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FACT SHEET

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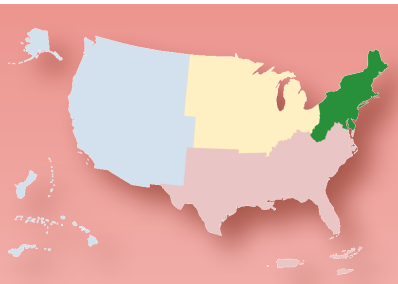

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Written by Pat Michalak

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Sustainable Pest Management in Greenhouses and High Tunnels

Geographic Adaptability: The techniques discussed here apply primarily to vegetables produced in unheated greenhouses and high tunnels in the northeastern United States, but may also be adapted to production in other regions with similar climates and pest populations.

Introduction

Growers using greenhouses in which temperature, light and relative humidity are controlled have relied for many years on releases of natural enemies to manage aphids, thrips and two-spotted spider mites. However, many of the natural enemies used to manage these pests in heated structures are too sensitive to swings in air temperature and relative humidity to be used in cool structures such as minimally heated greenhouses and unheated high tunnels. Because these season extension tools are widely used by organic and sustainable vegetable growers, SARE funded a project to study the efficacy of biological insect control in minimally heated greenhouses and high tunnels. Researchers conducted 23 case studies involving tomatoes, cucumbers, eggplants, winter greens and peppers grown in greenhouses and high tunnels at nine locations in upstate New York from 2007 to 2009. This fact sheet reports the results and provides detailed advice on how growers can use natural enemies to manage insect pests in minimally heated greenhouses and unheated high tunnels.

Note: In this fact sheet, a number in parentheses refers to one of 23 case studies from Reid, J. 2010b. For more information, see *Resources and References* (page 10).

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Biological Control

Biological control—the suppression or eradication of crop pests using their natural enemies—is a tool used by growers to manage plant pests. Biological control offers many benefits:

- Compared to repeated applications of organic sprays, releasing natural enemies requires less time.
- Once established, natural enemies work around the clock.
- When using natural enemies, re-entry and pre-harvest intervals are unnecessary.

In this study, researchers found that it was important to select the correct species of natural enemy, because most have narrow preferences for air temperature, relative humidity and pest hosts. The categories of natural enemies used in this study were predatory mites, parasitic wasps and the predatory minute pirate bug (*Orius insidiosus*).

Predatory Mites

Predatory mites feed directly on insect pests and then reproduce independently. Some predatory mites are generalist feeders because they can prey on several types of pests, while other mites are specific feeders that prey on only one type of pest. The predatory mites used in this study were the generalist feeders *Amblyseius californicus* and *Amblyseius cucumeris*, and the specific feeder *Phytoseiulus persimilis,* which preys on the two-spotted spider mite.

Parasitic Wasps

Parasitic wasp adults do not prey on plant pests; instead they lay their eggs inside the target pests. The pests are killed as the newly hatched wasp larvae develop inside the pest's body. Parasitic wasps need pests in order to reproduce. Growers using parasitic wasps need to know the species of their pests because parasitic wasps are very specific. In this study, *Aphidius colemani* and *Aphidius ervi* were used to manage aphids, and *Encarsia formosa* to manage whiteflies.

Predatory Minute Pirate Bug

The minute pirate bug (*O. insidiosus*) is a common predator of pests in most field-grown crops. It is a small (one-twelfth of an inch to one-fifth of an inch long) flying insect. The minute pirate bug is used to manage thrips, whiteflies, spider mites, aphids, psyllids, lygus bugs and small caterpillars.

How to Manage Crops for Natural Enemies

Most natural enemies need a specific temperature and relative humidity in order to be effective. This can be a problem in greenhouses and unheated high tunnels because these structures experience wide temperature and moisture fluctuations. Using natural enemies requires an understanding of the pest species, the temperature and humidity, the natural enemies themselves, the environment, and the grower's economic goals.

Scouting for Natural Enemies and Pests

Frequent scouting of the crop for pests is also necessary. Action levels for releases of natural enemies and effective release rates have not been established for every pest on every crop, so growers may need to establish their own guidelines.

A simple 10X to 20X hand lens is sufficient to identify most greenhouse pests and their natural enemies. To identify insects, hold the lens stationary in front of your eye while moving the plant or leaves in or out to focus.

Application

Many natural enemies attack only certain life stages (e.g., egg or larval stage) of their pests, therefore multiple releases may be needed to maintain pest suppression. To prevent pest infestations, release natural enemies early in the pest cycle when pest numbers are beginning to increase. For effective preventive releases, start early in the growing season and follow these steps:

1. Begin monitoring crops for pests as soon as environmental conditions are right for their development. Consult with your local Cooperative Extension personnel to track the development of pests at your location. You can also find this information on websites maintained by Cooperative Extension in your state. Just as crop plants develop at different rates within a county or region, the development of pests and their natural enemies will vary each year.
2. Determine the best method to use for scouting the pests on your crops, and then use the same method each week to track their development. Scouting methods are as simple as counting the number of aphids or mites found on 10 leaves, or recording the number of thrips found on yellow sticky cards placed at several locations around the greenhouse or high tunnel. While scouting, rate the amount of damage on new leaves.
3. Keep a record of the number of pests and their damage rating at each location.
4. When pest numbers or their damage rating begins to increase, order the appropriate natural enemies from your distributor. Be aware that distributors can take one to two weeks or more to process and ship your order. It is a good idea to familiarize yourself with your distributor's ordering policy well before you anticipate needing natural enemies. When your order arrives, follow the distributor's instructions for releasing the natural enemies.

5. Monitor the quality of the natural enemies by using a hand lens to check for activity. Stick with distributors who send natural enemies that are active and thriving after being shipped.
6. Learn to recognize the natural enemies you have released, as well as the signs that they are working. Commercial suppliers can provide you with pictures of the natural enemies you purchased.
7. If plants are heavily infested with pests, it may be necessary to apply a compatible pesticide to knock down their numbers before releasing the natural enemies that you have purchased. A knock-down spray of pure water is relatively harmless, but most other pesticides require a good understanding of the pests, pesticides, and natural enemies. Before using pesticides, read and follow label directions, and consult the Agricultural Use Requirements section for Personal Protective Equipment (PPE) and Restricted Entry Intervals (REIs). Researchers used knock-down sprays, in combination with natural enemies, to manage aphids (refer to Fig. 7 and Fig. 8).
8. Make sure there is no exposure to pesticide drift from adjacent areas and that residues are gone prior to releasing natural enemies. Pesticide residues on the crop or soil can remain toxic to natural enemies long after the pesticide was applied. To avoid residue problems, growers can use resources such as the *BioBest Sustainable Crop Management Side Effects Manual* or consult with their supplier for up-to-date information on the side effects of pesticide residues on natural enemies.

Management of Two-Spotted Spider Mites

Introduction

The most common spider mite pest in greenhouses and high tunnels in the Northeast is the two-spotted spider mite (*Tetranychus urticae*). This mite prefers hot, dry environments. It damages plants by puncturing plant cells and draining the contents of the cells, causing the leaves to become spotted or stippled. In the SARE study, the predatory mites *P. persimilis*, *A. californicus* and *A. cucumeris* were used to manage the two-spotted spider mite on tomatoes and cucumbers in greenhouses and high tunnels.

Researchers found that spider mite populations increase rapidly, and recommend releasing controls at the first sign of mites. They also found that it was useful to make a second release, use higher rates and/or release several generalist predators at one time.

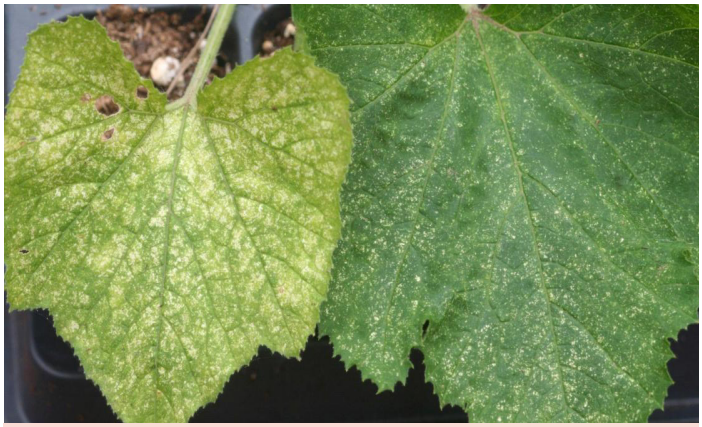

FIG 1. Two-spotted spider mite damage on zucchini plant leaves. *Photo courtesy Whitney Cranshaw, Colorado State University, Bugwood.org #5369740*

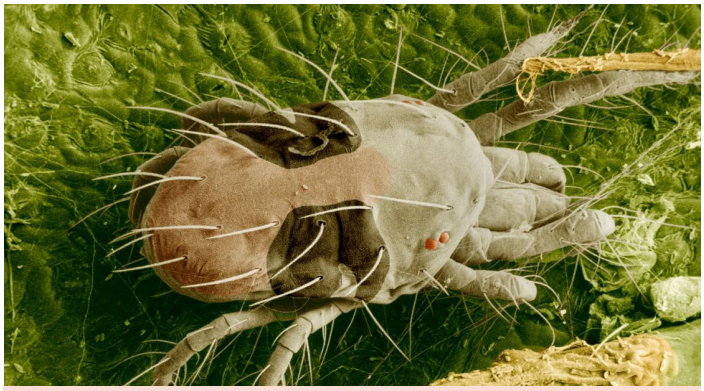

FIG 2. Scanning electron image of two-spotted spider mite feeding on rose leaf. *Photo courtesy E. Erbe, USDA-ARS*

How to Scout for the Two-Spotted Spider Mite

Prevent spider mite outbreaks by scouting weekly and releasing natural enemies as needed. Look for the characteristic spotting on plant leaves (Fig. 1). All spider mites have four pairs of legs. The two-spotted spider mite has two prominent spots on the upper surface of its body (Figs. 2 and 3). Look for mites on the undersides of leaves. Also look for their silken webbing (Fig. 3).

Natural Enemies of the Two-Spotted Spider Mite

Phytoseiulus persimilis

Phytoseiulus persimilis, a highly specialized predator mite, works best at a temperature of 65 to 80 degrees F and a relative humidity of at least 60 percent. This predatory mite preys only on the two-spotted spider mite, so in the absence of the spider mite the predatory mite will perish. It can be cannibalistic when spider mite prey is unavailable. For this reason, highly specialized predators such as *P. persimilis*

FIG 3. Two-spotted spider mite and web. *Photo courtesy D. Cappaert, Michigan State University, Bugwood.org #5371009*

are difficult to use in preventive programs and are more effective after pest populations become established.

This predatory mite is one of the mainstays of greenhouse biological control programs for management of spider mites on vegetables and ornamentals, but the SARE-funded researchers found that in high tunnels the temperature and humidity fluctuated too widely to support this species except for several weeks in spring and summer (Table 1). *P. persimilis* was the natural enemy most commonly released to manage the two-spotted spider mite in the SARE study, but results were inconsistent.

In 2007, *P. persimilis* was released to manage the two-spotted spider mite on tomatoes grown in a greenhouse at one location (3). Because scouting began too late, this predatory mite was not effective in reducing pest numbers. In the years that followed, scouting began earlier in the season and this natural enemy was released earlier.

In 2008 and 2009, releases of *P. persimilis* (16, 9) at several locations provided some control of the two-spotted spider mite on both tomatoes and cucumbers. The two-spotted spider mite was successfully controlled on the tomato crop; however, on the cucumber crop the predatory mite provided some control but failed to eradicate the pest. In 2010, releases of *P. persimilis* successfully controlled the two-spotted spider mite on cucumbers in high tunnels (19, 20).

P. persimilis was also used to manage the two-spotted spider mite on eggplants in high tunnels in 2008. The pest mite population was reduced but not eradicated, yet the plants continued to grow and produced good quality fruit.

In 2010, releases of this predatory mite almost eradicated the two-spotted spider mite on heavily infested baskets of strawberry plants in a greenhouse. As the population of the predatory mite grew and became established on the crop, pest mite numbers declined.

Application

In tomatoes and cucumbers, release 1,000 mites per 10,000 square feet. Follow the instructions provided by your distributor, but in general, release *P. persimilis* at the first sign of an infestation of two-spotted spider mites. It may be necessary to remove heavily infested plants or apply a knock-down spray before releasing this predatory mite. After releasing, continue to monitor the mites as well as the predatory mites. Repeat releases as needed.

Amblyseius californicus

Amblyseius californicus is a general predator that is most efficient at a temperature of 60 to 80 degrees F and a relative humidity of at least 60 percent. It feeds on spider mites, thrips, aphids and other pests. It prefers the two-spotted spider mite, and will consume all life stages of this pest. This predatory mite can survive longer than *P. persimilis* in the

TABLE 1. EFFECT OF PREDATORY MITES ON CONTROL OF TWO-SPOTTED SPIDER MITES IN UNHEATED GREENHOUSES AND HIGH TUNNELS[1]

CROP[3]	SUCCESS RATING OF TWO-SPOTTED SPIDER MITE CONTROL WITH THE FOLLOWING PREDATORY MITES[2]		
	Phytoseiulus persimilis	*Amblyseius californicus*	*Amblyseius cucumeris*
Tomatoes	3.5; 3.5	-	-
Tomatoes in Greenhouses	0; 3	3; 4	-
	-	2.75 (combined release of *A. californicus* and *A. cucumeris*)	
Cucumbers	3; 2.5; 4.5	-	-
Eggplants	3	-	-
Strawberry Baskets	4	-	-

[1] 2007 through 2010
[2] Each number represents the success rating of control in one season at one of 19 case studies where 0 = control failed; 3 = pest was controlled; 5 = pest was eradicated.
[3] Crops were produced in high tunnels unless noted otherwise.

absence of prey and has been shown to successfully control the two-spotted spider mite in greenhouses and high tunnels.

The SARE study results indicated that *A. californicus* can be used in both greenhouses and high tunnels (Table 1). Researchers recommend the release of general predators such as *A. californicus* for preventive pest control. *A. californicus* can sustain itself better than *P. persimilis* because it can be released when pest numbers are still low and sustain itself on pollen, insects and mites while pest numbers are still growing. Releases of *A. californicus* controlled the two-spotted spider mite on tomatoes grown in greenhouses at several locations in 2008 (6, 7).

Application

Release this beneficial mite when a combination of pest species, such as two-spotted spider mites and thrips, are present and require action. Release 1,000 mites per 4,500 square feet of infested area on tomatoes, cucumbers and most other crops in greenhouses and high tunnels. Follow the instructions provided by your distributor, but in general, release *A. californicus* at the first sign of an infestation of two-spotted spider mites. It may be necessary to remove heavily infested plants or apply a knock-down spray before releasing the beneficial mite. After releasing, continue to monitor the two-spotted mites as well as the predatory mites. Repeat releases as needed.

Combination of Management Tools

Researchers recommend using a combination of tools to manage one or more pests at the same time, or when pest numbers are very high. Strategies can include spraying with a pesticide to knock down pest numbers, followed by releases of one or more species of natural enemies. A combined release of *P. persimilis* and *A. californicus* provided a low level of control of the two-spotted spider mite on tomatoes in a greenhouse at one location in 2009 (15).

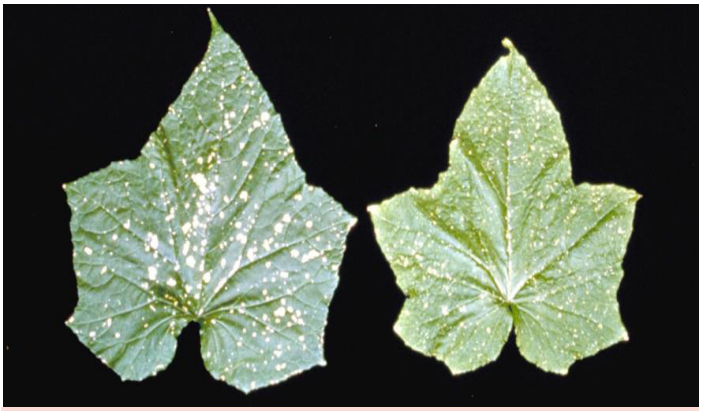

FIG 4. Thrips damage on cucumber: flower thrips (*Frankliniella*) with coarser pattern (left); onion thrips (*Thrips tabaci*) (right). *Photo courtesy Jack Reed, Mississippi State University, Bugwood.org #0660069*

FIG 5. Adult stage of western flower thrips. *Photo courtesy P.M.J. Ramakers, Applied Plant Research, Bugwood.org #5370035*

The release of *P. persimilis* and *A. cucumeris* also controlled the two-spotted spider mite and thrips, respectively, on tomatoes, cucumbers and blueberries in a high tunnel at one location in 2009 (16).

Management of Thrips

Introduction

The most common thrips in greenhouses and high tunnels in the Northeast are flower thrips (species of *Frankliniella*) and onion thrips (*Thrips tabaci*). Flower thrips damage flowers and leaves. Onion thrips are pests on several hundred host plants, including cucumbers, tomatoes, eggplants and peppers. Thrips reduce the yield of crops by puncturing plant cells with their mouthparts. They damage the leaves and blossoms of host plants as well as transmit viruses.

Thrips like dry conditions, so keep plants well watered and relative humidity high. Researchers examined the efficacy of two generalist predators, *A. cucumeris* (a mite) and *O. insidiosus* (the minute pirate bug), on controlling thrips on tomatoes and cucumbers in greenhouses and high tunnels.

How to Scout for Thrips

Prevent thrips outbreaks by scouting weekly and releasing natural enemies at the first sign of damage, or when first detected on sticky cards. Sticky traps may help to detect thrips up to a month before they are seen on plants. It is easier to find thrips damage than to find the actual thrips. Look for the characteristic white streaks or spots on leaves, flecked with black spots of feces (Fig. 4). Damage is often found on the lower leaves of cucumber and tomato. In sweet peppers, the damage first appears in the upper, youngest leaves. On vegetable flowers, thrips feeding makes silvery white streaks on the petals. Thrips do not leave behind silken webbing.

Thrips are difficult to identify without a hand lens. They have six legs and narrow wings and are often found with

TABLE 2. EFFECT OF NATURAL ENEMIES ON CONTROL OF THRIPS IN HIGH TUNNELS[1]

CROP	SUCCESS RATING OF THRIPS CONTROL WITH PREDATORY MITES AND MINUTE PIRATE BUGS[2]			
	PREDATORY MITES			MINUTE PIRATE BUG
	Phytoseiulus persimilis	*Amblyseius californicus*	*Amblyseius cucumeris*	
Cucumbers	-	-	4.75; 4; 4.5	
	-	-	5 (combined release of *A. cucumeris* and minute pirate bugs)	

[1] 2007 through 2010
[2] Each number represents the success rating of control in one season at one of 19 case studies where 0 = control failed; 3 = pest was controlled; 5 = pest was eradicated.

their wings folded, so they look like tiny brown flecks of peat moss on leaves and on sticky cards. Some specimens will have hairs on their wings when viewed with a hand lens (Fig. 5).

Natural Enemies of Thrips

Amblyseius cucumeris

Amblyseius cucumeris prefers a diet of thrips but is considered a generalist because it can survive on pollen and spider mites in the absence of thrips. *A. cucumeris* will work best at a temperature of 70 degrees F or above and a relative humidity above 65 percent.

Results indicate that *A. cucumeris* should be used to manage thrips in spring and summer crops of organic vegetables in high tunnels. In comparison with other predatory mites that prey on thrips, *A. cucumeris* costs less, has greater survivability and a broad range of prey, and works well when released preventively early in the growing season.

Preventive releases are especially important on cucumbers, which are more attractive to thrips than other common high tunnel crops. *A. cucumeris* is a generalist predatory mite, and it lends itself to preventive approaches because it can survive on pollen or other insect and mite pests in the absence of the target pest thrips. Control of thrips was consistent and this predatory mite was a repeated success story.

In 2009 and 2010, releases of *A. cucumeris* controlled thrips on cucumbers in high tunnels at several locations (14, 16, 19). Overall, thrips levels were reduced by an average of 85 percent after releases of *A. cucumeris* (Table 2).

Application

Follow the instructions provided by your distributor, but in general, release *A. cucumeris* at the first sign of an infestation of thrips. It may be necessary to remove heavily infested plants or to apply a knock-down spray before releasing the predatory mite. After releasing, continue to monitor the thrips as well as the predatory mites. Repeat releases of natural enemies as needed.

Orius insidiosus

Orius insidiosus (minute pirate bug) is a common generalist predator found naturally in many field-grown crops. It preys on thrips, whiteflies, spider mites, aphids and many other pests. It can survive on pollen in the absence of prey. The minute pirate bug will work best at a temperature of 70 to 90 degrees F and a day length of 11 hours or more.

Application

Make releases at any time, early or late in an infestation of thrips, because the minute pirate bug can control heavy infestations quickly. For preventive control, release one to two minute pirate bugs per plant in greenhouses. When treating a heavy infestation of thrips, aphids, or whiteflies release 500 minute pirate bugs per 250 square feet. Minute pirate bugs will move efficiently throughout the infested plants and will continue to kill even when they do not need to eat. After releasing, continue to monitor the thrips as well as the pirate bug.

Combination of Management Tools

Use a combination of tools to manage one or more pests at the same time, or when pest numbers are high. In 2007 (1), one release of minute pirate bugs together with three releases of the generalist predatory mite *A. cucumeris* eradicated thrips on cucumbers in a greenhouse (Table 2). Two releases of *A. cucumeris* made earlier in the season likely would have been sufficient.

Releases of *P. persimilis* and *A. cucumeris* successfully controlled the two-spotted spider mite and thrips on tomatoes, cucumbers and blueberries in a high tunnel at one location in 2009 (16).

Management of Aphids

Introduction

Many species of aphids can be found on vegetable crops in the Northeast. Low to moderate numbers of aphids are usually not harmful to vegetables. However, large populations

cause curling and yellowing distortion of leaves and stunting of shoots. Aphids can also transmit viruses to vegetable crops.

A. colemani and *A. ervi*, two pest-specific wasps that parasitize aphids, were used to manage a broad range of species on winter greens and peppers in high tunnels at several locations.

How to Scout for Aphids

Prevent outbreaks of aphids by scouting weekly and releasing natural enemies at the first sign of damage. Check plants regularly for aphids, including at least twice weekly when plants are growing rapidly. Look for the small, white flakes that are the cast-off skins of aphids. Many species of aphids cause the greatest damage when the temperature is from 65 to 80 degrees F. Aphids reproduce quickly, so catch infestations early. Once aphid numbers are high and they have begun to distort and curl leaves, it is often hard to reduce populations because the curled leaves shelter aphids from insecticides and natural enemies.

Aphids excrete a sugary, sticky liquid called honeydew, which promotes the development of black, sooty mold fungus on the leaf surface. Sooty mold is not pathogenic on the plant, but in severe infestations it can interfere with photosynthesis. Watch for honeydew on leaves, stems and other surfaces.

Aphids tend to be most prevalent along the upwind edge of fields and close to other sources of aphids, so scout these areas. Many aphid species prefer the undersides of leaves, so turn them over when checking for this pest. Also check for evidence of natural enemies such as lady beetles, lacewings, syrphid fly larvae and the mummified skins of parasitized aphids. Look for disease-killed aphids as well: They may appear off-color, bloated or flattened. Substantial numbers of any of these natural control factors can mean that the aphid population may be reduced rapidly without the need for treatment.

FIG 6. Aphid Mummies (light tan) parasitized by *Aphidius colemani. Photo courtesy D. Cappaert, Michigan State University, Bugwood.org #5255047*

Natural Enemies of Aphids

Aphidius colemani

Aphidius colemani works best at a temperature of 50 to 76 degrees F and tolerates cool temperatures. It is not affected by short day length. This tiny, black parasitic wasp attacks the green peach aphid and many closely related species, and eats honeydew, the sticky fluid produced by aphid infestations. It lays its eggs in aphids, and all of the wasp's life stages develop inside the aphid. When the wasp larvae spin cocoons, the aphid's body will swell. The adult wasp then exits the aphid body, leaving behind a hard brown shell called an aphid mummy (Fig. 6). *A. colemani* occurs naturally outdoors and frequently parasitizes aphids in greenhouses. It is a good searcher and can locate new aphid colonies when aphid populations are low.

TABLE 3. EFFECT OF PARASITIC WASPS ON CONTROL OF APHIDS IN UNHEATED GREENHOUSES AND HIGH TUNNELS[1]

CROP[3]	SUCCESS RATING OF APHID CONTROL WITH PARASITIC WASPS[2]		
	Aphidius colemani	*Aphidius ervi*	*Aphelinus abdominalis*
Winter Greens	5 (combination of *A. colemani* and *A. ervi*)		-
Tomatoes in Greenhouse	4 (plus Aphid Stop)	-	-
Eggplants	5 (plus PyGanic®)	-	-
Peppers	4.75 (plus insecticidal soap)	-	-
	5 (combination of *A. colemani* and *A. ervi*)		-
	5 (combination of *A. colemani* and *A. ervi*)		-
Cucumbers in Greenhouse	0 (combination of *A. colemani*, *A. ervi* and *A. abdominalis*)		

[1] 2007 through 2010
[2] Each number represents the success rating of control in one season at one of 19 case studies where 0 = control failed; 3 = pest was controlled; 5 = pest was eradicated.
[3] Crops were produced in high tunnels unless noted otherwise.

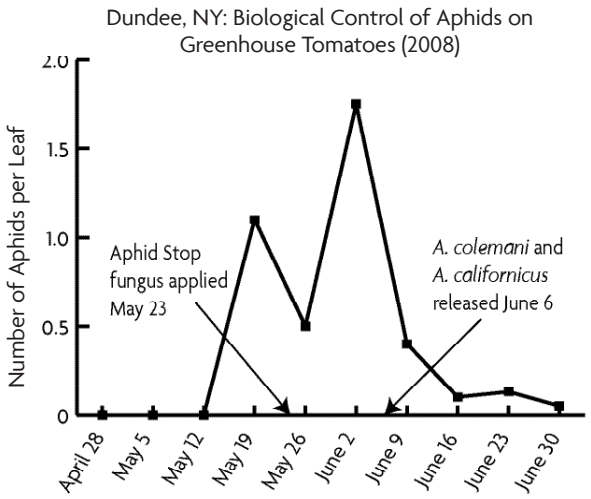

FIG 7. Effect of release of *Aphidius colemani* and *Amblyseius californicus* in combination with Aphid Stop on aphid population on tomatoes in a greenhouse (7).

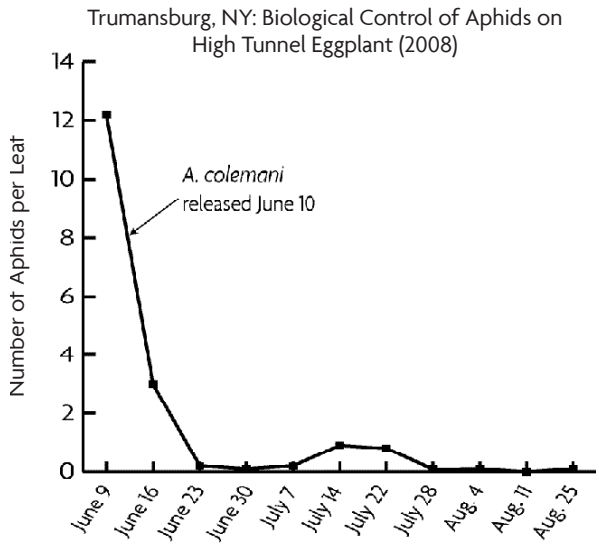

FIG 8. Effect of release of *Aphidius colemani* in combination with PyGanic® on aphid population on eggplant in a high tunnel (8).

Application

Depending on the extent of infestation, release 500 to 3,000 per acre two or three times, with one week between releases. Follow the instructions provided by your distributor, but in general, release *A. colemani* at the first sign of an infestation of aphids. It may be necessary to remove heavily infested plants or to apply a knock-down spray before releasing the parasitic wasp. However, leaves with parasitized aphids should remain in the greenhouse or high tunnel until the next generation of wasps emerge. After releasing, continue to monitor both live and parasitized aphids. Repeat releases of natural enemies as needed.

Aphidius ervi

This small, black wasp parasitizes all types of large aphids. It prefers an air temperature of 86 degrees F.

Application

Release one adult per 20 to 100 square feet for preventive releases, or five times as much for heavy infestations. Follow the instructions provided by your distributor, but in general, release *Aphidius ervi* at the first sign of an infestation of aphids. It may be necessary to remove heavily infested plants or to apply a knock-down spray before releasing the parasitic wasp. If pruning leaves, check for parasitized aphids. Leaves with parasitized aphids should remain in the greenhouse or high tunnel until the next generation of wasps emerge. After releasing, continue to monitor both live and parasitized aphids. Repeat releases of natural enemies as needed.

Combination of Management Tools

Researchers recommend using a combination of the parasitic wasps *A. colemani* and *A. ervi* to control aphids on warm season crops (8, 17, 21) (Table 3). This combination is effective when applied at the first sign of an aphid infestation and when environmental conditions are right. Release more than one species of parasitic wasp in order to cover a wider range of aphid species because each species of wasp parasitizes different aphid species, and waiting to confirm the presence of a particular aphid species is not practical. Researchers experienced two failures using this combination. In one instance, the wasps were released in a high tunnel in a cool fall environment, and in the other they were released in a greenhouse in a winter environment.

Researchers found other successful combinations. For example, aphid parasites in combination with an application of Aphid Stop eradicated aphids on tomatoes in a greenhouse (7) (Fig. 7) and on winter greens (10) and peppers (17, 18) in high tunnels at several locations in 2008. Aphid Stop is a commercial formula that claims to repel aphids.

A combination of the organically compliant, broad-spectrum contact insecticide PyGanic® and the aphid parasite *A. colemani* was also successful, eradicating aphids on eggplant in high tunnels at one location in 2008 (8) (Fig. 8).

The combination of insecticidal soap and one release of the aphid parasites *A. colemani* and *A. ervi* almost eradicated aphids on peppers at one location in 2008 (21). Releases of the aphid parasites *A. colemani*, *A. ervi* and *Aphelinus abdominalis* failed to control aphids on cucumbers grown hydroponically at one location in December 2010 (23).

Management of Whiteflies

Introduction

Several species of whiteflies can be found on vegetable crops and flowering annual plants in the Northeast. Like

aphids, whiteflies suck sap from plants and excrete honeydew. Adults lay eggs on the underside of leaves. The first-stage nymphs crawl on the plant for a short time before becoming immobile scales. The scales are flattened disks, much like one layer of a round cake.

Their feeding may cause stunting, wilting or yellowing of plants, defoliation, reduced yields, and plant death. The sticky honeydew they leave behind on the plant can interfere with photosynthesis. Whiteflies can reproduce rapidly in a favorable environment that is absent of natural enemies.

How to Scout for Whiteflies

Inspect the upper and lower surfaces of plant leaves weekly for adults, eggs and immobile scales. Look for adults near plant tops or the ends of branches. The adults are tiny, white insects with four wings. If you disturb the plant foliage, adults will fly up and be easier to spot. Use a hand lens to identify scales, because they are translucent and difficult to see. You can also use yellow sticky cards (one card per 1,000 square feet) to monitor adults. Place the cards just above the tops of plants and record the number counted once or twice each week.

Adults and eggs are more often found on younger leaves; scales are found on older leaves. Scales are difficult to see because they are translucent unless parasitized. If eggs and scales are found, scout more frequently in order to track the hatching of crawlers from those plants. If you plan to apply an insecticide, remember that the crawler is the only stage that is susceptible to insecticides.

Natural Enemies of Whiteflies

Encarsia formosa

Encarsia formosa is a tiny wasp that attacks greenhouse and silverleaf whiteflies. Adult female *E. formosa* kill whitefly scales in two ways: by puncturing and feeding on scales, or laying their eggs in scales. *E. formosa* eggs hatch into tiny larvae, causing the whitefly pupae to turn black as the young wasps mature. Suppliers ship the parasites inside the blackened whitefly scales, which are attached to cards in batches of 50 to 100 per card.

E. formosa prefers an average temperature above 64 degrees F, and 70 percent relative humidity. Release *E. formosa* at the first sign of whiteflies on yellow sticky cards. Release at one- to two-week intervals for six to eight weeks.

Researchers used *E. formosa* (Nile Delta) to manage whiteflies on tomatoes in high tunnels at one location in 2008 (5) (Table 4). They made only one release of *E. formosa* when whitefly numbers were high. The release managed but did not eradicate whiteflies; the whitefly population began to grow after several weeks and remained high, but the grower felt this pest was sufficiently controlled.

TABLE 4. EFFECT OF *ENCARSIA FORMOSA* ON CONTROL OF WHITEFLIES IN HIGH TUNNELS[1]

CROP	SUCCESS RATING OF WHITEFLY CONTROL WITH *ENCARSIA FORMOSA*[2]
Tomatoes	5; 3

[1] 2007 through 2010
[2] Each number represents the success rating of control in one season at one of 19 case studies where 0 = control failed; 3 = pest was controlled; 5 = pest was eradicated.

Application

Release *E. formosa* preventively at a rate of one card per 6 square feet every two weeks. At the first sign of whiteflies on plants, release one card per 3 square feet. Suppliers may have additional instructions.

Management of Multiple Pests

To manage multiple pests, researchers recommend two approaches: releasing multiple species of natural enemies at one time or releasing multiple natural enemies over the course of the growing season. For heavy infestations of pests, it may be necessary to remove the most infested plants or spray them with an insecticide to knock down the pest population before releasing the natural enemies. When using multiple controls, consult with Cooperative Extension personnel or commercial distributors of natural enemies to make certain the chosen tools work well together. Insecticides vary in their impact on natural enemies; some insecticides are toxic to natural enemies, even in residual form.

SARE Research Summary

In 2007, 2008 and 2009, SARE funded a research project, *Natural Pest Management in New York High Tunnel and Greenhouse Vegetables* (LNE07-262), to study the efficacy of releasing natural enemies to control insect pests on vegetables grown in minimally heated greenhouses and high tunnels. The researchers recruited vegetable growers to host the on-farm trials, conducted a poll to determine their most problematic pests, established randomized research plots on each farm, and monitored pest numbers before and after releasing the natural enemies. In total, this included 23 case studies involving tomatoes, cucumbers, eggplants, winter greens and peppers grown at nine locations in upstate New York. In several case studies, a pesticide was applied in addition to releasing the natural enemy.

The size of the plots, densities of the crop plants and methods of pest monitoring varied by crop, site and year. Researchers monitored pest populations before and after applying the natural enemies by counting the numbers of each pest and/or rating their damage every one to two weeks. In

addition, the overall success of the control method at each case study was rated on a scale of 0 to 5 as failed (0 rating), controlled (3 rating) or eradicated (5 rating). Pest population data was entered into spreadsheets and the mean population density or damage rating was calculated.

Thrips were monitored by counting their numbers on 12 leaves per block. Two-spotted spider mites were monitored by rating their damage to leaves on a scale of 1 (leaves are free of damage) to 10 (leaves are dead). Aphids and whiteflies were monitored by counting their numbers on approximately three to five leaves or leaflets per plant. Further details on scouting procedures are available in the Farm-by-Farm Demonstration Trial Results in Reid, J. 2010b.

Trial data and input from growers indicated that while biological pest control with natural enemies is difficult to quantify economically in field settings, it can be the difference between a crop and a failure, and for many organic growers it is their only option.

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