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CHEMICAL CONTROL AND MANAGEMENT APPROACHES OF THE ASIAN CITRUS PSYLLID, *DIAPHORINA CITRI* KUWAYAMA (HOMOPTERA: PSYLLIDAE) IN FLORIDA CITRUS

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Abstract. **The Asian citrus psyllid [*Diaphorina citri* Kuwayama (Homoptera: Psyllidae)] is a serious pest of Florida citrus, especially on young trees being brought to early production. Adults overwinter on both mature and young citrus leaf flush whereas the nymphs develop only on new flush. The insect attacks new growth and females deposit eggs on this newly expanding flush with subsequent establishment of nymphal colonies. The biology of this insect pest is reviewed along with damage produced as a result of feeding injury by both adult and nymphal stages. Methods of assessment of various insecticides for controlling both Asian citrus psylla adults and nymphs are presented from research conducted on Florida citrus since 2001. Management approaches using chemical control for psyllid on Florida citrus are discussed.**

The Asian citrus psyllid (ACP), *Diaphorina citri* Kuwayama (Homoptera: Psyllidae), was first identified in southeast Florida on 2 June 1998 (Halbert and Manjunath, 2004). Today, ACP occurs throughout the citrus growing areas in Florida and has slowed the development of young trees, especially in combination with the citrus leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae). Large populations of both of these insect pests have the potential to reduce young citrus tree growth and development. ACP was first reported in Texas in 2001 (French et al., 2001) and concern exists for its further spread into other citrus producing states.

ACP adults are 3-4 mm in length with a mottled brown coloration (Fig. 1A, B). Adults can feed (and survive) on mature citrus flush, especially through the winter months when new leaf flush may not be available. Adults often have been observed by the authors to gather at newly emerging growing tips and young flushes where they feed and mate. Considerable feeding activity may occur when several adults aggregate at these small points of new flush growth resulting in some initial flush distortion. Gravid females are readily identified by the orange coloration of their abdomens. Females oviposit only on the very young developing flush where the hatching nymphs subsequently feed and develop to adults. Eggs are about 0.3 mm in length, initially pale yellow when deposited, turn yellow and eventually become orange as they mature (Mead, 1977). Oviposition occurs between folds of very young developing terminal leaves which often are distorted. The almond-shaped eggs often are difficult to see (Fig. 1C).

After emerging from eggs, the nymphs begin feeding on the developing flush as well as flower stems and other green twigs. The Asian citrus psyllid has 5 nymphal instars that range from 0.25 to 1.7 mm in length (Liu and Tsai, 2000). Nymphs are readily identified by their yellow to orange coloration, large lateral wing pads, and red eyes (Fig. 1D). Large numbers of aggregating nymphs feed on the new terminals and can produce copious amounts of white, curled wax-like honeydew. Ants will readily feed on these secretions and tend the nymphal colonies. Large quantities of plant sap can be removed resulting in severe distortion and curling of leaves (Mead, 1977). Catling (1970) reported a personal communication from C. S. Celino in 1968 stating that heavy populations of ACP may cause blossom and fruitlet drop on sweet

Fig. 1 (A, B). Adult Asian citrus psyllid, (C) Asian citrus psyllid eggs deposited on newly developed citrus flush, (D) Aggregating ACP nymphs on new citrus flush and their white, curled wax-like honeydew secretions.

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*Corresponding author; e-mail: ccc@crec.ifas.ufl.edu orange, mandarins, lemons, limes, pomelos, and calamondins in the Philippines. We have observed individual ACP nymphs feeding on the stems of citrus flowers.

ACP vectors a gram-negative, phloem-limited bacterial-like organism (*Candidatus* sp.) placed in the class Proteobacteria (Garnier and Bove, 2000), that causes the disease called citrus greening or huanglongbing. This disease is a potentially serious threat to United States citrus production. Symptoms include chlorotic leaves with the veins retaining dark green coloration, misshapen, oblong and stunted fruits that impart a bitter taste. Trees become stunted, sparsely foliated and progressively unproductive (Halbert and Manjunath, 2004). Citrus greening is found in Asia, parts of Africa, Mauritius, Reunion and adjacent islands, and Saudi Arabia (Etienne et al., 2001). The African citrus psyllid, *Trioza erytreae* (del Guercio), is the vector of *Candidatus* Liberibacter africanus in Africa, and *D. citri* is the vector of *Candidatus* Liberibacter asiaticus in Asia (Halbert and Manjunath, 2004).

Citrus greening disease was first reported in the Americas from Araquara in São Paulo State, Brazil in 2004 (Coletta-Filho et al., 2004). Affected citrus leaf samples were analyzed using standard molecular techniques by Texeira et al. (2005). They compared their test results with both the African and Asian strains of citrus greening and determined that the Brazilian bacterium is a Liberibacter but sufficiently different from the other two forms or strains to be considered a new strain, *Candidatus* Liberibacter americanus. Growing concern exists with the occurrence of citrus greening in Brazil and the threat of yet another exotic disease entering the United States given that ACP already occurs on citrus in the Caribbean and Central America (Shivankar et al., 2000).

This paper reviews the biology of the Asian citrus psyllid, identifies insecticides, rates of application and timing to develop effective control strategies of ACP on young citrus trees, and to assess management approaches for its control.

Material and Methods

Four field experiments that evaluated various insecticides including several petroleum oil formulations were assessed for ACP control during 2002 in the Devil's Garden vicinity in Hendry County, Florida. Details of the chemical treatments, formulations, application rates, and timing are given in Tables 1 to 4 (corresponding to Tests 1 to 4). Treatments in all four tests were applied to 'Hamlin' orange trees that were 4 to 5 ft tall with canopy diameters less than 3 ft. Trees were planted on two row beds and spaced 9 by 23.5 ft (206 trees/acre). Treatments were assigned to (12 trees/row × 5 rows) = 60 tree to (20 × 6) = 120 tree plots in a randomized complete block design and replicated 5 times in each test.

Foliar treatments were applied in 250 gal/acre (gpa) (2.338 $kL \cdot ha^{-1}$) using a power take off (pto) pul-Tank sprayer at 125 psi (0.9 MPa) and driven at 1.5 mph (2.4 kmph) in tests 1, 3, and 4 and in 350 gpa (3.273 $kL \cdot ha^{-1}$) using an airblast sprayer at 25 psi (0.2MPa) and driven at 1.5 mph in test 2. The insecticide, Admire 2F, was applied at the rate of 0.25 oz (7 mL) formulated in 8 oz (237 mL) of water around the base of each tree within that treatment as a liquid drench. The insecticide, Temik 15G at 2 oz (56 g) was injected into the ground at the base of each treatment tree with a calibrated hand applicator. Treatments in test 1 were applied on 21-22 March, on 24-26 April in test 2, on 27-28 March in test 3, and on 16-17 May in test 4. Water pH was 8.1 in test 1, 6.9 in test 2, 7.9 in test 3, and 7.0 in test 4.

Two sample trees from within each treatment replicate were examined separately for 2 min each in a circular fashion to visually count the number of live adult ACP that were present. The two counts were averaged and recorded as live adult ACP per tree. Ten individual new terminal leaf flushes were collected at random from within each treatment replicate and placed individually into a labeled pint jar containing 80% ethanol. The jars were returned to the laboratory and the contents of each jar were poured into a black Petri dish and examined. The numbers of ACP eggs and nymphs present on the leaf flushes or within the alcohol sample were recorded as one observation.

In all experiments, data were subjected to analysis of variance using Waller-Duncan K-ratio procedures to separate treatment means when the ANOVA provided a significant F value ($P \leq 0.05$) (SAS Institute, 1991). Adult, egg and nymphal counts were subjected to $Log_{10}(X + 1)$ transformations for statistical analysis. Untransformed means are shown in all tables.

Results

In Test 1, Agri-mek + a 435 horticultural mineral oil (=HMO), Danitol, Lorsban, and Provado all provided excellent knockdown of ACP adults 5 d after treatment (=DAT)

Table 1 (Test 1). Mean numbers of Asian citrus psylla adults per 2 min tree count, and eggs and nymphs per 10 new leaf flushes. All treatments were applied on Mar 21-22; DAT = days after treatment.

			Pre-treatment means-adults	Post-treatment means[z]									
				Mar 26 (5 DAT)			Apr 1 (11 DAT)			Apr 5 (15 DAT)		Apr 9 (19 DAT)	
Treatment	Formulation	Rate/acre	Mar 19	Adults	Eggs	Nymphs	Adults	Eggs	Nymphs	Eggs	Nymphs	Eggs	Nymphs
Agri-mek + Sol-Oil 97	0.15 EC FC435-66	10 oz, 7 gal	70 a	5 c	16 c	39 a	25 bc	8 cd	3 c	7 a	11 bc	37 ab	43 bc
Danitol	2.4 EC	16 oz	67 a	0 d	28 abc	7 bc	37 ab	2 de	2 c	6 a	6 c	122 a	68 ab
Spintor	2 SC	6 oz	64 a	51 ab	59 ab	24 ab	44 ab	62 ab	32 ab	32 a	61 ab	39 ab	100 ab
Lorsban	4 EC	4 pints	63 a	3 c	23 bc	6 c	48 ab	20 bc	4 c	25 a	18 bc	20 bc	31 bc
Admire	2 F	0.25 oz/tree	64 a	22 b	28 abc	16 abc	9 d	7 cde	10 b	9 a	8 bc	12 cd	15 de
Provado	1.6 F	10 oz	58 a	0 d	14 c	16 abc	27 bc	2 e	3 c	18 a	4 bc	20 bc	17 cd
Assail	70 WP	2.29 oz	60 a	66 a	44 ab	28 a	63 a	72 a	55 a	94 a	85 a	45 ab	135 a
Temik	15 G	2 oz/tree	62 a	48 ab	97 a	24 a	12 cd	11 c	10 b	4 a	13 c	6 d	10 e
Untreated	—		60 a	75 a	80 a	25 a	32 ab	50 ab	43 a	17 a	51 ab	27 bc	39 bc

[z] Means within a column followed by the same letter are not significantly different by ANOVA followed by Waller-Duncan K-ratio (unless the ANOVA is significant $P \leq 0.05$).

whereas Danitol gave good suppression of eggs and nymphs through 15 DAT (Table 1). The systemic insecticide, Admire, had significantly lower adult ACP numbers 5 DAT while Temik did not. However, both systemic insecticides provided the longest residual control of nymphs through 19 DAT when the test was terminated. The insecticides Spintor and Assail were ineffective in reducing ACP.

In Test 2, Actara, Agri-mek + 435 HMO, Danitol, Lorsban, and Provado all provided significant reductions in adult ACP 4 DAT (Table 2). The foliar insecticides, Actara, Lorsban, and Provado all provided good suppression of ACP adults and nymphs through 18 DAT while both Actara and Provado remained effective in suppressing nymphs through 25 DAT. Agri-mek + HMO provided good egg and nymphal suppression through 14 DAT. Admire was not effective in suppressing ACP until 8 to 9 d after application. However, excellent residual control was achieved through 25 DAT when the experiment was terminated. Spintor provided initial reduction of ACP through 4 DAT with sustained activity against nymphs 8 DAT while Assail was ineffective.

Several HMOs were applied alone or in combination with either Kinetic or Citru-Film adjuvants for control of different citrus psyllid stages in Tests 3 and 4 (Tables 3, 4). Control of adults was not achieved in either test using any of the HMOs. In Test 3, there were significant reductions in egg counts 9 DAT with the Sol-Oil 97 (FC455), Sunspray 11E, Mite-E Oil alone, and Mite-E Oil + Citru-Film compared with the untreated check trees. Corresponding reductions in nymphal counts were recorded 9 DAT with Sol-Oil 97 (FC455), Sunspray 11E, Mite-E Oil alone or combined with Citru-Film. However, these reductions were not evident by 13 DAT in any of the HMO treatments. In Test 4, significant reductions in ACP egg numbers were obtained with the Mite-E Oil combinations with Kinetic or Citru-Film 5 DAT compared with the untreated check trees. These reductions were further reflected in nymphal counts in the same two treatments 12 DAT with no further control beyond that date (Table 4).

Discussion

The foliar insecticides: Actara, Danitol, Lorsban, and Provado each provided good knockdown and residual activity against the Asian citrus psyllid in these field studies. Use of the systemic insecticides Admire or Temik provided very effective control of ACP. However, earlier placement of these products prior to major flushing cycles would optimize their effectiveness. The smaller the tree the faster the uptake of either insecticide. Young citrus trees that range between 1.3 to 1.9 m tall require at least 5 to 7 d following application before control was observed. Assessment of both these foliar and systemic insecticides and their impacts on the beneficial insect predators and parasites needs to be addressed. Application of systemic insecticides likely will be required for effective psyllid control on young trees.

Chemical control of ACP on mature healthy citrus trees in Florida is not recommended since feeding injury would be minimal compared to young tree leaf flush. Reliance of an array of predators that include several predacious species of Coccinellidae, Syrphidae, Chrysopidae, and spiders as well as parasitoids should increasingly limit the potential destructiveness of this recently introduced pest as long as we do not have citrus greening disease (Hoy and Nguyen, 2000; Michaud, 2002). Both insecticidal and biological control approaches

Table 2 (Test 2). Mean numbers of Asian citrus psylla adults per 2 min tree count, and eggs and nymphs per 10 new leaf flushes. All treatments were applied on Apr 24-26; DAT = days after treatment.

			Pre-treatment means-adults	Post-treatment means^z														
				Apr 29 (4 DAT)			May 3 (8 DAT)		May 6 (11 DAT)			May 9 (14 DAT)		May 13 (18 DAT)			May 20 (25 DAT)	
Treatment	Formulation	Rate/acre	Apr 22	Adults	Eggs	Nymphs	Eggs	Nymphs	Adults	Eggs	Nymphs	Eggs	Nymphs	Adults	Eggs	Nymphs	Adults	Nymphs
Actara	25 WG	4 oz	20 a	1 c	1 e	6 a	0 e	0 c	2 cd	1 d	0.2 f	5 cd	0.2 c	1 c	4 f	2 ef	4 abc	4 bc
Agri-mek + Sol-Oil 97	0.15 EC FC435-66	10 oz, 5 gal	25 a	5 bc	15 bc	18 a	12 bc	5 bc	8 bc	17 bc	5 b-e	5 bc	3 bc	11 abc	33 abc	17 abc	20 b	—
Danitol	2.4 EC	16 oz	21 a	1 c	2 de	11 a	1 de	0.4 c	2 d	10 cd	4 d-f	3 cd	4 bc	37 a	18 bcd	8 bcd	15 b	17 a
Spintor	2 SC	6 oz	23 a	15 ab	9 cd	16 a	23 cd	3 c	17 a	16 bc	10 abc	17 ab	14 ab	39 a	38 abc	29 ab	39 ab	—
Lorsban	4 EC	5 pints	21 a	2 c	7 cd	11 a	3 cd	0 c	3 cd	8 bc	4 c-f	4 c	2 bc	16 ab	15 cde	5 cde	21 bc	18 ab
Admire	2 F	0.25 oz/tree	21 a	22 a	42 ab	17 a	13 abc	9 ab	5 cd	5 cd	6 bcd	0.4 d	5 bc	4 bc	4 ef	1 f	2 c	4 c
Provado	1.6 F	5 oz	22 a	3 bc	6 cd	12 a	3 de	3 c	3 cd	4 cd	1 ef	5 c	2 c	51 a	15 def	9 def	13 bc	2 bc
Assail	70 WP	2.29 oz	22 a	26 a	33 ab	17 a	31 ab	11 a	29 a	62 a	24 a	25 a	15 a	54 a	61 a	45 a	104 a	—
Untreated	—	—	22 a	43 a	43 a	17 a	43 a	18 a	22 a	26 ab	14 ab	37 a	20 a	19 a	46 ab	40 a	21 ab	17 a

^{z}Means within a column followed by the same letter are not significantly different by ANOVA followed by Waller-Duncan K-ratio (unless the ANOVA is significant P ≤ 0.05).

Table 3 (Test 3). Mean numbers of Asian citrus psylla adults per 2 min tree count, and eggs and nymphs per 10 new leaf flushes. All treatments were applied on Mar 27-28; DAT = days after treatment.

				Post-treatment means^z						
			Pre-treatment means-adults	Apr 1 (5 DAT)			Apr 5 (9 DAT)		Apr 9 (13 DAT)	
Treatment	Formulation	Rate/acre	Mar 19	Adults	Eggs	Nymphs	Eggs	Nymphs	Eggs	Nymphs
Sol-Oil 97	FC435-66	5 gal	57 a	51 a	10 a	9 a	29 ab	22 ab	23 a	27 a
Sol-Oil 97	FC455-88	5 gal	54 a	48 a	11 a	13 a	7 bcd	10 bc	28 a	23 a
Sunspray	11E	5 gal	56 a	34 a	7 a	22 a	2 c	4 c	34 a	18 a
Mite-E Oil	FC435-66	2 gal	57 a	45 a	10 a	14 a	4 cd	6 bc	28 a	23 a
Mite-E Oil + Kinetic	FC435-66	2 gal, 12.5 oz	57 a	26 a	10 a	8 a	16 ab	27 ab	19 a	12 a
Mite-E Oil + Citru-Film	FC435-66	2 gal, 0.5 gal	56 a	37 a	10 a	10 a	15 bc	22 bc	33 a	23 a
Untreated	—	—	54 a	69 a	37 a	25 a	48 a	78 a	11 a	18 a

^{z}Means within a column followed by the same letter are not significantly different by ANOVA followed by Waller-Duncan K-ratio (unless the ANOVA is significant P ≤ 0.05).

should be pursued to develop effective strategies for ACP suppression. Greater reliance on biological control should be the ultimate goal with possible occasional insecticidal treatments needed. However, in the case of hurricane damaged trees with substantial loss of foliage (>50%) and many new regrowth flushes, insecticide treatments for ACP may be needed.

Additional research is needed to look at single or multiple treatment applications of HMO products alone or in combination with different surfactants on young trees for ACP control. In addition, we need to combine these evaluations with sprayer technology and coverage issues. McKenzie et al. (2004) obtained effective suppression of ACP eggs and nymphs on young citrus trees with 2 gal of a 435 HMO in 15 gpa and applied with a Curtec sprayer with repeated applications. In contrast, Rae et al. (1997) recommended use of non-specified HMOs in China for control of ACP with treatment applications no farther apart than at 9-d intervals. Huang et al. (2002) stated that frequent HMO applications every 6-7 d during flushing periods were required to suppress ACP in China. Both studies were completed using handgun equipment. Use of HMOs applied with handgun equipment at low pressure in small plots versus use of selected airblast sprayers with superior coverage in large plots should equate to better overall performance of the HMO. Results presented in this paper and data from McKenzie et al. (2004) support the need for continued assessment of HMOs alone or with various surfactants. The HMOs are median-equivalent n-parafin carbon numbers of 21, 23, and 25 which equal the 414, 435, and 455 °F mid-boiling point petroleum oils used on Florida citrus (Kuhlmann and Jacques, 2002). Potential benefits likely remain to be identified with the use of HMOs applied alone or in combination with one or more surfactants that would enhance mortality effects against one or more stages in the life cycle of the Asian citrus psyllid. Taverner (2002) has reviewed the toxic effects of HMOs and listed several routes of potential mortality with HMO usage in addition to smothering effects. They included: fumigant action, narcosis, nervous disruption, corrosion of insect tissues, cell disruption, and desiccation.

Two recurring themes are evident in the literature regarding the use of petroleum-derived spray oils in integrated pest and disease management programs. First, an HMO is non-selective but has short residual activity. Second, an HMO gives minimal disruption of beneficials (Childers, 2002). A third, and very important benefit of using HMOs, is that no arthropod resistance development is known with the use of petroleum oil spray applications.

Catling and Annecke (1968) reported on four main factors that regulate *Trioza erytreae* in South Africa. They included: (1) flushing rhythm of citrus, (2) flush quality, (3) extremes of weather, and (4) natural enemies. These same

Table 4 (Test 4). Mean numbers of Asian citrus psylla adults per 2 min tree count, and eggs and nymphs per 10 new leaf flushes. All treatments were applied on May 16-17; DAT = days after treatment.

				Post-treatment means^z						
			Pre-treatment means-adults	May 21 (5 DAT)			May 28 (12 DAT)			Jun 4 (19 DAT)
Treatment	Formulation	Rate/acre	May 14	Adults	Eggs	Nymphs	Adults	Eggs	Nymphs	Nymphs
Sol-Oil 97	FC435-66	5 gal	24 a	10 a	5 ab	1 a	8 a	24 a	19 ab	6 ab
Sol-Oil 97	FC455-88	5 gal	27 a	21 a	6 ab	2 a	10 a	24 a	32 ab	8 ab
Sunspray	11E	5 gal	24 a	13 a	8 ab	1 a	12 a	18 a	26 ab	21 a
Mite-E Oil	FC435-66	2 gal	24 a	31 a	6 ab	1 a	16 a	14 a	25 ab	16 ab
Mite-E Oil + Kinetic	FC435-66	2 gal, 12.5 oz	25 a	11 a	2 b	1 a	8 a	16 a	16 b	13 ab
Mite-E Oil + Citru-Film	FC435-66	2 gal, 0.5 gal	27 a	5 a	1 b	1 a	11 a	12 a	13 b	6 ab
Untreated	—	—	21 a	23 a	16 a	2 a	15 a	39 a	67 a	5 b

^{z}Means within a column followed by the same letter are not significantly different by ANOVA followed by Waller-Duncan K-ratio (unless the ANOVA is significant P ≤ 0.05).

factors also apply to ACP in Florida. The main flushes (spring, summer, and fall) will regulate the population increase of ACP. Protracted fall flush events extending through the winter months will allow for increased population densities, especially if temperatures remain above 55 °F (Liu and Tsai, 2000). Conversely, low temperatures below the mid 50s °F will retard new flush growth and lower overwintering adult population levels of ACP. Such a scenario will result in low ACP population pressure on the spring flush, especially in the northern half of the citrus producing counties in Florida.

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