Project title:	Further development of earwig-safe spray programmes for apple and pear orchards
Project number:	TF 220
Project leader:	Dr Michelle Fountain, East Malling Research, New Road, East Malling, Kent, ME19 6BJ Tel: 01732 843833; Fax: 01732 849067
Report:	Year 2 report, 2015
Previous report:	Year 1 report, 2014
Key staff:	Dr Michelle Fountain, Mr Adrian Harris Dr Philip Brain (Biometrician)
Location of project:	East Malling Research, New Road, East Malling, Kent, ME19 6BJ
Industry Representative:	Dr Oliver Doubleday DPhil FRAgS, G H Dean & Co Ltd, Hempstead Farm, Tonge, Sittingbourne, Kent, ME9 9BJ. Tel: 01795 423981, email: oliver@ghdean.co.uk
Date project commenced:	1 April 2014
Date project completed (or expected completion date):	31 March 2017

DISCLAIMER

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.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Dr Michelle Fountain

Research Leader in Entomology

East Malling Research, New Road, East Malling, Kent, ME19 6BJ

Signature .... Date ...07 October 2015...........

Report authorised by:

Professor Jerry Cross

Propgramme Leader

East Malling Research

Signature .... Date ....19 October 2015....................

CONTENTS

Headline.....5

Background and expected deliverables.....5

Summary of the project and main conclusions.....5

Financial benefits.....7

Action points for growers.....7

SCIENCE SECTION

Introduction.....8

Materials and methods.....10

Results.....14

Discussion and Conclusions.....21

Knowledge and Technology Transfer.....24

Acknowledgements.....24

References.....24

GROWER SUMMARY

Headline

- In field trials significant effects of Calypso and Gazelle were not detected in an orchard with abundant earwig populations.

Background and expected deliverables

Earwigs are important generalist predators in both apple and pear orchards. They play a key part 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 by EMR and experiments by other European scientists have indicated that several commonly used crop protection products including thiacloprid (Calypso), indoxacarb (Steward), chlorpyrifos and spinosad (Tracer) have harmful effects on earwigs and could be responsible for low populations in some orchards. However, growers need to be able to use products containing acetamaprid (Gazelle), thiacloprid (Calypso), abamectin (Agrimec) and spirodiclofen (Envidor) for control of aphids, mussel scale, weevils, capsids, pear sucker and sawfly.

This project builds on research carried out by NIAB EMR in AHDB Horticulture Project TF 196, which showed that earwigs can be disrupted by routine crop protection programmes. It tests how to integrate key products into pest management programmes without causing harm to earwig populations in orchards and further investigates the sub-lethal effects (growth and reproduction) that these products have on nymph and adult earwigs in highly replicated laboratory trials.

In the first year of the project laboratory tests on nymph and adult earwigs exposed to acetamaprid (Gazelle), thiacloprid (Calypso), abamectin (Agrimec) or spirodiclofen (Envidor) compared to a water only control, demonstrated that earwig nymphs avoided feeding on bean leaves sprayed with Calypso, but Envidor appeared to stimulate adult earwig feeding. Calypso also slowed the growth of earwig nymphs and male adults. In the short term Gazelle, Envidor and Agrimec appeared to be safe to earwig nymphs and adults.

Summary of the project and main conclusions

In the second year of the project, adult earwigs exposed to one of four of the products tested in the laboratory in 2014 were maintained as paired males and females, kept in cool conditions over the winter and then allowed to reproduce in the spring of 2015. Fecundity measurements were recorded to determine long-term effects of exposure to acetamaprid (Gazelle), thiacloprid (Calypso), abamectin (Agrimec) or spirodiclofen (Envidor) in comparison to a water only control.

There was significant female earwig mortality with previous exposure to Agrimec and Envidor residues compared to the water only control. In addition, Envidor significantly delayed egg laying by a month compared to the control. It was noted, in the previous year, that Envidor stimulated feeding of residue contaminated bean leaves. How these effects are manifested in commercial orchards was beyond the scope of this project. However, the combined effects of autumn and spring earwig mortality and delayed egg laying meant there were a third more eggs laid in the water only control, overall, compared to the Envidor, Calypso and Abamectin treatments.

A replicated field trial was done to assess the impacts of Calypso and Gazelle at recommended field rates on earwig numbers in apple trees. The orchard used was a Gala apple orchard in Kent. The plots were blocks of 24 trees sprayed with an air assisted knapsack sprayer either pre-blossom or mid-season with one or two applications of Calypso or Gazelle compared to unsprayed blocks of trees.

No significant effects of either Calypso or Gazelle were found on earwig populations with either one or two spray applications in the spring or mid-season. In previous field tests (Project TF 196), foliar applications of Calypso reduced the numbers of earwigs in trees. Differences may be due to canopy density and hence spray coverage or earwig population levels in the orchards.

The results of these experiments suggest that an occasional application of Gazelle, or, potentially, Calypso, to control early season pests are unlikely to have long term effects on earwig populations if earwig populations are already high in the orchard and the application is made in response to pest thresholds as part of Integrated Pest Management.

Future research will test Envidor and Agrimec in pear orchards in the early- and mid-growing season, and 1-2 applications.

Financial benefits

- The industry had been provided with independently obtained information on the relative safety of critical orchard crop protection products on earwigs; important natural enemies of several damaging pests.
- Growers will be able to judge when best to use which products for essential pest control tasks such as control of aphids, weevils, capsids, pear sucker and sawfly.
- There will be fewer problems with many important pests if earwig populations are allowed to thrive.

Action points for growers

- Growers should make considered choices of products based on the knowledge of important predators in the orchard at the time of spraying (see Table 6 in the Science Section of this report).
- Growers can consult agronomists to determine which products are safe to apply at key times of the earwig lifecycle.
- Gazelle could be an alternative to Calypso for sawfly, muscle scale or weevil control, but further work is needed on Gazelle efficacy for this purpose.

SCIENCE SECTION

Introduction

Earwigs (Dermaptera) are important predators of many pests (Fig. 1a) of orchards including scale insects (Karsemeijer 1973; McLeod & Chant 1952), psyllids (Sauphanor *et al*., 1994), woolly apple aphid (Phillips, 1981; Ravensburg, 1981; Noppert *et al*,. 1987; Mueller *et al*., 1988; Solomon *et al*., 1999; Nicholas *et al*., 2005) and codling moth (Glen, 1977). Reports that earwigs are declining in some orchards (Gobin *et al*., 2008) has raised concern for this effective, natural, biocontrol agent. The earwig most commonly encountered in UK orchards is *Forficula auricularia* (Fitzgerald and Solomon, 1996; Solomon *et al*., 1999). A female *F. auricularia* lays 50 to 90 eggs in the spring (Fig. 1b). She attends the first stage nymphs and then dies before midsummer. Third instar nymphs move into the tree canopy (Phillips, 1981) from May onwards and, after the fourth instar, emerge as adults (July-August) (Gobin *et al*., 2008). Earwigs are nocturnal and their numbers are often underestimated in orchards.

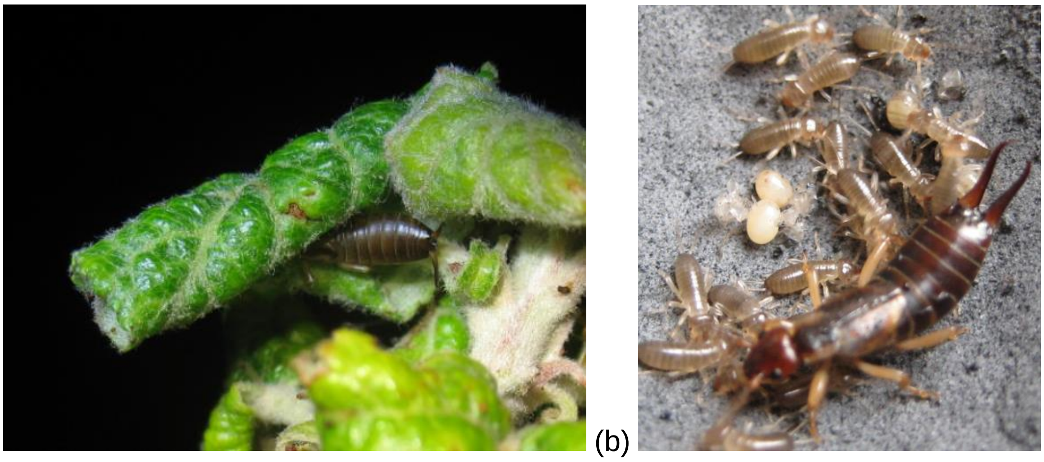
(a)  (b)

Figure 1. (a) Female earwig feeding on rosy apple aphid (b) and with offspring

Insecticides applied between March and October could have effects on earwig populations and effects on earwig behaviour may have consequences on populations of earwigs the following year. Earwigs are exposed to spray residues whilst moving around and feeding at night in the tree canopy and on the ground (Ffrench-Constant and Vickerman, 1985). The data available for sensitivity of earwigs to many modern insecticides is building (Table 6); however, growers need to apply insecticides which are potentially harmful to earwigs at certain times of the year. These insecticides are used to protect against pests such as aphids, weevils, capsids, pear sucker and sawfly and include the neonicotinoids, acetamiprid (Gazelle) and thiacloprid (Calypso), and two products used to help manage pear sucker in the summer, abamectin (Agrimec) and spirodiclofen (Envidor). The vulnerability of the different earwig life stages to these products requires investigation in well replicated trials.

Laboratory experiments have screened adult earwigs at experimental doses of a few pesticides (Peusens & Gobin, 2008) and EMR/AHDB project TF 196 has screened the most commonly used UK insecticides in laboratory trials (Table 7), but more research is needed on the timing of applications in real orchards and any sublethal effects of the few pesticides available for aphid, weevil, capsid, pear sucker and sawfly control.

AHDB project TF 196 began testing spray programmes on two farms, but no consideration was made to sprays of thiacloprid and abamectin. It is also not known whether acetamaprid (more water soluble than thiacloprid) would have less detrimental effects on earwigs. Evidence from studies of predatory mites suggests that these latter products differ in toxicity (Beers and Himmel 2002; Bostian *et al*. 2009).

Project aim:

To determine whether (if and when) acetamiprid (Gazelle), thiaclorpid (Calypso), abamectin (Agrimec) and spirodiclofen (Envidor) can be used in earwig safe spray programmes on apple and pear.

Year 2 objective:

Evaluate the effects on earwig populations of early season (pre-petal fall) versus mid-season (fruit development) applications of one versus two sprays of acetamaprid (Gazelle) or thiacloprid (Calypso) in apple orchards.

Materials and methods

Laboratory experiment - reproduction

Treatments

The toxicity of orchard insecticide residues, at the recommended field concentrations, were tested in 2014 by exposing male and female earwigs (Table 1) on bean leaf disks. Short term effects were recorded and are detailed in the Year 1 annual report. We maintained surviving males and females (from 20 replicates) in mating pairs over the winter to assess the reproduction the following spring. Insecticides were tested on earwig nymphs in 2014, the details of this are in the Year 1 annual report.

Table 1. Treatments applied in the laboratory earwig toxicity test in 2014 (see Year 1 annual report for details)

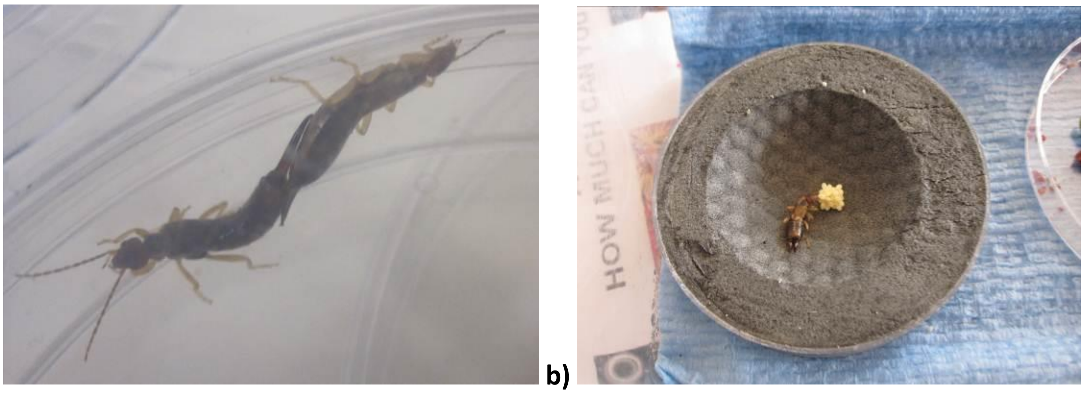
Treatment Code	Product	Active ingredient	Mode of action	Chemical class
A	Agrimec	abamectin	chloride channel activator	Avermectin
G	Gazelle	acetamiprid	acetylcholine agonist (mimic)	Neonicotinoid
E	Envidor	spirodiclofen	lipid biosynthesis inhibition	Tetronic acid
Ca	Calypso	thiacloprid	binds to acetylcholine receptor	Neonicotinoid
U	Untreated control	-	-	-

Maintenance of earwig male/female pairs

Earwig ‘couples’ (one male and one female) were paired from the same treatment (short-term toxicity test). Pairings were housed in clear ventilated Petri dishes with dried cat food and water. Mating in most Petri dishes occurred within 10 minutes of introduction (Fig. 2a). Food was supplemented with vegetable matter in some weeks, e.g. cabbage, carrot, apple, etc. On 03 November all pairs of earwigs were housed in Perspex boxes with a plaster of Paris and graphite powder constructed nest chamber in a 6°C room under constant darkness to mimic winter conditions in the soil. On 21 January 2015 all boxes were removed from the cold store, cleaned and the water and dried cat food (+ other vegetable matter) was refreshed. The boxes were then placed in front of a window (natural daylight) at room temperature. Males and females in some of the replicates were observed to mate again. Males were removed once eggs were laid by the female earwigs (Fig. 2b) to prevent cannibalism.

Assessments - *Sub-lethal/ long-term toxicity*

The effects of the insecticides on reproduction were investigated. The first eggs were laid on 28 January 2015 (Day 1) and the weekly assessments were ended on 13 May 2015. Each box was removed from the experiment once the eggs had hatched into nymphs. The numbers of eggs and successfully hatched eggs were recorded.



a) b)

Figure 2. (a) Male and female earwig mating; (b) Female earwig in nest chamber with eggs (lid removed)

Experimental design and statistical analyses

The data for the number of days to first egg hatch and the number of eggs in the first clutch were normally distributed and therefore a one-way ANOVA used in GenStat.

For the analysis of earwig-pairing data the number of earwig pairs in each Treatment by Status category were recorded, omitting the excluded earwig pairs. The counts were analysed using a GLM with the Poisson distribution and a log-link. The Treatment x Status interaction was significant indicating that the proportions in the different statuses (the profiles) differed between treatments. Pairwise comparisons were then made of the different treatments vs control to see which profiles differed from Water.

A further analysis compared the proportion in individual statuses vs water (e.g. %Dead). This was tested using a GLM with a Binomial distribution and a logit link, using the total number of pairs for each treatment as the binomial total. Again the excluded pairs were excluded from the totals.

Field trial

Site

'Orchard 1' (4.7 ha) of cv. Gala on M26 rootstock (row spacing 4.27 m, tree spacing 2.13 m, planted in 1995) was used by kind permission of Peter Checkley, Howard Chapman Ltd, Broadwater Farm, Broadwater Lane, West Malling, Kent.

Treatments

Treatments were foliar sprays of Gazelle (acetamiprid; acetylcholine agonist (mimic); neonicotinoid) or Calypso (thiacloprid; binds to acetylcholine receptor; neonicotinoid) applied at the recommended field concentration (Table 2).

Table 2. Treatments applied in the orchard trial

Product	**Active ingredient**	**Field rate/ha**	**No. of applic-ations**	**Minimum application interval**	**Timing**
Year 2 (apple)					
Gazelle	acetamiprid	375g	2	20 days	Pre blossom
Calypso	thiacloprid	0.375l	2	Not stated	Pre blossom
Gazelle	acetamiprid	375g	2	20 days	mid-season
Calypso	thiacloprid	0.375l	2	Not stated	mid-season
Untreated	-	-	-	-	-

Experimental design and statistical analyses

Two experiments were done as part of the same trial. One was done pre-blossom and one was mid-season. Each treatment was replicated four times. The treatments were applied twice and the assessments done after the first application and again after the second application to determine the effects of single or two sprays of either Gazelle or Calypso (Fig. 3). The treated plots were compared to unsprayed plots of trees.

Eight trees on three rows were sprayed on both sides of each tree (218.28 m^2) on each spray occasion (24 trees per plot (Fig. 3)). There was a minimum of 20 days between sprays, both pre and mid-season (20 plots), comparing numbers and timing of treatments.

Each plot was sprayed twice with a Birchmeier B 245 motorised knapsack sprayer at 500 l/ha with a pink micron restrictor. Spray dates for the treatments were 09, 30 April and 09, 29 July 2015. The applications were within 93-105% of the target volume required. The grower applied the normal programme of plant protection products, but avoided products harmful to earwigs.

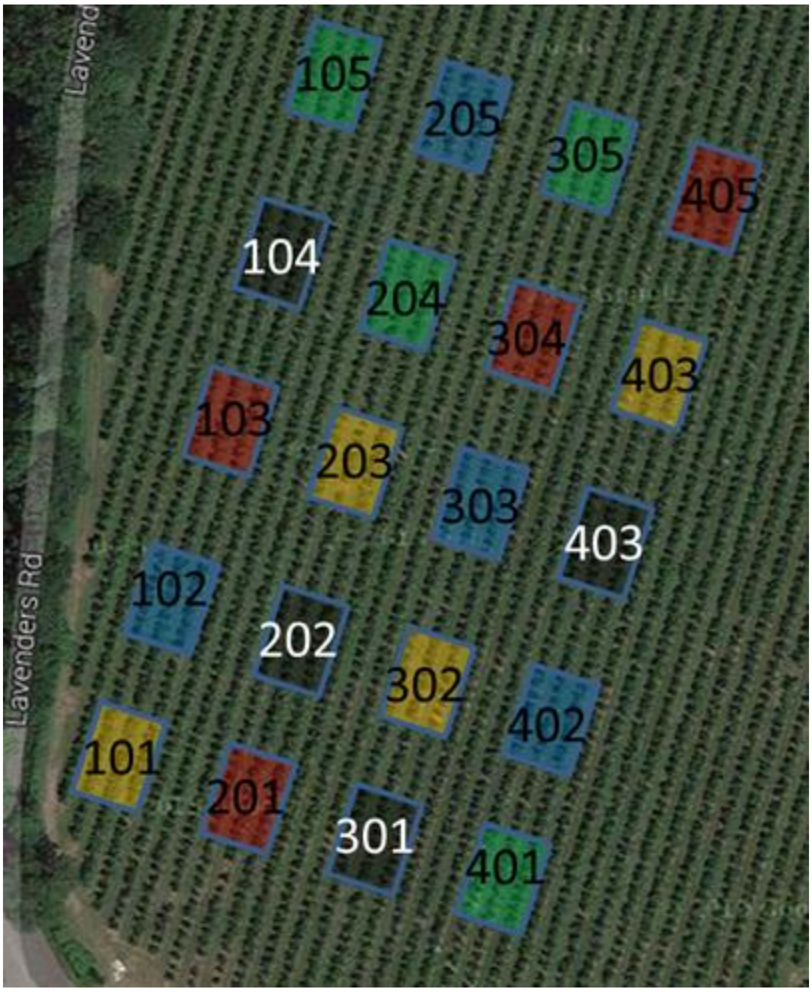


Figure 3. Plan of the plots in the foliar spray field trial (yellow = Gazelle pre-blossom, blue = Calypso pre-blossom, red = Gazelle mid-season, black = Calypso mid-season)

Assessments

The central 6 trees in each plot were assessed. For the pre assessment, visual inspections of the trees were made after dusk (60 second search per tree) and the numbers of earwigs counted. For the mid-season assessments, it was found that tap sampling in the day was more productive for earwig counts. White sheets were laid out under the tree on each side and the tree was shaken to dislodge the earwigs. Records of numbers of male, female and nymph earwigs were made at each assessment. Assessment dates were 8 April (pre-assessment), 14 April (after 1 spray), 8 May (after 2 sprays) then 8 July (pre assessment), 17 July (after 1 spray) and 05 August (after 2 sprays).

Statistical analyses

Repeated measures analysis of variance (adjusted for covariate) were done in GenStat on square root transformed data to stabilise for variances.

Results

Laboratory experiment - reproduction

Adult long-term toxicity test

In the 2014 laboratory tests there was no evidence of gender differences in behaviour or sensitivity to Agrimec, Gazelle, Envidor or Calypso. Adult earwigs were less susceptible to Calypso than earwig nymphs for mortality, but were equally affected in their behaviour. The numbers of surviving adults that were paired up from the short-term 2014 toxicity tests are shown in Table 3. Due to the experimental design, it was not possible to perform statistical analysis on all data.

Table 3. Numbers of paired earwigs and subsequent egg laying by females in the long term toxicity test

	No. mating pairs	**First date eggs laid**	**Last date eggs laid**	**No. (range) eggs laid in 1st clutch**	**Days (range) to lay first clutch**	**Total eggs in experiment**
Water	12	28-Jan	26-Mar	0-42	1-57	283
Agrimec	13	28-Jan	26-Mar	0-46	1-57	168
Calypso	11	28-Jan	12-Mar	0-40	1-84	176
Envidor	14	05-Mar	14-Apr	0-32	36-105	138
Gazelle	16	28-Jan	30-Apr	0-43	1-71	205

Overall, Agrimec and Envidor detrimentally effected earwigs that had been exposed to the residues of the products the previous year in the laboratory (Table 4a). This was because more overwintered females died the following spring in the Agirmec and Envidor treatments and there were fewer eggs laid by females that had been exposed to Envidor (Table 4b, Fig 4).

Table 4. a) Percentage of earwig females that died or that did or did not lay eggs and b) comparisons of individual statuses (excluding females that died in 2014). NSD = no significant difference (i.e. P>0.05).

	Died	Eggs	No. Eggs	Overall significance
Water	0	92	8	-
Agrimec	38	62	0	0.013
Calypso	20	80	0	NSD
Envidor	29	57	14	0.045
Gazelle	19	63	19	NSD

b) Significance vs. water control. NSD = no significant difference (i.e. P>0.05).

Status	Agrimec	Calypso	Envidor	Gazelle
Died	0.008	0.065	0.018	0.057
Eggs	NSD	NSD	0.038	0.064
No Eggs	NSD	NSD	NSD	NSD

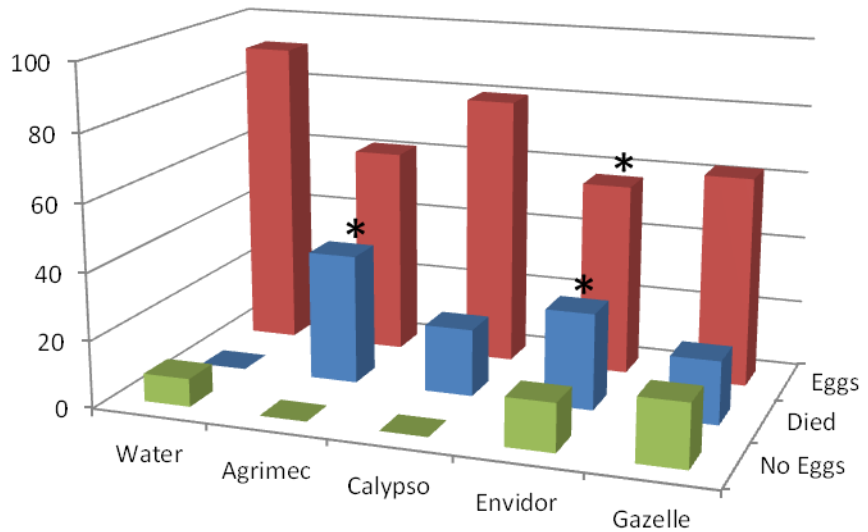


Figure 4. Percentage of female earwigs that died after overwintering in each treatment and the percentage of females that laid eggs or did not lay eggs. *= significantly different from the water only control.

The average numbers of eggs laid by an individual female earwig did not significantly differ (mean=23, range 2-46) between treatments. The total numbers of eggs laid over the duration of the experiment could not be analysed but numbers of eggs laid in the control (water only) was a third higher than in the Agrimec, Envidor or Calypso exposed earwigs over the duration of the experiment (Table 3).

The number of egg clutches that successfully hatched to nymphs was between 40-83% but was not significantly different between treatments. Very few females went on to lay a second batch of eggs (averaged female per treatment) and hence this data was not analysed.

The length of time taken to lay the first batch of eggs by female earwigs exposed to Envidor the previous year was significantly delayed (ANOVA, P=0.034, s.e.d.=1.277, l.s.d.= 2.593) by approximately 33 days (Fig. 5). In the water only, Agrimec, Calypso and Gazelle treatments females were first observed to lay eggs on 28 January; the first female to lay eggs in the Envidor treatment was 05 March (Table 3).

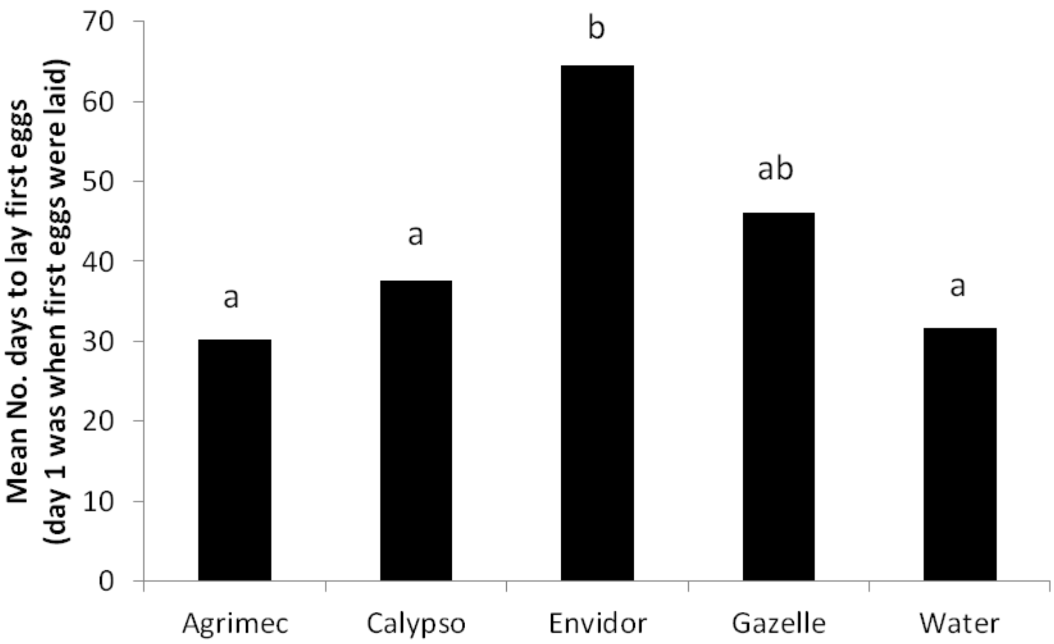


Figure 5. Mean number of days for female earwigs to lay first batch of eggs.

Field trial

In the field trial there were no differences in the numbers of earwigs in apple trees treated with either 1 or 2 sprays of Calypso or Gazelle in either the pre-blossom or mid-season trials (Tables 4, 5). There was a high variability in the numbers of earwigs in individual trees and this may account for the lack of detection of significant differences. On average the numbers of earwigs in the control and Gazelle treated plots were fairly similar with slightly fewer in the Calypso treated plots at both the pre-blossom and mid-season assessments (not significant).

At pre-blossom there were very low numbers of earwigs in the trees; less than 1 per tree. Numbers of females generally increased and males decreased over this trial period (Table 5). By mid-season the numbers of males and females in the trees significantly increased over time as nymphs moulted into adults (Table 6).

Table 5. Repeated measures ANOVA table with analyses on square root transformed data (SQRT) of mean numbers of female, male and total earwigs in each tree following treatment pre blossom. Treatments were applied on 09 and 30 April. NSD = no significant difference

	Actual mean		**SQRT mean**	
	Females			
	14 April	8 May	14 April	8 May
Calypso	0.024	0.316	0.018	0.261
Gazelle	0.024	0.524	0.018	0.392
Untreated	0.076	0.451	0.089	0.439
	P value	**d.f.**	**s.e.d.**	**l.s.d.**
Covariate	NSD			
Treatment	NSD	5	0.1147	0.2949
Time	<0.001	69	0.0657	0.1311
	Males			
	14 April	8 May	14 April	8 May
Calypso	0.464	0.506	0.366	0.355
Gazelle	1.508	0.000	0.994	0.069
Untreated	1.402	0.069	0.826	0.065
	P value	**d.f.**	**s.e.d.**	**l.s.d.**
Covariate	NSD			
Treat	NSD	5	0.2286	0.5877
Time	<0.001	69	0.0919	0.1834
	Total earwigs			
	14 April	8 May	14 April	8 May
Calypso	0.513	0.846	0.384	0.549
Gazelle	1.486	0.444	0.993	0.443
Untreated	1.501	0.543	0.851	0.523
	P value	**d.f.**	**s.e.d.**	**l.s.d.**
Covariate	NSD			
Treatment	NSD	5	0.3046	0.7829
Time	0.023	69	0.1024	0.2042

Table 6. Repeated measures ANOVA table with analyses on square root transformed data (SQRT) of mean numbers of female, male, nymph and total earwigs in each tree following treatment mid-season. Treatments were applied on 09, 29 Jul. NSD = no significant difference

	Actual mean		**SQRT mean**	
	Females			
	17 July	05 August	17 July	05 August
Calypso	0.28	3.50	0.250	1.619
Gazelle	0.68	2.45	0.604	1.261
Untreated	0.88	3.63	0.699	1.608
	P value	**d.f.**	**s.e.d.**	**l.s.d.**
Covariate	NSD			
Treatment	NSD	5	0.1507	0.3874
Time	<0.001	57	0.1313	0.2630
	Males			
	17 July	05 August	17 July	05 August
Calypso	0.25	2.81	0.250	1.462
Gazelle	0.70	2.31	0.552	1.285
Untreated	0.38	3.17	0.303	1.632
	P value	**d.f.**	**s.e.d.**	**l.s.d.**
Covariate	<0.001			
Treatment	NSD	5	0.2037	0.5237
Time	<0.001	57	0.1162	0.2327
	Nymphs			
	17 July	05 August	17 July	05 August
Calypso	4.64	4.09	2.047	1.911
Gazelle	8.15	8.09	2.711	2.675
Untreated	6.21	7.75	2.288	2.586
	P value	**d.f.**	**s.e.d.**	**l.s.d.**
Covariate	NSD			
Treatment	NSD	5	0.2834	0.7285
Time	NSD	57	0.1259	0.2522
	Total earwigs			
	17 July	05 August	17 July	05 August
Calypso	5.18	10.40	2.179	3.044
Gazelle	9.53	12.86	2.966	3.423

Untreated	7.46	14.54	2.586	3.622
	P value	**d.f.**	**s.e.d.**	**l.s.d.**
Covariate	NSD			
Treatment	NSD	5	0.2963	0.7617
Time	<0.001	57	0.1415	0.2834

Discussion and Conclusions

Laboratory experiment - reproduction

In 2014 earwig nymphs exposed to residues of Calypso on bean leaves took longer to reach adulthood (>42 days) compared to the control (water only) earwigs (35 days); other pesticide treatments (42 days). In those tests Gazelle and Agrimec appeared to be relatively safe to earwig nymphs and adults. In the same year adult earwigs tested using the same methodology (Year 1 report) were maintained throughout the winter for reproduction assessments in spring 2015. Earwigs that had been exposed to Envidor consumed more leaf material than leaves which had been sprayed only with water. The length of time taken to lay the first clutch of eggs by female earwigs exposed to Envidor the previous year was delayed by approximately 33 days compared to the water treated control. It is possible that the increased consumption of the insecticide resulted in a higher uptake which had long term effects on reproduction. It is not certain whether this would occur in field conditions and whether this effect would be seen from earwigs consuming pear sucker which had been sprayed with Envidor. If Envidor stimulates earwigs to feed it may account for some reports of feeding on young unfurled leaves in the spring but this would need to be tested.

In addition significantly more female earwigs died in the spring if exposed to Agrimec and Envidor the previous year, compared to the water only control.

The total numbers of eggs produced from each of the pesticide exposed pairs of earwigs was at least a third greater in the water treated control compared to the Agrimec, Envidor or Calypso (although these differences were not statistically significant). The success of eggs hatching in natural conditions is not known and it is difficult to conclude if the results in the laboratory test are normal or whether the laboratory conditions were not optimal. It was also not possible to ascertain whether inter-nymph cannibalism had occurred.

In the field tests no significant effects of either Calypso or Gazelle were found on earwig populations with either one or two spray applications in the spring or mid-season. In previous field tests (HDC TF 196) foliar applications of Calypso reduced the numbers of earwigs in trees. Differences may be due to canopy density and hence spray coverage or earwig population levels in the orchards.

It is interesting that pesticides applied to earwigs in the laboratory could have detrimental effects, including reduced survival in the spring and delayed egg laying (e.g. Envidor), the following year after the earwigs have overwintered. How this effects earwig populations and subsequent pest control in commercial orchards is not known. The earwigs in our laboratory tests were only exposed to one insecticide, but earwigs in commercial orchards may be exposed to up to 5 insecticides throughout the growing season.

The results of these experiments suggest that an occasional application of Gazelle, or, potentially, Calypso, to control early season pests are unlikely to have long term effects on earwig populations if the latter are already in good numbers in the orchard and the application is made in response to pest thresholds as part of Integrated Pest Management.

Future research will test Envidor and Agrimec in pear orchards in the early- and mid-growing season, and 1-2 applications.

Table 7. Summary of data from this project and data published by other researchers on the safety of active ingredients to earwigs

Active ingredient	Data from this project	Other researchers	Reference*
abamectin	Some long-term mortality	Harmful	1
acetamiprid	Minimal effects	-	
Bacillus thuringiensis	-	Safe	9
chlorantraniliprole	No detectable effects	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 to nymphs field)	Safe, harmful	1,3,5
indoxacarb	Harmful (males), knockdown	Harmful, knockdown	1,3,4,5,10
methoxyfenozide	Harmful to nymphs (growth)	Safe to adults	4, 10
pirimicarb	-	Safe	1,8
potassium bicarbonate	-	Safe	12
spinosad	Harmful, knockdown	Harmful	1,2,3,5,6, 10
spirodiclofen	Some long-term mortality, delayed egg laying	-	
thiacloprid	Harmful, some long-term mortality	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

Knowledge and Technology Transfer

9 April 2014 Michelle Fountain and Jerry Cross - Conservation of the common earwig, *Forficula auricularia*, in orchards. University of Reading Seminar

24 April 2014 Michelle Fountain and Adrian Harris - Further development of earwig-safe spray programmes for apple and pear orchards, HDC Tree Fruit day

8 May 2014 Michelle Fountain - Pests, Predators and Pollinators, Warwick

25 September 2014 Michelle Fountain - Pests, Predators and Pollinators, Ornamental Nursery Group, EMR

20 November 2014 Michelle Fountain, Adrian Harris - Conservation of the common earwig, *Forficula auricularia*, in orchards. AAB conference

5 February 2015 Michelle Fountain, Northern Ireland Apple Growers Association – Pollination, Pest Control and Blastobasis in Orchards

11 February 2015 Michelle Fountain Cider Growers Association – Pollination and Pest Control in Orchards

Acknowledgements

We would like to thank the funders of the research Horticultural Development Company for their support. We would also like to thank Maddie Cannon, Bethan Shaw, Emilio Fernandez Rico, Dieter Baets, Alvaro Delgado, George Laws, Janie Morton, Rebeca Conde-Ruiz, Gloria Endredi and Adrian Harris for their help with treatment application and assessments. Thanks are owed to Phil Brain for his advice on the statistics used.

References

Beers E.H., Himmel P.D. 2002. Effect of chloronicotinyl insecticides on phytophagous and predatory mite populations in a cover spray program. Chemical Control/New Products, Proceedings of the 76th Annual Western Orchard Pest & Disease Management

Conference. 9-11 January 2002, Hilton Hotel, Portland, OR v Publ. By Washington State Univ., Pullman, Washington

Bostanian N.J., Thistlewood H.A., Hardman J.M., Laurin M.C., Racette G. 2009. Effect of seven new orchard pesticides on Galendromus occidentalis in laboratory studies. *Pest Manag Sci.* 65(6):635-9

Ffrench-Constant R.H., Vickerman G.P. (1985). Soil contact toxicity of insecticides to the European earwig *Forficula auricularia* (Dermaptera). Entomophaga, 30 (3), 1985, 271-278.

Fitzgerald, J.D., Solomon, M.G. (1996). Artificial refuges for enhancing populations of natural enemies of pests in apples and pear orchards. *APRC News*, 12, 16-17

Glen D.M. (1977). Predation of codling moth eggs, *Cydia pomonella*, the predators responsible and their alternative prey. *Journal of Applied Ecology*, 14, 445-456

Gobin B., Moerkens R., Leirs H., Peusens G. (2008). Earwigs in fruit orchards: phenology predicts predation effect and vulnerability to side-effects of orchard management. *Pesticides and Beneficial Organisms*. IOBC/wprs Bulletin 35, 35-39

Karsemeijer, M.M.D. (1973) Observations on the enemies of the oyster shell scale, *Lepidosaphes ulmi*, on apple in The Netherlands. Journal of Plant Pathology 79, 122-124.

McLeod, J. H., Chant, D. A. (1952). Notes on the parasitism and food habits of the European earwig, *Forficula auricularia* L. (Dermaptera: Forficulidae). *Canadian Entomologist*, 84, 343-345

Mueller T.F., Blommers L.H.M., Mols P.J.M. (1988). Earwig (*Forficula auricularia*) predation on the woolly apple aphid, *Eriosoma lanigerum*. *Entomol. Exp. Appl*., 47, 145-152

Nicholas A.H., Spooner-Hart, R.N., Vickers, R.A. (2005). Abundance and natural control of the woolly aphid *Eriosoma lanigerum* in an Australian apple orchard IPM program. *BioControl,* 50, 271-291

Noppert F., Smits J.D., Mols P.J.M. (1987). A laboratory evaluation of the European earwig (*Forficula auricularia* L.) as a predator of woolly apple aphid (*Eriosoma lanigerum* Hausm.).

Mededelingen van de Faculteit Landbouuwwetenschappen, Rijksuniversiteit Gent, 52, 413-422

Peusens G., Gobin B. (2008). Side effects of pesticides on the European earwig *Forficula auricularia* L. (Dermaptera: Forficulidae). Pesticides and Beneficial Organisms, IOBC/wprs Bulletin 35, 40-43

Phillips M.L. (1981). The ecology of the common earwig *Forficula auricularia* in apple orchards. PhD Thesis, University of Bristol

Ravensburg W.J. (1981). The natural enemies of the woolly apple aphid, *Eriosoma lanigerum*, and their susceptibility to diflubenzuron. Mededelingen van de Faculteit Landbouuwwetenschappen, Rijksuniversiteit Gent, 46, 437-441

Sauphanor B., Stäubli A. (1994). Evaluation au champ des effets secondaires des pesticides sur *Forficula auricularia*: Validation des résultats de laboratoire. IOBC/WPRS Bulletin 17, 83- 88

Solomon M.G., Fitzgerald J.D., Jolly R.L. (1999). Artificial refuges and flowering plants to enhance predator populations in orchards. IOBC/WPRS Bulletin, 22 (7), 31-37

