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Integrated Approaches for Managing the Asian Citrus Psyllid *Diaphorina citri* (Homoptera: Psyllidae) in Florida

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The Asian citrus psyllid (ACP), *Diaphorina citri* Kuwayama, is an invasive insect pest of citrus in Florida. It is an efficient vector of the bacterium *Candidatus* Liberibacter asiaticus, the causal organism of citrus greening or "huanglongbing" (HLB) disease. The pest was first detected in Florida in 1998 and is now present in all citrus growing areas throughout the state. HLB was first detected in Florida in 2005 and is spreading rapidly. Effective means of control are required to manage this pest and disease while maintaining ecological and economic sustainability. Natural mortality of uncaged ACP nymphs averaged 36% and 58% more than caged nymphs in 2005 and 2006, respectively, across three experiments per year. The increased mortality of unprotected nymphs was attributed mainly to the predation by ladybeetles, *Curinus coeruleus*, *Olla v-nigrum*, *Harmonia axyridis*, and *Cycloneda sanguinea,* as evidenced by their abundance on trees infested with psyllid immatures. Incidence of lacewings, *Ceraeochrysa* sp. and *Chrysoperla* sp., and the parasitoid *Tamarixia radiata* was very low. Foliar applications of broad-spectrum insecticides provided short-term (1–2 weeks) control of ACP and suppressed populations of ladybeetles. In contrast, drench applications of imidacloprid and other neonicotinoid systemics to young citrus trees were very effective in controlling ACP for about 2 months. However, similar application of a carbamate, oxamyl, was not very effective. Our results suggest that the contributions of biological control agents to mortality of ACP need to be conserved and enhanced for successful long-term management of pest and disease. Drench applications of neonicotinoid systemics provide long-term control to young trees but would be better made in late spring for best effect. Foliar application directed against immatures on young flush provide only short-term control at the cost of useful biological control agents, particularly ladybeetles. Therefore, foliar applications of insecticides are better targeted at ACP adults during the dormant winter period when ladybeetles and other beneficial insects are either cryptic or absent from the orchard.

The Asian citrus psyllid, *Diaphorina citri* Kuwayama (Homoptera: Psyllidae), is an invasive pest of sweet orange *Citrus sinensis* (L.) Osbeck and other citrus species and near relatives in Florida. *Diaphorina citri* was first discovered in Stuart, FL, on hedges of jasmine orange, *Murraya paniculata* (L.) Jack. (Rutaceae), in 1998 (Halbert, 1998). It has now spread to almost all the citrus growing regions of the state (Halbert and Manjunath, 2004; Michaud, 2002; Tsai et al., 2002) and has also been identified in Texas (French et al., 2001). *Diaphorina citri* is a primary vector of the bacterium *Candidatus* Liberibacter asiaticus, one of the causal organisms of huanglongbing or citrus greening disease (Catling, 1970; Garnier et al., 2000). Citrus greening was identified in southern Florida in 2005 (Halbert, 2005) and has now spread throughout the citrus growing regions of the state. Greening is a devastating disease of citrus that can render fruit unsuitable and destroy trees within 5 to 10 years (Aubert et al., 1996; Roistacher, 1996). Both pest and disease pose a very serious threat to citrus production in Florida and elsewhere.

Diaphorina citri is now well established in Florida, so eradication is no longer an option. Complete control of pest or disease may not be feasible until plants expressing high levels of resistance against pest or disease are available. Therefore, an integrated approach involving biological and chemical control strategies is required for sustainable management of the pest to reduce the spread of disease.

Several biological control agents are known to attack eggs, nymphs, and adults of *D. citri* in Florida citrus. Predators include ladybeetles (Coleoptera: Coccinellidae), lacewings (Neuroptera: Chrysopidae), spiders (Aranae), and hoverflies or syrphids (Diptera: Syrphidae) (Michaud, 2004). Among native or exotic ladybeetles species in Florida, *Curinus coeruleus* Mulsant*, Olla v-nigrum* Mulsant*, Harmonia axyridis* Pallas, *Cycloneda sanguinea* (L.), and *Exochomus childreni* Mulsant are the most common (Michaud, 2004; Stansly and Qureshi, 2007a, 2007b). These predators are generalists and also feed upon other prey, particularly aphids. However, they do respond positively to psyllid infestations and have been observed to inflict 80% to 100% mortality on psyllid eggs and nymphs (Qureshi, unpublished data). Michaud (2001) also observed an increase in the populations of a native predatory ladybeetle, *O. v-nigrum,* in response to psyllid invasion in Florida.

The exotic parasitoids *Tamarixia radiata* (Waterston) (Hymenoptera: Eulophidae) and *Diaphorencyrtis aligarhensis* (Shafee, Alam and Agaral) (Hymenoptera: Encyrtidae) were imported from Asia and released in Florida in 1999–2001 (Hoy and Nguyen, 2001; Skelley and Hoy, 2004). Only *T. radiata* was recovered and is now widely distributed and well established across citrus growing regions of the state (Qureshi et al., 2007). However, parasitism rates are variable and average below 20% during spring and summer, and between 39% to 56% during fall.

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Entomopathogenic fungi are also important biological control agents that can significantly impact psyllid populations. However, these fungi are most effective under high relative humidity conditions. For example, *Cladosporium* sp. nr. *oxysporum* Berk and M.A. Curtis and *Capnodium citri* Mont. caused high mortality of *D. citri* nymphs, when minimum relative humidity exceeded 87.9% in Réunion (Aubert, 1987). Similarly, *Hirsutella citriformis* Speare was effective in regulating *D. citri* populations when humidity was above 80% in Guadeloupe (Étienne et al. 2001). Despite high relative humidity in Florida, this fungus appears to contribute little to the mortality of *D. citri* (Halbert and Manjunath, 2004).

Some recommended soil and foliar insecticides for psyllid control include chlorpyrifos (organo-phosphate), fenpropathrin (pyrethroid), imidacloprid (nicotinoid), and aldicarb (carbamate). Several experimental insecticides are also under evaluation to assess their impact on *D. citri* populations. Judicious use of effective chemicals can reduce psyllid populations. However, frequency and timing of applications is critical in achieving the desired objectives. The effect of these applications on the above-mentioned biological control agents is one of the important considerations in developing a long-term sustainable pest management program in citrus.

This paper reports results of the experiments that investigated the impact of natural factors and of soil and foliar applications of some recommended and experimental insecticides in reducing the *D. citri* populations in citrus. The implications of these results in psyllid management are discussed.

Materials and Methods

All experiments were conducted at the University of Florida Southwest Florida Research and Education Center in Immokalee (lat. 26°28´00˝N, long. 81°26´37˝W).

Natural mortality of Asian citrus psyllid

2005–06. Experiments were designed to assess the natural mortality in *D. citri* cohorts developing on the leaf flushes (young shoots containing feather stage and newly expanded soft leaves) of 5- to 10-year-old sweet orange trees in the field. All trees were planted on double-row raised beds at a density of 132 trees/acre on ‘Swingle’ and ‘Volkameriana’ rootstocks. Experiments were conducted in Aug., Oct., and Dec. 2005 and in Jan., May, and June 2006. In each experiment, 20–40 young shoots containing feather-stage leaves infested with psyllid eggs or neonates were selected at random. Selected shoots were protected individually for 2 d with a 15.24 × 30.48 cm (6 × 12 inch) sleeve cage made from fine mesh organdy to exclude predators, parasitoids, and additional oviposition from female psyllids. This practice provided time for tightly appressed leaves in the bud to expand somewhat and ease the counting of eggs and first instars. On day 3, cages were removed and eggs and young instars were counted on each flush. About 20–24 infested flushes were selected and equal numbers of these were randomly distributed between two groups. They were either protected individually inside the organdy sleeve cages or left unprotected and exposed to natural mortality factors. Selected flushes were tagged with flagging tape and numbered within each group. Every other day, eggs, nymphs, and any emerging adults or their exuviae were counted. Adults and exuviae were removed following each observation. Cohorts were tracked until no nymphs were available on the flush. During May and June, cohorts and predator populations were assessed on each experimental tree by direct observation by searching the foliage at approachable height around the tree for 1 min.

Chemical control of Asian citrus psyllid

Soil applications—2005. This experiment was conducted to evaluate effectiveness of thiamethoxam (Platinum 2SC, Syngenta Crop Protection, Inc., Greensboro, NC) and imidacloprid (Admire Pro 4.6FL, Bayer Crop Science, Research Triangle Park, NC) to control ACP on young trees. The study block consisted of 3-year-old ‘Valencia’ orange trees on ‘Swingle’ rootstock planted at 15 × 22-ft spacing in double-row beds separated by a swale. Four adjoining rows were used for a completely randomized block design with three treatments replicated four times. Each plot consisted of six to eight trees. Treatments consisted of a water suspension of the desired amount of Platinum 2SC at 0.16 lb (a.i.) per acre and Admire Pro 4.6 FL at 0.17 lb (a.i.) per acre, in 8 fl oz of water poured in a circular band within a 1-ft radius from the base of each tree on 17 Aug. 2005. Evaluations were made by examining the young shoots containing feather-stage and tender leaves flush available at 28, 37, 43, and 59 d after treatment (DAT) for a total of six flushes per plot. The numbers of adult ACP per flush were counted, except on the first evaluation in which the ACP population was rated on a 0 to 3 scale (0 = none and 3 = high). The same rating scale was used for the nymphs. Trees were trimmed on 10 Oct. to induce new flush and encourage psyllid infestation; however, a hurricane on 24 Oct. damaged the new flush and no more evaluations could be made.

Soil applications—2006. This experiment was conducted to evaluate the impact of drench applications of imidacloprid (Admire Pro 4.6FL, Bayer Crop Science) and oxamyl (Vydate L, DuPont, E.I. de Nemours & Inc. Agricultural, Wilmington, DE) on ACP and predatory ladybeetles on young trees. The study block consisted of 5-year-old ‘Valencia’ orange trees on ‘Swingle’ rootstock planted on double-row raised beds at a density of 132 trees/acre. Trees were subjected to conventional cultural practices and manually pruned to induce new flush and encourage psyllid infestation. Experimental design was a completely randomized block with three treatments replicated five times. Each of the five replicates consisted of two rows with an average of 26 trees per row. Each row was divided into three plots consisting of six to seven trees. Plots within rows were separated by an untreated tree. Three treatments and an untreated control were randomly assigned to four plots within each replicate. Soil drench applications of Admire Pro at 9 oz/acre and Vydate at 0.5 gal/acre and 1.0 gal/acre were made on 21 July 2006 using EZE-DOSE (Model CCI DO 35) applicator. Two rates of Vydate were applied again on 21 Aug. 2006 as before. The pretreatment and posttreatment data were taken from four central trees in each plot. The pretreatment data were collected 19 July, and posttreatment data on 1 and 11 Aug. (10 and 21 DAT, respectively), and on 6, 19, and 27 Sept. (47, 60, and 68 DAT, respectively). Adult psyllid density was estimated by counting individuals falling on a 22 × 28 cm (8.5 × 11 inch) white paper sheet (on a clipboard) placed at random under branches, which were then tapped three times. Five randomly selected flushes were observed per tree and the number infested with psyllid eggs or nymphs recorded. One infested flush of these was collected and examined in the lab under a stereoscopic microscope to count different instars of *D. citri*. The number of ACP nymphs per flush was estimated by multiplying the proportion of five infested flushes by the number counted from the collected flush. The number of larvae and adults of four predatory coccinellids, *Curinus coeruleus*, *Olla v-nigrum*, *Harmonia axyridis*, and *Cycloneda sanguinea*, were recorded for 1 min per tree.

Foliar applications—2006. The first experiment was conducted to assess the impact of foliar applications of acetamiprid (Assail 30 SC, Cerexagri, Inc., King of Prussia, PA) and imidacloprid (Provado 1.6 F, Bayer Crop Science) on ACP and ladybeetles. The study block consisted of 12-year-old 'Valencia' orange trees on 'Swingle' rootstock planted on double-row raised beds at a density of 132 trees/acre. Trees were irrigated by microsprinklers and subjected to conventional cultural practices. The bed sides of the experimental trees were pruned with a tractor-mounted box blade mower to induce new flush and encourage psyllid infestation. Each of four replicates consisted of a row of 21 trees divided into three plots of seven trees each. Plots within rows were separated by an unsprayed tree and replicates by an unsprayed buffer row. Treatments of Assail 30 SG at 0.131 lb (a.i.) per acre and Provado 1.6 F at 0.125 lb (a.i.) per acre were applied on 20 June 2006 to the bed side of the trees using a tractor-mounted Durand Wayland 3P-10C-32 air blast speed sprayer with an array of seven # 5 T-Jet stainless steel cone nozzles per side operating at a pressure of 200 psi delivering 150 GPA at a tractor speed of 1.5 mph. Pretreatment and posttreatment data were taken from the bed side of four central trees in each plot. Pretreatment data were collected 1 d before the application of the treatments, and posttreatment data on 3, 7, and 14 DAT. Adult psyllids, immatures, infested flush, and ladybeetles were observed, as in the soil application experiment in 2006, except that 20 flushes were observed instead of five per tree, and two infested flushes were brought to the lab for examination under the microscope to count nymphal instars of psyllid.

The second experiment was conducted to assess the impact of foliar applications of diflubenzuron (Micromite 80 WGS, Uniroyal Chemical Co., Inc.. Middlebury, CT), metasystox-R (MSR 2E) and pyridaben, GWN-1715 75WP (Gowan Co., Yuma, AZ), spirotetramat 150 OD, spirodiclofen (Envidor 2 SC), and imidacloprid (Provado 1.6 F) (Bayer CropScience), and a horticultural spray oil Fl-435-66 (Drexel Chemical Co., Memphis, TN) on ACP and ladybeetles. The study block consisted of 12-year-old sweet 'Valencia' orange trees on 'Swingle' rootstock planted on double-row raised beds at a density of 132 trees/acre. Trees were subjected to conventional cultural practices and pruning as above. Eight treatments and an untreated control were randomly distributed across four replicates, each of which consisted of three rows of 21 trees each interspersed with three buffer rows. Treatments were applied on 8 Sept. 2006 to the bed side of the trees as above. Data were taken from the bed side of four trees in the center of each plot. Pretreatment data were collected 1 d before application, and posttreatment data were collected 3, 10, and 18 DAT. Adult psyllids, immatures, infested flush, and ladybeetles were observed as in the soil application experiment in 2006, except that 10 flushes were observed instead of five per tree.

Data analysis. Data from each experiment were subjected to ANOVA and the means separated using LSD ($P = 0.05$) (SAS Institute, 2004). The number of larvae and adults of all four ladybeetles species were combined and transformed by log(x+1) for analysis, although actual means are presented.

Results and Discussion

Natural mortality of Asian citrus psyllid

There was significantly more mortality ($P<0.05$) of ACP nymphs in unprotected cohorts exposed to natural enemies compared to cohorts that were protected by cages from natural enemies in five of the six experiments conducted in 2005–06 (Fig. 1). In 2005, mortality in uncaged cohorts was greater than caged cohorts by 14% in August, 34% in October, and 59% in December. In 2006, mortality in unprotected cohorts was greater by 33% in January, 56% in May, and 86% in June. Most of the mortality in uncaged cohorts resulted in the disappearance of early instars. As much as 100% of total disappearance of unprotected individuals occurred by day 6 or 7 of cohort development.

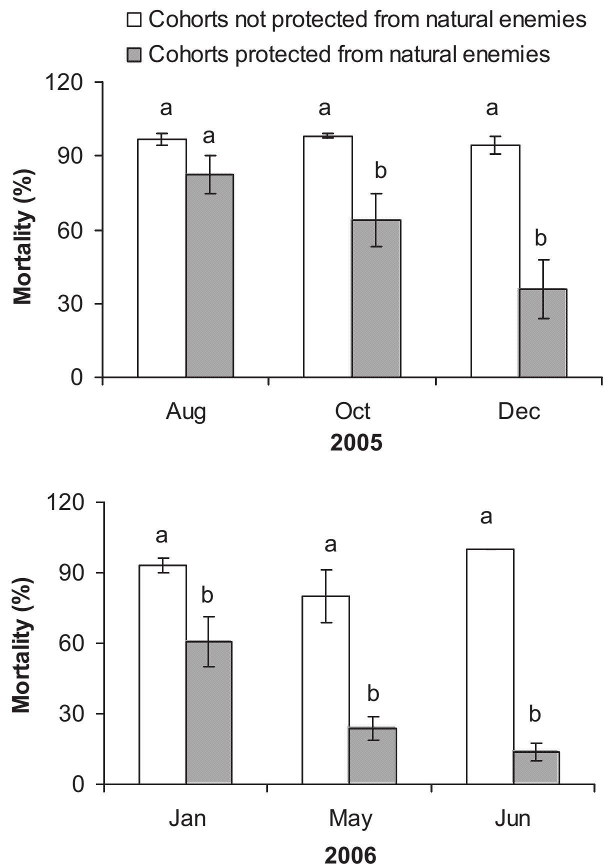

Fig. 1. Percentage of natural mortality (mean ± SEM) in cohorts of *Diaphorina citri* during development from egg or first instar to adult on flushes of citrus trees in six experiments conducted in 2005–06. Columns with different letters are significantly different for a particular month representing an independent experiment (LSD, $P < 0.05$).

Observations in May and June indicated that *C. coeruleus*, *O. v-nigrum*, *H. axyridis,* and *C. sanguinea* were dominant among generalist predators and the most likely perpetrators of the observed disappearance of ACP nymphs. Among the four species, *C. coeruleus* and *O. v-nigrum* were most abundant (Table 1).

Table 1. Mean numbers of larvae and adults of the four ladybeetles (Coleoptera: Coccinellidae) per 1-min observation per tree on five 5-year-old 'Valencia' orange trees infested with different life stages of *Diaphorina citri* in May and June cohorts, 2006.

Species	May 2006	June 2006
Curinus coeruleus	1.18 a[z]	0.30 a
Olla v-nigrum	0.58 b	0.63 a
Harmonia axyridis	0.51 b	0.03 b
Cycloneda sanguinea	0.93 ab	0.05 b

[z]Means within each column not followed by the same letter are significantly different (LSD, $P < 0.05$).

We also recorded occasional lacewings *Ceraeochrysa* sp. and *Chrysopera* sp., and several species of spiders. However, these are cryptic organisms, especially spiders, so their incidence relative to ladybeetles could be greater than indicated by our observations. Lacewings are well-documented generalist predators of *D. citri* (Michaud 2004); however, the contribution of spiders to mortality of *D. citri* is not well understood. Lacewings numbers increase during fall and probably contribute more to the mortality of *D. citri* at that time (Qureshi, unpublished data).

Parasitism by *T. radiata* was also very low in these experiments (<5%). Incidence of *T. radiata* was found to be variable and generally low (<20%) across the state particularly during spring and summer, with increased levels averaging 39% to 56% at some locations in fall (Qureshi et al., 2007). Predatory ladybeetles were more abundant early in the growing season. Therefore, it is likely that low natural mortality of ACP nymphs in Aug. 2005 was due to the low incidence of predation and parasitism.

Chemical control of Asian citrus psyllid

Soil applications—2005. Fewer ACP nymphs were observed at 28 and 37 DAT on trees treated with Platinum compared to Admire-treated trees, which themselves had fewer ACP than the control (Table 2). At 43 DAT, there were no differences between Platinum and Admire treatments, and at 50 DAT, no significant treatment effect. Fewer adult ACP were seen on trees treated with Platinum compared to untreated trees through 43 DAT, but only at 37 DAT for Admire-treated trees (Table 2). So we saw 37–43 d suppression of ACP with both Admire Pro and Platinum, with somewhat better activity exhibited by Platinum.

Soil applications—2006. No significant differences were found among blocks for ACP populations 2 d before treatment application. No treatment effects on ACP nymphs were observed on 1 Aug, 10 DAT. However, there were significantly fewer nymphs on Admire-treated trees on 11 Aug. and 6 Sept., 21 and 47 DAT, respectively, compared to untreated trees or trees treated

Table 2. Mean rating or count of nymphs and adults of *Diaphorina citri* on flushes of 3-year-old 'Valencia' orange trees left untreated or treated with soil applications of Platinum and AdmirePro on 17 Aug. 2005.

Treatment/ formulation	Rate lb (a.i.)/acre	ACP nymphs: Rating/flush[z] 28 DAT[y]	37 DAT	43 DAT	50 DAT
Platinum 2 SC	0.16	0.63 c[x]	0.29 c	0.21 b	0.17 a
Admire Pro 4.6 FL	0.17	1.25 b	1.13 b	0.50 b	0.58 a
Untreated control	---	2.29 a	2.17 a	1.42 a	0.54 a
		ACP adults: Rating and count/flush			
		28 DAT Rating[z]	37 DAT Count	43 DAT Count	50 DAT Count
Platinum 2 SC	0.16	0.13 b	0.21 b	0.63 b	1.00 a
Admire Pro 4.6 FL	0.17	0.54 ab	1.63 b	1.42 ab	1.79 a
Untreated control	---	0.79 a	5.00 a	2.79 a	1.88 a

[z]0–3 rating scale (0 = none, 3 = high)
[y]Days after treatment application.
[x]Means within each column not followed by the same letter are significantly different (LSD, $P < 0.05$).

Table 3. Mean numbers of *Diaphorina citri* nymphs per flush, adults per tap sample, and ladybeetles (larvae + adults) per 1-min observation per tree on 5-year-old 'Valencia' orange trees left untreated or treated with drench application of AdmirePro and Vydate. AdmirePro treatment received only one application on 21 July, whereas the Vydate treatments received two applications each on 21 July and 21 Aug. 2006.

Treatment/ formulation	Rate amt product/acre	ACP nymphs/flush[z] 1 Aug.	11 Aug.	6 Sept.	19 Sept.	27 Sept.
Admire Pro	9.0 oz	11.96 a	0.17 b	0.18 b	0.05 a	0.00 a
Vydate L	0.5 gal	20.24 a	25.80 a	15.06 a	2.34 a	2.85 a
Vydate L	1.0 gal	27.13 a	18.80 a	12.10 a	2.82 a	1.58 a
Untreated control	---	16.78 a	25.69 a	11.55 a	3.93 a	0.86 a
		ACP adults/tap sample				
		1 Aug.	11 Aug.	6 Sept.	19 Sept.	27 Sept.
Admire Pro	0.9 oz	0.20 b	0.05 a	0.10 b	0.05 c	0.00 b
Vydate L	0.5 gal	1.05 a	0.70 a	0.40 ab	0.55 ab	0.70 a
Vydate L	1.0 gal	1.00 ab	0.40 a	0.25 b	0.15 bc	0.15 b
Untreated control	---	1.45 a	0.55 a	0.80 a	0.70 a	0.30 ab
		Ladybeetles/min				
		1 Aug.	11 Aug.	6 Sept.	19 Sept.	27 Sept.
Admire Pro	0.9 oz	0.00 a	0.05 a	0.05 b	0.00 a	0.00 a
Vydate L	0.5 gal	0.10 a	0.50 a	0.10 b	0.15 a	0.10 a
Vydate L	1.0 gal	0.15 a	0.45 a	0.05 b	0.15 a	0.15 a
Untreated control	---	0.35 a	0.40 a	0.55 a	0.15 a	0.10 a

[z]Means within each column not followed by the same letter are significantly different (LSD, $P < 0.05$).

with either rate of Vydate. These latter were not different from untreated even though they had received the second application on 21 Aug. (Table 3). There were very few ACP nymphs on all plants on 19 Sept. and 27 Sept. with no significant treatment effect.

Fewer adult ACP were seen on trees treated with Admire compared to untreated trees on 1 Aug. (10 DAT), 6 Sept. (47 DAT), and 19 Sept. (60 DAT), but only on 6 and 19 Sept. for trees treated with a high rate of Vydate (Table 3). Although there was a consistent trend for fewer adults on Admire-treated trees compared to those treated with a high rate of Vydate, differences were not statistically significant on any sampling date nor on 6 Sept. for the low rate of Vydate (Table 3). The inability of Vydate to control nymphs may have indicated tolerance to toxin levels in the plants. Adults, on the other hand, may have abandoned all treated plants.

Fewer ladybeetles were seen on the Admire- or Vydate-treated trees than on the untreated trees on 6 Sept. (Table 3). Incidence of ladybeetles is associated with the presence of immature psyllids, which were fewest on Admire-treated trees. Therefore, the lack of ladybeetles on Vydate-treated trees may indicate a direct effect of soil-applied oxymyl on ladybeetles.

Foliar applications—2006. In the first experiment, no significant differences were found among blocks for ACP populations the day before treatment. At 3 DAT, significantly more nymphs were seen on untreated trees compared to treated trees with no difference between the two treatments (Table 4). At 7 DAT, significantly more nymphs were observed on trees treated with Assail than on untreated trees or trees treated with Provado, with no significant difference between the latter and untreated trees. At 14 DAT, there was no longer a significant treatment effect on nymphs. Fewest nymphs and adults were seen on trees treated with Provado compared to the trees treated with Assail or untreated trees over all three sampling dates.

More ladybeetles were observed on untreated trees than treated trees (Table 4). The large number of nymphs on trees treated with Assail at 7 DAT and their relative paucity on untreated trees appeared to be due to movement away from treated trees into untreated trees. The fact that nymphs did not increase in Provado-treated trees indicated that the product was controlling the psyllids. However, this benefit was short lived. Furthermore, the sprays appeared to suppress ladybeetles, the primary natural enemies of ACP, indicating a need to evaluate the long-term benefits of spraying flushes with these materials for nymphal psyllid control.

In the second experiment, no significant differences were found among blocks for ACP populations the day before treatment. The number of ACP adults on treated plants did not differ from untreated plants on any posttreatment sampling date, with an overall mean (±SEM) of 0.21 ± 0.04 adults per tap sample observed. At 3 DAT, all treatments significantly reduced nymphs compared to the untreated control except GWN-1715 (Table 5). Fewest nymphs were seen on trees treated with high rate of Spirotetramat, followed by MSR and Micromite with oil. Nymphs at the two later sample dates had decreased in the untreated control due to predation from increased numbers of ladybeetles that moved in from treated plots (Table 5). Perhaps due to decreased nymphal populations on untreated trees, no treatment resulted in significantly reduced nymphal densities compared to

Table 4. Mean numbers of *Diaphorina citri* nymphs per flush, adults per tap sample, and ladybeetles (larvae + adults) per 20 flushes on 12-year-old 'Valencia' orange trees left untreated or treated with foliar application of Assail and Provado on 20 Jun 2006.

Treatment/ formulation	Rate lb (a.i.)/acre	ACP nymphs per flush				ACP adults/ tap sample[y]	Ladybeetles/ 20 flushes[y]
		3 DAT[z]	7 DAT	14 DAT	Total over three samplings		
Assail 30 SG	0.131	28.59 b	27.63 a	5.17 a	20.46 a	3.52 a	0.23 b
Provado 1.6 F	0.125	27.09 b	1.98 b	5.38 a	11.48 b	0.98 b	0.02 c
Untreated control	---	48.02 a	7.44 b	3.28 a	19.58 a	3.04 a	1.13 a

[z]Days after treatment application.
[y]ACP adult and ladybeetle numbers were low; therefore, totals over three sampling dates are presented.
Means within each column not followed by the same letter are significantly different (LSD, $P < 0.05$).

Table 5. Mean numbers of *Diaphorina citri* nymphs per flush, and ladybeetles (larvae + adults) per 10 flushes on 12-year-old 'Valencia' orange trees left untreated or treated with foliar application of a horticultural spray oil 435, Micromite, MSR, Envidor, Provado, and two experimental products GWN-1715 75WP and Spirotetramat 150 OD on 8 Sept. 2006.

Treatment/ formulation	Rate amt product/acre	ACP nymphs/flush			Ladybeetles/10 flushes[z]
		3 DAT[y]	10 DAT	18 DAT	Total over three samplings
435 Oil	5 gal	2.24 bc	0.36 dc	1.48 ab	0.81 bc
Micromite 80WGS + 435 Oil	6.25 oz	0.83 bc	0.28 dc	0.69 bc	1.00 b
MSR 2E	3 pints	0.25 c	0.06 d	0.12 bc	0.00 e
GWN-1715 75WP	10.60 oz	4.50 ab	2.20 ab	5.89 a	0.19 de
Spirotetramat 150 OD	12 fl oz	1.55 bc	2.12 a	1.39 bc	0.25 cde
Spirotetramat 150 OD	16 fl oz	0.08 c	0.81 bcd	0.08 c	0.13 de
Envidor 2 SC	20 fl oz	3.58 b	1.81 abc	0.13 bc	0.63 bcd
Provado 1.6F	15 fl oz	3.07 b	0.00 d	0.01 c	0.00 e
Untreated control	---	6.33 a	0.49 bdc	0.32 bc	2.06 a

[z]Ladybeetle numbers were low; therefore, totals over three sampling dates are presented. ACP adult numbers were very low and did not differ between treated and untreated plants on any posttreatment sampling date, with an overall mean (±SEM) of 0.21 ± 0.04 adults per tap sample
[y]Days after treatment application.
Means within each column not followed by the same letter are significantly different (LSD, $P < 0.05$).

the untreated control. Nymphal densities were relatively lower in the Provado, MSR, and spirotetramat high rate treatments at 10 DAT or 18 DAT compared to the untreated control. Nymphal densities were significantly higher than the untreated control in the low rate of spirotetramat at 10 DAT and GWN-1715 at 18 DAT. These surprising results may have been a consequence of significantly more ladybeetles observed in the untreated control compared to all other treatments. Thus, while some short-term benefit was again achieved with certain of these foliar applications, the sustained activity of natural enemies appeared to provide better long-term control.

Implications of biological and chemical control for Asian citrus psyllid management

Significant natural mortality (average 36% to 58%) of ACP attributed to predation mainly by ladybeetles and some additional mortality from lacewings and the parasitoid *T. radiata* suggest that these natural enemies should be important players in the overall management of ACP. Therefore, the contribution of natural enemies to ACP mortality needs to be conserved and enhanced for successful long-term management of pest and disease.

Drench applications of Admire and Platinum to young citrus trees were effective in controlling psyllids for at least 2 months. These studies were conducted during an unusually dry summer. Normally, heavy rains could lead to leaching of the materials below the root zone. Thus, the optimal time for application of these products is late spring, when psyllid populations are high and application conditions good. Unfortunately, the amount of nicotinoid insecticides allowed for soil application in Florida citrus is insufficient to control ACP in mature trees or provide season-long control in young trees. Therefore, foliar sprays may be necessary.

Foliar applications of insecticides directed at immatures on young flush during the growing season reduced ACP populations for a short time, but significantly impacted ladybeetle populations. Young trees flush more often than mature trees, but all flushing after the main spring flush tends to be sporadic. Thus, frequent sprays are not likely to provide more than short-term control, and that at the cost of valuable natural enemies. An alternative would be to target at ACP adults before they are able to heavily infest the flush, particularly the all-important spring flush. The preferable time for foliar applications would thus be the period of tree dormancy prior to the spring flush in February and March. During this time, overwintering populations of adult psyllids are present and vulnerable. However, flush and thus psyllid nymphs are scarce as are ladybeetles and other predators. Many types of parasitoids tend to be inside their hosts at that time and not actively foraging where they would be exposed to contact insecticides. Therefore, the danger of secondary pest outbreaks would also be reduced by dormant applications of insecticides. Recent studies have shown that foliar applications of broad spectrum insecticides during dormant winter period provide ACP suppression for 5–6 months with minimal impact on natural enemies (Qureshi, unpublished data). Colonization of treated trees by coccinellids and other predators appears to be one reason why these treatments lasted so long.

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