and thus protect the aphid colonies from natural enemies. Install traps to control ants.
- Activity of parasites is reduced at high temperatures (above 86° F).
- Determine specific release rates with a bio-control advisor or consultant.

Benefits

- Long lasting form of aphid control
- Black parasitized aphids are easy to recognize
- Parasitize and feed on aphids

Biological Control of Mites in High Tunnels

The spider mite was the first greenhouse pest to be controlled by a commercial application of predatory mites. There are a limited number of pesticides available for treatment of this pest in greenhouse and high tunnel production; consequently, an integrated approach using biological control in conjunction with compatible bio-rational materials is recommended.

The Two-Spotted Spider Mite (Tetranycus urticae)

The two-spotted spider mite is the most problematic spider mite in greenhouse crops and can infest a variety of crops including tomatoes, peppers, eggplants and ornamental plants. Most of the difficulty involved in controlling this pest is initial detection for timely treatment. Since there is no winged stage, sticky traps are ineffective; consequently, plant inspection is the only reliable method for determining the presence of mites and assessing their numbers.

Damage is caused by larvae, nymphs and adults piercing the plant cells and sucking out the contents. The damaged cells appear as yellowish white spots on the upper surface of the leaf, due to the loss of chlorophyll. As populations increase, the whole leaf will eventually turn yellow. Crop losses may occur when about 30% of the leaf surface is damaged.

A population of two-spotted spider mites can increase rapidly during hot, dry periods. Both chemical and biological control treatments must be initiated when spider mite numbers are low for greatest efficacy.

Biology

Two-spotted spider mite has five life stages, egg, larva, first nymphal stage (proto-nymph), second nymphal stage (deutonymph), and the adult mite. The female deposits round eggs on the underside of the leaf. These eggs hatch into larva with six legs that begin feeding immediately. After they have eaten, their color changes and two dark spots appear in the middle of the body. The larvae take in enough food before they settle on the leaf with their legs drawn in until they develop into the proto-nymph.

After a period of feeding the proto-nymph develops into the deutonymph. The two body spots are very visible on these two stages compared to the larvae. The total development time varies with temperature, humidity and the host plant. Approximate 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 webs. At this point, obtaining control is difficult and biological control is not effective.

Monitoring

Mites usually develop on the undersides of leaves and are often found at certain spots in the greenhouse. These areas have a more favorable climate for development (dry, warm). Inspect plants for mite development near heaters, doors and vents. It is important to have at a 16x hand lens to monitor for this pest. If you have difficulty detecting mites on leaves, tap the leaves over a sheet of white paper. This technique dislodges mites (and other pests) and provides for easier identification.

Remember to maintain broadleaf weed control inside the greenhouse and 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 the weeds and destroy!

Biological Control of Spider Mites: Predatory Mite *(Phytoseiulus persimilis)*

Phytoseiulus persimilis is a predatory mite and the mainstay in spider mite control since it can be used on many crops including tomato, pepper, cucumber, squash, beans, flowers and interior landscapes. It can also be an effective predator in field crops such as strawberries and other small fruits.

Biology

The adult mite is pear shaped and shiny orange, while the nymph stage is pale salmon-colored. Predatory mites have longer legs than the pest mites. A *Phytoseiulus* adult deposits her eggs (oval shaped compared to round spider mite eggs) near spider mite colonies. The larval stage is followed by the proto-nymph, deuto-nymph and adult stage.

Development time from egg to adult is 5 days at 86°F. Usually, *Phytoseiulus* will develop faster than the spider mite if the temperature is below 86°F and humidity above 60%. At low humidity, the egg of the predatory mite will die. The activity of *Phytoseiulus* can be extended by creating high humidity by spraying water through a fine nozzle and high pressure.

The adult mite will feed on all stages of spider mites, while the nymphs will feed only on eggs, larvae or proto-nymphs. Upon finding prey, *P. persimilis* kills the mite and consume the body contents. If spider mite populations are high and webbing is evident, these populations should first be treated with soft pesticides before introducing predatory mites. Consult a bio-control supplier for information on compatible compounds.

Method(s) of dispersal

Phytoseiulus persimilis is supplied in tubes of 1000 to 2000 adults mixed with vermiculite or wood chips. Shake the tube to mix the predatory mites equally in the carrier before application.

Scout crop and flag active spider mite colonies. Return to these flagged areas to monitor the effectiveness of the introduction. A 10x hand lens is required when inspecting for spider mites life stages. Concentrate predator introductions at spider mite hot spots (flagged areas) as soon as possible after delivery.

Introduction interval and duration

Introduce predators weekly for three weeks or until desired control is achieved. Spider mite colonies should clean-up within 2 to 3 weeks. If adequate control is not achieved, increase the rate of predatory mites.

Considerations

- Start early to control spider mite populations since spider mites reproduce faster than predatory mites at high temperatures and low humidity.
- Monitor for effectiveness by inspecting plants for dead spider mites that appear as tiny black dots on plants. Inspect spider mite colonies for the oval predator mite eggs and the adult predator mite.
- Consult a bio-control supplier for precise rate determination.

Benefits

- Active year round – no diapause
- Feeds on spider mite eggs, larvae, nymphs and adults
- Reproduction is faster than spider mite at 86°F
- Can be used on a variety of vegetable crops and ornamental plants

Biological control of spider mites: Predatory mite *(Feltiella acarisuga)*

The most commonly used bio-control for two-spotted spider mite is the predatory mite, *Phytoseiulus persimilis*. A natural enemy that can be used with predatory mites is the predatory midge, *Feltiella acarisuga*. *Feltiella* is good at finding hot spots, so the two predators are complimentary.

Feltiella can be an effective year-round predator and is particularly useful on hairy leaved plants (such as tomatoes). This is a predator that may occur naturally in greenhouses and high tunnels if spider mites densities are high and pesticides are not being used.

Biology

The adult is a delicate, pink-brown fly, only about 1 mm long, with long legs. They do not feed and only live 3 to 4 days after emerging from the cocoon. High humidity improves midge emergence. Optimal conditions for *Feltiella* are 68-81°F and relative humidity greater than 60%. Larvae can tolerate a wider range of conditions than the adult.

Adults actively search for spider mite colonies. Each female lays an average of 30 shiny yellow eggs near high densities of mites, usually where webbing occurs. The tiny eggs hatch in 5 to 7 days. The brownish yellow midge larvae grow to about 2 mm long. Upon hatching they move to a spider mite, sink their mandibles in, and suck out the contents. They can consume over 300 mite eggs as they complete their development in about a week in the greenhouse. Under cooler conditions the larval stage may take up to a month to complete. They spin fluffy white cocoons on the underside of leaves, usually along a leaf vein, in which to pupate. The pupal stage lasts approximately one week in the greenhouse, but longer under cooler conditions.

Method(s) of dispersal

Feltiella acarisuga is shipped to the grower as pupae on leaves in units of 250. Open the box containing predators in the high tunnel and place as close as possible to spider mite infestations. Let the box stand for at least one week until adults have emerged.

Introduction interval and duration

Start early to control spider mite populations since spider mites reproduce quickly at high temperatures and low humidity. Concentrate predator introductions at spider mite hot spots as soon as possible after delivery. Monitor for predator activity by checking spider mite colonies for larval development and for shriveled mites that have been fed upon. Monitoring should be done once a week, consistently.

Considerations

- Always use *Feltiella acarisuga* in conjunction with a predatory mite such as *Phytoseiulus persimilis*.
- *Feltiella* larva feeds on eggs, nymphs and adults of two-spotted spider mites.
- Consult your supplier for rates and introduction schedule.

Benefits

- The adult midge is capable of flying and locating colonies of spider mites.
- Applicable in crops where scouting is difficult (ie. ornamentals)
- Can and should be introduced with predatory mites such as *Phytoseiulus persimilis*.
- Active in cold and dark weather in spring and fall.
- May provide long lasting protection with several introductions.

Biological Control of Spider Mites: Predatory mite *(Neoseiulus californicus)*

The most commonly used predatory mite is *Phytoseiulus persimilis*. This is used in many vegetable and ornamental crops for quick knockdown of spider mites. The predatory midge, *Feltiella acarisuga* is also effective in reducing high populations of spider mites. Both of these natural enemies require prey to persist and relative humidity above 60% for reproduction.

If the environmental situation has high temperatures and variation in humidity (below 60%), an alternative bio-control option would be the predatory mite, *Neoseiulus (Amblyseius) californicus*. In crops where it is hard to detect spider mite populations, this mite can be introduced on preventative basis since it can survive in the absence of prey.

Biology

The five different stages of this mite are the egg, larva, protonymph, deutonymph and adult. The adult predatory mite lives about 20 days and can lay up to 3 eggs a day. It is able to consume 5 adult spider mites daily in addition to feeding on eggs and larvae. The life cycle can be completed within 4 days with high temperatures.

Method(s) of dispersal

N. californicus is shipped to the grower as mobile stages.

Introduction interval and duration

Start early to control spider mite populations since spider mites reproduce quickly at high temperatures and low humidity. If used on a curative basis, introduce *N. californicus* with *Phytoseilus persimilis* to clean up hot spots. Concentrate predator introductions at spider mite hot spots as soon as possible after delivery.

Monitor for predator activity by checking spider mite colonies for larval development and for shriveled pest mites that have been fed upon. Monitoring should be done once a week, consistently to determine if future introductions of predatory mites are needed.

Considerations

- Can be used on outdoor crops.
- *N. californicus* also attacks the broad mite (*Polyphagotarsonemus latus*) and the cyclamen mite (*Tarsonemus pallidus*).