Project Title:	Investigation of the effects of commonly used insecticides on earwigs, important predators in apple and pear
HDC Project Number:	TF 196
Project Leader:	Dr Michelle Fountain
Key Workers:	Dr Michelle Fountain Adrian Harris G Arnold BA, MSc, CStat (Biometrician)
Location of Project:	East Malling Research New Road, East Malling, Kent ME19 6BJ Tel: 01732 843833 Fax: 01732 849067
Project coordinators:	Andrew Tinsley
Report	Year 1 report 2011- (issued 14 March 2012)
Previous reports:	None
Date Project commenced:	1 April 2011
Expected completion date:	31 March 2014
Keywords:	abamectin, Agrimec, acetamiprid, Gazelle, chlorantraniliprole, Coragen, chlorpyrifos, Equity, flonicamid, Tepekki, indoxacarb, Steward, methoxyfenozide, Runner, spinosad, Tracer, spirodiclofen, Envidor, thiacloprid, Calypso, feeding, development, reproduction, *Forficula auricularia*

East Malling Research is an officially recognised efficacy testing station and this work is registered as study number ORETO 2010/007

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.

CONTENTS

GROWER SUMMARY

Headline

- Earwigs are very important predators in top fruit crops, but are sensitive to insecticide products.

Background and expected deliverables

Earwigs are very 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 in other European countries indicate that several very commonly used insecticides including thiacloprid (Calypso), indoxacarb (Steward) and spinosad (Tracer) have harmful effects on earwigs and could be responsible for the low populations of these important predators in some orchards. This project is further investigating the lethal and sub-lethal effects of these and other commonly used insecticides on different earwig life stages.

In the first year it was intended to screen a range of commonly used insecticides in the laboratory, including; abamectin (Agrimec), acetamiprid (Gazelle), chlorantraniliprole (Coragen), chlorpyrifos, flonicamid (Mainman), indoxacarb (Steward), methoxyfenozide (Runner), spinosad (Tracer), spirodiclofen (Envidor), thiacloprid (Calypso) and a coded product, and to compare these to an untreated control. The short-term and long-term sub-lethal effects on feeding, development, longevity and reproduction will be measured. The effects of typical programmes of insecticide sprays used in UK apple and pear production will be investigated in years 2 and 3.

Summary of the project and main conclusions

In laboratory tests, adult male adult female (27 day exposure) and nymph stage (7 day exposure) earwigs were exposed to one application of each pesticide sprayed onto a leaf disk in a Petri dish. Chlorpyrifos was by far the most toxic insecticide for earwigs with most dying within a couple of days. In order of decreasing toxicity, Tracer (spinosad) > Runner (methoxyfenozide) > Calypso (thiacloprid) > Steward (indoxacarb)/Envidor (spirodoclofen)/Gazelle acetamaprid) were also harmful. Abamectin (Agrimec), chlorantraniliprole (Coragen), flonicamid (Mainman), thiacloprid (Calypso) and the coded product showed very few signs of toxicity. Runner was toxic to nymphs, but less so to adult earwigs.

It is well known that laboratory tests may overestimate the toxicity of insecticides, but these tests were used to screen the most commonly used products for field testing in 2012. This study did not take into consideration mixtures or repeated exposures to plant protection products. However, combined with data from other researchers it acts as a baseline for field studies in the coming growing seasons.

In field studies by other workers (Vogt *et al*. 2009), flonicamid (Tepekki) resulted in fewer earwigs in trees. A recent review of the literature by Logan *et al*. (2011) rated residues of chlorpyrifos, spinosad, bifenthrin, diazinon and thiacloprid as highly toxic (>50% mortality) to earwigs. Abamectiin, methoxyfenozide, spirotetramat, tebufenozide and thiamethoxam were noted as low toxicity to earwigs. An older field study by Sauphanor *et al*. (1993) demonstrated that diflubenzuron (Dimilin Flo) was highly toxic to earwigs in pear orchards causing a subsequent rise in pear sucker numbers.

Based on the findings from this experiment and other researchers, the most toxic products will be tested in the field in 2012 to ascertain a more realistic field exposure and assess the resulting effects.

Financial benefits

The industry will be provided with independently obtained vital information on the relative safety of the most commonly used insecticides in UK apple and pear production on earwigs, an important natural enemy of several damaging pests.

Growers will be better able to judge which insecticides to use for vital pest control tasks such as control of codling moth, aphids, mussel scale and pear sucker.

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.

- In particular, growers should use the precautionary principle in pear orchards and only use products known to be harmless to important pear sucker predators, including anthocorids, earwigs, ladybirds and spiders.

SCIENCE SECTION

Introduction

Background

There are only seven species of earwig (Dermaptera) in Britain. The earwig most commonly encountered in UK orchards is *Forficula auricularia* (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 (Karsemeijer 1973; McLeod and Chant 1952), psyllids (Solomon *et al*. 1999; Lenfant *et al*. 1994), 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 (Glenn 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 (Gobin *et al*. 2008) has raised concern for this effective natural biocontrol agent. 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 of this. Other influences could be migration, starvation, pathogens, parasitoids, parasites, predation and/or cannibalism (Moerkens *et al*. 2009).

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 midwinter 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 first stage nymphs, which are very delicate, and regurgitates food to them (Staerkle & Kolliker 2008). Females die before midsummer but can be found foraging in trees in May. Third instar nymphs move into the tree canopy (Phillips 1981) from June onwards and after the fourth instar emerge as adults (July-August) (Gobin *et al*. 2008).

Studies have revealed that the species is composed of a complex of two sibling species, one species being one-brooded and the other two (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 effects on earwig populations. Even small effects on behaviour may have consequences on populations for the rest of the year. In reality it is not known whether orchards in the UK are dominated by one sibling species or whether they are a mixture of the two.

Because earwigs are nocturnal their numbers can also 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 (French-Constant & Vickerman 1985).

Laboratory studies are invaluable for examining sub-lethal effects of pesticides often overlooked in the field and can be used as a rapid screening technique for a range of pesticides. 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 (encapsulating on sprayed trees or field sprays).

In the first year of this project, reported here, earwigs nymphs and adults (male and female) were exposed to the pesticides by direct (oral) and indirect (residues on leaves) in one experiment.

Objectives

The objective of this study was to investigate the short-term and long-term sub-lethal effects of abamectin (Agrimec), acetamiprid (Gazelle), chlorantraniliprole (Coragen), chlorpyrifos (Equity), flonicamid (Tepekki), indoxacarb (Steward), methoxyfenozide (Runner), spinosad (Tracer), spirodiclofen (Envidor), thiacloprid (Calypso) and of a coded product on feeding, development and longevity of different earwig (*Forficula auricularia*) life stages in the laboratory (year 1).

Materials and methods

Treatments

Insecticides commonly used in top fruit orchards, and with different modes of action (Table 2.1), were tested at the maximum recommended field concentrations. A coded product and a distilled water control were included.

Earwig (Forficula auricularia) collections

On 1 April, ~100 corrugated card bottle traps were tied to trees in an organic apple orchard at East Malling Research (EMR) for nymph collection in May and June. The traps were checked on 20 May but only 28 nymphs were collected. On 22 May tap sampling of branches on unsprayed apple trees (Wiseman orchard) was done (21:00-23:00 h) and 80 earwig nymphs were recovered. The numbers of nymphs active in the trees had decreased by 23:00.

On 12 July over 400 adult earwigs were collected from an organic orchard at EMR. These were found in bottle traps that had been in place for over a year. Males and females were separated and kept overnight to ensure that they were undamaged.

Treatment application

Treatments (Table 2.1) were made up to 1 litre with distilled water in graduated flasks. The spraying apparatus was a Burkard computer controlled sprayer (EMR Standard Operating Procedure 767; APPENDIX). The standard tree PACE model (pesticide adjustment canopy environment, P. Walklate & J. Cross), supported by CRD (Chemicals Regulation Directorate), was used. This calculates the amount of spray in a litre that actually contacts the tree. The model uses a tree height of 3 m and a row spacing of 3.5 m and a full canopy density. Based on a spray volume of 300 l/ha it predicts a best case scenario of 80 l/ha of leaf (outer leaves upper surfaces unshielded), and a worst case of 400 l/ha of leaf (inner leaves/and undersides well shielded). Because this is a single sided application, the mean of these two extremes was used; 60 l/ha (0.6 µl/cm^2) of leaf.

The Burkhard bench top sprayer was calibrated to ensure that the required amount was applied (EMR SOP 767). Runner bean (*Phaseolus coccineus*) leaves grown on an outdoor organic plot were cut into discs (4 cm), sprayed with the pesticide and then left to dry (~10 minutes). The untreated control was sprayed with distilled water only. The bean leaf disc was placed onto an agar layer (1% = 4 g in 400 ml distilled water; APPENDIX) in a 5 cm Petri dish.

An individual earwig was added (picking up with soft forceps) to each Petri dish and maintained at 16^{o}C. Trays holding Petri dishes were placed inside polythene bags to prevent drying out in the temperature control cabinets.

Table 2.1. Treatments

Treat-ment Code	Product	Active ingredient	Mode of action	Chemical class	/ha	/l at 300 l/ha
A	Agrimec	abamectin	chloride channel activator	Avermectin	50 ml	0.5 ml
G	Gazelle	acetamiprid	acetylcholine agonist (mimic)	Neonicotinoid	375 g	1.25 g
Co	Coragen	chlorantraniliprole	activation of ryanodine receptors	Phenylpyrazole	175 ml	0.58 ml
L	Lorsban	chlorpyrifos	acetylcholinesterase inhibitor	Organophosphate	2 l	6.66 ml
M	Mainman	flonicamid	feeding inhibitor	Pyridinecarboxamide	140 g	0.466 g
S	Steward	indoxacarb	sodium channel blocker	Pyrazoline	250 ml	0.83 ml
R	Runner	methoxyfenozide	moulting hormone agonist	Diacylhydrazine	0.6 l	2 ml
T	Tracer	spinosad	alters acetylcholine receptor site	Spinosyn	150 ml	0.5 ml
E	Envidor	spirodiclofen	lipid biosynthesis inhibition	Tetronic acid	0.6 l	2 ml
Ca	Calypso	thiacloprid	binds to acetylcholine receptor	Neonicotinoid	0.375 l	1.25 ml
B	Coded product		-	-	1.875 l	6.25 ml
U	Untreated control	-	-	-	-	-

Tests

Short-term toxicity tests - nymphs

The nymphs were added to the sprayed leaves in the Petri dishes on 24 May (7 day exposure period). During the exposure period the earwig nymphs fed on the bean leaves (Fig. 2.4.1). On 3 June nymphs (L3-L4) were transferred to clean 9 cm Petri dishes and maintained at 16°C (18:6 light:dark). They were given crushed "Iams" cat food and "Wasser Gel" (Trixxi) *ad lib* as a source of food and water (Fig. 2.4.1). The test was ended on 28 June (35 days after initial exposure).

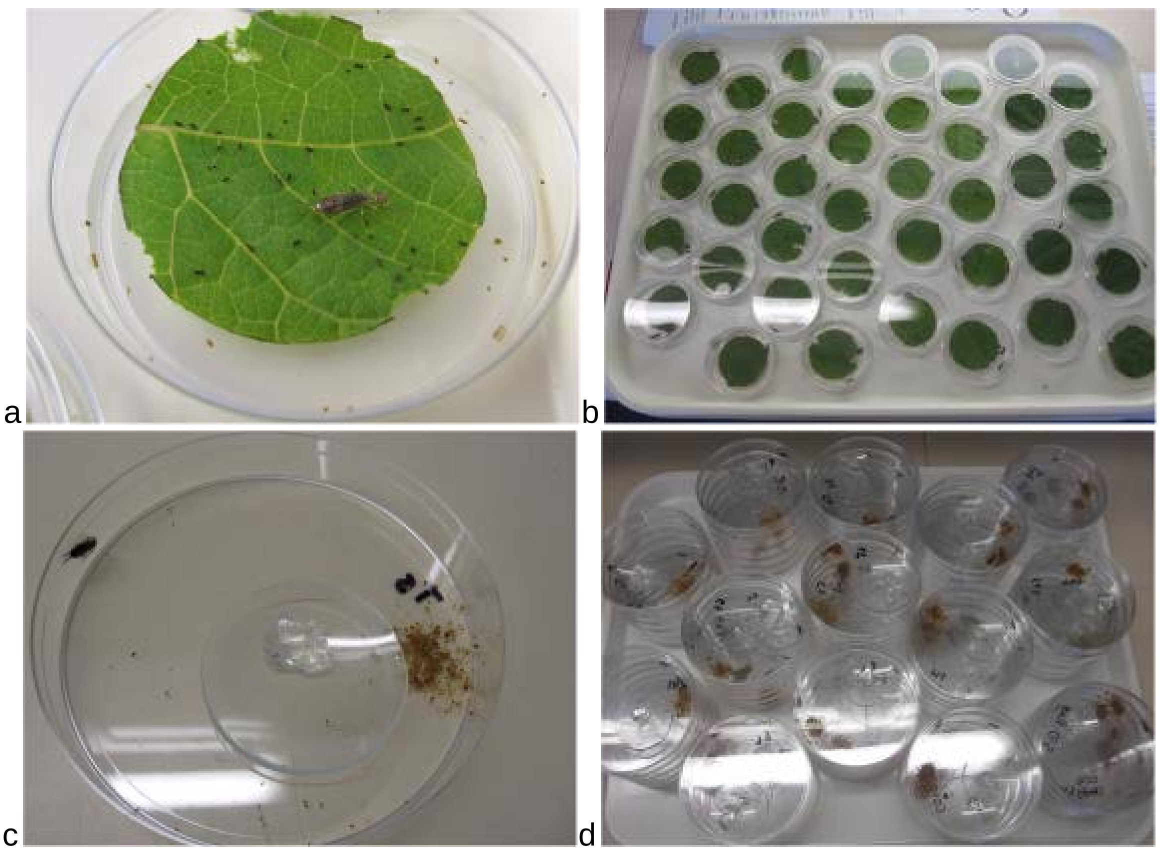


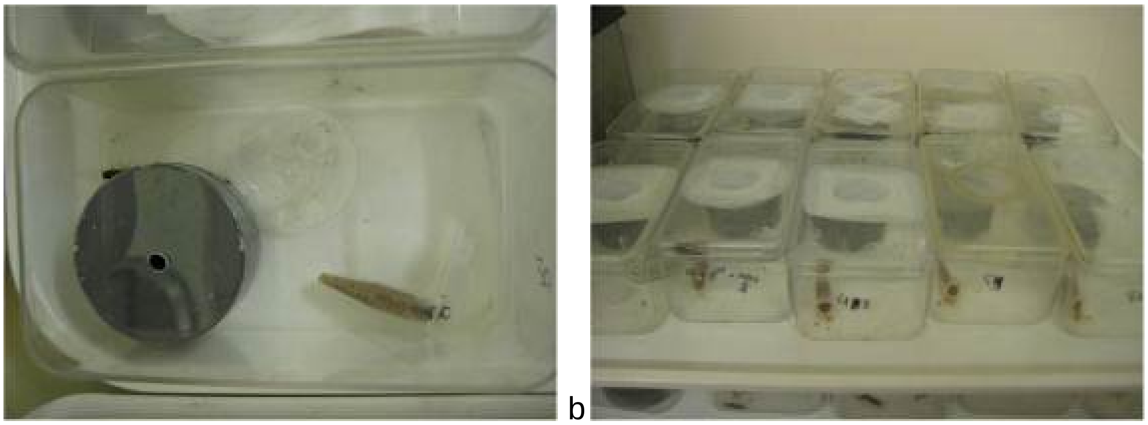
Figure 2.4.1. (a) Nymph earwig on sprayed bean leaf disk, (b) Replicates set up on tray, (c) Nymph transferred to clean Petri dish and given gel water and crushed cat food, (d) Replicates set up on tray

Analyses of earwig weight

Surviving earwig nymphs were killed by freezing for 24 hours. They were then oven dried at 60°C for 24 hours and weighed.

Short-term toxicity tests - adults

Adult earwigs in particular can be very robust, with mortality often occurring several weeks after the exposure period. The experiment with individual males and females was set up on 13 July. Earwigs were transferred to clean boxes on 9 August (27 days exposure) (Fig. 2.4.2).



a b

Figure 2.4.2. (a) Adult earwigs in long-term study boxes (female feeding on cat food), (b) Replicates set up on tray

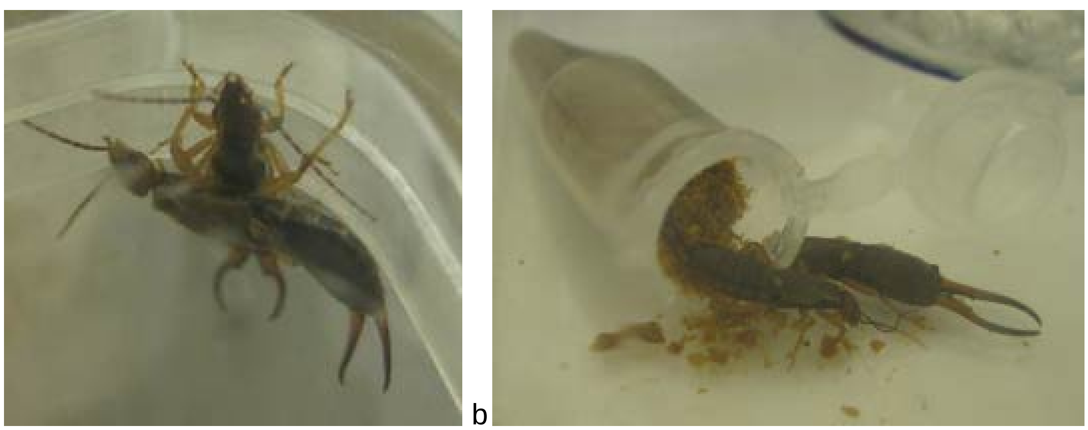
Long-term toxicity tests

On 9 August adult earwigs were transferred to small (13 x 7.5 x 5 cm) ventilated boxes (Fig. 2.4.2) with cat food, water gel (as above) and a nest box (Fig 2.4.3). Males and females were paired up with a replicate partner where possible. Where no male partner was available because of death, either another single treated male was added or an unexposed male from the culture was added. Adult pairs were maintained at 20^{o}C in laboratory 18A for one week to enable courtship and mating to take place (Fig. 2.4.4). On 16 August adult pairs were moved into ‘winter conditions’ 5^{o}C (constant darkness) for 2 months (removed on 6 October). Males were removed (to prevent possible egg cannibalism) and boxes cleaned of mould and old food.

a b

Figure 2.4.3. (a) Preparation of nests in small Petri dishes with a mix of plaster of Paris and graphite powder. The impression was made with a golf ball. The nest was soaked in water before use to provide humidity, (b) Drilling hole in lid of nest for earwig to enter

Females were maintained at 20°C in 18:6 light:dark. By 27 October no eggs had been laid so females were moved to 10°C (6 hours daily light) to try to re-initiate egg-laying. Two females had laid eggs by 9 December, but most females not. On 18 December females were placed into an unheated room next to a window to mimic natural conditions. From 4 January females were maintained at 20°C in 18:6 light:dark in a controlled environment room. Temperature and humidity data loggers were used with the earwigs at each stage of the experiment. The test was ended on 29 February 2012.



a b

Figure 2.4.4. (a) Courtship behaviour of male and female earwigs, (b) Female (left) and male (right) earwig feeding on cat food

Experimental design and statistical analyses

Ten individual L3-L4 instars, adult males and adult females and were tested with each insecticide (3 life stages x 10 replicates x 12 treatments = 360 Petri dishes). A control with distilled water was included (Table 2.1). Graphs were produced on percentage survival and percentage ‘unaffected’. Affected individuals were classified as those unable to turn themselves onto their ventral sides after being turned onto their dorsal sides with a paintbrush. Pesticides were ranked in order of most toxic to nymph/female/male survival and condition, and nymph body weight.

ANOVA was done on raw data for dry body weight of nymphs at the end of the experiment and angular transformed data for the measure of female reproduction (number of eggs). Graphs were based on mortality and ‘worse case’ measures. Worse case included any behavioural changes, such as twitching limbs or an inability of an earwig to right itself once turned onto its back. Any females which had had parasitoids were omitted from the data as the effect on reproduction was unknown.

Results

Adult and nymph earwigs fed on the bean leaf disks (Fig 2.4.1). It was not possible to do a reliable comparison of the amount of leaf disk eaten as leaf thickness varied and hence weighing did not give consistent and reliable results. During the experiment some earwigs escaped (Females T1, T2, T8 and Ca8; males T2, T8, Ca8) and some suffered from parasitism by a large nematode (Females Co1 and R4). These individuals died as a result and were omitted from the data analyses.

Short-term toxicity tests – nymphs

The percentage survival of the earwig nymphs in the control by the end of the experiment was 100% (all 10 nymphs survived). All of the nymphs in the chlorpyrifos (Equity) treatment died within a week of exposure. The other most toxic compounds were spinosad (40% survival), thiacloprid (Calypso, 60% survival) and spirodiclofen (Envidor, 70% survival). Nymphs in all other treatments had less that 20% mortality (Fig. 3.1.1). Spinosad (Tracer), in particular, had detrimental effects on nymph mobility, including locomotion and an inability to turn over if the insect was turned onto its back. Thiacloprid also affected earwig behaviour (Fig. 3.1.1). These young earwigs did not recover and died within a week or two.

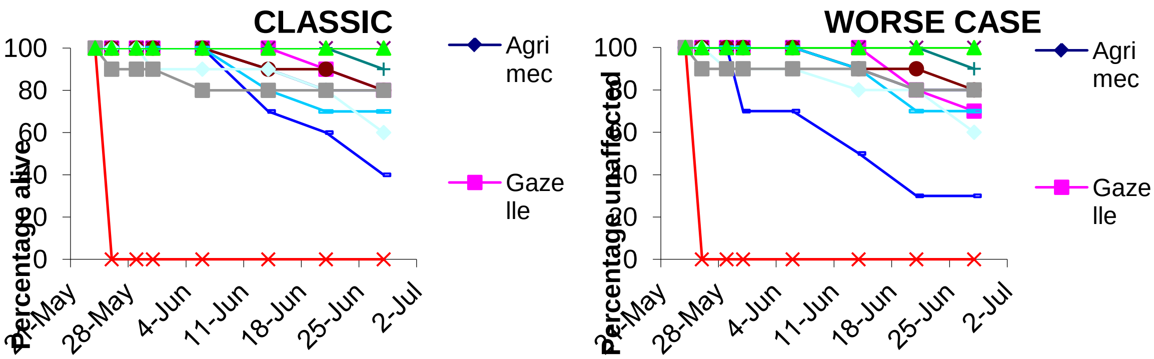


Figure 3.1.1. Earwig nymph survival (left) and mobility (right) over time when exposed to insecticides

a

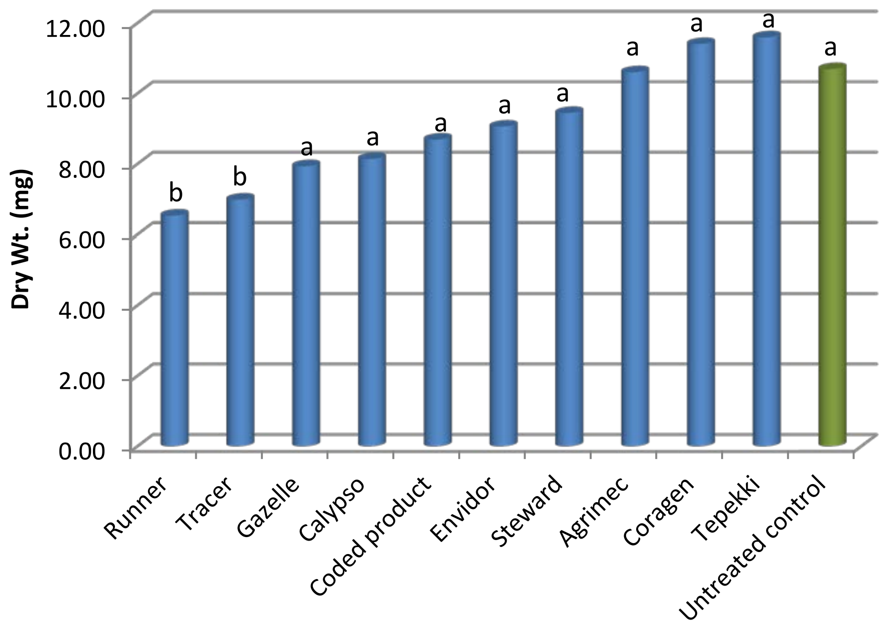


Figure 3.1.2. Mean dry weight of earwig nymphs after exposure to pesticide treated bean leaves

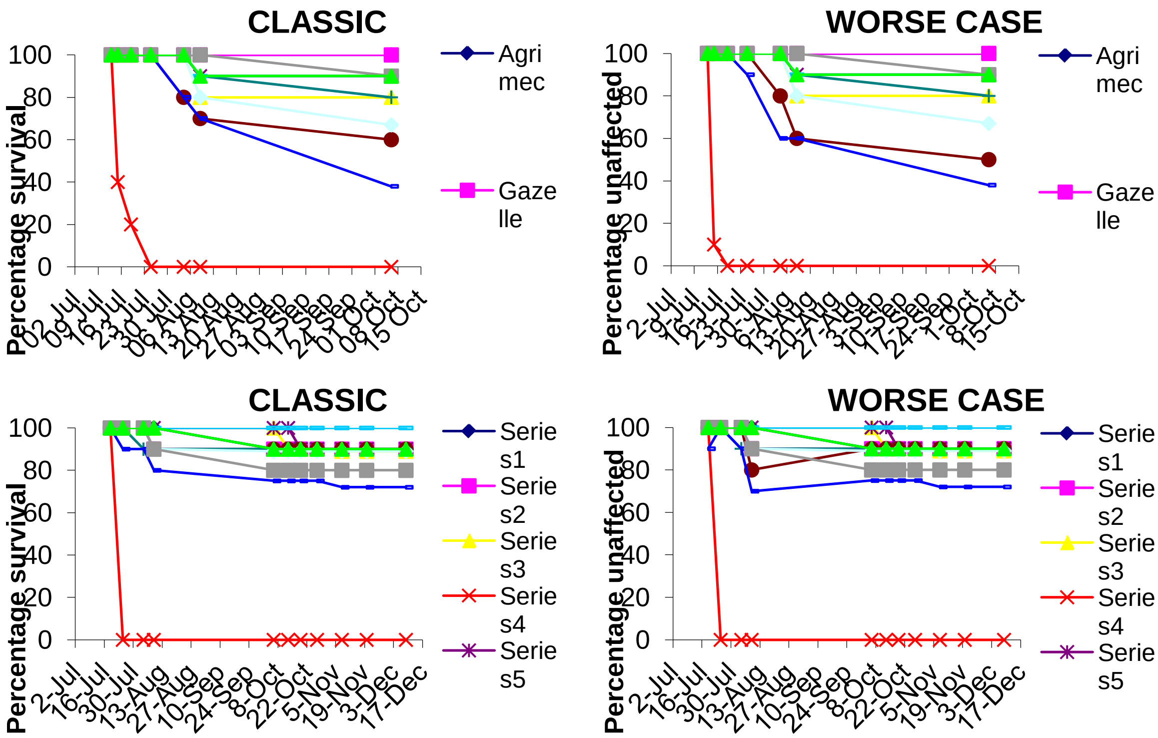


Figure 3.1.3. Earwig male (top) and female (bottom) survival (left) and mobility (right) over time when exposed to insecticides

Long-term toxicity tests

The artificial nest design was a success, with most females laying eggs inside the nests (Fig. 3.1.4). Of the females that survived the pesticide exposure and laid eggs, there was no significant difference between the treatments in the mean number of eggs laid (Fig. 3.1.5). Very few nymphs hatched from the eggs: Only between 1-4 nymphs from one female hatched from the coded product, Gazelle and Runner treatments. This suggests that mating was unsuccessful in the test chambers and implies that in future experiments males should be left for longer with females after winter emergence.

a b c

Figure 3.3.4. (a) Female in nest chamber with eggs (lid removed), (b) Female with first instar nymphs, (c) Female with older nymphs – note newly moulted white individual

Most females laid eggs on 17 January after the temperature was increased to 20^{o}C (Table 2.2). Because the replicate number of surviving females was low at this point (parasitized earwigs were removed from the analyses) it is difficult to draw significant conclusions. Half the number of females from the Gazelle and Steward treatments laid eggs on 31 Jan – one week after the main egg laying. Two of the surviving five females exposed to Tracer did not lay eggs by the end of the experiment.

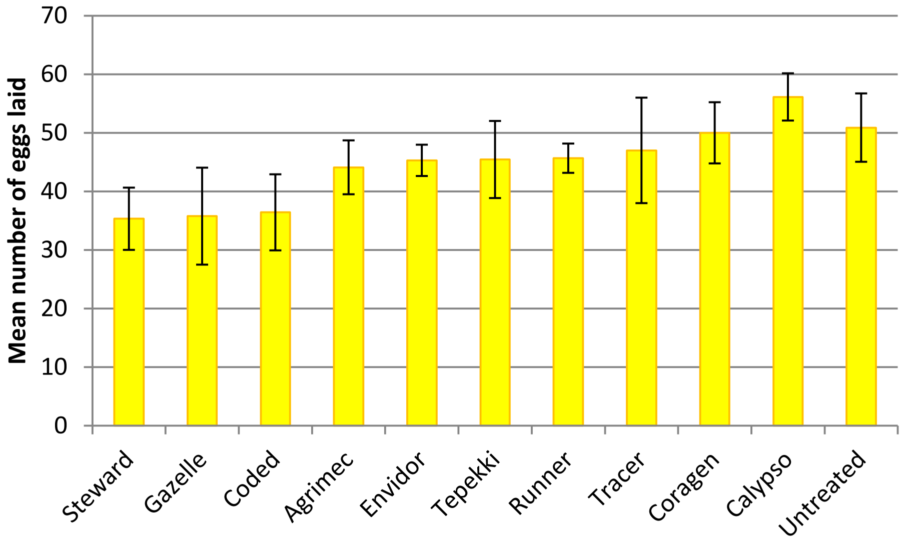


Figure 3.1.5. Mean of the maximum number of eggs laid by females earwig after exposure to insecticides

Table 2.2. Number of females that had laid eggs by each date

	09 Dec	17 Jan	24 Jan	31 Jan	14 Feb	29 Feb	Number not laying eggs	Total females alive at end of test
Agrimec		8			1			9
Coded	1	4		1			1	7
Calypso		7			1			8
Coragen		9		1				10
Envidor		9		1				10
Gazelle	1	3		3			1	8
Tepekki		4	2	1	1			8
Runner		5		1				6
Steward		4	1	3	1			9
Tracer		3					2	5
Untreated		7		1		1		9

Discussion

Some earwigs suffered from parasitism by a large nematode. The nematode (80-200 mm long) was likely to have been *Mermis nigrescens* (Fig. 4.1). These can be found moving around on the soil surface or vegetation in wet weather in June. Development is dependent on an insect (often earwigs and grasshoppers) eating the eggs of the nematode. The larva of the nematode pierces the gut wall of the insect and passes into the body-cavity. Once they emerge from the host they return to the soil until spring. (http://nematode.unl.edu/merminig.htm)

Some earwigs had tachinid (Diptera) parasitoids (Females R8 and R9; Males R8). Common species in UK orchards are *Rhacodineura pallipes*, *Digonochaeta spinipennis* and *Zenilla nemea*. *Digonochaeta* oviposit close to resting earwigs and the larvae bore into their new earwig host. *Rhacodineura pallipes* females lay their eggs on anything that earwigs fed on during the previous night; foraging earwigs then ingest the eggs with their food, which hatch in their guts and then burrow into the body cavities (Phillips 1983). Other species include *Triarthria setipennis* and *Ocytata pallipes* (Dimick and Mote 1934; Clausen 1978; Kuhlmann 2009). All of the earwigs parasitised by tachinid flies in the tests survived (Fig. 4.1).

a 

b  c 

Figure 4.1. (a) Nematode parasite emerged from earwig, (b) Tachinid pupae emerged from earwig, (c) Emerged tachinid fly

Earwigs exposed to chlorpyrifos (Equity) in Petri dishes died within a week of exposure to the insecticide. The causes of such rapid mortality are uncertain, but it is suspected that some vapour action may be involved (enclosed in Petri dish). Future field tests will help to establish if confinement to Petri dishes was a contributory factor. The most toxic products to the nymphs were spinosad (Tracer, 40% survival), thiacloprid (Calypso, 60% survival) and spirodiclofen (Envidor, 70% survival) (Table 4.1). Spinosad (Tracer) and thiacloprid (Calypso) also had detrimental effects on nymph mobility. In addition, nymphs exposed to methoxyfenozide (Runner) or spinosad (Tracer) had a significantly reduced body weight by the end of the experiment (Table 4.1). For adult earwigs indoxacarb (Steward) reduced male survival and spinosad (Tracer) reduced survival of males and females. This time it was indoxacarb (Steward) and spinosad (Tracer) that effected adult mobility. However, unlike the nymphs, adults sometimes recoved and survived.

In tests by other researchers mortality of adult earwigs caused by dried residue of deltamethrin and indoxacarb was highest on an inert substrate (Petri dishes) (90 and 100%, respectively), compared to a natural substrate (bean leaf disk) (<30%). Topical applications onto the backs of earwigs caused 100 and 67% mortality respectively. In food, the deltamethrin caused 75% mortality and indoxacarb and methoxyfenozide less than 30% mortality. The latter (moulting agonist) appeared to be harmless with topical applications (Peusens *et al*. 2010). These results highlight the differences in toxicity of pesticides, depending of the route of exposure and the mode of action of the compound.

In our tests indoxacarb (Steward) had little effect on nymphs and adult female earwigs but caused 40% mortality in adult males when earwigs were exposed to the pesticide on a bean leaf (residue contact and ingestion). Methoxyfenozide (Runner) had little effect on earwig mortality but the growth of the nymphs (dry weight) was reduced by at least 40%. This is probably not surprising as methoxyfenozide is a moulting hormone agonist. Hence some products will only directly affect juvenile stages of earwigs. In agreement with our tests Peusens *et al*. (2010) also noted behavioural changes with exposure to indoxacarb (sodium channel blocker). Although changes in behaviour and mobility of earwigs may not result in mortality directly, it does leave individuals vulnerable to predation (e.g. birds and small mammals) and therefore may indirectly cause mortality in field conditions.

Spinosad causes significant toxicological effects, with nymphs being more susceptible than adults (Peusens *et al* 2009). In our study nymphs and males were more susceptible than females to the effects of spinosad (Tracer, Table 4.1). The earwig species *Doru taeniatum* was also highly susceptible to spinosad, with individuals contained within gauze bags on trees and then sprayed showing 83% mortality compared to applications of chlorpyrifos 33% (Cineros *et al*. 2002).

Peusens and Gobin (2008) screened 17 classes of insecticide in laboratory tests using *F. auricularia* exposed to the insecticides on sprayed bean leaves. They concluded that carbamates, juvenile hormone mimics, feeding blockers, mite growth inhibitors, microbial disrupters, organotin acaricides, benzoylureas, diacylhydrazines, tetronic acid derivatives, paraffin oils and herbicides were harmless to adult earwigs. However, juvenile earwigs were not tested in their study (Peusens and Gobin 2008). Organophosphates, pyrethroids, pyrethrins, neonicotinoids, avermectins, METI-acaracides and oxadizines were slightly harmful, whereas, the spinosyn was moderately harmful. Side effects often occurred after 12 days or sometimes longer (34 days). In our study the effects of the insecticides were often not seen until 3-4 weeks after initial exposure (e.g. methoxyfenozide and spinosad).

When testing thiacloprid, spinosad, indoxacarb and flonicamid sprayed on trees with earwig shelters Vogt *et al*. (2009) found that all of the treatments reduced earwig numbers in the shelters compared to untreated trees. Reductions were most pronounced for indoxacarb with a maximum of 76% followed by thiacloprid 60%, spinosad 59% and flonicamid 48% two weeks post spray application. Populations continued to decline in the trees sprayed with flonicamid and spinosad at the final assessment, four weeks later (Vogt *et al*. 2009). In further experiments where trees were installed with earwig refuges and sprayed with insecticides, thiacloprid, spinosad, indoxacarb and flonicamid were all found to reduce the numbers found on the trees, the most toxic being indoxacarb, followed by thiaclopird, spinosad and then flonicamid. The effects of indoxacarb persisted for at least four weeks (Vogt *et al*. 2010). In our laboratory experiments spinosad appeared to be more toxic to earwigs compared to thiacloprid, with flonicamid showing no toxic effects. It is not clear from the field study of Vogt *et al* (2010) whether the effects were due to mortality (direct exposure or starvation) or avoidance – i.e. earwigs repelled by the treatments. This obviously has implications for control of pests in orchards as repellence of earwigs from the trees will have an impact on pest populations.

For a summary of data from this study and published data see Table 4.2. Differences in toxicity may depend on the methodology used in tests.

Conclusions

Laboratory tests in Petri dishes could over-estimate the toxicity of insecticides. However, earwigs were exposed to only one application of a single insecticide. This study does not take into consideration mixtures or repeated exposures to plant protection products. However, combined with data from other researchers it acts as a baseline for field studies in the coming growing seasons.

In the laboratory test chlorpyrifos was by far the most toxic insecticide for earwigs (Table 5.1). In order of decreasing toxicity the other insecticides were Tracer (spinosad) followed by Runner (methoxyfenozide, nymphs) then Calypso (thiacloprid) followed by Steward (indoxacarb)/Envidor (spirodoclofen)/Gazelle acetamaprid) (Table 5.1). In studies by other workers (Vogt *et al*. 2009) flonicamid (Tepekki) has resulted in fewer earwigs in trees. A recent review of the literature by Logan *et al*. (2011) rated residues of chlorpyrifos, spinosad, bifenthrin, diazinon and thiacloprid as highly toxic (>50% mortality) to earwigs and abamectiin, methoxyfenozide, spirotetramat, tebufenozide and thiamethoxam of low toxicity to earwigs. Their review did not include data on acetamaprid, chlorantraniliprole, flonicamid, indoxacarb or spiridoclofen. An older study by Sauphanor *et al*. (1993) demonstrated that diflubenzuron (Dimilin Flo) was highly toxic to earwigs in a pear orchard causing a subsequent rise in pear sucker numbers.

Table 5.1. Pesticides ranked in order from most to least harmful. Up to 70% survival or lowest mean weight of nymphs at end of tests

Nymph survival	Female survival	Male survival	Nymph weight
Equity	Equity	Equity	Equity
Tracer	Tracer	Tracer	Runner
Calypso		Steward	Tracer
Envidor		Calypso	Gazelle

Based on the findings from this experiment and other researchers it is recommended that field tests in 2012 include chlorpyrifos, spinosad, methoxyfenozide, thiacloprid and flonicamid. No significant additional toxicity information was gained from the reproduction data because the replicates were too low some of the treatments following the direct toxicity tests. However, much was learned about the maintenance of overwintering males and females and potentially future endpoints which could be measured (number of eggs, number of nymphs and time to lay eggs).

Acknowledgments

We would like to thank the funders of the research, HDC and a specific un-named agrichemical company, for their support and the East Malling Research students Tracie Evans and Gloria Endredi for their contribution to searching for earwigs in the night.

Table 4.1. End survival and mobility of nymph and adult male and female earwigs and final nymph earwig bodyweight after exposure to insecticides

Product	Active ingredient	Nymphs		Females		Males		Nymphs
		Survival (%)	Mobility (%)	Survival (%)	Mobility (%)	Survival (%)	Mobility (%)	Weight (mg)
Agrimec	abamectin	80	80	90	90	100	100	10.60
Gazelle	acetamiprid	80	70	90	90	100	100	7.93
Coragen	chlorantraniliprole	100	100	89	89	80	80	11.40
Equity	chlorpyrifos	0	0	0	0	0	0	0.00
Tepekki	flonicamid	100	100	90	90	90	90	11.59
Steward	indoxacarb	80	80	90	90	60	50	9.44
Runner	methoxyfenozide	90	90	90	90	80	80	6.53
Tracer	spinosad	40	30	72	72	38	38	6.98
Envidor	spirodiclofen	70	70	100	100	90	90	9.06
Calypso	thiacloprid	60	60	89	89	67	67	8.14
Coded product		80	80	80	80	90	90	8.69
Untreated control		100	100	90	90	90	90	10.69

Table 4.2. Summary table of data on safety of active ingredients on earwigs. Data is for adult earwigs unless stated otherwise

a.i.	Laboratory test in this report	Other researchers	Reference*
Abamectin	Safe	Harmful	1
Acetamiprid	Safe	-	
Bacillus thuringiensis	-	Safe	9
Bifenthrin	-	Harmful	1,7
Chlorantraniliprole	Safe	-	
Chlorpyrifos	Harmful	Harmful	1,2
Cypermethrin	-	Harmful to nymphs and knockdown effect	1,8
DDT	-	Harmful	8
Deltamethrin	-	Harmful and knockdown effect	1,4,7,8
Dimethoate	-	Harmful	1,8
Fenitrothion	-	Harmful	8
Flonicamid	Safe	Safe or harmful	1,3,5
Indoxacarb	Harmful to adult males and knockdown effects	Harmful and knockdown effects	1,3,4,5
Methoxyfenozide	Harmful to nymphs	Harmful	4
Permethrin	-	Harmful	7
Pirimicarb	-	Safe	1,8
Spinosad	Harmful to nymphs and adults. Knockdown	Harmful to nymphs and adults	1,2,3,5,6
Spirodiclofen	Harmful to nymphs	-	
Thiacloprid	Harmful to nymphs	Harmful	1,3,5

*1 Peusens & Gobin 2008; 2 Cineros *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 & Cranshaw 2010; 8 Ffrench-Constant & Vickerman 1985; 9 Maher *et al*. 2006

REFERENCES

Cisneros, J., Goulson, D., Derwent, L.C., Penagos, D.I., Herna´ndez, O., Williams, T. (2002) Toxic effects of spinosad on predatory insects. *Biological Control*, 23, 156–163.

Clausen, C.P. (1978) Dermaptera - Forficulidae - European Earwig. In: Clausen, C.P. (ed.) *Introduced Parasites and Predators of Arthropod Pests and Weeds: A World Review*, Handbook No. 480, United States Department of Agriculture, Washington, DC, pp. 15-18.

Colvin, B., Cranshaw, W. (2010) Comparison of over-the-counter insecticides for managing the European earwig, *Forficula auricularia* L. (Dermaptera: Forficulidae). *Southwestern Entomologist*, 35, 69-74.

Dib, H., Sauphanor, B., Capowiez, Y. (2010) Effect of codling moth exclusion nets on the rosy apple aphid, *Dysaphis plantaginea*, and its control by natural enemies. *Crop Protection*, 29, 1502-1513.

Dimick, R.E. and Mote, D.C. (1934) Progress report regarding the introduction in Oregon of *Digonocheata setipennis*, a tachinid parasite of the European earwig. *Journal of Economic Entomology,* 27, 863-865.

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

He, X.Z., Wang, Q., Xu, J. (2008) European earwig as a potential biological control agent of apple leaf-curling midge. Biocontrol of Insect Pests. *New Zealand Plant Protection*, 61, 343-349.

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.

Kuhlmann, U. (2009) *Ocytata pallipes* (Fallén) (Dipt., Tachinidae), a potential agent for the biological control of the European earwig. *Journal of Applied Entomology,* 117, 262-267.

Lenfant, C., Lyoussoufi, A., Chen, X., Darcier, F.F., Sauphanor, B. (1994) Potential of *Forficula auricularia* L. as a predator of pear-psylla *Cacopsylla pyri* (L). *Entomologia Experimentalis et Applicata,* 73, 51-60.

Logan, D.P., Maher, B.J., Connolly, P.G. (2011) Increased numbers of earwigs (*Forficula auricularia*) in kiwifruit orchards are associated with fewer broad-spectrum sprays. *New Zealand Plant Protection* 64: 49-54

Maher, B.J., Logan, D.P., Connolly, P.G. (2006) Effect of mineral oil and diazinon residues on the predator European earwig, *Forficula auricularia*, in Kiwifruit. *New Zealand Plant Protection*, 59, 202-207.

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.

Moerkens, R., Leirs, H., Peusens, G., Gobin, B. (2009) Are populations of European earwigs, *Forficula auricularia*, density dependent? *Entomol. Exp. Appl.,* 130, 198-206.

Moerkens, R., Leirs, H., Peusens, G., Gobin, B. (2010) Dispersal of single- and double-brood populations of the European earwig, *Forficula auricularia*: a mark-recapture experiment. *Entomol. Exp. Appl.,* 137, 19-27.

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., Beliën, T., Gobin, B. (2010) Comparing different test methods for evaluating lethal side effects of some insecticides on the European earwig *Forficula auricularia* L.. Pesticides and Beneficial Organisms IOBC/wprs Bulletin, 55, 95-100.

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.

Peusens, G., Moerkens, R., Beliën, T., Gobin, B. (2009) Side effects of plant protection products and biological interactions on the European earwig *Forficula auricularia* L. *Communications of Agriculture and Applied Biological Sciences,* 74, 411-417.

Phillips, M.L. (1983) Parasitism of the common earwig *Forficula auricularia* [Dermaptera : Forficulidae] by tachinid flies in an apple orchard*. Entomophaga*, 28, 89-96.

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., Chabrol, L., Faivre d'Arcier, F., Sureau, F., Lenfant, C. (1993) Side effects of diflubenzuron on a pear psylla predator: *Forficula auricularia*. *BioContro*l, 38, 2, 163-174.

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.

Staerkle, M., Kolliker, M., (2008) Maternal food regurgitation to nymphs in earwigs (*Forficula auricularia*). *Ethology*, 114, 844-850.

Vogt, H., Just, J., Grutzmacher, A. (2009) Field test of the impact of four insecticides on European earwig, *Forficula auricularia*, in an apple orchard. *Journal of Plant Diseases and Protection*, 116**,** 90–95.

Vogt, H., Just, J., Grutzmacher, A. (2010) Impact of four insecticides on the European earwig, *Forficula auricularia* L., in an apple orchard. Integrated Fruit Protection in Fruit Crops IOBC/wprs Bulletin, 54, 141-145.

Wirth, T., Le Guellec, R., Vancassel, M., Veuille, M. (1998) Molecular and reproductive characterisation of sibling species in the European earwig (*Forficula auricularia*). *Evolution*, 52, 260-265.