Increased numbers of earwigs (*Forficula auricularia*) in kiwifruit orchards are associated with fewer broad-spectrum sprays

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Abstract European earwigs are sensitive to the residues of broad-spectrum insecticides. More earwigs are found on organically-managed than on conventionally-managed kiwifruit orchards. Since 2007 there have been changes in insecticide use on kiwifruit orchards. In particular, the broad-spectrum insecticide diazinon was replaced by so-called “reduced-risk” insecticides. In the current study earwig numbers were measured in nine conventionally-managed and seven organically-managed orchards for 4 years (2006-07 to 2009-10). Numbers of earwigs on orchard blocks under organic management did not differ between years and were initially higher than on conventionally-managed orchard blocks. There was a trend for earwig numbers to increase on conventionally-managed orchard blocks. Earwig abundance decreased by approximately 60% with each spray application after allowing for differences between years.

Keywords European earwig, diazinon, insecticide residues, population.

INTRODUCTION

European earwigs (*Forficula auricularia* L.) are common in modified habitats in New Zealand where they prey on arthropods. Within kiwifruit orchards European earwigs provide an ecosystem service as predators of pests such as diaspidid scale insects and tortricid larvae. Application of insecticide is the basis for pest management in kiwifruit. Insecticides can be applied when threshold counts of scale insects and fruit damage (due to tortricids) are crossed (KiwiGreen system) or prior to known periods of high-risk (early season). Spray frequency is greatest around late spring and early summer (October-December) coinciding with the period that juvenile European earwigs disperse from

underground nests into the canopy of kiwifruit vines and moult into adults. European earwigs shelter in crevices during the day and probably avoid direct contact with most sprays. However, nymphs and adults are highly sensitive to the residues of some insecticides (French-constant & Vickerman 1985; Nicholas & Thwaite 2003; Maher et al. 2006; Shaw & Wallis 2010) and there is potential for large reductions of European earwig populations. Recovery of populations from toxic insecticide applications within orchard blocks may be slow because earwigs have just one generation per year. On organically-managed orchards (5% and 1.7% of the ZESPRI® GREEN and GOLD Kiwifruit export crop respectively in

2004, T. McLaughlin, ZESPRI Group Ltd, pers. comm.), diaspidid scale insects and leafrollers are controlled by spraying mineral oil products and *Bacillus thuringiensis*-based insecticides respectively. Neither insecticide has residues that are toxic to earwigs (Maher et al. 2006). More earwigs were found in organic than conventional kiwifruit orchards during 2006-07 (Maher & Logan 2007), suggesting that insecticides used in the conventional growing system may be contributing to mortality.

The broad-spectrum organophosphate insecticide diazinon was removed from the ZESPRI crop protection programme in 2007 (Steven et al. 2007). Removal was the result of a European Commission (EC) decision to reduce the maximum residue limit (MRL) for diazinon to 0.01 mg/kg (Anon. 2009b). So-called “reduced-risk” insecticides (Anon. 2011) with relatively low toxicity to non-target organisms have replaced diazinon. This change in insecticide use may have an effect on the abundance of European earwigs on conventional orchards. This paper reports annual counts of earwigs in organic and conventionally-managed kiwifruit orchards in the four consecutive years from 2006-07 to 2009-10 including sampling by Maher & Logan (2007). Counts were related to numbers of earwig-toxic sprays applied to each monitored orchard block. The aim was to determine whether changes to the spray programme for kiwifruit orchards, in particular the removal of diazinon, was associated with changes in the number of earwigs.

MATERIALS AND METHODS

European earwigs were sampled from one commercial block of Hayward kiwifruit (marketed as ZESPRI® GREEN Kiwifruit) on each of seven organic and nine conventionally-managed orchards in the Te Puke-Tauranga region. Sampling followed the method of Maher & Logan (2007) and was carried out each summer from 2006-07 to 2009-10. At each orchard block, a cardboard shelter trap (100 mm wide × 850 mm long) was placed in the canopy of each of 25 vines. Vines were numbered and shelters allocated to vines based on a list of random

numbers. Shelters were secured to the vine leader by wire and protected from rainfall and sprays by an inverted wax-paper cup. The sampling period was 5-6 weeks from mid December until late January, when counts of earwigs in shelters were made. Maher & Logan (2007) reported earwig counts from eight organic and eight conventionally-managed orchards in 2006-07. One conventionally-managed site was erroneously reported as having organic management. These data were corrected for this study.

Insecticides applied to each orchard block were determined for the 12-month period before and including the sampling period (i.e. from February to the following January). Data were from grower spray diaries supplied by ZESPRI Group Ltd. Insecticides were rated for toxicity to European earwigs according to published laboratory assays and field studies (Table 1). Insecticides were rated high for toxicity when residues of recommended field rates were associated with ≥50% mortality of earwigs in bioassays using treated plant material or inert surfaces. Three insecticides (abamectin, methoxyfenozide and tebufenozide) were classified as of low toxicity based on having an LC_{50} higher than the registered field rate; conversely chlorpyrifos was rated as highly toxic based on having an LC_{50} less than the registered field rate. Toxicity for thiacloprid varied between studies from high (94% 10DAT) to none for unknown reasons (Table 1). As two of the three studies indicate that thiacloprid killed >50% earwigs within 10DAT, it was rated as a highly toxic spray in this study. Data from all four summers of sampling (2006-07 to 2009-10) were analysed to determine whether there was an interaction between years and the number of sprays rated as highly toxic to earwigs.

Counts from 25 traps for each orchard block were summed for analysis. A generalized linear model was used to test for differences between the 4 years using R version 2.12.1 (R Development Core Team 2010). The model used the quasi Poisson family to allow for the overdispersion of the counts. Similarly, the conventionally-managed orchards were analysed to test for differences between years and the

Table 1 Estimated toxicity of residues to European earwigs for insecticides used in kiwifruit orchards. Insecticides were rated high for toxicity when residues of recommended field rates were associated with $\geq 50\%$ mortality in bioassays using treated plant material or inert surfaces.

Active ingredient	Toxicity estimate	Toxicity rating	Reference
Bifenthrin	75% 2DAT ¹	High	Colvin & Cranshaw 2010
Chlorpyrifos	50% 6DAT	High	Maher & Connolly 2009
Chlorpyrifos	LC ₅₀ =0.03 $\mu\text{g a.i./cm}^2$	High	Nicholas & Thwaite 2003
Diazinon	>90% 1DAT	High	Maher et al. 2006
Diazinon	70% 10DAT	High	Shaw & Wallis 2010
Spinosad	72% 10DAT	High	Shaw & Wallis 2010
Thiacloprid	94% 10DAT	High	Shaw & Wallis 2010
Thiacloprid	56% 7DAT	High	Vogt et al. 2008
Thiacloprid	0	Low	Maher & Connolly 2009
Abamectin	0	Low	Nicholas & Thwaite 2003
<i>Bacillus thuringiensis</i>	0	Low	Maher et al. 2006
Methoxyfenozide	0	Low	Nicholas & Thwaite 2003
Methoxyfenozide	0	Low	Shaw & Wallis 2010
Mineral oil	0	Low	Maher et al. 2006
Mineral oil	0	Low	Sterk et al. 1999
Spirotetramat	0	Low	Maher & Connolly 2009
Spirotetramat	0	Low	Shaw & Wallis 2010
Tebufofenozide	0	Low	Nicholas & Thwaite 2003
Thiamethoxam	0	Low	Maher & Connolly 2009

¹DAT=days after treatment.

effect of the number of insecticide sprays during the 12 months preceding counts of earwigs. Orchards were separated by a maximum of 30 km and were within 20 km of the coast. They were assumed to share the same environmental conditions and differ only for management system. Organic or conventional management systems were assumed to be the same for all orchards, with the exception of insecticide spray frequency for conventionally-managed orchards. The number of earwigs captured was assumed to be directly proportional to the numbers present in the orchard blocks studied and their capture and removal was assumed not to affect numbers in the following generations. The seven organic orchards were assumed to give a representation of the background earwig density.

RESULTS

Numbers of earwigs varied widely between orchard blocks (from 1 to 21.5/trap in the least variable year), with differences between organically-

managed and conventionally-managed orchard blocks in most years (Figure 1). There was a trend of increasing earwig numbers in conventionally-managed orchard blocks with time. Numbers of

Figure 1 Numbers (mean $\pm$ SE) of European earwigs in 25 shelter traps for seven organically- and nine conventionally managed Hayward kiwifruit orchard blocks.

applications of insecticides rated as having highly toxic residues to European earwigs varied from 1 to 5 on conventionally-managed orchard blocks, with a trend of decreasing highly toxic insecticide applications with time (Figure 2). No sprays rated as highly toxic were applied to organically-managed orchard blocks.

There were no differences in numbers of earwigs between years for the orchards under organic management ($P > 0.05$). Earwig numbers in conventionally-managed orchards showed an effect of year and of the number of sprays ($P = 0.02$ and 0.03 respectively), but no interaction between these effects. Earwig numbers were reduced by approximately 60% for each spray application on conventionally-managed orchards after allowing for the between-year differences (Figure 3).

DISCUSSION

Reduction of natural enemies in conventionally-managed systems is often attributed to the application of broad-spectrum insecticides (e.g. Koss et al. 2005). Laboratory assays confirm that natural enemies can be highly susceptible to broad-spectrum insecticides (e.g. Bozsik et al. 2002). Fewer broad-spectrum insecticides are now used in crop protection programmes in developed countries than in the recent past. Insecticides used in developed countries have changed often since

the 1950s mainly as a result of regulation. Nearly all spray applications against diaspidid scale insects in a survey of 24 conventionally-managed kiwifruit orchards in 2004-05 were broad-spectrum sprays (diazinon and chlorpyrifos) (Steven & Bengé 2007). In 2007 the EC revised the MRLs for diazinon and subsequently it was removed from the ZESPRI crop protection programme in New Zealand kiwifruit (Steven et al. 2007; Anon. 2009b). Chlorpyrifos was widely used in 2007-08 to reduce numbers of diaspidid scale insects. However, since then sprays for diaspidid scale control have almost exclusively been reduced-risk insecticides. In general these newer insecticides have more selectivity and hence cause less harm to natural enemies than those first used in the 1950s-1970s. Toxicity to natural enemies is not always low for reduced-risk insecticides but varies with different modes of action and the type of natural enemy-prey interaction. Emamectin-benzoate has translaminar activity and surface residues are rapidly degraded. It was effective against lepidopteran larvae feeding on treated vegetation, but had low contact toxicity to hemipteran predators (Boyd & Boethel 1998). Insect growth regulators did not reduce densities of most predator taxa in cotton (Naranjo et al. 2004) and had minimal negative effects on a parasitoid of two lepidopteran pests (Hewa-Kapuge et al. 2003).

Figure 2 Number (mean $\pm$ SE) of earwig-toxic sprays applied to nine conventionally managed orchard blocks for each of four consecutive years (2006-07 to 2009-10).

Figure 3 Predicted numbers of earwigs for each year (symbols) and for 0 to 4 sprays on conventionally-managed kiwifruit orchards. Dashed line added to indicate trends only.

Spinosad, a neurotoxin, had significant negative effects on three mandibulate predators (Cisneros et al. 2002). Diazinon is a neurotoxin with contact activity against a broad-range of insects including European earwigs. Its removal from the spray programme may be a major factor in the increased numbers of earwigs observed on conventionally-managed orchards since 2007. Several other earwig-toxic insecticides remain on the ZESPRI crop protection programme. One (chlorpyrifos and its formulations) has been removed from the ZESPRI crop protection programme for 2011-12 pre-empting a scheduled review by ERMA in 2013 (Anon. 2009a). In the two most recent growing seasons of the survey (2008-9, 2009-10), the earwig-benign insecticide spirotetramat (Movento®) has largely replaced other sprays targeting diaspidids. In addition to the changes of insecticides, application has been largely restricted to the pre-flowering window (October-November) because of a lack of MRLs. There are now few earwig-toxic sprays applied during October-December when earwigs are abundant in the canopy of kiwifruit. Post-flowering sprays are limited to two earwig-benign insecticides, mineral oil and *Bacillus thuringiensis*.

Recent changes to insecticide use in kiwifruit may result in increased numbers and diversity of arthropods on fruit at harvest. Invertebrate biodiversity is marginally but consistently greater on organic than on conventionally-managed orchards (Todd et al. 2011). However, response to changes in insecticide use may vary according to taxon. Numbers of *Czenzipskia* mites were greater on the leaves of organically- than on conventionally-managed kiwifruit vines, while the opposite trend occurred for two tydeid mites (Steven & Bengé 2007).

Annual variation in numbers of earwigs occurred that was independent of predicted spray effects. On organic orchards the average number of earwigs was relatively stable, varying annually by less than two-fold during the 4 years of the survey. There was no consistent pattern to annual changes in numbers. Earwig abundance tended to be low on conventionally-managed orchards for the first three summers of sampling. Two

orchard blocks had relatively high numbers of earwigs that were consistent with numbers more typically found on organic orchards. Mortality factors and the range of survival for immature earwigs in kiwifruit orchards are poorly known. Predation by birds and cannibalism associated with inadequate prey may limit earwig densities in the absence of broad-spectrum insecticides. Factors associated with variable populations on conventionally-managed orchards require further study.

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