BioControl Agent: Missing In Action!

Side effects of Amitrol-based herbicides on non-target arthropod *Forficula auricularia L.*

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Side-effects of Amitrole-based herbicides on non-target arthropod Forficula auricularia

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Contents

Abstract

In crop production there is a growing trend, led by both market and government, to reduce and or eliminate pesticide residues found on fresh produce and in the natural environment. Although these reductions might benefit society and consumers, the expenses are above all the growers' (Cooley, 2009). The continuous search for and development of affordable and effective non-chemical means of crop protection is therefore of utmost importance. This paper takes a specific look at one alternative method of crop protection, the use of Biological Control Agents (BCA) in temperate apple cultivation. This study acknowledges and builds on previous work carried out on the common Earwig (*Forficula auricularia L.*), as a predator of major pests within Dutch apple orchards. The efficacy of this BCA has been proven both under laboratory conditions and in field trials (Helsen & Simonse 2006; Helsen & Winkler 2008). The main focus in this project has been the factors inhibiting Earwig establishment within apple orchards in The Netherlands. Several agro-management decisions as well as hypotheses have been put forward (Moerkens *et al*., 2009) which are most likely preventing the BCA from colonizing the fruit orchard and thus failing to display the potential of the organism in helping to suppress pest outbreaks. Considering the ecology of the BCA and the nature of the agro-ecosystem in which it is to reside, one particular factor that is most likely causing Earwig population to stagnate or even disappear is the application of pesticides in general and herbicides in particular. Both in laboratory experiments as well as out in semi-field studies, adverse effects have been identified due to the spraying of Amitrole containing herbicides. The toxicity of these Amitrole containing herbicides become evident during the reproduction phase of the BCA, where early embryo mortality prevented the majority of the treated eggs from hatching. Recommendations are done for improved management of weed control.

1.0 Introduction

This bachelor thesis is the product of time spent with Applied Plant Research (PPO: Praktijkonderzoek Plant en Omgeving) experimental station for fruit, under the supervision of entomologist Herman Helsen. For a period of six months I was attached to this station in which I was part of a team conducting research into an ongoing project centered on the common European earwig *Forficula auricularia*, as a predator of some key apple pests in The Netherlands. The project I was to participate in focused on the side-effects of pesticides on the common earwig population in apple orchards. Research had been started in 2007 and will be finalized in 2010; the intention is to make the findings available to growers within 2010.

Research in the field of biological control is highly relevant in temperate fruit production. Fruit growers are driven to use less toxic means in producing their crop and that is why viable alternative options need to be presented to the orchardist. Among these options biopesticides are perhaps the first thought of in substituting a certain conventional insecticide. A more indirect and less costly means of suppressing pest outbreaks is the use of Biological Control Agents (BCA's). These are usually natural enemies to one or more pests occurring in the fruit orchard. Integrated Pest Management[1] could offer the setting in which BCA's can perform their duty as long as BCA-friendly methods such as selective pesticides are used.

The amount of research conducted, concerning the earwig in general and as a predator in particular, is restricted. It is therefore worth mentioning the limited research already carried out on the common earwig as a natural enemy. This specific BCA appeared for the first time in the literature in Philips' Phd thesis *The Ecology of the common earwig in apple orchards* (1981). In this work the biological aspects pertaining to the behavior of the creature within agroecosystems were investigated and gave significant insight for re-evaluating the organism, considered up till then, as part of the key apple pests. The common held belief by most fruit growers, that the common earwig is 'just another harmful insect' within the orchard, has been proven otherwise by the discovery that the insect will only damage fruit and blossoms if the crop has already been tampered with by true apple pests such as the woolly apple aphid (*Eriosoma lanigerum Hausmann*). Philips (1981) paved the way for further research into the possibilities of the common earwig as a viable predator within apple orchards. It wasn't until Sauphanor *et al* (1994) proved that under laboratory conditions the common earwig would consume the eggs of *Cacopsylla pyri*, a key pest in apple and pear orchards. Mueller *et al* (1988) have found that two to five earwigs per apple tree can considerably reduce woolly apple aphid infestation. As soon as the earwig nymphs seek refuge in the tree, which in Holland takes place in June; their biggest contribution in pest suppression commences (Helsen, 1998). Inventories held in both Dutch and Belgian apple orchards further prove a strong relationship between earwig population densities and woolly apple aphid induced damage: outbreaks of the latter pest occurred where low earwig population densities were recorded (Helsen & Simonse, 2006).

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[1] Integrated Pest Management (IPM) is an effective and environmentally sensitive approach to pest management. It employs natural predators, pest-resistant plants and other methods to preserve a healthy environment in an effort to decrease reliance on harmful pesticides (Radcliffe *et al*., 2009).

The research objective is *to identify factors inhibiting the common earwig in colonizing the apple orchard* (for the control of pest populations within IPM systems in The Netherlands). With the possibility of non-target arthropod effects of certain pesticides on the common European Earwig (Helsen & Winkler, 2008), several pesticides were evaluated for their effect on the common Earwig.

The methods used in determining adverse effects on the earwig were set up in a controlled environment and a semi-controlled environment, i.e. *laboratory* and *extended laboratory test* respectively. For each of the experimental strategies the following structure of methodology is used:

1. How the research was designed
2. How the data were collected
3. How the data were processed

Concerning the structure of this paper, a review of literature and contextual framework is presented in chapter two, followed by materials and methods in chapter three. The latter will present the research conducted in detail including the research design, data collection and analysis. The results acquired through statistical analysis are presented in chapter four. A discussion of these results in chapter five, and chapter six is the concluding segment in which answers to the research question are given based on the findings in the preceding chapter.

2.0 Literature review

Temperate fruit production in the Netherlands has experienced a gradual shift in orchard management. Due to legislative restrictions on toxic emissions emanating from agriculture, Dutch fruit growers had to seek less chemical-intensive pest management systems. Professor Cross and Dr. Berry however, observe that non-chemical methods of control are less common in actual practice. They say alternative methods of assuring marketable fruit are usually too costly and are subject to climatic instability (Cross et al., 2009).

It is estimated that approximately 400 species of insects infest the apple and 25 are of economic importance, i.e. threaten marketability by negatively affecting yield quantity and quality. Most of these harmful insects are phytophagous (strictly plant feeding) organisms which suck from or bore into plant tissues, acting as vectors of disease (Romoser, 1981). According to Blommers (1994), the variety of insect life that orchards harbor depends a great deal on its location; New Zealand and Dutch apple growers have to deal with different pest spectra. This makes defining a universal apple IPM system nearly impossible without taking into account geographic variability.

The era of indiscriminate spraying of broad-spectrum pesticides was brought to an end after adverse effects were observed in the health of people and animals, and the contamination of natural resources (Vijver & Zelfde *et al*., 2008).

Fruit growers learned to view their orchard as a more complex and interdependent web of harmful as well as beneficial organisms. This ecological perspective presented fruit growers with less harmful and more selective methods from which they could equip themselves to control pests and diseases (Romoser, 1981).

The chief characteristic of this new methodology was that it considered the orchard as a man-made ecosystem, with similarity of components with their wild natural counterparts. Less reliance on chemical pest control meant a more profound understanding of the orchard-ecosystem was needed. The role of the orchardist was to become more in-tuned with the living environment of the orchard and how each component could be made to exert influence on processes driving pest dynamics (Huffaker, 1980).

Croft (1990) concluded from research that pesticide applications may directly kill natural enemies or have indirect effects through reduction in the numbers of availability of hosts. The direct effect of pesticides have been traditionally focused on acute toxicity, but often non lethal side-effects, such as the effect on longevity and reproductive capacity, play a role in the establishment of BCA's in the orchard (Nicholas & Thwaite, 2003). Helsen & Winkler (2008) add that the timing of pesticide application affects the toxicity; this is mainly attributed to the phase of the lifecycle the BCA is in.

In this paper the case of the European earwig, a predacious omnivore, is evaluated in terms of its integration within a pest management system in apple. At the experimental station of Applied Plant Research in Randwijk (The Netherlands), earwigs are reared and evaluated as natural enemies of the Woolly apple aphid (*Eriosoma Lanigerum Hausmann*) and pear sucker (*Cacopsylla pyri L.*). After several trials in both IPM and organic apple and pear orchards, earwig population densities were not sufficient to contribute significantly to the suppression of the abovementioned pests (Helsen & Simonse, 2006).

Although Moerkens et al. (2009) suggests the use of extra food sources (floral understories), shelters and alternative prey, the effect these measures may have however on earwig population densities is nearly impossible to measure. Indeed, the causes for these low densities are to be sought within the orchard and according to Helsen & Simonse (2006) no correlation was found between soil cultivation (e.g. mechanical weeding) and earwig density. Neither was there any particular soil type which showed higher earwig densities.

The systematic evaluation of the pesticides most commonly used in Dutch apple orchards were then tested for toxicity and other side-effects on the European earwig both under laboratory and semi-field conditions (Helsen & Winkler, 2008).

3.0 Materials and Methods

The research design is based on laboratory experimentation and observation (structured observational research) as well as a so-called extended-laboratory test or semi-field experiment (field research). With this experimental setup the aim was to find answers to the main research question: *what are the side-effects of amitrol-based herbicides on the common Earwig?*

3.1 Extended Laboratory test

3.1.1 Research design

The main experimental research was lab based, to test the side effects of pesticides on the female earwig. Only females were used because reproductive capacity and the effect on fertility is crucial in determining what is at the root of impairing earwig population to colonize the orchard.

The chemical treatments applied varied in the:

a. type of pesticide

b. amount

c. concentration

With each treatment it was sought to replicate the actual professional practice for apple orchards in Dutch agro climates. Therefore, the choice for commonly used plant protection products and their respective dosages sprayed by the commercial fruit grower were applied in the experiment.

The laboratory treatments to test the side-effects of different pesticides on female earwigs are presented below in Table 1.

Treatment	Dosage[2]
1. Control - Water	N.A.
2. Toxic Control - Steward	0.17g dissolved in 410ml water
3. Brabant Amitrol	1/3 of field dosage
4. Brabant Amitrol	1
5. Brabant Amitrol	3 (16ml dissolved in 136,7ml water)
6. Trolata	1/3 of field dosage
7. Trolata	1
8. Trolata	3 (16ml dissolved in 136,7ml water)
9. Weedazol	1/3 of field dosage
10. Weedazol	1
11. Weedazol	3 (17.5g dissolved in 136.7ml water)
12. Basta	1 (5.55g dissolved in 410ml water)
13. Kerb	1 (2.34g dissolved in 410ml water)
14. RoundUp ECON 400	1 (6.53g dissolved in 410ml water)

Table 1: Different treatments used under laboratory conditions

Protocol for the laboratory experiment

- For each treatment shown in table 1, 20 replicates, i.e. 20 females were used
- Petri dishes (4cm in diameter) were prepared for each female in every treatment
- An agar solution (concentration:7g/L) of 2ml/dish was poured
- Untreated, fresh and perforated bean leaves (*Phaseolus Vulgaris L.*), 4cm in diameter, placed on lukewarm agar
- The prepared dishes were placed in a Potter Spray tower[3] where each dish was treated with 3ml spray solution (see table 1 for details)

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[2] To keep true to actual amounts applied in practice (410l/ha), the aim was to reach an application of 4100 microgram/cm^2 of spray solution. This was done by taking the product amount for 1l and mix it with 410ml water instead

[3] Pressurized (7.5lbs/$inch^2$) laboratory chemical spraying apparatus for studying the biological effects of contact poisons on organisms. See manufacturer website: www. burkardscientific.co.uk

- Prior to exposing the earwigs to the treatments, they were kept at 16 ^{o}C for two weeks with food and drink (dry cat food and Eppendorf tubes (1.5ml) containing water were sealed off with a cotton plug - to facilitate drinking & conserve water as well)
- 5 days after treatment (DAT), using 'insect-friendly' tweezers, the earwig females were placed in (deeper than average) 9cm Petri dishes, together with the 4cm treated dishes and food and drink as stated above
- Each treatment and its 20 replicates were placed in individual white containers
- According to Philips (1981) the common Earwig (*Forficula auricularia L.*) is sensitive to changes in RH levels. This is why the aim was to keep Relative Humidity (RH) at 70% and during the monitoring process we succeeded to maintain RH and temperature levels as stated above
- RH levels were reached and kept stable by laying out large wetted cotton swabs across each container and placing the containers in large white plastic bags

3.1.2 Data collection

Data was obtained through regular observation, twice a week.

During these monitoring sessions the following information was collected per replicate (dish #) per treatment:

- Number of eggs
- Date of new egg batch
- Egg color (black is indicative of embryo mortality)
- Number of nymphs
- Date of egg hatching

Next to noting down the abovementioned data, the following action was taken when necessary:

- Exclusion of male in case of new egg batch
- Food and drink substituted
- Removal of excessive mould

3.1.3 Data processing

The registration of the collected data during the structured observation was entered into Microsoft Excel® for analysis. With the following information constituting the main data collected for processing:

- Behavior (normal, affected, moribund and dead)
- Number of eggs
- Date of new egg batch
- Number of nymphs
- Date of egg hatching

Dish	Female	# eggs	Date 1	# nymph	Date 2	max # nyn	# ny. 1wk	state	
1	1	60	23-feb	3	16-mrt				
2	1	30	12-feb	2	2-mrt		16		
3	1	50	12-feb	22	5-mrt		18		
4	1	50	2-mrt	0			0		
5	1	40	10-feb	20	2-mrt		12		
6	1	60	12-feb	28	5-mrt		24		
7	1	40	8-feb	9	26-feb		11	no nymp	
8	1	50	12-feb	4	5-mrt		0		
9	1	30	16-feb	0			0	moribund	
10	1	30	19-feb	6	12-mrt		5		
11	1	40	8-feb	28	5-mrt		20	affected	
12	1	50	16-feb	40	9-mrt		35		
13	1	50	10-feb	30	2-mrt		35		

Table 2: Data collection sheet for laboratory-based experiment

As can be read in the table, the *dish* column signifies the 20 replicates for each of the 14 treatments (see table 1). The *female* column says something about survival, indicated by the number '1' and death expressed by the number '2'.

 # eggs means number of eggs per batch laid. *Date 1* is the specified date on which the first egg batch was laid. *# nymph* is the number of larvae hatched. *Date 2* signifies the date on which the first nymphs were seen. *# ny. 1wk* gives a headcount of the total amount of nymphs after one week. Any suspicious behavior was noted in the *state* column.

In analyzing the data, a graph was plotted in Excel® in which the percentage of hatched eggs per treatment was visualized. A less significant dataset which was considered nonetheless was the number of eggs per female.

See Annex I for the full data set of the laboratory data set.

3.2 Semi-field test

3.2.1 Research design

Orchard location: Randwijk West 1

Fruit: Apple

Objective:

To identify the side effects of herbicidal application, under semi-field circumstances, on:

1. Earwig oviposition and
2. the number of viable eggs per batch

As opposed to the laboratory-based experiment, this test is limited to the side-effects of Amitrol[4] containing herbicides only. Furthermore, the effects of different application moments (indicated by 'early' and 'late') are also compared.

NB: The early and late treatments are both indicative for time of spraying as well as the placing of the earwigs within the orchard.

For the experimental plot: Randwijk West 1, the so called 'Early' application (Oct. 9th 2009) is compared with the 'late' (Oct. 28th 2009) spraying moment.

There is also a 'non' applied treatment (control), in this particular section of the row, untreated samples were placed at different times, namely: Oct. 9th (early) and Oct. 28th (late). This is indicated by the 'Non-early' and 'Non-Late' inscriptions on both the PVC rings in the field as well as the Petri dishes in the lab.

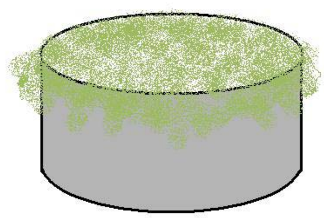

Figure 1: PVC ring used to contain earwigs in the orchard

On the left a sketch of such a PVC ring used in the field, within the tree row, to contain the earwigs for the winter period (October 2009 – March 2010). While housed in these 30cm in diameter rings, some were exposed to Amitrol-containing herbicides, early or late, and some were not. The cover consists of a wire-mesh screen to ensure confinement of the earwigs.

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[4] Chemical formula: 1H-1,2,4-Triazol-3-amine. Commercial products which contain amitrole as the active ingredient include: Weedazol™

The organization of the experimental plot (Randwijk W1) is as follows:

Length 30m.	Early	Non	Late	Late
Length 30m.	Late	Early	Early	Non
Length 30m.	Non	Late	Non	Early
<--- West	Row 1	Row 4/5	Row 8/9	Row 12/13

Remarks:

- The PVC rings were labeled and beaten into the topsoil layer beneath the trees
- 2 females and 2 males were put in the PVC rings and covered with a wired mesh to confine the earwigs
- In case multiple females are found in a particular sample, the females are attributed the letters **a** & **b** respectively.
- When collecting the field samples, nests were recovered and identified in the text below as "**c**".

3.2.2 Data collection

Having spent the entire winter (oct. 2009 – march 2010) below ground in an artificially enclosed PVC ring in the orchard, the rings were harvested the following spring, March 2010.

The rings were inspected for:

- Survival and number of female earwigs
- Egg nests

Those female earwigs that were recovered from the field were then transferred to Petri dishes and:

- provided with food and drink
- pared up with a male if no eggs were found
- labeled (Row, field)
- Kept under controlled environment at 17 ^{o}C and 70% RH
- Monitored for oviposition

Table 3 below is an example of the recording of information during laboratory observation once the recovered earwigs were transferred to the controlled environment, the conditions were equal to those of the laboratory based experiment: 17 ^{o}C and 70% RH.

Row	Treatmnt	Dish	a of b	Female	# eggs	Date	# nymph	Date	# ny. 1wk
4	Not-Early	1	b	1	40	9-mrt	0	30-mrt	0
4	Not-Early	1	a	1	30	12-mrt	0	13-apr	0
4	Not-Late	1	b	1	20	9-mrt	8	30-mrt	8
4	Not-Late	6		1	40	9-mrt	0	30-mrt	0
4	Late	6	a	1	20	9-mrt	0	30-mrt	0
4	Late	6	b	1	50	9-mrt	6	30-mrt	0
4	Early	5	a	1	25	9-mrt	0	30-mrt	0
4	Early	5	b	1	8	9-mrt	0	30-mrt	0
4	Early	6	a	1	30	9-mrt	28	30-mrt	0
4	Early	6	b	1	30	9-mrt	0	30-mrt	0

Table 3: Extended laboratory data registration

3.2.3 Data processing

The analysis included the following four variables:

1. *Early* – exposed to Amtirol on October 9th 2009
2. *Late* – exposed to Amitrol on October 28th 2009
3. *Not-early* – non-treated and placed in orchard on October 9th 2009
4. *Not-late* – non-treated and placed in orchard on October 28th 2009

As can be seen in the organization of the experimental plot in paragraph 3.2.1, each tree row is divided into three fields: early – late – not. The latter being subdivided into a *not-early* and a *not-late* treatment as explained above.

In the analysis the distinction between rows no longer applied due to the insignificance of the segregation. More interesting was to group the variables mentioned above, which contained obvious commonalities. In doing so, quantitative analysis could be carried out by gathering all the information from all rows in the experimental plot and categorically grouping the data according to the four distinctions presented above.

This particular organization of data in Excel® facilitated the computation of:

- Average number of eggs/batch/treatment (e.g. 33 eggs on average/batch for the *early* treatment)
- Number of hatched egg batches
- Number of un-hatched egg batches
- Nymph/Egg ratio
- Average amount of nymphs/treatment
- Percentage of egg batches that did not hatch per treatment

Annex II provides the data overview discussed above.

4.0 Results

4.1 Laboratory based experiment

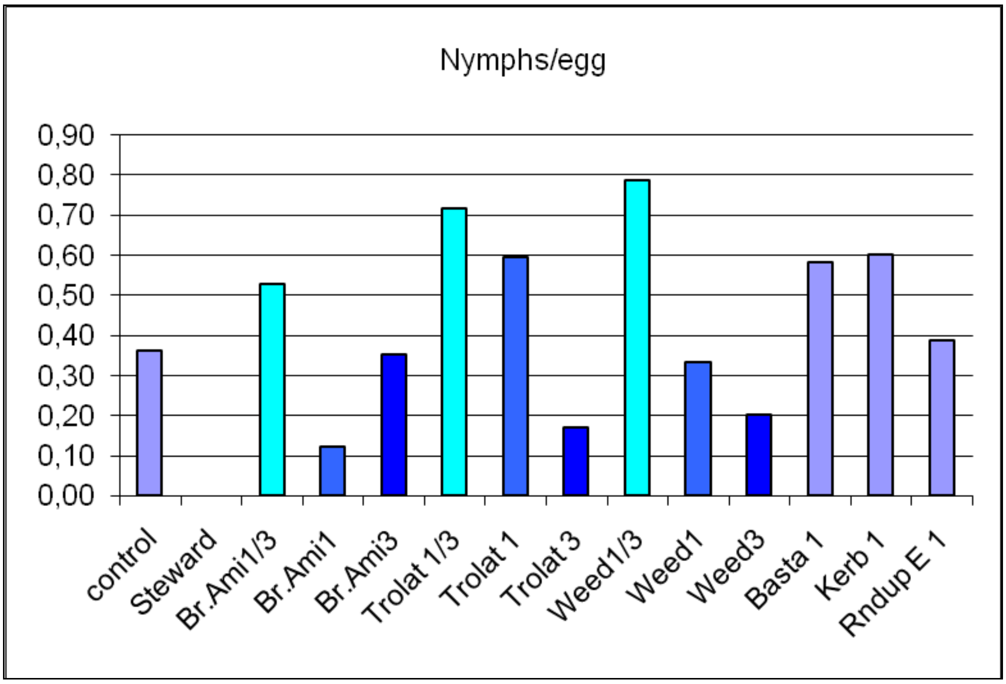
For the laboratory based experiment the essential outcomes are the number of eggs per female and the percentage of nymphs per egg, shown left and right respectively. We can read from the tables below that for Weedazol and Trolata the toxicity increases, especially for the nymph/egg ratio, when the concentration of the item is increased threefold. For Br. Amitrol, the highest concentration seems to cause a reversal of the effect observed in Trolata and Weedazol.

Tabel 2: Pesticides used in the test

Treatment item	eggs/female	nymphs/egg
Control	2,1	0,36
Steward	0,1	0,00
Brabant amitrol 1/3	1,8	0,53
Brabant amitrol 1	1,7	0,12
Brabant amitrol 3	2,0	0,35
Trolata 1/3	2,0	0,72
Trolata 1	2,0	0,59
Trolata 3	1,7	0,17
Weedazol 1/3	2,3	0,79
Weedazol 1	2,3	0,33
Weedazol 3	2,1	0,20
Basta	2,1	0,58
Kerb	1,7	0,60
Roundup ECON400	1,5	0,39

From the abovementioned data the graph below is plotted. We can see the degrading effect of the higher concentrations of both Trolata and Weedazol very clearly now. Whereas a third of the recommended concentration of Weedazol permits around 80% of the eggs to hatch and produce nymphs, the threefold application of the same item causes 80% embryonic mortality.

Tabel 3: the ratio of eggs which actually hatched



4.2 Semi-field test

In the extended laboratory test, as stated before, only amitrol-containing herbicides were used. In the results of this test we can note interesting similarities with the strictly lab-based experiment, such as the effect that amitrol-based herbicides have on nymph per egg ratios in a semi-field setting.

	av. Nymphs	batches non hatched	nymph/egg	% batch non hatch	av. Eggs
Early	5,0	15	0,15	68	33,1
Late	13,2	11	0,37	46	35,3
Not-Early	10,9	5	0,33	56	32,8
Not-Late	12,4	7	0,34	35	36,3

Next to the toxicity, there seems to be a clear difference in the amount of nymphs per egg between the early and late application. A temporal aspect has thus been identified in the extended laboratory experiment which was hypothesized upon commencement of the project. That indeed, a significant influence has occurred on the nymph count per egg produced.

The statistics furthermore point towards severely reduced hatching of eggs when we look at the percentage of egg batches that did not hatch in the early treatment (68% for the early treatment as opposed to the late: 46%).

5.0 Discussion

Maintaining a weed free strip beneath the trees, to minimize competition for nutrients and moisture, is in line with 'state-of-the-art' agronomical knowledge (Cross & Berrie, 2009). However, this study has shown that the means and method by which undesired vegetation is removed can have a profound effect on a crucial component within an IPM system. In the studied orchard the BCA is an integral part of the IPM system, and thus considered a Non-Target Arthropod (NTA) as defined by the IOBC[5]. What this means is that the Earwig should only be introduced or augmented[6] in orchard management systems where the array of plant protection products are aligned to the susceptibility of the BCA. Broad-spectrum pesticides however, are increasingly being replaced by less indiscriminate and more selective products with the latter aimed at catering to the orchardist implementing IPM with the use of natural enemies.

No doubt that one would expect unintended side-effects primarily from insecticides rather than from herbicides when dealing with arthropod organisms. Nevertheless, it is only when one is thoroughly acquainted with the biology and ecology of an organism that meaningful steps can be taken to trace back and identify whatever constraint the BCA is facing in maintaining and increasing population densities. In case of the mechanisms regulating Earwig population densities, Moerkens *et al*. (2009) considers migration, starvation, pathogens, parasites, predation and even cannibalism before reaching the conclusion that lack of food, both in quantity and diversity, is the most limiting of factors. He goes on to disregard orchard management in terms of pesticide use by indicating that pesticides: "…cannot explain the population decline either".

Most ecologists would agree with the proposed increase of environmental capacity and its consequence: causing a reduction in competition for food sources (Irvin *et al*, 2006). Sure, the addition of alternative prey, food and shelter might provide the BCA the necessary conditions to proliferate within the fruit orchard. The reality however, is such that measuring and quantifying the added value has proven difficult (Lavendero *et al*, 2006).

What does this mean for the modern fruit grower in The Netherlands and other temperate agro-ecosystems?

When the results of this paper are taken into account one cannot be entirely certain that amitrol containing herbicides interfere with the establishment of the common earwig in the apple orchard. Especially the higher dosages of commercial items such as Weedazol and Trolata suggest considerable damage to the reproductive capacity of the earwig in the orchard, more trials are needed to confirm the results found in this research.

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[5] International Organization for Biological and Integrated Control of Noxious Animals and Plants. The IOBC was established in 1955 to promote environmentally safe methods of pest and disease control in plant protection (www.iobc-wprs.org).

[6] As acknowledged by Helsen & Winkler (2008), the most impractical method (for the fruit grower) of establishing a natural enemy is through augmentation. It is the periodic mass-release of thousands of BCA's to reduce pest numbers.

What was interesting to notice as a result of this research is how great the influence of spray time can be on the number of eggs hatching, with twenty days earlier in October the period in which the earwig finds itself in its lifecycle apparently is a vulnerable position indeed. This appears to be exactly what Nicholas & Thwaite (2003) and Helsen & Winkler (2008) have hypothesized as being a major point of attention in evaluating the common earwig as a BCA in apple orchards.

All in all, external influences, such as an exceptional winter, and an isolated case study do not constitute enough evidence to prove the observed outcomes in embryo mortality of the earwig. More trials are needed under several differing abiotic and biotic conditions to prove the reproductive toxicity of amitrole containing herbicides to the common European earwig.

6.0 Conclusion

Based on the findings of this research one can be confident to have come a step closer in the evaluation of the earwig as a predator with potential in European apple orchards. This research project has aimed to get answers in regards to the factors inhibiting earwig colonization of the European apple orchards. As part of orchard management pesticides are applied sometimes without the knowledge of or the intention to harm so-called non-target arthropods.

It has been found that the main side-effect of amitrol-based herbicides have a degrading effect on reproductive capacity of the common earwig. The results suggest that female earwigs exposed to amitrol, who then go on to mate and produce eggs, are inclined to lay egg batches which will suffer from embryo mortality. The severity and percentage of embryonic mortality depends on two aspects, 1) the timing of herbicide application, with later sprayings having reduced impact on the amount of eggs that will hatch. 2) And the concentration of the dosage applied, with the exception of Brabant amitrol. The latter factor, amitrol concentration, increases exponentially with the embryo mortality percentage.

This paper has failed to prove that at least one component of orchard management can have grave consequences for those who seek to establish the common earwig as a BCA in their respective orchards. The path from here should be in the direction of alternative solutions for weed management, such as plant pathogens and insects. Although we recognize that biological control of weeds is more of a long-term endeavor, it is strongly recommended to seek such solutions. On the part of the fruit grower, a 'lifecycle awareness' should provide flexibility. What is meant here is timing of application of amitrol-based herbicides, since we now know that a later application of herbicides causes less stress on the reproductive capacity of the earwig, it remains however a short-term solution. Since the area right beneath the tree is where the earwig lays its eggs and hopes to emerge from come summer, the fruit grower should consider selective methods of weed management, methods that spare and respect the habitat of the natural enemy and preserve its food sources.

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Annex