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ROLE OF PESTICIDES AND WEATHER IN THE FIRST REPORTED OUTBREAK OF CALIFORNIA RED SCALE (HOMOPTERA: DIASPIDIDAE) ON FLORIDA CITRUS

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Abstract. **California red scale (CRS), *Aonidiella aurantii* (Maskell) was virtually unknown in Florida citrus until an unprecedented, though short-lived outbreak in 1998. That was a so-called "El Niño" year characterized by an relatively wet winter and dry summer, in contrast to the usual dry winter and wet summer. The predominant variety affected was the tangor *Citrus reticulata* var. Murcott, most of which had been sprayed with a newly registered acaricide, pyridaben (Nexter® 75WP). Replicated experiments were conducted in a commercial 'Murcott' grove to evaluate the effects of pyridaben under different application regimes (1999) and companion pesticides (2000). Moderate populations of CRS were observed in 1999 that temporarily increased in response to pyridaben compared to the grower standard where abamectin (AgriMek® 0.15 EC) was used. An accompanying decrease in parasitism of CRS was also observed. Nonetheless, pack-out was normal, and no differences in scale incidence among treatments were observed the following spring. Populations of CRS were lower in 2000 with many fewer complaints from growers. A trial comparing pyridaben to another standard acaricide, diflubenzuron (MicroMite®) did not result in differences in CLM populations, although parasitism of CLM was again somewhat reduced on trees treated with pyridaben. The atypical Mediterranean-like weather pattern in 1998 may have provided favorable conditions for CRS that were further enhanced by pyridaben applications, possibly through secondary effects on parasitoids. CRS populations subsequently became less responsive to pyridaben following establishment of normal weather patterns.**

During the 1998-99 growing season I observed outbreaks of armored scale on some mandarin varieties, as well as on orange and grapefruit, in south and central Florida. An unusual aspect of these reports was the prevalence of California red scale (CRS), *Aonidiella aurantii* (Maskell) (Homoptera: Diaspididae). Identifications were confirmed by Avas Hammon, DACS/DPI Gainesville. CRS is a polyphagous armored scale

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and the principal citrus pest in many areas of the world, particularly those characterized by Mediterranean climates. Although CRS was identified in Florida as early as 1918 from a variety of hosts (A. Hammon, Florida Department of Agriculture and Consumer Services (FDACS), Division of Plant Industry (DPI) pers. comm.), it had not previously been reported as a citrus pest from our state. Browning (1994) characterized CRS populations in Florida as "nearly undetectable", and noted that visits in 1949 to reported CRS infestations in Florida (DeBach, 1950) yielded only low numbers of yellow scale, *Aonidiella citrina* (Coquillett). Deckle (1976) listed the main hosts of CRS in Florida as *Cocculus* sp., *Ficus carica* L. and *Ligustrum lucidum* Ait.

One explanation for this unusual infestation might have been the so-called El Niño weather pattern in 1998 that reversed normal trends by providing an especially wet winter and an early summer drought (Fig. 1). Florida weather thus approached the typical Mediterranean rainfall pattern where CRS is a citrus pest. Seeking additional causes, I conducted a survey of scale incidence and pesticide use in Florida citrus. A total of 73 responses were received from growers in the Southwest, Indian River, and Ridge regions (Stansly, 2000 and unpublished data). Ten growers reported recent problems with CRS and all 10 had used Nexter 75WP (pyridaben) 1 to 3 times at the recommended rate of 6.6 oz of product/ac [0.35 kg ai/ha]. All but two of an additional 11 growers who had used pyridaben reported higher than normal armored scale populations, albeit of different species. In contrast, only 9 of 55 growers who had not used pyridaben reported unusually heavy armored scale infestations. 'Murcott', a high-value crop often treated with acaracides for control of citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) (Acari: Eriophyidae) was sprayed with pyridaben in 5 out of 10 cases reported in the survey. All five 'Murcott' growers using pyridaben reported CRS problems, as did three others that did not spray with pyridaben.

The year 1998 marked the first season pyridaben was registered in Florida citrus and there was no history of commercial scale use in our state. However, pyridaben had reportedly increased CRS densities up to eight times that of the untreated controls in southern California, albeit at high rates (0.56 and 1.1 kg ai/ha, Grafton-Cardwell and Reagan, 1999). The two experiments reported here were conducted in southwest Florida with the objective of evaluating the effect on CRS populations of different pesticides regimes with or without pyridaben.

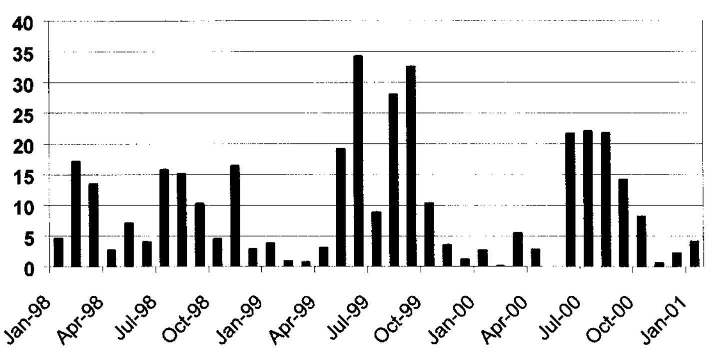

Fig. 1. Rainfall (cm) at SWFREC in Immokalee Florida (http//fawn.ifas.ufl.edu).

Materials and Methods

An 18 acre block of mature mandarin orange, *Citrus reticulata* × *C. sinensis* (L.) 'Murcott' with 80 tree rows orientated north to south was divided into 11, 4-row plots. Four treatments were assigned to each 4-row plot in an RCB design with tree replications for all treatments but one.

1999 Trial. The four treatments compared the number and timing of applications of pyridaben 75 WP at the recommended rate of 0.26 kg ai/ha pyridaben (10.7 oz product per acre): (1) June only, (2) September only (2 replicates only), (3) June and September, (4) Control (no pyridaben). Treatment dates were 9 June 1999 and 24 Aug. 1999. Control trees were sprayed at the grower's request with AgriMek 0.15EC at (0.015 kg ai/ha abamectin = 8 oz product per acre) plus 6% v/v FC 435-66 horticultural mineral oil (HMO) on June 9 1999 to control citrus rust mite (CRM) *P. oleivora.* All applications on June 9, 1999 included zinc and manganese at 1.12 $kg \cdot ha^{-1}$ and copper at 4.5 $kg \cdot ha^{-1}$ as a tank mix. Treatments were applied with an airblast sprayer at 1170 $L \cdot ha^{-1}$ (125 gal/acre).

CRS populations were assessed by direct counts on fruit and also with pheromone traps. The first three scale counts were conducted in the field using a 5×-magnifying headset on each of two randomly chosen fruit from both of the two middle rows of each bed (plot) at each of 5 locations along the bed (20 fruit per plot). The last two evaluations were conducted in the laboratory by removing the same number of fruit and counting all scale under a stereoscopic microscope. Only CRS was counted although chaff scale (*Parlatoria pergandi* Comstock) and to a lesser extent Florida red scale [*Chrysomphalus aonidum* (L)] were also encountered. Data were analyzed by one-way ANOVA. Ten additional fruit with high scale counts were taken from each plot and held individually for 21 d in 0.47 L cardboard ice cream box. Parasitoids emerging from this fruit were counted after 20 d incubation at ambient temperature. Percentage parasitism was calculated for each fruit by dividing the total number of emerging parasitoids by the total number of mature scales initially present. Resulting values were arcsine square root transformed before analysis by one-way ANOVA. Voucher specimens of parasitoids were sent to G. Evans (FDACS-DPI) for identification. An additional sample of the following year's fruit was taken on 30 June 2000 and evaluated in the laboratory to serve as a pretreatment sample for a subsequent experiment.

A pheromone lure (Trécé, Salinas, Calif.) was attached to the center of a folded 15.2 × 30.5 cm yellow sticky trap (Olson Products, Medina, Ohio) placed centrally in the middle row of each 4-row plot on 2 Sept. 1999, 9 Sept. 1999, 22 Oct. 1999 and 4 Nov. 1999. The traps were removed after 3-6 d and CRS males were counted within six 2.26 cm^2 circles placed as templates on each side of the trap, for a total area of 15.6 cm^2. Data were subjected to a one way ANOVA followed by Fisher's LSD ($\alpha \leq 0.05$) for separation of means.

2000 Trial. Plot assignments in the same grove were rerandomized for three new treatments plus a control (grower standard) without pyridaben: (1) Pyridaben 75 WP @ (0.7 kg ai/ha) (13.2, oz product per acre), (2) Pyridaben @ 0.7 kg ai/ha + Esteem 0.86 EC @ (0.128 kg ai/ha pyriproxyfen (17 oz product per acre) + 5% Fl-435-66 horticultural mineral oil (HMO), and (3) as 2 without the HMO (2 replicates only). Two treatments included pyriproxyfen to test the effectiveness of this insect growth regulator against scales under Florida conditions. At the grower's request, control trees were sprayed with MicroMite 25 WP (0.35 kg ai/ha diflubenzuron = @ 20 oz/acr) for CRM control. Tank mixes of all treatments included 6.3 kg ha^{-1} 98% basic copper sulfate (for control of fungal diseases) and 6.8 kg ha^{-1} potassium nitrate as a foliar fertilizer. Applications were made on 31-V-2000 using the same equipment to apply the same volume per unit area as treatments applied in the previous year. All trees were sprayed in August with 0.73 L AgriMek 0.15 EC + 18.7 L·ha^{-1} HMO and nutrients, and in September with 5.8 L·ha^{-1} Ethion 4EC, again at the grower's request for control of CRM.

A pretreatment sample was taken on 30 May 2000 and post-treatment samples taken on 29 June 2000, 27 July 2000, 11 Sept. 2000 and 11 Jan. 2001 using the same sampling protocols as described above. Fruit were taken to the laboratory, inspected under a stereoscopic microscope, and CRS were classified by instar. Beginning with CRS samples taken on 11 July, scale covers were removed from 2nd and 3rd instar CRS and these were classified as alive, parasitized or dead. The percentage of CRS parasitized was calculated for each life stage by dividing the number of CRS parasitized by the total number (parasitized plus unparasitized). Data was arcsine, square root-transformed prior to analysis, although actual percentages are presented in tables.

Male CRS flight activity was monitored with a single pheromone trap placed in two centralized plots on 29 April and increased to three plots (Treatment 4) on 21 May 2000. One quarter of the double-sided 15.2 × 30.5 cm trap was exposed at a time (15.2 × 15.2 cm), with a new surface exposed at approximately 10-d intervals. Pheromone was changed after four exposures, or at approximately 40-d intervals.

Results

1999 Trial. Five to 15 times more CRS were observed in June, July and August on fruit from trees treated with pyridaben compared to fruit from control trees (Table 1). Observations later that year following the second treatment showed significantly more CRS on fruit randomly sampled from trees sprayed in both June and September compared to all other treatments, with no differences among the latter (Table 2). No significant differences in scale incidence among treatments were observed on the next year's fruit crop sampled 30 May 2000. Over all four collection dates from September through November, most male scales were caught in plots sprayed with pyridaben in June and September, although the treatment effect was not significant (F = 3.2; df = 3,5; ns; Table 3).

Treatment effects on percent parasitoid emergence from fruit collected on 15 November were significant (F = 3.18; df = 3,100; $P = 0.027$). Relatively more parasitoids emerged from scales on fruit taken from trees sprayed with pyridaben in June only compared to trees sprayed with pyridaben in September only, with the other two treatments intermediate (Table 4). Percent parasitism was not correlated with number of scales (r = 0.03; $P = 0.77$, n = 104). Few parasitoids emerged from the sample taken on 18 Jan 2000 and no significant treatment effect was observed ($F = 0.94$, df = 3,102; $P = 0.42$). A diverse assemblage of parasitoid species were represented in samples: *Encarsia lounsburyi* (Berlese and Paoli), *Encarsia citrina* (Craw), *Encarsia* nr *auranti, Aphytis comperei* DeBach and Rosen, *Aphytis chrysomphali* (Mercet), *Aphytis lingnanensis* group (Hymenoptera: Aphelinidae) and *Comperiella bifasicata* (Hymenoptera: Encyrtidae). All except for possibly *A. comperei* are generalists that have been reported on various armored scales in Florida (Browning, 1994). Although originally collected on CRS (Krombein et al. 1976), *A. comperei* had previously been reported in Florida from chaff scale *Parlatoria pergandii* Comstock (Homoptera: Diaspididae). Chaff scale was the second most common armored scale seen on fruit in the grove and therefore may have been the source of the *A. compere* recovered.

Table 1. Mean (±SEM) number of CRS observed (n = 20 fruit) on three sampling dates after first application of 1999 trial.

	Mean CRS per fruit		
Treatment	22 May 99	15 July 99	13 Aug. 99
Pyridaben 75WP	2.2 ± 0.60 a	24.4 ± 4.7 a	99.4 ± 13.3 a
Control	0.4 ± 0.12 b	1.6 ± 0.59 b	17.3 ± 4.9 b

Means within columns followed by the same letter were not significantly different (LSD, $P < 0.05$).

2000 Trial. Captures of male CRS in pheromone traps peaked on 8 May, with secondary peaks observed on 18 July and 4 October, suggestive of three CRS generations over the sampling period (Fig. 2). Captures were considerably less than the previous year and the lack of any reports from growers suggested that populations were probably low throughout the region. Proportional representation of CRS stages sampled on fruit post-treatment was (mean ± SEM) 68.3 ± 2.5, 22.5 ± 2.0 and 9.2 ± 1.6% for 1st, 2nd and 3rd instars respectively, with no significant effects of treatment or sample date.

There were no significant differences between CRS densities in plots treated with pyriproxyfen and pyridaben, with or without HMO ($F = 0.55$: df = 3,121; $P = 0.65$), so results from these two treatments were pooled for analysis. There were no significant differences in the total number of CRS observed on the pre-treatment fruit sample compared with the first post-treatment sample on 29 June (Table 5), although all three subsequent samples showed significant treatment effects. Two months after treatment on 27 July, about four times more scales were seen on fruit from trees sprayed with diflubenzuron and HMO compared to trees sprayed with pyridaben plus

Table 2. Mean number of CRS (±SEM) observed on 20 fruit on three sampling dates after 2nd application of 1999 trial.

		Mean CRS per fruit		
Treatment	Application Date	15 Nov. 99	18 Jan. 00	30 May 00
Pyridaben 75WP	9 June 99	33.7 ± 14.2 b	13.9 ± 2.0 b	6.8 ± 1.9 a
Pyridaben 75WP	24 Sept. 99	13.7 ± 6.7 b	7.7 ± 1.2 b	3.4 ± 1.6 a
Pyridaben 75WP	9 June 99 and 24 Sept. 99	101.2 ± 23.3 a	91.0 ± 18.9 a	4.6 ± 0.92 a
Control	None	11.1 ± 1.8 b	4.0 ± 0.85 b	3.9 ± 1.2 a

Means within columns followed by the same letter were not significantly different (LSD, $P < 0.05$).

Table 3. Mean (±SEM) density of male CRS on yellow sticky cards baited with pheromone attractant over four collection dates in 1999. Differences among treatments were not significant ($F = 3.2$, df = 3,5; ns).

Treatment	Application Date	CRS males per cm²
Pyridaben 75WP	9 June and 24 Sept.	5.3 ± 0.85
Pyridaben 75WP	24 Sept.	2.4 ± 0.57
Pyridaben 75WP	9 June	2.5 ± 0.62
Control		3.7 ± 0.62

pyriproxyfen and or pyridaben plus HMO alone. Scale counts were still highest on diflubenzuron-treated fruit for the 11 September sample, although they had also risen significantly on trees treated with pyridaben + HMO relative to those also receiving pyriproxyfen. By 11 January 2001, there were no differences between the diflubenzuron and the pyridaben + HMO treatments, although both treatments had an order of magnitude more scales than fruit receiving pyriproxyfen.

Proportionately fewer 2nd and 3rd instar CRS were parasitized on fruit sampled on 27-VII-2001 from trees sprayed with pyriproxyfen compared to trees sprayed with diflubenzuron (Table 6). On the 11 Sept. 2000 and 11 Jan. 2001) no significant treatment effect on parasitism was observed (data not shown). In contrast to the previous year, there was a weak correlation between percent parasitization and live CRS (r = 0.35, $P = 0.022$).

Discussion

Even though weather conditions were presumably unfavorable to CRS in 1999, a notable increase in CRS populations was observed, apparently in response to pyridaben treatments. CRS populations could still have been high from the previous year, and may have escaped control due to suppression of parasitic wasps by the June spray. However, scales on these trees could have attracted wasps from adjoining plots, thereby reducing the next generation of CRS on the trees that were not sprayed again in September. On the other hand, further suppression of parasitism by the September

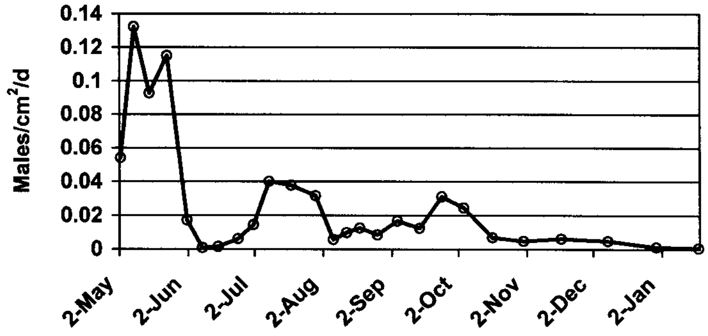

Fig. 2. Mean number of male CRS per 15.2 × 15.2 cm sticky trap, 2000-2001.

spray of pyridaben may have allowed scale populations to continue to increase. However, the September application of pyridaben may have been late enough that insufficient time remained in the year for scale population increase, despite suppression of parasitism. Parasitoid populations would have had adequate time to re-establish by the following spring negating any further effect of pyridaben.

Parasitism of CRS was again reduced in association with pyridaben in 2000, but scale populations were never greater than in control treatment not receiving pyridaben. Granted, the grower's choice of sprays in the control was different from the previous year, but low CRS populations and/or a possible direct effect of diflubenzuron on parasitoids may also have obscured any potential differences.

The outbreak of CRS in Florida was short-lived. Of 10 infestations of commercial citrus groves observed in 1998, only one still active in 1999 and none were reported in 2000. Although an increase in CRS was induced using pyridaben in 1999, the level of damage was not economic and the grower was satisfied with the condition of the fruit regardless of the treatment. Conditions may have been especially favorable for CRS development in 1998. Perhaps a wet cool winter is key to CRS survival. Indeed, low populations were observed in the spring of 2000 after a dry, warm winter.

Table 4. Mean number of parasitoids (±SEM) and percentage [100 × Parasitoids/(Scales + Parasitoids)] emerging per 10 fruit selected for high CRS infestation on 15 Nov. 1999.

		Scales per 10 fruit	Parasitoids per 10 Fruit	
Treatment	Application date	(No.)	(No.)	(%)
Pyridaben 75WP	9 June	25.7 ± 4.7	5.3 ± 2.3	13.6 ± 4.1 a
Pyridaben 75WP	24 Sept.	9.3 ± 4.0	0.2 ± 0.1	1.9 ± 1.5 b
Pyridaben 75WP	9 June and 24 Sept.	87.5 ± 9.6	7.0 ± 3.7	4.6 ± 1.6 ab
Control		6.2 ± 1.1	0.05 ± 0.2	5.9 ± 2.7 ab

Means within columns followed by the same letter were not significantly different (LSD, $P < 0.05$).

Table 5. Mean number of CRS from 20 fruit in 2000 and 2001.

	CRS per 20 Fruit				
Treatment	30 May 00	29 June 00	27 July 00	11 Sept. 00	11 Jan. 01
Pyriproxyfen + Pyridaben	4.92 a	7.9 a	10.2 b	1.3 c	0.24 b
Diflubenzuron + HMO	3.87 a	9.6 a	49.5 a	45.2 a	20.1 a
Pyridaben + HMO	5.47 a	10.8 a	12.9 b	19.8 b	19.4 a

Means within columns followed by the same letter are not significantly different (LSD, $P < 0.05$).

Table 6. Mean number (±SEM) live, parasitized and percent parasitized 2nd and 3rd instar CRS per 20 fruit collected on 27 July 2000.

	CRS		
	(No. Live)	(No. Parasitized)	(% Parasitized)
Diflubenzuron + HMO	16.0 ± 4.6 a	3.1 ± 0.9	16.0 ± 2.7 a
Pyridaben + Pyriproxyfen	3.6 ± 1.1 b	0.2 ± 1.2	4.1 ± 2.6 b
Pyridaben + HMO	4.1 ± 1.0 b	0.13 ± 0.09	2.2 ± 1.6 b

Means within columns followed by the same letter are not significantly different (LSD, $P < 0.05$).

In the aftermath of a favorable CRS year, infestations increased with a single spring application of pyridaben in 1999. The effect was enhanced by an additional application in the fall, although a single fall application was not sufficient to cause an increase. No increase with pyridaben was observed in 2000, although CRS populations were successfully reduced to extremely low levels with pyriproxyfen. Thus, we should not expect pyridaben to exacerbate CRS populations under typical Florida conditions. However, if the climate again approaches a Mediterranean rainfall pattern, we might again see increases in CRS populations in response to applications of pyridaben. Under such conditions, pyridaben would best be reserved for fall applications, and pyriproxyfen could be used effectively for CRS suppression if necessary.

Acknowledgments

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