Targeted insecticides to control Australian citrus whitefly (*Orchamoplatus citri*)

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Abstract The recent invader Australian citrus whitefly (ACW) is causing severe sooty mould problems on citrus varieties throughout Northland, Auckland, Bay of Plenty, Gisborne and Hawke's Bay. Five insecticide programmes were applied to two orchards in Kerikeri and two orchards in Gisborne. Four programmes used foliar insecticide targeting adults in November 2009 (pymetrozine, diazinon, polyether modified polysiloxane or pyrethrin) followed by another targeting crawlers/young instars in December (spirotetramat, buprofezin, mineral oil or pyrethrin, respectively). The fifth programme was a single soil drench of imidacloprid in November. Reductions in ACW populations were achieved on trees treated with pymetrozine, then spirotetramat, diazinon then buprofezin or polyether modified polysiloxane, then mineral oil. These reductions were greater than those observed on untreated trees, pyrethrin-treated trees or imidacloprid-treated trees. Sooty mould on fruit and foliage was reduced with pymetrozine/spirotetramat, diazinon/buprofezin or polyether modified polysiloxane/mineral oil treatments at the sites where sooty mould was severe on untreated trees.

Keywords *Orchamoplatus citri*, Australian citrus whitefly, insecticides, sooty mould.

INTRODUCTION

Australian citrus whitefly (ACW) (*Orchamoplatus citri*) was first detected in New Zealand in 2000 (Gill 2001) and has now spread from Auckland to all the main citrus growing regions in New Zealand. It is an endemic Australian whitefly (Russell 1958; Carver & Reid 1996) that feeds only on species of citrus (Martin 1999). In its native Australia, the species is a minor pest (Cooper 1961; Hely 1968; Smith et al. 1997). However, in New Zealand ACW has arrived without effective natural enemies (Jamieson et al. 2009a & b) and causes significant sooty mould problems in backyard and commercial citrus, resulting

in the downgrading of up to 90% of mandarin and orange crops (Pyle 2009) and possible tree health issues. Classical biological control has been identified as a long-term control strategy for ACW (Jamieson et al. 2010), but effective insecticidal control strategies are required in the meantime.

ACW overwinter as immature nymphs or pupae that emerge as adults in spring (Jamieson et al. 2009a). Adults move on to the young leaves to lay eggs, from which crawlers emerge and develop through their nymphal stages over summer. In Kerikeri and Auckland there is one main generation per year, although in some

orchards there is a small emergence of adults in autumn. Most late instars and pupae overwinter until the following spring.

Previous laboratory bioassays and a potted plant trial revealed that young nymphs and adults were the most susceptible life stages of ACW to eight foliar insecticides and one soil drench (Jamieson et al. 2010). This study aimed to determine the efficacy of five spray programmes, four consisting of two targeted canopy insecticide applications (the first insecticide targeting adults and the second targeting crawlers) and the fifth being a soil drench, in a large-scale grower-based field trial.

METHODS

The trials were conducted from November 2009 to April 2010 in commercial orchards with ACW populations. Two of the orchards were located in Kerikeri (mandarin) and two in Gisborne (Navel orange). Each of the six treatments (Table 1) was applied to an entire block of trees (0.3 to 1 ha) at each site, except for the imidacloprid soil drench at the Gisborne sites, which was applied to one row of 20 trees within the unsprayed block. The first insecticide in each treatment targeted adults and was applied when 80% had emerged from pupal

cases (determined by assessing one sample of pupae on each of 10 trees in each block) and after petal drop to avoid bee toxicity (13 November 2009 in Kerikeri and 17 November in Gisborne). The second insecticide targeted crawlers and young nymphs and was applied when 80% of eggs had hatched (10 December in Kerikeri and 23 December in Gisborne), determined by assessing one batch of eggs on each of 10 trees in each block. Foliar insecticides were mixed using the rates in Table 1 and applied at 2000 litres/ha using commercial spray equipment.

Imidacloprid was applied on 13 November in Kerikeri and 20 November in Gisborne to enable the uptake by trees to coincide with crawler hatch in December. In Gisborne, 5 ml imidacloprid was diluted in 500 ml of water in a 10-litre knapsack and applied to each tree with a coarse droplet spray directed to the trunk out to 20 cm from the trunk. In Kerikeri, 3 ml imidacloprid was diluted in 50 ml of water and applied to each tree using a drenching gun with a short length of alkathene pipe attached to the end. The mixture was applied around the lower 10 cm of the trunk and immediate surrounding soil. The higher rate per tree was used in Gisborne because of the larger tree size.

Table 1 Treatments applied to each citrus plot at the Gisborne and Kerikeri sites (rates/100 litres unless otherwise specified).

Treatment no.	First application Gisborne 17 November 2009 Kerikeri 13 November 2009	Second application Gisborne 23 December 2009 Kerikeri 10 December 2009
1	pymetrozine (Chess® WG, 40 g) + Latron® B-1956 (25 ml)	spirotetramat (Movento® 240 SC, 20 ml) + Partner® (50 ml)
2	diazinon (Dew™ 500, 100 ml) + Latron (25 ml)	buprofezin (Ovation™ 50WDG, 25 ml) + Excel® Oil (500 ml)
3	polysiloxane (AGPRO Organosilicone 100 ml)	mineral oil (Excel Oil (1000 ml)
4	imidacloprid (Confidor® ¹) soil drench (3 ml Confidor in 50 ml water per tree in Kerikeri, 5 ml Confidor in 500 ml water per tree in Gisborne)	
5	pyrethrin (Pyradym®, 50 ml) + Excel Oil (250 ml) premixed	pyrethrin (Pyradym, 50 ml) + Excel Oil (250 ml) premixed
6	Untreated control	

¹Treatment 4, imidacloprid soil drench was applied 20 November in Gisborne.

Growers applied some non-trial insecticides during the trial to control other pests. A mineral oil was applied on 29 January at Gisborne 1 and spinosad on 7 December and 20 January at the Gisborne 2 and Kerikeri sites, respectively.

ACW flight activity was monitored from the end of October (2 weeks before the first spray) until the beginning of December (2–3 weeks after the first spray) by placing three yellow sticky traps (18 × 16 cm) in the centre of each plot and replacing these weekly (dates are specified in Table 2), to determine the impact of the first insecticide on ACW flight activity.

The number of ACW in each trap was estimated by marking a 2-cm transect (2 × 16 cm) across the centre of the trap and counting the number of ACW adults within the transect. This number was then multiplied by 9 to give the total on the trap. If the number of ACW in the 2 × 16 cm transect appeared > 200, then adults within a 2 × 2 cm section were counted and the result was multiplied by 72 to give the total on the trap. If the number of ACW on the 2 cm transect was < 3, then the number of ACW on the entire trap was counted.

The number of ACW on leaves was assessed on 10 trees within the central part of each plot. On each tree, one inside and one outside ACW-infested branch and at least five young (young in October) and five mature leaves were tagged before spray application. These branches were monitored before the first spray, 3 days and 1 week after the first spray, before the second spray, 2, 4, 6 and 8 weeks after the second spray. On each monitoring occasion, the number of each ACW life stage on each of the five young and five mature leaves on tagged branches were categorised as: 0 = none; 1 = 1–20; 2 = 21–50; 3 = 51–100; 4 = 101–300; 5 = ≥301.

At 10 weeks after the second spray, the amount of sooty mould on each of the 10 trees was assessed firstly by recording the percentage of canopy with sooty mould within 1 m³ (1 m × 1 m × 1 m, length × width × depth) on each side of each tree; and secondly by recording the severity of sooty mould on 20 fruit (five each at 0–1 m height or 1–2 m height and located on inner or outer canopy) from each tree. For fruit

assessments, the amount of sooty mould was recorded using the following scoring system: 0 = none, 1 = < 1 cm², 2 = 1–2 cm², 3 = 2–3 cm², 4 = >3 cm².

At the 4- and 8-week counts, five branches per tree were examined for the presence or absence of other pesticide-induced pests, to record any adverse pest repercussions that could have arisen from the treatments disrupting natural enemies of these pests. These included citrus red mite (*Panonychus citri*), olive/hemispherical scale (*Saissetia oleae*/S. *coffae*), soft wax scale (*Ceroplastes destructor*), Chinese wax scale (*Ceroplastes sinensis*) and armoured scale (*Aonidiella aurantii*, *Lepidopahes beckii*, *Hemiberlesia* sp.).

Statistical analyses

The average whitefly counts for the different life stages were calculated at the site*date*plot level. The average counts data were logarithm₁₀ transformed before the analyses. One-way ANOVA was used to test the treatment effects on the transformed average counts for each site × date combination. Tukey's HSD ($\alpha = 0.05$) was used post hoc in the treatments' pairwise comparisons. The ANOVA was carried out using the general linear model procedure (PROC GLM) in SAS 9.2 system.

The sooty mould fruit scores were transformed to 'not infested'/'infested' scores (0 for not infested and 1 for infested) at the replicate level. The proportions of fruit infested with sooty mould were used in a binomial model to test the treatment effects. The least square means were used in the treatments' pairwise comparisons. The treatment effects are interpreted as the proportions of fruit infested with sooty mould. The treatment differences are interpreted as the odds ratio.

RESULTS AND DISCUSSION

Trap catch alone was not a reliable measure of the efficacy of insecticides targeting adults. However, trap catch data when combined with adult count data on leaves were useful indicators of treatment efficacy (Table 2). Pyle & Minchin (2009) also reported that trap catch alone was not a reliable indicator of treatment efficacy.

Table 2 Mean numbers of Australian citrus whitefly adults in traps and mean score for various life stages on citrus leaves at times of peak numbers for each site in 2009-10.

	Adults in traps (mean/trap/day)	Leaves (mean score)			
Site/Treatment	28/10-9/12/09	Adults ¹	Eggs ²	Young nymphs ³	Pupae ⁴
Gisborne 1					
pymetrozine/spirotetramat	742±253	0.56c ⁵	0.51bc	1.74bc	0.38c
diazinon/buprofezin	700±57	0.56c	0.22c	1.72cd	0.28c
polysiloxane/mineral oil	430±102	0.76bc	0.29bc	1.06d	1.03bc
imidacloprid soil drench	636±202	1.36a	0.58b	2.71ab	3.12a
pyrethrin/ pyrethrin	688±149	1.53a	0.30bc	2.65ab	1.71b
Untreated control	572±158	1.23ab	1.23a	3.06a	2.98a
Gisborne 2					
pymetrozine/spirotetramat	164±74	0.32b	0.49abc	1.48bcd	1.11b
diazinon/buprofezin	103±26	0.30b	0.66ab	1.08dc	0.63b
polysiloxane/mineral oil	178±66	0.45b	0.30bc	0.92d	1.18b
imidacloprid	158±47	0.81a	0.62abc	2.03ab	1.09b
pyrethrin/pyrethrin	139±47	0.52ab	0.23c	1.71abc	1.20b
Untreated control	121±33	0.85a	0.69a	2.37a	2.34a
Kerikeri 1					
pymetrozine/spirotetramat	57±15	0.08bc	0.91c	1.01b	0.03d
diazinon/buprofezin	112±46	0.00c	1.40bc	2.06a	0.80bc
polysiloxane/mineral oil	71±37	0.76bc	1.75b	2.10a	1.02abc
imidacloprid	411±75	1.62abc	2.96a	2.92a	0.73cd
pyrethrin/pyrethrin	107±34	0.39ab	1.39bc	2.28a	1.55ab
Untreated control	79±17	1.22a	1.67bc	2.53a	1.71a
Kerikeri 2					
pymetrozine/spirotetramat	14±5	0.16bc	0.90a	1.14a	0.14bc
diazinon/buprofezin	17±5	0.00c	1.06a	1.34a	0.15bc
polysiloxane/mineral oil	18±3	0.16bc	0.92ab	1.36a	0.69a
imidacloprid	13±3	0.17abc	0.37b	0.19b	0.00c
pyrethrin/pyrethrin	8±2	0.20ab	0.65ab	0.84a	0.53ab
Untreated control	33±2	0.38a	1.10a	1.56a	1.02a

¹3-7 days after spray 1.²2 days before spray 2.³2 weeks after spray 2.⁴8 weeks after spray 2.⁵Means in the same column and orchard group, followed by the same letter, are not significantly different (P=0.05).

ACW leaf score data from the unsprayed block at Gisborne 1 orchard are presented in Figure 1 to show the timing of spray applications relative to the abundance of each life stage during the season and is representative of all trial sites. In Northland and Auckland there is one main generation of ACW per year and a partial second generation (Jamieson et al. 2009a) and this trial confirms that in Gisborne the phenology of ACW is similar. This information reveals distinct windows of time when ACW life stages that are most susceptible to insecticides (adults and crawlers/young nymphs) are abundant and can be targeted.

An application of pymetrozine or diazinon applied at ~80% adult emergence reduced the abundance of ACW adults on leaves 1 week after application at all sites compared with that on unsprayed leaves (Table 2). A previous field trial testing the efficacy of a range of insecticides against ACW during the main period when adults are most abundant found that pymetrozine also reduced adult re-infestation 1 week after application (Pyle & Minchin 2009). At the Gisborne 1 orchard, where the ACW population was extremely high, polysiloxane also reduced the number of adults on trees for 1 week after spraying (Table 2). Orchards with very large ACW populations may require more than one application of an insecticide targeting adults to

reduce numbers. The timing of such applications is important to ensure that ACW are treated when adult rather than as pupae or eggs, which are very tolerant to insecticides in bioassays (Jamieson et al. 2009a). Targeting these life stages (e.g. winter application targeting pupae) is likely to be ineffective and is not recommended.

By following a pymetrozine, diazinon or polysiloxane application (targeted at adults) with spirotetramat, buprofezin or mineral oil applications, respectively, at the time of 80% egg hatch in order to target young nymphs, reductions in ACW populations were achieved for 8 weeks after the second spray (Table 2). These reductions were greater than those observed in untreated trees, pyrethrin-treated trees (two applications targeting adults and young nymphs) or trees receiving an imidacloprid soil drench. Potted plant trials have also demonstrated that spirotetramat, buprofezin and mineral oil were effective against ACW young nymphs (Jamieson et al. 2010). However, the high efficacy of pyrethrin and imidacloprid reported in those trials was not consistently recorded in this investigation. A field trial to determine the efficacy of three rates (0.5, 1.0 and 2.0 ml/tree) of imidacloprid soil application also revealed no apparent differences between ACW infestations on two tree plots treated with different imidacloprid rates and that on the untreated trees (Pyle & Minchin 2009).

Figure 1 Mean Australian citrus whitefly (ACW) score per leaf in the untreated block at the Gisborne 1 site for each life stage. 0 = none, 1 = 1-20, 2 = 21-50, 3 = 51-100, 4 = 101-300, 5 = >301. Arrows indicate the timing of insecticide applications in other treated blocks.

The amount of sooty mould on fruit and foliage in this trial was reduced on trees treated with pymetrozine/spirotetramat, diazinon/buprofezin or polysiloxane/oil combinations at the sites where sooty mould was a severe problem on untreated trees and trees treated with pyrethrin or a soil drench of imidacloprid

(Table 3). Should further reduction in ACW and sooty mould incidence be required at sites where ACW populations are extremely high, more than one insecticide targeting young nymphs may be required to maximise the chance of insecticide exposure to ACW as vulnerable young nymphs rather than as tolerant eggs.

Table 3 Mean sooty mould score and percentage of citrus fruit or leaves infested with Australian citrus whitefly (ACW) for each treated area at each site in 2009–10. Values are mean $\pm$ SEM at 10 weeks after spray 2.

Site/Treatment	Sooty mould score	% fruit infested	% fruit infested severe	% foliage infested
Gisborne 1				
pymetrozine/spirotetramat	0.43 $\pm$ 0.04	38.3 d ¹	6.7 $\pm$ 2.3	83.5 $\pm$ 2.3
diazinon/buprofezin	0.28 $\pm$ 0.04	24.0 d	4.4 $\pm$ 1.6	44.5 $\pm$ 3.8
polysiloxane/mineral oil	0.48 $\pm$ 0.04	42.9 d	8.5 $\pm$ 2.6	47.0 $\pm$ 3.0
imidacloprid soil drench	1.45 $\pm$ 0.10	79.1 c	66.7 $\pm$ 5.7	92.5 $\pm$ 1.6
pyrethrin/ pyrethrin	1.75 $\pm$ 0.08	90.0 b	86.1 $\pm$ 3.3	94.8 $\pm$ 1.2
Untreated control	2.70 $\pm$ 0.08	99.4 a	99.3 $\pm$ 0.7	98.5 $\pm$ 0.5
Gisborne 2				
pymetrozine/spirotetramat	0.00 $\pm$ 0.00	0.0 a	0.0 $\pm$ 0.0	0.3 $\pm$ 0.1
diazinon/buprofezin	0.00 $\pm$ 0.00	0.0 a	0.0 $\pm$ 0.0	0.3 $\pm$ 0.2
polysiloxane/mineral oil	0.05 $\pm$ 0.02	3.5 a	0.5 $\pm$ 0.5	11.0 $\pm$ 1.0
imidacloprid	0.06 $\pm$ 0.02	6.0 a	0.0 $\pm$ 0.0	6.8 $\pm$ 1.4
pyrethrin/pyrethrin	0.09 $\pm$ 0.02	8.5 a	0.0 $\pm$ 0.0	7.0 $\pm$ 1.2
Untreated control	0.05 $\pm$ 0.02	5.0 a	1.0 $\pm$ 0.7	13.9 $\pm$ 1.3
Kerikeri 1				
pymetrozine/spirotetramat	0.00 $\pm$ 0.00	0.0 a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
diazinon/buprofezin	0.01 $\pm$ 0.01	1.0 a	0.0 $\pm$ 0.0	0.5 $\pm$ 0.3
polysiloxane/mineral oil	0.02 $\pm$ 0.02	0.5 a	0.5 $\pm$ 0.5	4.8 $\pm$ 1.3
imidacloprid	0.03 $\pm$ 0.01	1.5 a	1.0 $\pm$ 0.7	6.4 $\pm$ 2.0
pyrethrin/pyrethrin	0.05 $\pm$ 0.02	3.5 a	1.5 $\pm$ 0.9	8.4 $\pm$ 2.1
Untreated control	0.11 $\pm$ 0.03	6.5 a	3.1 $\pm$ 1.3	33.8 $\pm$ 7.2
Kerikeri 2				
pymetrozine/spirotetramat	0.00 $\pm$ 0.00	0.0 a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
diazinon/buprofezin	0.00 $\pm$ 0.00	0.0 a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
polysiloxane/mineral oil	0.00 $\pm$ 0.00	0.0 a	0.0 $\pm$ 0.0	0.1 $\pm$ 0.1
imidacloprid	0.00 $\pm$ 0.00	0.0 a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
pyrethrin/pyrethrin	0.00 $\pm$ 0.00	0.0 a	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0
Untreated control	0.00 $\pm$ 0.00	0.0 a	0.0 $\pm$ 0.0	2.4 $\pm$ 0.7

¹Means in the same column and orchard group, followed by the same letter, are not significantly different (P=0.05).

None of the treatments resulted in an increase in the insecticide-induced pests (data not shown), indicating that biological control at the sites was not significantly disrupted by treatment of the relatively small trial area. However, on a larger scale insecticide-induced pests should be continually monitored when incorporating insecticides to control ACW in a citrus integrated pest management (IPM) programme.

ACW has been reported to be a threat to citrus production once 30% of leaves become infested (Pyle & Minchin 2009). The incidence of ACW on leaves (% leaves infested) could not be used in this trial to determine the risk of sooty mould, because branches with ACW were preferentially selected for monitoring of treatment efficacy and not randomly selected. However, levels of ACW that contributed to high risk of sooty mould on fruit in this trial were combinations of 400-600 adults caught/trap/day in November, with mean adult abundance scores on leaves of >1 in November (with or without egg abundance scores of >1 in December) and young nymph abundance scores of >2.5 in January (with or without pupae abundance scores of >2.5 in February).

Given that there are many records of insecticide resistance in whitefly species, it is important to have a variety of insecticides available for rotation within a resistance management strategy. The present findings indicate that there are several effective insecticides available for ACW control that could be used within such a spray programme. However, use of diazinon could be restricted or prohibited in the future depending on the results of a review being conducted by the Environmental Risk Management Authority.

Good spray coverage is essential for the foliar applications of contact insecticides to be effective. ACW populations are located on the undersides of citrus leaves and efficient targeting of sprays to these areas will be critical if the pest is to be controlled. Use of systemic materials would be advantageous if lethal concentrations can reach the leaves of infested, mature citrus trees. The rate of imidacloprid used in this trial did not result in consistently good control of ACW.

Although insecticides will provide some interim control of ACW, the most effective long-term strategy is most likely to be the implementation of a biological control programme. In the meantime, insecticide combinations such as pymetrozine/spirotetramat, diazinon/buprofezin or polysiloxane/oil applied in late spring targeting adults, and in early summer when the young nymph stages are most abundant, have been shown to reduce the abundance of ACW and the risk of sooty mould and are unlikely to disrupt other control agents in a citrus IPM strategy.

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