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Project Leader:	Michelle Fountain, East Malling Research
Key Workers:	Michelle Fountain Philip Brain (Biometrician)
Location of Project:	East Malling Research New Road East Malling, Kent ME19 6BJ Tel: 01732 843833 Fax: 01732 849067
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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

CONTENTS

GROWER SUMMARY

Headline

Earwig 'compatible' spray programmes can increase earwig numbers in orchards.

Background and expected deliverables

Earwigs are very important generalist predators in both apple and pear orchards. They play a key role in regulating populations of several highly damaging pests including woolly aphid and other aphid pests, mussel scale, codling moth and pear sucker. Recent laboratory tests and field experiments at EMR and in other European countries indicate that several very commonly used insecticides including Calypso (thiacloprid), Steward (indoxacarb), Equity (chlorpyrifos) and Tracer (spinosad) have harmful effects on earwigs and could be, at least partly, responsible for the low populations of these important predators in some orchards. This project further investigated the lethal and sub-lethal effects of these and other commonly used insecticides on different earwig life stages in laboratory and field studies with a view to devising earwig compatible spray programmes for UK orchards.

Summary of the project and main conclusions

In laboratory tests in year 1 (2011), chlorpyrifos was the most toxic of the insecticides tested to earwigs with most dying within a couple of days of exposure in Petri dishes. In order of decreasing toxicity Tracer (spinosad)> Calypso (thiacloprid)> Runner (methoxyfenozide)> Steward (indoxacarb)/Envidor (spirodoclofen)/Gazelle (acetamaprid) were also harmful. Runner significantly reduced nymph growth, but showed no effects on adult earwigs. Agrimec (abamectin), Coragen (chlorantraniliprole), Mainman (flonicamid) and a coded product were not deemed toxic in the laboratory study.

Based on the findings from the laboratory experiment and other researchers, Pyrinex (chlorpyrifos), Mainman (flonicamid), Runner (methoxyfenozide), Envidor (spirodiclofen), Calypso (thiacloprid) and two novel plant protection products were selected to test in a small plot (six trees) field study at the recommended field dose (in 2012). Earwigs exposed to chlorpyrifos on trees were less affected by the pesticide product than in laboratory studies in

Petri dishes. However, numbers of adults decreased over time in trees treated with it in the spring compared to the untreated control. Calypso was the most detrimental of the tested products, to earwig adult and nymph numbers in the canopy of the trees. In addition, small numbers of dead earwigs were found in the feeding bottles on trees treated with this product. Mainman also reduced earwig numbers in trees. In laboratory experiments, nymphs exposed to Runner had a significantly reduced body weight, but in field tests the product had no effect on nymph numbers.

In the final year of the project, a large scale, whole orchard, trial was done to investigate 'earwig compatible' spray programmes. Orchards were divided into two; one half received the growers conventional spray programme and the other half avoided using any products known to be harmful to earwigs. Insecticides screened in years 1 and 2 and those of other researchers (Table 1) deemed as most toxic to earwigs, were omitted from the earwig compatible programme at key stages of the earwig lifecycle (notably females feeding in trees in spring and nymphs in trees in the summer). These included; chlorpyrifos, cypermethrin, spinosad, thiacloprid, deltamethrin, indoxacarb, methoxyfenozide (in the summer), and spirodiclofen. Sprays were applied according to the label recommendations (dose and max number) using the grower's standard air assisted sprayers. Populations were monitored in the spring, early summer and late summer. Whilst earwig numbers increased in the halves of the orchards with the 'earwig compatible' programme, populations were significanly negatively affected by products incorporated into programmes and known to be detrimental. One or two sprays of an earwig harmful product (chlorpyrifos) between April and July had detrimental effects on earwig numbers.

Table 1. Summary of data from this project and data published by other researchers on the safety of active ingredients to earwigs

a.i.	Data from this project	Other researchers	Reference*
Abamectin	Safe	Harmful	1
Acetamiprid	Safe	-	
Bacillus thuringiensis	-	Safe	9
chlorantraniliprole	Safe	Safe to adults	10,12
Chlorpyrifos	Harmful	Harmful	1,2
Cypermethrin	-	Harmful (nymphs), knockdown	1,8
Deltamethrin	-	Harmful, knockdown	1,4,7,8
Diflubenzuron	-	Harmful	9,11
Dimethoate	-	Harmful	1,8
Flonicamid	Safe (lab) harmful (nymphs, field)	Safe, harmful	1,3,5
Indoxacarb	Harmful (males), knockdown	Harmful, knockdown	1,3,4,5,10
methoxyfenozide	Harmful to nymphs	Safe to adults	4, 10
Pirimicarb	-	Safe	1,8
potassium bicarbonate	-	Safe	12
Spinosad	Harmful, knockdown	Harmful	1,2,3,5,6, 10
Spirodiclofen	Harmful nymphs (lab), safe (field)	-	
Thiacloprid	Harmful	Harmful	1,3,5,10

*1 Peusens and Gobin 2008; 2 Cisneros *et al*. 2002; 3 Vogt *et al*. 2010; 4 Peusens *et al*. 2010; 5 Vogt *et al*. 2009; 6 Peusens *et al* 2009; 7 Colvin and Cranshaw 2010; 8 Ffrench-Constant and Vickerman 1985; 9 Maher *et al*. 2006; 9 Sauphanor *et al*. 1993; 10 Shaw and Wallis 2010, 11 Ravensberg 1981, 12 Beliën 2012.

Financial benefits

- Growers will be able to use the information in Table 1 to make decisions on which insecticides to use to control codling moth, aphids, mussel scale and pear sucker whilst avoiding using insecticides which harm the key life stages of earwigs.
- The resulting increase in earwig numbers in commercial orchards will lead to greater natural predation of these pests, reducing reliance on costly crop protection products.

Action points for growers

- Growers should make considered choices of pesticide products based on the knowledge of important predators in the orchard at the time of spraying.
- Growers can consult Table 1, when selecting products for pest control and take into consideration the time of year the application is being made and the potential harm to earwig populations.

SCIENCE SECTION

Background

There are only seven species of earwig (Dermaptera) in Britain. The earwig most commonly encountered in UK orchards is the common European earwig, *Forficula auricularia* L. (Fitzgerald and Solomon 1996; Solomon *et al*. 1999).

Earwigs are omnivorous, feeding on other arthropods, plants, microscopic algae and fungi and are even cannibalistic. They are important predators of many pests of orchards, including scale insects (McLeod and Chant 1952; Karsemeijer 1973;), psyllids (Lenfant *et al*. 1994; Solomon *et al*. 1999), woolly apple aphid (Phillips 1981; Ravensburg 1981; Noppert *et al*. 1987; Mueller *et al*. 1988; Nicholas *et al*. 2005; Dib *et al*. 2010) and codling moth (Glen 1977). Excluding earwigs from woolly apple aphid or psyllid infested trees leads to a proliferation of the pests (Mueller *et al*. 1988; Sauphanor *et al*. 1993; Nicholas *et al*. 2005; Gobin *et al*. 2008). Also, in laboratory tests, He *et al*. (2008) found that earwigs were capable of eating up to 68 apple leaf curling midge larvae in a single evening and trees with earwig refuges were more actively foraged for the larvae than trees without refuges.

Reports that earwigs are declining in some orchards in Belgium and the Netherlands (Gobin *et al*. 2008) has raised concern for this effective, natural predator. Moerkens *et al*. (2009) and Gobin *et al*. (2008) also recognised the inter-orchard and inter-annual variation in earwig populations with a population crash at the time of moulting to adults. They concluded that contributing factors could include pesticides or orchard management, but that there was no conclusive evidence for these. Other influences could be migration, starvation, pathogens, parasitoids, parasites, predation and/or cannibalism (Moerkens *et al*. 2009) or even flooding of nest sites in the winter.

In September male and female earwigs pair bond, begin to mate and can be found together in the autumn and winter. They live in a chamber, often in the soil, about 2.5-10 cm deep. After mating, the sperm may remain in the female for months before the eggs are fertilized. From mid-winter to early spring the male will leave or be driven out by the female. A female *F. auricularia* lays 50 to 90 eggs. She attends the delicate first stage nymphs and regurgitates food to them (Staerkle and Kolliker 2008). Females die before mid-summer but can be found foraging in trees in May. Third instar nymphs move into the tree canopy (Phillips 1981) from June onwards and then the 4^{th} instars emerge as adults (July-August) (Gobin *et al*. 2008).

Studies have revealed that *F. auricularia* is composed of a complex of two sibling species, one species being single-brooded and the other with two broods (Wirth *et al*. 1998). In 2011 earwig females in at least two UK orchards had at least two broods (C. Nagy pers. comm.). This has consequences for earwig dispersal. Single brood earwigs disperse four times the distance of double brood earwig populations; up to 29 m compared to 8 m in a month, respectively (Moerkens *et al*. 2010). There does not appear to be a difference in dispersal between the sexes (Moerkens *et al*. 2010) and as earwigs rarely fly dispersal is almost always by walking. The number of broods earwigs have and the stage of development have consequences for spray application timings through the season. Harmful insecticides applied between June and October are likely to have an effect on earwig populations. Even small effects on behaviour may have consequences on populations for the rest of the year.

Because earwigs are nocturnal their numbers can be underestimated in orchards and, although they may not be directly exposed to pesticide applications applied in the daytime, they may be exposed to chemical residues whilst moving around and feeding at night. The sensitivity of earwigs to many modern insecticides at recommended field doses remains unknown. In addition, the vulnerability of the different life stages to pesticides requires investigation (Ffrench-Constant and Vickerman 1985).

Earwigs can be exposed to pesticides in tests by direct exposure (topical or oral), indirect exposure (contact with residue on glass, soil or leaves) or field exposure (enclosing on sprayed trees or field sprays).

Objectives

Year 3 objectives were to evaluate earwig compatible spray programmes against a grower's standard spray programme in the protection of apple from pests and:

- Assess the response of earwig populations to earwig compatible spray programmes
- Analyse the efficacy of the programme to control common apple orchard pests

Materials and methods

Sites

In 2013, two orchards on each of two farms were divided into two halves. One half of each orchard was treated with the grower's conventional insecticide spray programme and the other half with a proposed earwig compatible spray programme based on evidence from previous studies (Table 2).

- Farm 1

  Howard Chapman Ltd, Broadwater Farm, Broadwater Lane, West Malling, Kent
  Long: 51.284 Lat: 0.421
    - Orchard 1; Gala 4.69 ha, planted 1995
    - Orchard 2; Gala, 5.0 ha, planted 2001

- Farm 2

  G H Dean & Co Ltd, Hempstead Farm, Tonge, Sittingbourne, ME9 9BJ
  Long: 51.335 Lat: 0.776
    - Orchard 3; Gala 2.25 ha, planted 1990
    - Orchard 4; Gala, 5.0 ha, planted 2008

Treatments

Insecticides screened in years 1 and 2, and those of other researchers which showed evidence of toxicity to earwigs (Tables 1 and 2), were omitted from the earwig compatible spray programme at key stages of the earwig lifecycle (notably females feeding in trees in spring and nymphs in trees in the summer). These included: chlorpyrifos, cypermethrin, deltamethrin, indoxacarb, methoxyfenozide, spirodiclofen, flonicamid, spinosad and thiacloprid. Sprays were applied according to the label recommendations (dose and max number) and normal grower best practice using the growers' standard air assisted sprayers. The earwig compatible programme was closely monitored to ensure that pests did not become a problem.

Table 2. Spray programmes applied to the four orchards. Half of each orchard received the growers' standard spray programme and half received a programme where insecticides were deemed less harmful to earwigs, 'earwig compatible'. Products in bold were considered to be detrimental to earwigs. B.t. = *Bacillus thuringiensis*

	Earwig safe		**Grower standard**	
Farm 1	**Orchard 1**	**Orchard 2**	**Orchard 1**	**Orchard 2**
7 May	flonicamid	flonicamid	flonicamid	flonicamid
7 May	-	-	**chlorpyrifos**	**chlorpyrifos**
26 Jun	-	-	-	**chlorpyrifos**
17 Jul	chlorantraniliprole	chlorantraniliprole	chlorantraniliprole	chlorantraniliprole
8 Aug	chlorantraniliprole	chlorantraniliprole	chlorantraniliprole	chlorantraniliprole
Farm 2	**Orchard 3**	**Orchard 4**	**Orchard 3**	**Orchard 4**
27 Apr			**chlorpyrifos**	**chlorpyrifos**
7 May	flonicamid	flonicamid	flonicamid	flonicamid
4 Jul	chlorantraniliprole	chlorantraniliprole	chlorantraniliprole	chlorantraniliprole
22 Jul	pirimicarb	pirimicarb	pirimicarb	pirimicarb
22 Jul	*B.t.*	*B.t.*	**methoxyfenozide**	**methoxyfenozide**
14 Aug	chlorantraniliprole	chlorantraniliprole	chlorantraniliprole	chlorantraniliprole

Experimental design

Four replicates of two treatments were used with each orchard as a block. Twenty earwig refuge bottles were placed in the centre of each half (plot) of each orchard (=200). The traps were in the centre four rows – five traps per row on every other tree. Refuges were tied to the tree stake of the tree at a height of 1.5 m (as above). Trees received a routine protective spray programme against plant pathogens.

Assessments

Assessments of the number of *F. auricularia* on each tree in each orchard half was done by a 30 second search of the centre 20 trees (10 minutes per plot, 20 minutes per orchard) in the evening from 22.00 to 24.00 (April, June and August). Sex and nymph stage were identified. In addition, the numbers of *F. auricularia* were also assessed from the bottle refugia the following day. After sampling, earwigs were released beneath the trees from which they were collected.

Apple pest assessments were done the day following the earwig night assessments by looking over the same trees where the earwig assessments were concluded. Assessments at Farm 1 were completed on 1 May (night), 2 May (day), 13 June (night), 14 June (day), 29 August (night), 30 August (day) and at Farm 2 on 30 April (night), 1 May (day), 18 June (night), 19 June (day), 27 August (night) and 28 August (day).

Statistical analyses

Data were analysed by ANOVA with square root transformations of count data to normalise for variances.

Results

There were very few differences in numbers of pest species on the trees between the two treatment spray programmes (conventional and 'earwig compatible'). For example, rosy apple aphid and woolly apple aphid numbers did not differ. This may be because applied insecticides controlled these pests where they were not kept in check by the earwigs. Damage caused by capsid, codling moth and rhynchites weevils was too low to analyse in this study.

However, there were significantly more apple grass aphids, *Rhopalosiphum insertum,* on the earwig compatible (mean / tree 0.104) compared to the conventionally sprayed (0.013) halves of the orchards (ANOVA square root transformed data, P=0.015). In addition, there were also slightly higher numbers of rolled shoot tips damaged by apple leaf curling midge, *Dasineura mali*, on the earwig compatible spray programme halves of the orchards (conventional 2.553, compatible 2.908 damaged per 10 shoots) (ANOVA square root transformed data, P=0.046). Neither of these species are significant pests of established, mature, apple trees.

A pilot study (not reported here) showed that the numbers of earwigs foraging in trees is closely related to numbers of earwigs in refuge bottles and so the analyses for the farm trials was done using the data from the numbers of earwigs in refuges (Table 3). Numbers of male *F. auricularia* were not affected by the spray programmes. However, numbers of female and nymph *F. auricularia* were significantly higher in the 'earwig compatible' programme compared to the conventional spray programme (Table 3). Numbers of female earwigs increased over the duration of the experiments, with nymph numbers peaking in June (Table 3). Earwig nymphs were higher at Farm 1 compared to Farm 2 (Table 3). One or two sprays of chlorpyrifos between April and July had a detrimental effect on earwig numbers.

Table 3. Mean numbers and square root (SQRT) numbers of earwigs, *F. auricularia,* per tree on the two farms, over the growing season for the two spray programmes. NSD = no significant difference

	Actual mean	**SQRT mean**				
Farm	**Male**		**P**	**sed**	**lsd**	**df**
1	2.82	0.731				
2	0.53	0.242				
			NSD			
Season						
May	4.22	1.087				
June	0.03	0.031				
August	0.76	0.342				
			<0.001	0.1053	0.2079	156
Treat						
Conventional	1.84	0.437				
'Earwig compatible'	1.50	0.537				
			NSD			
Farm	**Female**		**P**	**sed**	**lsd**	**df**
1	0.175	0.145				
2	0.833	0.316				
			NSD			
Season						
May	0.050	0.046				
June	0.219	0.178				
August	1.244	0.467				
			<0.001	0.0597	0.1179	156
Treat						
Conventional	0.104	0.082				
'Earwig compatible'	0.904	0.379				
			<0.001	0.0420	0.0828	234
Farm	**Nymph**		**P**	**sed**	**lsd**	**df**
1	5.89	1.162				
2	0.17	0.092				
			0.009	0.1001	0.4307	2
Season						
May	0.00	0.000				
June	9.07	1.867				
August	0.02	0.015				
			<0.001	0.0923	0.1823	156
Treat						
Conventional	1.33	0.386				
'Earwig compatible'	4.72	0.869				
			<0.001	0.0846	0.1666	234

Discussion

The results of this project have contributed to a growing evidence of the effects of pesticides on different stages of earwigs, a key predator of tree fruit pests (Table 1, shown again in Conclusions below). By using laboratory, small plot field and orchard scale studies we have determined the harmfulness of some commonly used orchard insecticides in order to better time and advise on their use throughout the growing season.

Conclusions

In the final year of this project it was demonstrated that by avoiding pesticides known to be harmful to earwigs at key stages of the earwig lifecycle – when they are present in trees – it was possible to maintain high numbers of earwigs foraging in trees. Orchards which previously had low numbers of earwigs showed an increase in earwig numbers over the course of a season if harmful products were avoided when the earwigs were in the trees.

However, with some products there are still uncertainties over the earwig safety and timing. Examples include abamectin, acetamiprid and spiridoclofen. These products are used to control sporadic pests, such as capsids, pear sucker and weevils. A deeper understanding of the long term effects of these insecticides in the laboratory and field will enable growers to use them more effectively without harming the earwigs in their orchards.

Growers should consult Table 1 (below), when selecting products for pest control and take into consideration the time of year the application is being made and the potential harm to earwig populations.

Table 1. Summary of data from this project and data published by other researchers on the safety of active ingredients to earwigs

a.i.	Data from this project	Other researchers	Reference*
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dimethoate	-	Harmful	1,8
flonicamid	Safe (lab) harmful (nymphs, field)	Safe, harmful	1,3,5
indoxacarb	Harmful (males), knockdown	Harmful, knockdown	1,3,4,5,10
methoxyfenozide	Harmful to nymphs	Safe to adults	4, 10
pirimicarb	-	Safe	1,8
potassium bicarbonate	-	Safe	12
spinosad	Harmful, knockdown	Harmful	1,2,3,5,6, 10
spirodiclofen	Harmful nymphs (lab), safe (field)	-	
thiacloprid	Harmful	Harmful	1,3,5,10

*1 Peusens and Gobin 2008; 2 Cisneros *et al*. 2002; 3 Vogt *et al*. 2010; 4 Peusens *et al*. 2010; 5 Vogt *et al*. 2009; 6 Peusens *et al* 2009; 7 Colvin and Cranshaw 2010; 8 Ffrench-Constant and Vickerman 1985; 9 Maher *et al*. 2006; 9 Sauphanor *et al*. 1993; 10 Shaw and Wallis 2010, 11 Ravensberg 1981, 12 Beliën 2012.

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