

Photo 1. Asian citrus psyllid adult
(Photo by J. Lewis)



DEVELOPMENT OF AN ACP MANAGEMENT PLAN FOR ORGANIC CITRUS

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SUMMARY

Control of the Asian citrus psyllid (ACP), which is the vector for the phloem-limited bacterium 'Candidatus Liberibacter asiaticus' (CLAs) that is associated with huanglongbing (HLB or greening disease) in all habitats – including organic citrus – is critical for area-wide management of this vector-disease complex and sustainable citrus production. Organic citrus is produced in California, as well as in Florida and Texas.

We evaluated the impact of three separate organic programs – organic insecticides applied alone (Program 1) or with horticultural mineral oil (Program 2) and insecticidal soap (Program 3) – compared with one conventional program on populations of ACP and beneficial insects in bearing citrus trees during dormant and growing seasons in southwest Florida. During the dormant winter season, Pyganic alone or with 435 oil or M-pede applied in November, December and January, and Danitol applied in November and January all

provided significant reduction in ACP through the first week of March. This was when ACP adult numbers started to escalate with the organic programs while still held to the 0.1 per tap threshold in the conventional program. Pyganic with M-pede performed better than with 435 oil and both performed better than Pyganic alone. ACP reduction from Pyganic with M-pede was similar to Danitol through the first week of March after which only the Danitol residual was effective. A total of six applications for the organic programs and five in the conventional program were made during the growing season. Organic Programs 2 and 3 rotated organic insecticides with 435 oil or M-pede resulting in a 50 percent reduction in the use of organic insecticides while providing better control than Program 1 with organic insecticides only.

However, ACP was reduced more in the conventional program. Reduction to 0.1 adults per tap sample was observed after the treatments of Closer and Aza-Direct plus M-pede in March, Micromite and Azera plus M-pede in April, and Entrust plus 435 oil and Imidan in May. Lacewings, spiders, ants and ladybeetles were observed in all treatments that also may have contributed to ACP reduction. Green lacewings were most abundant. Ladybeetles known for significant predation on ACP were rare, reflecting the negative impact of increased use of broad-spectrum insecticides to control ACP since the advent of HLB.

Tamarixia radiata was released in all programs, but more were recovered from ACP nymphs in the trees from the organic program compared to the conventional program. Significant effects of organic insecticides with 435 oil or M-pede on ACP indicate potential use in all citrus, including where conventional products may not be appropriate. In the coming cycle, we will be repeating and extending these studies to confirm results, include additional products and evaluate on ACP, other pests and beneficial insects.

BACKGROUND

'*Candidatus*' Liberibacter species that are known to be associated with HLB are vectored by ACP (**Photo 1**). Both adults and nymphs of this insect are capable of acquiring and transmitting '*Candidatus* Liberibacter asiaticus' (CLAs), a phloem-limited bacterium associated with HLB. However, the adult is responsible for spreading CLAs through its movement, whereas the primary role of the nymphs is acquisition of the bacterium. Therefore, it is important to control both stages of ACP to reduce the spread of CLAs among habitats including organic citrus.

ACP and HLB are established in Florida and spreading in California, Texas and other regions. Monitoring of ACP, beneficial insects, insecticides, plant nutrition and removal of disease-infected trees are tools currently used to manage this vector-disease complex. Beneficial insects such as predators and parasitoids mainly attack eggs and nymphs of ACP. Predatory insects generally are larger than their prey, which they kill or consume. Predators are more or less generalists, meaning they consume more than one type of prey and are thus useful against multiple pests. Insect predators common in citrus include ladybeetles, lacewings, spiders and ants. In addition to ACP, they also attack other pests such as citrus leafminer (CLM), thrips and aphids, thus playing an important role in overall citrus pest management.

The small parasitic wasp, *Tamarixia radiata*, only attacks ACP and can contribute to its control through both feeding and parasitization of nymphs (**Photo 2**). The female lays her egg under the body of the mid-age nymph. Upon hatching, the developing larva consumes the body contents of the host and finally pupates inside the remaining "mummy." *T. radiata* is now mass-produced and released in Florida, California



Photo 2: A female *Tamarixia radiata* laying egg on an ACP nymph. (Photo by J. Lotz).

Table 1. Insecticides, rates, manufacturer and timing of spray applications in organic and conventional programs made using final spray volume of 100 gallons per acre.

Treatment date	Asian Citrus Psyllid Control Programs			
	Organic 1	Organic 2	Organic 3	Conventional
	Organic insecticide*	Organic insecticide with oil*	Organic insecticide with Soap*	Synthetic insecticide*
Winter/Dormant Season Treatments 2014-2015				
Nov 11, 2014	Pyrethrins Pyganic 5.0EC 17 oz MGK Corp.	Pyrethrins + Mineral oil Pyganic 5.0EC + 435 Oil 17 oz + 2 gallon MGK Corp., Drexel	Pyrethrins + Potassium salts of fatty acids Pyganic 5.0EC + M-pede 17 oz + 2 gallon MGK Corp., Dow	Fenpropathrin Danitol 2.4 EC 16 oz Valent
Dec 10, 2014	Pyrethrins Pyganic 5.0EC 17 oz MGK Corp.	Pyrethrins + Mineral oil Pyganic 5.0EC + 435 Oil 17 oz + 2 gallon MGK Corp., Drexel	Pyrethrins + Potassium salts of fatty acids Pyganic 5.0EC + M-pede 17 oz + 2 gallon MGK Corp., Dow	None
Jan 12, 2015	Pyrethrins Pyganic 5.0EC 17 oz MGK Corp.	Pyrethrins + Mineral oil Pyganic 5.0EC + 435 Oil 17 oz + 2 gallon MGK Corp., Drexel	Pyrethrins + Potassium salts of fatty acids Pyganic 5.0EC + M-pede 17 oz + 2 gallon MGK Corp., Dow	Fenpropathrin Danitol 2.4 EC 16 oz Valent
Growing Season Treatments 2015				
Mar 10, 2015	Azadirachtin Aza-Direct 48 oz Gowan	Azadirachtin + Mineral oil Aza-Direct + 435 Oil 48 oz + 2 gallon Gowan, Drexel	Azadirachtin + Potassium salts of fatty acids Aza-Direct + M-pede 48 oz + 2 gallon Gowan, Dow	Sulfoxaflor Closer 240 SC 5 oz Dow
Apr 1, 2015	<i>Chromobacterium subsugae</i> Grandevo 3 lbs Marrone	Mineral oil 435 Oil 2 gallons Drexel	Potassium salts of fatty acids M-pede 2 gallons Dow	Spirotetramat Movento MPC 16 oz Bayer
Apr 14, 2015	Azadirachtin + Pyrethrins Azero 56 oz MGK Corp.	Azadirachtin + Pyrethrins + Mineral oil Azero + 435 Oil 56 oz + 2 gallon MGK Corp., Drexel	Azadirachtin + Pyrethrins + Potassium salts of fatty acids Azero + M-pede 56 oz + 2 gallon MGK Corp., Dow	Diflubenzuron Micromite 80 WGS 6.25 oz Chemtura
May 8, 2015	<i>Burkholderia</i> spp. Venerate 3 gal Marrone	Mineral oil 435 Oil 2 gallons Drexel	Potassium salts of fatty acids M-pede 2 gallons Dow	Phosmet Imidan 70 W 1.5 lb Gowan
May 27, 2015	Spinosad Entrust 80W 10 oz Dow	Spinosad + Mineral oil Entrust 80W + 435 Oil 10 oz + 2 gallon Dow, Drexel	Spinosad + Potassium salts of fatty acids Entrust 80W + M-pede 10 oz + 2 gallon Dow, Dow	None
July 7, 2015	Kaolin Surround WP 50 lbs AgNova	Mineral oil 435 Oil 2 gallons Drexel	Potassium salts of fatty acids M-pede 2 gallons Dow	Dimethoate Dimethoate 4 E 16 oz Cheminova

*Product information is arranged as active ingredient followed by trade name, rate and manufacturer.

and Texas to control ACP. Reduction in populations of ACP by predators and *T. radiata* can play an important role in its management and ultimately that of HLB, as well. These beneficial insects are present in the environment at some level and capable of moving among habitats.

ACP adults are primarily controlled through foliar sprays, often of broad-spectrum insecticides. ACP is attracted to young shoots or flush for development and reproduction. Therefore, it is especially important to target adults before trees begin to flush. Predators and parasitic wasps are also attracted to these shoots where they are searching for prey such as immature ACP, as well

as citrus leafminer (CLM) and aphids. Therefore, applying broad-spectrum insecticides prior to flush reaps the maximum benefit in suppressing adult ACP while conserving key beneficial insects.

Citrus trees go through periods of dormancy during cold or dry weather, producing little or no new growth. Adult ACP living on these trees need to wait for new growth to emerge and lay eggs. Insecticidal sprays made during winter, before bud break, in Florida are commonly known as dormant sprays. The aim is to reduce psyllid entry into spring flush and, therefore, subsequent reproduction during the growing season. Generally, broad-spectrum pyrethroids and organophosphates are preferred in winter followed by selective insecticide chemistries, microbials and horticultural spray oil during the growing season. Such programs to manage ACP in conventional citrus are now common in Florida and are being adopted in California and Texas.

In this project, we are focused on developing holistic ACP management programs for organic citrus, which is grown more in California than any other state. Findings will be useful for organic growers to manage ACP in their groves and contribute to its area-wide management by reducing the spread to conventional citrus and other habitats. Organic products also will be suitable for conventional citrus growers as selective options to avoid excessive use of non-selective insecticides, to limit pesticide resistance and harm to beneficial insects. Conservation of naturally-occurring populations of beneficial insects and augmentation of *T. radiata* will be useful for ACP control across habitats. In contrast, synthetic chemicals are expensive and not always welcomed in residential areas that may be suitable for organic products.

RESEARCH OBJECTIVES

1 Determine the effectiveness of the organic insecticide Pyganic® (natural pyrethrum) to suppress ACP during dormant winter months in comparison with Danitol® (synthetic pyrethroid extensively used for ACP control) as a conventional grower standard.

2 Evaluate rotations of organic products potentially effective against ACP for impact on ACP and its natural enemies during the growing season.

3 Release and evaluate *Tamarixia radiata* to determine the feasibility of parasitoid use in conjunction with insecticides.

DESIGN, TREATMENTS AND SAMPLING PROCEDURES

One study site consists of a 22-acre block of mature Valencia oranges in Hendry County, Florida. The block was divided into 20 plots each with three to five rows and 50 trees distributed among three organic

programs, one conventional program (**Table 1**) and one untreated control in a randomized complete block design experiment with four replicates. Organic insecticides alone (Program 1) or rotated with 435 oil (Program 2) and M-pede (Program 3) were evaluated. Synthetic insecticides were evaluated in the conventional program (**Table 1**).

Treatments included:

Organic program 1: Nine treatments using seven insecticides (Pyganic, Aza-Direct, Grandevo, Azera, Venerate, Entrust and Surround);

Organic program 2: Nine treatments using four insecticides and horticultural mineral oil (Pyganic, Aza-Direct, Azera, Entrust and 435 oil);

Organic program 3: Nine treatments using four insecticides and insecticidal soap (Pyganic, Aza-Direct, Azera, Entrust and M-pede); and conventional program: Seven treatments using six insecticides (Danitol, Closer, Movento, Micromite, Imidan and Dimethoate),

Horticultural mineral oil (HMO) "FL 435-66," a narrow-range petroleum-based oil, is standard in Florida. M-pede is insecticidal soap that contains potassium salts of fatty acids. Both are commonly used adjuvants applied with insecticides to enhance their effect and also provide significant reduction in ACP when applied alone. Their use is approved for organic citrus. They were used at two percent of the total application volume when applied with an insecticide or alone. Recommended rates of insecticides mixed in 100 gallons of water per acre were sprayed by ground using a Durand Wayland AF100-32 air blast speed sprayer (**Table 1, Photo 3**).

Pyrethroids are typically used as (winter) dormant sprays because of their broad spectrum activity and sensitivity to heat. Pyganic contains natural pyrethrins, which also are broad spectrum and break down quickly in sunlight and are, therefore, more suited for use in winter. Pyganic was applied in November 2014, December 2014 and January 2015 for dormant season control



Photo 3. Durand Wayland AF100-32 air blast speed sprayer (Photo by J. Qureshi).



Photo 4. Demonstration of the stem tap sampling method and resulting adult psyllids (Photo by P. Stansly).



Photo 5. Suction sampling (Photo by J. Qureshi).

of ACP in all three organic programs, either alone (Program 1) or with 435 oil (Program 2) or M-pede (Program 3). Danitol is a synthetic pyrethroid extensively used for ACP control in conventional citrus. Danitol, intended for January application in conventional program also was used in November to reduce the spread of ACP to other programs, considering that populations at this time were high this year compared to the previous year.

During the 2014-15 growing season, due to low ACP populations in the Valencia block, we added another replicated experiment in a block of younger Hamlin orange trees with higher psyllid populations to evaluate the organic plus 435 oil and conventional programs compared to an untreated check. This block was used again this year to compare these three

treatments in the dormant season using methods described for the Valencia block.

Organic insecticides used during the growing season included Aza-Direct, Grandevo, Azera, Venerate, Entrust and Surround. Aza-Direct is a neem-based product that acts as a feeding deterrent, repellent and insect growth regulator. Grandevo and Venerate are microbial insecticides obtained from the bacterium *Chromobacterium subtsugae* and *Burkholderia* species, respectively. Both contain multiple compounds to create a complex mode of action. Azera contains two active ingredients, azadirachtin and pyrethrins, to enhance its effectiveness. Entrust, an insecticide that contains spinosad (a naturally occurring compound found in the bacterial species *Saccharopolyspora spinosa*), is expected to act by contact and ingestion. Surround is derived from kaolin clay, a natural mineral that creates a physical barrier on the foliage to deter insects. Closer (sulfoxaflor) was used in March in the conventional program because it is recommended for use during bloom when bees and other beneficial insects are common.

T. radiata colonies were maintained at the Southwest Florida Research and Education Center (SWFREC) in Immokalee and the Division of Plant Industry (DPI) in Gainesville, Florida. A total of 92,821 *T. radiata* wasps were released in the Valencia block from May 2014–June 2015.

ACP adult and predator populations were monitored using the stem tap sampling method. Samples were collected onto sheets of 8.5 x 11-inch laminated white paper held on a clipboard. The clipboard was held horizontally under randomly selected branches at three to six feet above the ground in the outer tree canopy. The branches were struck sharply three times with a short length of PVC pipe (Photo 4). The number of individual insects that fell onto the paper sheet were identified and counted.

This method provides rapid and reproducible information on psyllid and other pests and beneficial insects important in making management decisions. Four tap samples were taken on each of three trees at three randomly selected locations for a total of nine trees per plot; for a total of 36 trees and 144 samples per treatment. We used a threshold of 0.1 adults per

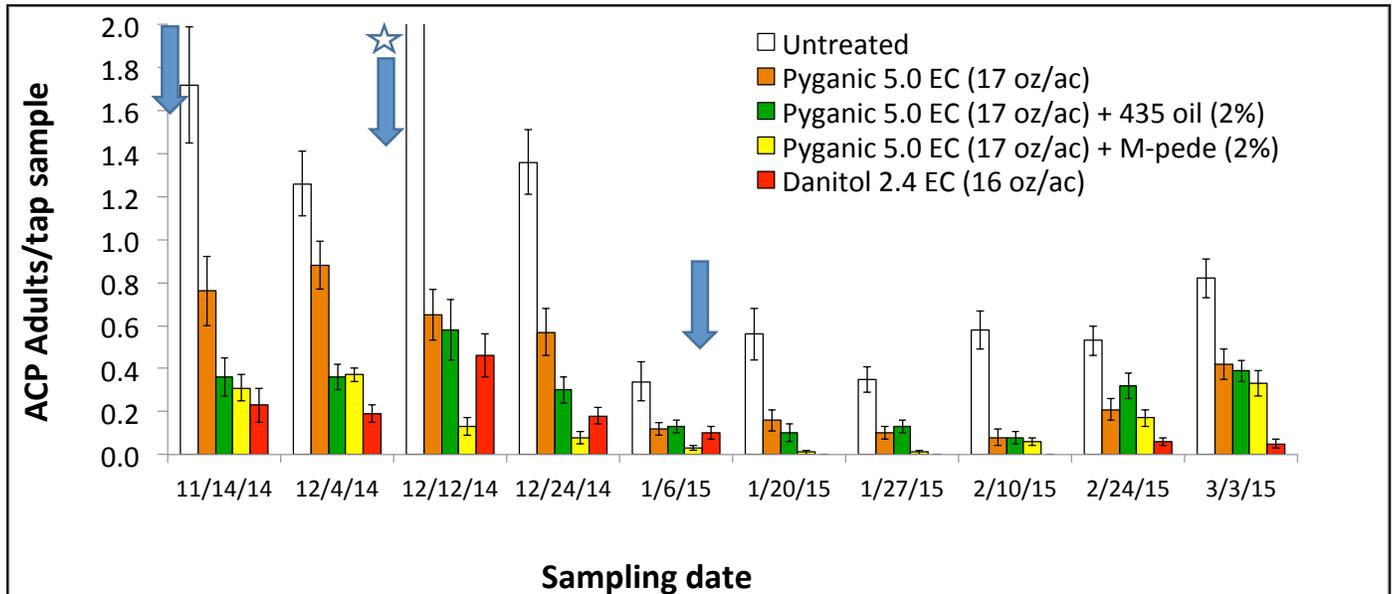


Figure 1. Density estimates of ACP populations (mean \pm SE) in organic and conventional control programs in a Valencia orange block. Pyganic alone and with M-pede or 435 oil was applied on November 11, December 10, January 12, and Danitol on November 11 and January 12. Arrows indicate spray applications except with asterisk when Danitol was not sprayed.

tap sample (10 adults in 100 tap samples) to trigger a spray during the growing season, considering the high incidence of HLB in Florida. Obviously, no ACP is always the best scenario, but it is impossible to achieve where ACP is well established. We also took suction samples using a leaf blower operating in reverse (Photo 5), which collects more psyllids at low density, as well as active and other predators such as green lacewings lady beetles, spiders and ants. Pseudomyrmex ants are common in Florida. Small colonies nest in twigs, but ants forage individually, are highly predaceous and do not tend other insects such as aphids.

Flush density was estimated by placing a one-foot-square quadrat frame made from PVC pipe at randomly chosen locations in the outer tree canopy and counting the number of shoots at the feather stage to recently expanded leaves. Depending upon availability, 15 randomly selected shoots were collected from each plot and examined in the laboratory using a stereoscopic microscope to determine the percentage of shoots infested with ACP nymphs. Depending upon availability, shoots containing three to five instar nymphs were collected in June, July, August, September and October 2014 and in March and June 2015 and brought back to the laboratory. These shoots were held under ventilated cylinders in the laboratory to allow for the emergence of adult psyllids or *T. radiata* to estimate percentage of ACP nymphs parasitized.

RESEARCH FINDINGS

ACP control in dormant winter season

Adults averaged 0.2 or more per tap sample in the Valencia block before the start of the first dormant application. After the first dormant application made on November 11, adults remained significantly fewer in all treatments compared to the untreated control through second application on

December 10 made only in organic programs (Table 1). Reduction with Pyganic plus 435 oil or M-pede averaged 73-79 percent, significantly more than 46 percent with Pyganic alone, but not different from 85 percent with Danitol (Figure 1). A similar trend of psyllid suppression persisted after the second application in organic programs, and the impact was enhanced with Pyganic plus M-pede treatment. Significant drop in populations, including control, was observed in the first week of January. On January 12, applications were made in all programs. An average reduction of 76 percent with Pyganic alone, 77 percent with Pyganic plus 435 oil, 95 percent with Pyganic plus M-pede, and 100 percent with Danitol was observed from samples taken for one month after application. Significant effects of treatments in all programs were observed through the first week of March when ACP adult numbers were exceeding 0.1 per tap sample in organic programs; therefore, additional treatment evaluations were initiated (Figure 1).

ACP adults averaged less than 0.2 per tap sample before dormant sprays in the Hamlin block. Only Pyganic plus 435 oil and Danitol were evaluated. Treatment effects were more apparent after the application on January 12. Significant reduction with Pyganic plus 435 oil lasted through February 24 and with Danitol through March 3, averaging 76 percent and 85 percent, respectively (Figure 1).

ACP control in growing season

All programs initiated for winter control of ACP continued into the growing season. Between March 10 and July 7, 2015, six treatments were applied in organic programs and five in the conventional programs. All six applications in Program 1 were organic insecticides. Programs 2 and 3 received three applications of organic insecticides each and three of 435 oil or M-pede, respectively.

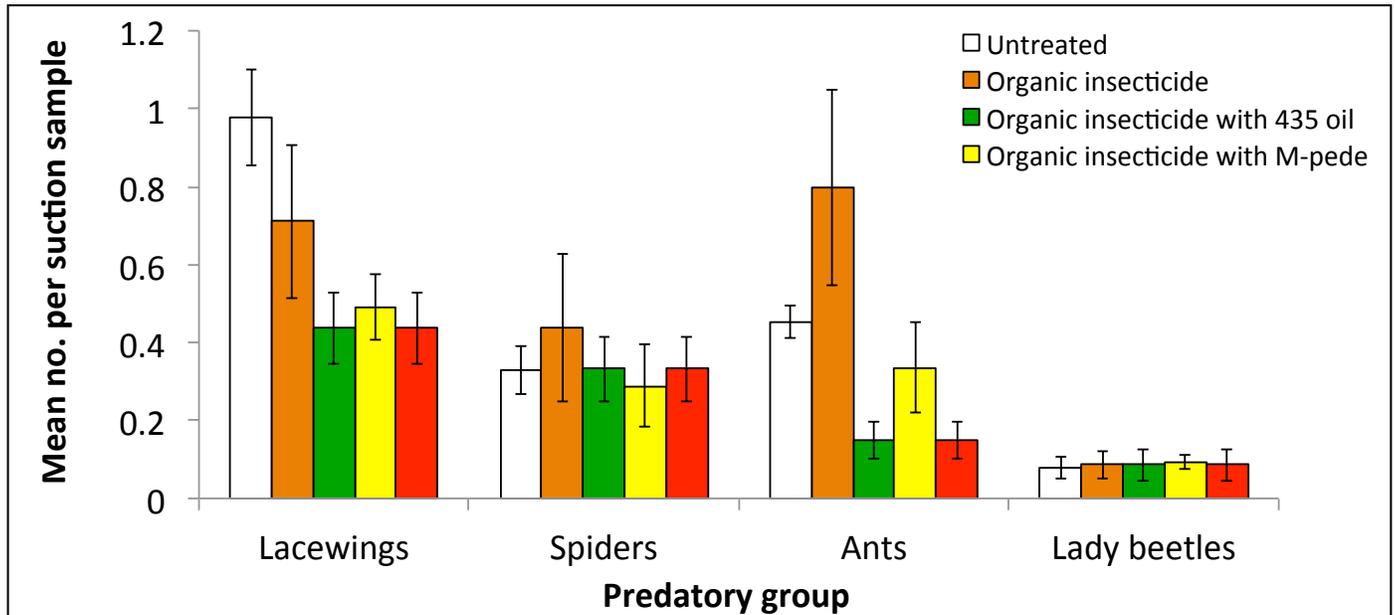


Figure 2. Populations of different predatory groups of beneficial insects (mean \pm SE) in the organic and conventional control programs in a Valencia orange block.

Aza-Direct alone and with 435 oil or M-pede and Closer alone sprayed on March 10 provided a significant reduction in ACP adults through March 24 averaging 75 percent, 71 percent, 92 percent and 97 percent, respectively. Only Aza-Direct plus M-pede and Closer reduced adults to 0.1 per tap sample. Application of Grandevo, 435 oil, M-pede and Movento all made alone on April 1 provided 54 percent, 69 percent, 69 percent and 82 percent reductions, respectively, but did not reduce adults to the desired threshold. Follow-up applications of Azera alone and with 435 oil or M-pede and Micromite alone made on April 14 provided adult reductions of 41 percent, 69 percent, 82 percent and 83 percent, respectively, through May 5.

Only Azera plus M-pede and Micromite reduced adults to 0.1 per tap sample on May 5. Reductions of 45 percent, 77 percent, 68 percent and 99 percent were observed for about two weeks with microbial insecticide Venerate, 435 oil, M-pede and Imidan all applied alone on May 8, respectively; but only Imidan held ACP at 0.1 per tap sample. Application made on May 27 of Entrust alone and with 435 oil or M-pede provided reductions of 53 percent, 84 percent and 72 percent, respectively, for about three weeks. Although no application was made in the conventional program on May 27, an average reduction of 87 percent and 0.1 adults per tap sample indicated a prolonged effect from Imidan applied on May 8. Applications made in July are being evaluated.

Biological Control

Green lacewings were the most abundant predator in all treatments (Photo 6). They attack ACP, CLM, aphids, thrips, whiteflies and several other pests. Ladybeetles known for significant predation on ACP were rare (Figure 2). *Cycloneda sanguinea* (Photo 7) and *Olla v-nigrum* (Photo 8) were the species most commonly observed. Ladybeetle numbers in Florida have dropped significantly due to the increase in the use of insecticidal sprays after the advent of HLB.

Mostly adults (rather than larvae) of lacewings and ladybeetles were observed. Adults can fly between habitats and thus may have moved back into treated plots following sprays. Spiders and ants also were present in all treatments. Certain species of both spiders and ants are reported as predators of ACP, although their roles in suppression of the pest are as yet unclear. Colonies of ACP nymphs are tended by some ants, where they are attracted to honeydew produced by the nymphs. On the other hand, *Pseudomyrmex* ants forage for prey individually, do not tend honeydew producers and have been observed feeding on ACP nymphs. Argentine ants tend and protect honeydew-producing insects and also have been observed feeding on ACP nymphs, without discriminating between those parasitized or not by *T. radiata*. Thus while ants do prey on ACP, there is potential for interference between them and *T. radiata*.

From June to October 2014, average parasitism of 20 ± 3 percent (13-29 percent), 20 ± 11 percent (6-69 percent), 11 ± 7 percent (0-40 percent), 4 ± 4 percent (0-19 percent) and 2 ± 2 percent (0-10 percent) were observed in the untreated, Organic Program 1, Organic Program 2, Organic Program 3 (at that time with vegetable oil Citru-Soy) and the Conventional Program, respectively. While some individual samples showed 100 percent, 40 percent, 58 percent and 10 percent parasitism in the Organic Programs 1, 2 and 3, and in the conventional program, respectively; nymphs were most easily available from untreated plots, and parasitism rates there were more consistent compared to treated plots.

In March 2015, parasitism rates averaged 31 ± 6 percent in the untreated control, 40 ± 10 percent in the Organic Program 1, 23 ± 8 percent in Organic Program 2 and 10 ± 10 percent in Organic Program 3. Plots designated for conventional control had fewer nymphs and none were parasitized. Parasitism in June averaged 17 ± 6 percent in the untreated control, 7 ± 4 percent in Organic Program 1, 14 ± 7 percent in Organic



Program 2 and 12 ± 5 percent in Organic Program 3. Nymphs were available in the conventional program but only 3 ± 2 percent were parasitized. These findings suggest that *T. radiata* was able to contribute to ACP control, particularly in organic programs. 🌱

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Photo 6. Green lacewing predator of ACP and other pests (Photo by the University of Florida)



Photo 7. Adults of *Cycloneda sanguinea* feeding on ACP nymphs (Photo by J. Qureshi)



Photo 8. Larva and adult of *Olla v-nigrum* feeding on ACP nymphs (Photo by P. Stansly)