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Insecticidal Control of Asian Citrus Psyllid *Diaphorina citri* (Hemiptera: Psyllidae)

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The Asian citrus psyllid (ACP) *Diaphorina citri* vectors the bacterium *Candidatus* Liberibacter asiaticus, the causal organism of "huanglongbing" (HLB) or citrus greening disease. Therefore, ACP control is critical to management of HLB. Foliar ground applications of newly developed, experimental and commonly used insecticides alone or with adjuvants were evaluated for their effectiveness against ACP control in 13-year-old *Citrus sinensis* (L.) Osbeck 'Valencia' orange trees during the growing season. Significantly more psyllid adults were observed for one month on untreated trees compared to trees treated with phosmet (Imidan® 70 W at 1 and 1.5 lb/acre) alone or with azadirachtin (Azadirect® 8 oz/acre), GWN 1708 (16, 24, and 30 oz/acre) with 435 Oil, fenpropathrin (Danitol® 2.4 EC 16 oz/acre), and methidathion (Supracide® 2 E at 1 qt/acre). The high rate of phosmet and the medium and high rates of GWN 1708 provided relatively better control compared to the low rates. Azadirachtin alone or with phosmet was not effective. In another study, spinetoram (Delegate WG 4 oz/acre) + Copper Hydroxide with 435 Oil or Induce, a non-ionic surfactant, Danitol 2.4 EC (16 oz/acre), Chlorpyrifos EW (5 pts/acre), and zeta-cypermethrin (Mustang® 1.5 EC 4.3 oz/acre) were all equally effective and reduced psyllid adults for 24 days after treatment (DAT) compared to untreated control whereas spinetoram alone was effective through 17 DAT. Both 435 Oil and Induce, a non-ionic surfactant, appeared to increase the efficacy of Delegate. Treatment effects on adults were more long lasting than those seen on immature ACP. However, these effects were much shorter lived compared to previous studies when foliar sprays were made during the dormant winter period when adult numbers were low and trees were not growing new shoots for psyllid reproduction. Therefore, growers are encouraged to target adult psyllids by making effective foliar applications during winter and prior to anticipated new growth during the growing season based on monitoring.

The Asian citrus psyllid (ACP), *Diaphorina citri* Kuwayama (Hemiptera: Psyllidae), is an economically important insect pest of citrus worldwide, mainly because it vectors the bacterium *Candidatus* Liberibacter asiaticus, the causal organism of "huanglongbing" (HLB) or citrus greening disease (Halbert and Manjunath, 2004). HLB is one of the world's most devastating diseases of citrus, responsible for the decline and death of infected trees (Bové, 2006; Roistacher, 1996). ACP was identified from Florida in 1998 and HLB in 2005 (Halbert, 1998, 2005). Both pest and the disease are now established in Florida and have spread rapidly throughout the citrus growing region of the state (FDACS-DPI, 2008; Qureshi et al., 2009).

Psyllid control is critical in order to slow the spread of HLB. Soil and foliar applied insecticides are important tools in the management of the pest and the disease. Compared to other crops, few pesticides are registered for citrus due to its minor use status (McCoy et al., 2009). However, the advent of HLB has greatly intensified insecticide use in Florida citrus (Rogers, 2008; Rogers et al., 2008). New insecticides are being developed and tested against the psyllids. Two systemic insecticides, imidacloprid and aldicarb, allowed for use in Florida citrus are subject to rate and seasonal restrictions. Imidacloprid 0.56 kg/ha per year is sufficient to provide good psyllid control in small citrus trees and can be applied at different times, whereas aldicarb 5.6 kg/ha per year can also be applied to large trees but is restricted to application between 15 Nov. and 30 Apr. (Qureshi and Stansly, 2007, 2008; Rogers et al., 2008). Therefore, citrus in spring and summer has become the target of foliar sprays of broad spectrum insecticides. Compared to soil applied insecticides, there are more choices of broad spectrum insecticides available for foliar applications. However, foliar sprays are most effective against adult psyllids because they are more exposed than the immature psyllids that are protected in the newly developing shoots and are more susceptible to systemic toxins. Additionally, adults are responsible for the spread of *C.* Liberibacter asiaticus from infected trees to the healthy trees. Field tests are warranted to determine the effectiveness of the foliar sprays of broad spectrum insecticides against psyllids and several effective natural enemies of citrus insect pests that are present in the citrus groves (McCoy, 1985; Stansly and Qureshi, 2008). Several effective insecticides will enable growers to use and rotate insecticides in order to effectively manage psyllids and to slow the evolution of insecticide resistance which can happen with the repeated use of insecticides with same mode of action. The objective of our experiments was to test the efficacy of foliar ground applications (as opposed to aerial sprays) of newly developed, experimental, and commonly used insecticides, with or without adjuvants, against adults and immatures of ACP in mature citrus trees.

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Materials and Methods

Two separate experiments designed as randomized complete blocks were conducted in a bedded citrus orchard of Southwest Florida Research and Education Center (SWFREC) in Immokalee, FL. The experimental block consisted of 13-year-old *Citrus sinensis* (L.) Osbeck 'Valencia' orange trees planted on double-row raised beds at a density of 132 trees/acre. Trees were irrigated by microsprinklers and subjected to conventional cultural practices. Bed and swale sides of the trees were pruned with a hand-held hedger to induce new flush and encourage ACP infestation. Treatments were applied to both bed and swale sides of the trees using a Durand Wayland 3P-10C-32 air-blast speed sprayer with an array of six no. 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.

In the first experiment, 10 treatment materials and an untreated control (Table 1) were randomly distributed across 4 replicates in 21 rows that included a buffer row after every treated row. Each replicate contained 11 plots of 5 trees. Treatments were applied to both bed and swale sides of the trees on 9 July 2008. Three central trees per plot were included in post treatment evaluations made on 14 (5 d after treatment = DAT), 21 (12 DAT), and 28 (19 DAT) July and 4 (26 DAT) and 11 (33 DAT) Aug. A "tap" sample made by striking a randomly chosen branch 3 times and counting adult ACP falling on a clipboard covered with an 8 1⁄2 × 11 inch laminated white sheet was used to assess density of ACP adults (Qureshi and Stansly, 2007). Two tap samples, one each on the bed and swale sides, were conducted on 14, 21, and 28 July and increased to four tap samples per tree including the other two sides within rows on 4 and 11 Aug. due to low populations of ACP. Ten shoots suitable for ACP oviposition and nymphal development were tagged on each tree prior to treatment application. Eight of these shoots were examined per tree and presence or absence of eggs and nymphs recorded. Nymphal density on each shoot was rated on a scale of 0 to 4, where 0 = none; 1 = 1–5; 2 = 6–15; 3 = 16–25; and 4 = more than 25. The oldest nymphal instar observed on each shoot was rated on a scale of 1 to 3 where 1 = eggs and first instars; 2 = second and third instars; and 3 = fourth and fifth instars.

In the second experiment, eight treatment materials and an untreated control (Table 4) were randomly distributed across 4 replicates in 17 rows that included a buffer row after every treated row. Each replicate contained 9 plots of 5 plants. Treatments were applied to both bed and swale sides of the trees on 10 Oct. 2008. Three central trees per plot were included in post treatment evaluations made on 13 (3 DAT), 20 (10 DAT), and 27 Oct. (17 DAT) and 3 Nov. (24 DAT). The density of adult ACP was evaluated using a "tap" sample described above. Shoots were tagged on each tree prior to treatment application as above. Three shoots were examined per tree to record the presence or absence of ACP eggs and nymphs. One randomly selected shoot from each tree was brought to the lab and examined under the microscope to count ACP nymphs. Ladybeetles, lacewings, and spiders were recorded if observed in the tap samples or shoots examined for ACP immature in both experiments.

Data were subjected to ANOVA to evaluate treatment effects on ACP and treatment means separated using LSD contingent on a significant treatment effect ($P = 0.05$) (SAS Institute, 2004).

Results and Discussion

Experiment 1. Significantly fewer adults were observed in all treatments compared to untreated trees for more than a month after applications except for AZA-Direct alone on the first four dates, the low rate of Imidan 70 W + AZA-Direct on 28 July and the low rate of GWN 1708 + 435 Oil on 11 Aug. (Table 1). On the last observation date (33 DAT), no adults were sampled from trees treated with 16 oz/acre Danitol. The percentage of shoots infested with ACP eggs on 14 July (5 DAT) was significantly lower than the untreated trees in all treatments except for Imidan 70 W alone at either rate, and on 21 July (12 DAT) with the low rate of Imidan 70 W alone, the high rate of Imidan 70 W + AZA-Direct, and the low and medium rates of GWN 1708 + 435 Oil (Table 2). In contrast, all treatments were effective in reducing percentage of flush infested with nymphs on both dates except AZA-Direct alone on 14 July (Table 2). Similar results were observed for the nymphal density rating and the mean oldest nymphal instar rating per shoot on 14 July (Table 3). On 21 July, nymphal density rating was low in all treated trees compared to untreated trees but there were no differences in mature instar presence with the high rate of Imidan 70 W alone or in combination with AZA-Direct and with Supracide 2 E compared to the untreated trees (Table 3). Treatment effects on immatures were short-lived and none were observed on 28-July (19 DAT). Effects on adult ACP were more long lasting than those seen on immature stages and showed significant rate responses.

Experiment 2. On 13 and 20 Oct., 3 and 10 DAT, numbers of ACP adults, percentage infested shoots (Table 4) and numbers of nymphs per shoot (Table 5) were all significantly less than the untreated trees with no differences between sprayed treatments.

Table 1. Mean number of *Diaphorina citri* adults per tap sample conducted in 13-year-old 'Valencia' orange trees untreated or treated with foliar sprays of insecticides on 9 July 2008 at Southwest Florida Research and Education Center, Immokalee, FL.

Treatment/ formulation	Rate amt product/ acre or % v/v	Adult ACP per tap sample 14 July 5 DAT	21 July 12 DAT	28 July 19 DAT	4 Aug. 26 DAT	11 Aug. 33 DAT
Untreated control	---	0.96 a[z]	1.50 a	0.50 a	0.63 a	0.58 a
Danitol 2.4 EC	16 oz	0.00 e	0.04 b	0.00 d	0.08 b	0.00 e
Imidan 70 W	1.0 lbs	0.13 de	0.21 b	0.08 bcd	0.15 b	0.21 cd
Imidan 70 W	1.5 lbs	0.13 de	0.08 b	0.04 cd	0.00 b	0.04 de
Imidan 70 W + AZA-Direct 1.2%	1.0 lbs + 8 oz	0.00 e	0.42 b	0.29 abc	0.15 b	0.17 de
Imidan 70 W + AZA-Direct 1.2%	1.5 lbs + 8 oz	0.00 e	0.21 b	0.00 d	0.06 b	0.06 de
AZA-direct 1.2%	8oz	0.79 ab	1.25 a	0.33 ab	0.65 a	0.38 bc
GWN 1708 + 435 Oil	16 oz + 2%	0.42 cd	0.38 b	0.17 bcd	0.10 b	0.46 ab
GWN 1708 + 435 Oil	24 oz + 2%	0.08 de	0.17 b	0.00 d	0.17 b	0.19 cde
GWN 1708 + 435 Oil	30 oz + 2%	0.50 bc	0.25 b	0.13 bcd	0.15 b	0.17 de
Supracide 2E	1 qt	0.13 de	0.00b	0.04 cd	0.08 b	0.06 de

[z]Means in a column followed by the same letter are not significantly different ($P = 0.05$, LSD).

Table 2. Percentage of shoots infested with *Diaphorina citri* eggs and nymphs in 13-year-old 'Valencia' orange trees untreated or treated with foliar sprays of insecticides on 9 July 2008 at Southwest Florida Research and Education Center, Immokalee, FL.

		Shoots infested with eggs (%)			Shoots infested with nymphs (%)		
Treatment/ formulation	Rate amt product/ acre or % v/v	14 July 5 DAT	21 July 12 DAT	28 July 19DAT	14 July 5 DAT	21 July 12 DAT	28 July 19 DAT
Untreated control	---	50.0 a[z]	26.0 a	16.7 a	65.6 a	82.3 a	5.2 a
Danitol 2.4 EC	16 oz	12.5 d	5.2 c	7.3 a	8.3 d	9.4 e	1.0 a
Imidan 70 W	1.0 lbs	43.8 ab	13.5 abc	32.3 a	36.5 b	16.7 cde	11.5 a
Imidan 70 W	1.5 lbs	34.4 abc	5.2 c	15.6 a	18.6 bcd	7.3 e	0.0 a
Imidan 70 W + AZA-Direct 1.2%	1.0 lbs + 8 oz	28.1 bcd	7.3 c	10.4 a	18.6 bcd	9.4 e	1.0 a
Imidan 70 W + AZA-Direct 1.2%	1.5 lbs + 8 oz	16.7 cd	14.6 abc	20.8 a	12.5 cd	12.5 de	2.1 a
AZA-direct 1.2%	8oz	19.8 cd	6.3 c	25.0 a	60.4 a	46.9 b	5.2 a
GWN 1708 + 435 Oil	16 oz + 2%	28.1 bcd	22.9 ab	10.4 a	29.1 bc	30.2 c	1.0 a
GWN 1708 + 435 Oil	24 oz + 2%	14.6 d	21.9 ab	26.0 a	17.7 bcd	20.8 cde	9.4 a
GWN 1708 + 435 Oil	30 oz + 2%	17.7 cd	9.4 bc	20.8 a	19.8 bcd	16.7 cde	1.0 a
Supracide 2 E	1 qt	24.0 cd	7.3 c	17.7 a	19.8 bcd	25.0 cd	2.1 a

[z]Means in a column followed by the same letter are not significantly different ($P = 0.05$, LSD).

Table 3. Mean rating for *Diaphorina citri* nymphal density and oldest nymphal instar per shoot in 13-year-old 'Valencia' orange trees untreated or treated with foliar sprays of insecticides on 9 July 2008 at Southwest Florida Research and Education Center, Immokalee, FL.

		Nymphal density rating per shoot		Oldest nymphal instar rating per shoot	
Treatment/ formulation	Rate amt product/ acre or % v/v	14 July 5 DAT	21 July 12 DAT	14 July 5 DAT	21 July 12 DAT
Untreated control	---	1.35 a[z]	1.57 a	2.03 ab	2.71 ab
Danitol 2.4 EC	16 oz	0.06 d	0.14 ef	1.0 e	2.11 bcd
Imidan 70 W	1.0 lbs	0.30 bc	0.21 def	1.31 cde	1.88 cd
Imidan 70 W	1.5 lbs	0.18 bcd	0.08 f	1.0 e	2.71 ab
Imidan 70 W + AZA-Direct 1.2%	1.0 lbs + 8 oz	0.20 bcd	0.17 def	1.06 de	1.89 cd
Imidan 70 W + AZA-Direct 1.2%	1.5 lbs + 8 oz	0.13 cd	0.13 ef	1.33 cde	2.33 abcd
AZA-direct 1.2%	8oz	1.44 a	0.75 b	2.34 a	2.78 a
GWN 1708 + 435 Oil	16 oz + 2%	0.33 bc	0.53 c	1.46 cd	1.93 cd
GWN 1708 + 435 Oil	24 oz + 2%	0.19 bcd	0.33 de	1.71 bc	1.75 d
GWN 1708 + 435 Oil	30 oz + 2%	0.40 b	0.34 cd	1.37 cde	2.00 cd
Supracide 2 E	1 qt	0.29 bc	0.37 cd	1.52 de	2.42 abc

[z]Means in a column followed by the same letter are not significantly different ($P = 0.05$, LSD).

Table 4. Mean number of *Diaphorina citri* adults per tap sample and percentage of shoots infested with eggs and nymphs in 13-year-old 'Valencia' orange trees untreated or treated with foliar sprays of insecticides on 10 Oct. 2008 at Southwest Florida Research and Education Center, Immokalee, FL.

		ACP adults per tap sample				Shoots infested with eggs and nymphs (%)			
Treatment/ formulation	Rate amt product/ acre or % v/v	13 Oct. 3 DAT	20 Oct. 10 DAT	27 Oct. 17 DAT	3 Nov. 24 DAT	13 Oct. 3 DAT	20 Oct. 10 DAT	27 Oct. 17 DAT	3 Nov. 24 DAT
Untreated control	---	0.75 a[z]	0.71 a	0.86 a	0.58 a	47.2 a	44.4 a	61.1 a	38.9 ab
Danitol 2.4 EC	16 oz	0.04 b	0.00 b	0.42 b	0.00 d	2.8 b	8.3 b	16.7 bc	16.7 bcd
Chlorpyrifos EW	5 pts	0.00 b	0.00 b	0.04 bc	0.00 d	13.9 b	2.8 b	19.4 bc	27.8 abc
Mustang 1.5 EC	4.3 oz	0.00 b	0.04 b	0.04 bc	0.00 d	16.7 b	0.0 b	0.0 c	0.0 d
Delegate WG	4 oz	0.00 b	0.04 b	0.00 c	0.42 ab	2.8 b	2.8 b	55.6 a	38.9 ab
Delegate WG + 435 Oil	4 oz + 2%	0.00 b	0.00 b	0.08 bc	0.04 dc	8.3 b	2.8 b	27.8b	44.4a
Delegate WG + 435 Oil + Copper hydroxide	4 oz + 2% + 3 lbs	0.00b	0.04 b	0.13b c	0.00 d	2.8 b	0.0 b	41.7 ab	22.2 abcd
Delegate WG + Induce	4 oz + 0.2%	0.00 b	0.00 b	0.04 bc	0.17 dc	0.0 b	2.8 b	38.9 ab	11.1 cd
Delegate WG + Induce + Copper Hydroxide	4 oz + 0.2% + 3 lbs	0.25 b	0.13 b	0.08 bc	0.21 bc	8.3 b	5.6 b	58.3 a	44.4 a

[z]Means in a column followed by the same letter are not significantly different ($P = 0.05$, LSD).

Adult ACP densities remained significantly lower in all treatments at 17 DAT, but at 24 DAT numbers observed on trees sprayed with Delegate alone were not different from the untreated control in contrast to the remaining treatments. At 17 DAT, there were no differences compared to the untreated control in the percentage of ACP-infested shoots among treatments of Delegate except the one including oil alone. No infested shoots were seen on trees sprayed with Mustang, although this was not significantly different from Danitol or Chlorpyrifos. At 24 DAT, the percentage of ACP-infested shoots in the Delegate + Induce treatment was

Table 5. Mean number of *Diaphorina citri* nymphs per shoot in 13-year-old 'Valencia' orange trees untreated or treated with foliar sprays of insecticides on 10 Oct. 2008 at Southwest Florida Research and Education Center, Immokalee, FL.

Treatment/ formulation	Rate amt product/ acre or % v/v	ACP nymphs/infested shoot 13 Oct. 3 DAT	20 Oct. 10 DAT	27 Oct. 17 DAT	3 Nov. 24 DAT
Untreated control	---	12.5 a[z]	4.8 a	8.1 ab	5.7 a
Danitol 2.4 EC	16 oz	0.0 b	0.2 b	1.8 c	0.9 a
Chlorpyrifos EW	5 pts	0.0 b	0.1 b	0.4 c	1.3 a
Mustang 1.5 EC	4.3 oz	0.1 b	0.0 b	0.2 c	0.3 a
Delegate WG	4 oz	0.4 b	0.3 b	4.2 bc	9.8 a
Delegate WG + 435 Oil	4 oz + 2%	0.0 b	0.0 b	5.3 bc	4.3 a
Delegate WG + 435 Oil + Copper hydroxide	4 oz + 2% + 3 lbs	0.0 b	0.0 b	3.4 bc	6.4 a
Delegate WG + Induce	4 oz + 0.2%	0.0 b	0.1 b	1.4 c	0.1 a
Delegate WG + Induce + Copper hydroxide	4 oz + 0.2% + 3 lbs	0.1 b	0.9 b	12.5 a	4.4 a

[z]Means in a column followed by the same letter are not significantly different ($P = 0.05$, LSD).

significantly lower than the untreated control and not significantly different from trees treated with Mustang, chlorpyrifos, Danitol, or Delegate + oil and copper. At 3 and 10 DAT, ACP nymphal density was significantly lower in all treatments compared to the untreated control (Table 5). However, at 17 DAT there was no difference between the Delegate treatments and untreated control except for the Delegate + Induce treatment in contrast to chlorpyrifos, Danitol or Mustang treatments. At 24 DAT there were no significant differences among any treatments. Feral populations of generalist predators such as ladybeetles, lacewings, and spiders were too low throughout these experiments to observe treatment effects.

Treatment effects on adults were more pronounced than those seen on immatures. However, these effects were much less prolonged compared to those seen following foliar sprays made during dormant winter period (Stansly and Qureshi, 2008). This may be due to the relatively low numbers of adults during that season and the lack of young shoots for psyllid reproduction. Therefore, growers have been encouraged to target adult psyllids by making effective foliar applications during winter and prior to anticipated new growth during the growing season based on monitoring (Stansly et al., 2009). Delegate is a newly registered product for use in citrus that appears to be as effective as other commonly used and less selective insecticides such as Danitol, Lorsban, and Mustang. Therefore, Delegate is a good candidate to rotate with the already registered products to manage ACP, especially during the growing season when compatibility with beneficial insects and mites is most important. Both 435 Oil and Induce, a non-ionic surfactant, appear to increase the efficacy of Delegate.

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