Project title:	Evaluation of insecticides for control of adult vine weevil under controlled conditions.
Project number:	SF/HNS 112
Project leader:	John Buxton, ADAS
Report:	Final (additional), December 2011
Previous report:	-
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Location of project:	ADAS Rosemaund & ADAS Boxworth
Industry representatives:	Dr Paul Sopp, Fargro Ltd Mr Graham Moore, FAST Ltd
Date project commenced:	April 2010
Date project completed (or expected completion date):	December 2011

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.

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GROWER SUMMARY

Headline

Growers should not rely solely on insecticide sprays against adults for control of vine weevil. Although Hallmark gave complete control of adult weevils under semi-field conditions in 2010 it was not effective in 2011, when Steward and Chess were the most effective products.

Background and expected deliverables

Vine weevil is a serious pest of soft fruit and hardy nursery stock and control of the larvae in soil-grown soft fruit crops is difficult. As an alternative strategy, growers may apply timely insecticide sprays to control adult weevils, ideally before they can lay eggs. The main product used until recently was bifenthrin (Talstar), but EU legislation led to the withdrawal of this pyrethroid insecticide. Therefore there was an urgent need to screen replacement products, so growers retain access to effective insecticides for use against adult vine weevils.

The objective of this project was to evaluate a range of mainly IPM compatible insecticides for efficacy against adult vine weevil in order to help ensure that growers continue to effectively control this difficult pest.

Summary of the project and main conclusions

Evaluation of insecticides under semi-field conditions

Six insecticide treatments were tested against adult vine weevils collected from strawberry crops under semi-field conditions at ADAS Rosemaund in June 2010 and a similar range of insecticide treatments was tested in the same way at ADAS Boxworth in June 2011. In total, eight insecticides, one applied at two rates, were tested in 2010 and 2011. The rates used were label or Specific Off Label Approval (SOLA, now renamed Extension of Approval for Minor Use or EAMU) rates. Three of the insecticide treatments were the same for the two experiments.

Both experiments used mesh cages placed within a ventilated polytunnel. The vine weevils used were collected from crops of strawberry and raspberry. To simulate the field environment as far as possible, each cage contained refuges for the weevils, including a layer of compost on the floor and food plants. The plants and all interior surfaces of the cages were sprayed during the early evening, when adult weevils would be expected to become active.

Assessments were made (at intervals of seven and 14 days in 2010 and eight and 15 days in 2011) after treatment application, classifying weevils as dead, dying (moribund) or alive. The levels of weevil mortality in insecticide-treated cages were compared to levels of mortality in cages treated with water only.

In 2010, natural mortality of weevils in untreated cages was 55% after 14 days while in 2011 it was just 7% after 15 days. The high level of mortality recorded in 2010 was most likely due to the very high temperatures recorded throughout this experiment. The timing of the 2011 experiment coincided with a period of relatively cool weather.

Results, corrected for control mortality, are summarised in Table 1.

2010

- In 2010, the pyrethroid insecticide Hallmark at 100 ml/ha gave complete control of adults within 14 days of application.
- When Hallmark was tank-mixed with chlorpyrifos (Equity) at 1,500 ml/ha, complete control was achieved within seven days.
- Steward (170 g/ha) also gave good control of adult vine weevil.

2011

- In 2011, Steward at 250 g/ha was the most effective of the insecticide treatments tested (71% mortality after 15 days).
- Chess (400 g/ha) was the next most effective (60% mortality after 15 days).
- For both insecticide treatments, most of the adult vine weevils died within eight days of the spray being applied.
- A lower rate of Steward (170 g/ha) and the neonicotinoid product Calypso (250 ml/ha) were less effective and did not significantly increase weevil mortality compared with the untreated control.
- The pyrethroid insecticides Hallmark and Toppel were also ineffective.

Table 1. Summary of insecticide efficacy against adult vine weevil in experiments done in 2010 and 2011 (data adjusted for control mortality)

Treatment no.	Product	Active ingredient	Rate (ml or g/ha) used	Mean % mortality after treatment			
				2010		2011	
				7 days	14 days	8 days	15 days
1	Control	N/A	N/A	N/A	N/A	N/A	N/A
2	Calypso	thiacloprid	250	23	67	21	25
3	Chess	pymetrozine	400	-	-	**58**	**60**
4	Gazelle	acetamiprid	250	-51	-22	-	-
5	Hallmark	lambda cyhalothrin	100	49	**100**	0	-4
6	Hallmark + Equity	lambda cyhalothrin + chlorpyrifos	100 + 1500	100	**100**	-	-
7	Pyrethrum	pyrethrins	20 ml/5 l water	-42	3	-	-
8	Steward	indoxacarb	170	45	**91**	32	26
9	Steward	indoxacarb	250	-	-	**70**	**71**
10	Toppel	cypermethrin	250	-	-	5	15

NB:

1. Figures in bold are significantly different from the untreated ($P<0.05$)
2. Negative figures indicate that mortality for that treatment was lower than in the control
3. A dash (-) means not tested

Evaluation of insecticides under controlled laboratory conditions – 2011

In contrast to the results obtained in 2010, Hallmark at 100 ml/ha was not effective under similar but much cooler semi-field conditions in 2011. Hallmark and Steward were therefore compared under controlled temperature (21°C) conditions in the laboratory in order to provide more definitive information on the inherent activity of these insecticides against adult vine weevils.

Two experiments were completed, one testing three rates of Hallmark and Steward when the adult vine weevils were directly sprayed. In a second experiment Hallmark at 100 ml/ha and Steward at 250 g/ha were sprayed onto foliage and soil before exposing weevils to these spray residues after 0, 12 or 24 hours.

In these experiments direct contact with Hallmark had little effect on weevil mortality (13-27% mortality after 14 days) or on the proportion of moribund weevils recorded (7-20% after 14 days). In the residue experiment weevil mortality (7-33% after 14 days) was again low but the proportion of moribund weevils (27-47% after 14 days) was higher. Hallmark and Steward also had a noticeable adverse effect on the behaviour of surviving weevils. These effects included abnormal/slow walking and, in the case of Steward, a liquid produced from the mouth. These sub-lethal effects may affect weevil survival or fecundity and so further reduce weevil populations over time.

The approval status on outdoor and protected crops of raspberry, strawberry and ornamentals of the insecticides used in the trials is shown in Table 2.

Table 2. Approval status of insecticides tested in this project for use on fruiting crops of strawberry and raspberry, and ornamentals – November 2011

Product	Approved for use on					
	Raspberry		Strawberry		Ornamentals	
	Outdoor	Protected	Outdoor	Protected	Outdoor	Protected
Calypso	EAMU (0336/06)	EAMU (0534/07)	EAMU (0333/06)	EAMU (0334/06)	EAMU (2831/08)	-
Chess	-	EAMU (0498/07)	-	EAMU (0499/07)	Label	Label & EAMU (2834/08)
Equity	Label	Label	Label	Label	-	-
Gazelle	-	EAMU (2856/08)	-	EAMU (2856/08)	Label	Label
Hallmark	EAMU (0728/06)	-	EAMU (1705/11)	EAMU (1705/11)	EAMU (2944/08)	EAMU (2944/08)
Pyrethrum	Label	Label	Label	Label	Label	Label
Steward	EAMU (2905/08)	EAMU (2905/08)	EAMU (2905/08)	EAMU (2905/08)	EAMU (2905/08)	Label
Toppel	-	-	-	-	Label	Label

NB:

1. A dash (-) means not approved
2. Note that the maximum rate of use, harvest interval and other statutory conditions for a product can vary between crops and situation of use (outdoor or protected)
3. The approval status of pesticides is subject to change
4. Consult the relevant label or EAMU before using a product

- Full details of conditions of use in the work in this project are given in the science section of this report

Effect of environmental conditions on treatment efficacy

The observed differences in levels of mortality and speed of kill between 2010 and 2011 strongly suggest that the efficacy of insecticides may be determined in part by environmental conditions as all other conditions of the trials were similar. The semi-field experiment completed in 2010 was characterised by high temperatures (daytime temperatures, mean = 28.3°C, range = 18.6-37.8°C) while in 2011 conditions were relatively cool (daytime temperatures, mean = 22.7°C, range = 19.0-26.0°C). The high temperatures in 2010 led to high levels of mortality within seven days in all treatments including the untreated (55%).

For the insecticide treatments (except Hallmark + Equity) tested in 2010 weevils died throughout the 14 days of the experiment. In 2011 control mortality was low and nearly all of the mortality in the insecticide treatments occurred within eight days. It seems likely then that a combination of insecticide treatment and high temperatures in 2010 led to large numbers of weevils dying more than a week after the sprays were applied. In 2011 the weevils were not stressed by high temperatures and so may have been better able to survive any long-term effects of the insecticide treatments.

Financial benefits

Vine weevil is a serious pest of soft fruit, and estimates suggest that, in the absence of bifenthrin, losses in strawberries and raspberries alone could increase to over £10 million per annum (Defra project IF01100). In nursery stock the feeding of adults on the foliage, causing characteristic “notching” of the leaves, is important, as it can lead to rejection of plants by buyers. In addition, the feeding of larvae on roots of containerised shrubs, alpines and herbaceous plants causes losses and reduction in quality unless controlled.

The estimated cost (both material and application) of treating one hectare of protected strawberries with a single spray of Hallmark (100 ml/ha) is around £39 and for Steward (250 g/ha) £85. Using the assumptions that one hectare would yield 20 tonnes of strawberries and that the value of the fruit is £3,000/tonne it is possible to estimate the financial benefit of these applications. As there are often hot-spots of adult vine weevil within a crop the affected area may be relatively small (e.g. approximately 5% of the total area). Therefore, if the affected area is left untreated and these plants either die or do not produce fruit then a loss of £3,000/ha can be estimated.

To be cost effective Hallmark would need to be at least 1% effective in reducing losses caused by vine weevil. Steward would need to be 3% effective to be cost effective. However, the relationship between adult vine weevil numbers and numbers of larvae in the soil or growing media is poorly understood. As such it is not possible to directly relate adult weevil numbers to damage caused by larvae. Insecticide applications against adult vine weevils also need to be considered within an IPM programme in order to avoid negative impacts on biological control agents being used against other pests within the crop.

Application later than September is expected to show a reduced financial benefit because, by that time of year, adult weevils would have already laid some eggs within the crop, allowing another generation of the pest to develop. The financial benefits from treatment of hardy nursery stock crops are difficult to quantify, but the area treated for control of adult weevils is likely to be significantly less than that on soft fruit.

Action points for growers

- Do not solely rely on insecticide sprays against adults for control of vine weevil. Consider how to optimize control of larvae with insecticides or biological control agents.

- If treatment is considered necessary against adult vine weevil, this project has indicated that several insecticides may give some control:

- Hallmark (and Hallmark + Equity) were effective in the 2010 semi-field trial but Hallmark was not effective in the 2011 semi-field trial. These inconsistent results may have been due to temperature effects but they indicate that Hallmark may give unreliable control. See Table 2 for crops that Hallmark and Equity may be used on.

- The 2011 semi-field trial indicated that Steward applied at 250 g/ha could give good control. However, this rate may only be used on outdoor ornamentals and outdoor, un-cropped raspberry and strawberry where a one year harvest interval is possible (EAMU 2905/08). For protected crops spray concentrations for this product should not exceed 12.5 g/100 l (the efficacy of this label rate was not tested in this project).

- The 2011 semi-field trial also indicated that Chess applied at 400 g/ha (EAMU 2834/2008) may also provide useful control on protected soft fruit crops. Chess may be applied to protected ornamentals at 60 g per 100 l water (EAMU 2834/2008) thus if applied at 600g in 1000 l water/ha, this rate should give useful control. The label rate for Chess is 20g per 100 l water so if this rate is used on outdoor ornamentals the effect on adult vine weevil is currently unknown.

- Steward and Chess are more compatible than Hallmark and Equity with naturally occurring vine weevil predators, such as native carabid and staphylinid beetles, as well as biological control agents introduced for control of other pests.

SCIENCE SECTION

Introduction

Vine weevil continues to be a serious problem in both soft fruit and nursery stock. Outbreaks in soft fruit crops such as strawberry and raspberry can cause serious crop losses, due to the larvae feeding on roots. In nursery stock, high crop losses are rare, but the presence of weevil larvae in pots, or feeding damage by the adult weevils can lead to rejection of plants by the customer or buyer, and so the tolerance threshold for this pest is extremely low. Sprays to control adult weevils may be needed, especially in soft fruit and also at times in nursery stock, although containerized plants normally have an insecticide incorporated into the compost for preventative control of the larvae. Because the weevils are nocturnal and not all individuals within a population are active every night, control is difficult and repeat applications, using high water volumes, are often needed to gain control. The most frequently-used insecticide in recent years has been bifenthrin (Talstar), which proved effective in earlier HDC funded trials (HNS 161, 1997). This product was withdrawn from the market on 30 May 2010 and so is now unavailable to growers. Therefore, there was an urgent need to evaluate alternative insecticides against this pest.

Materials and methods

Source of vine weevils

Vine weevils were collected from strawberry and raspberry crops, mainly in Herefordshire, during June 2010 and May and June in 2011. Weevils were kept in ventilated containers with corrugated cardboard for shelter and cut foliage of *Taxus* (yew) as food. In 2010 over 500 weevils were collected and in 2011 over 800 weevils were collected for use in the trials.

Semi-field experiments

Experimental units

Wooden cages, 800 mm long, 620 mm high and 500 mm deep (Figure 1) were constructed using insect-proof mesh (1 mm diameter) stapled to the outside and a removable top, which fitted tightly to the frame to make an insect-proof seal. Each cage had a layer of compost 50 mm deep and two pieces of corrugated cardboard acting as refuges for the weevils. In addition, two potted evergreen *Euonymus* plants (free from any pesticide residues) in 1 litre pots were placed in each cage to act as food for the weevils. A total of 25 weevils were placed into each cage and allowed to acclimatize for a minimum of 24 hours before the insecticide treatments were applied.

Figure 1. Mesh cage as used in this work.

The aim of the cage layout was to try to replicate the field environment as far as possible. In soft fruit crops such as strawberry, there is usually a layer of leaf debris, weeds and also a polythene cover over the raised beds, which provide cover for adult weevils, making spray penetration difficult. By using large cages, with organic compost on the floor, refuges and food for the weevils, it was intended to partially replicate this environment. Results should therefore be more consistent with those likely to be achieved in the field. However, the large size of these cages and range of materials used meant that recovering all of the weevils at the end each experiment was difficult and time consuming.

Experimental design and statistical analysis

A total of 21 cages were arranged in a randomized block design with three replicates each of seven treatments in a ventilated polythene tunnel at ADAS Rosemaund in 2010 and at ADAS Boxworth in 2011. The data were analysed using a generalized linear model, which calculated the proportion of weevils alive or dead after seven and 14 days in 2010 and eight and 15 days in 2011. The data were logit transformed before the analysis of variance was completed. This method corrected for any non-normality in the data. Data that had been adjusted to take account of control mortality (using Abbotts Formula) were analysed using analysis of variance (ANOVA) in GenStat (12^{th} Edition).

Treatments

The treatments and rates applied in 2010 and 2011 are shown in Table 3. In both experiments treatments were chosen in conjunction with ADAS soft fruit consultants and also Dr Paul Sopp, hardy nursery stock industry representative. The rates of use were those recommended on product labels or Specific Off-Label Approvals (SOLAs, now renamed Extension of Approval for Minor Use or EAMUs). Details of the approved use of these products on different crops and cropping situations are shown in Table 4.

Table 3. Details of insecticide treatments evaluated for control of vine weevil in 2010 and 2011

Treat. no.	Trial year	Product	Manufacturer	Rate/ha	Active ingredient	Formulation	Chemical group
1	2010/11	Water	-	-	-	-	-
2	2010/11	Calypso	Bayer	250 ml	thiacloprid	SC 480 g/l	neonicotinoid
3	2011	Chess	Syngenta	400 g	pymetrozine	WG 50% w/w	pymetrozine
4	2010	Gazelle	Certis	250 g	acetamiprid	WG 300 g/kg	neonicotinoid
5	2010/11	Hallmark	Syngenta	100 ml	lambda cyhalothrin	EC 100 g/l	pyrethroid
6	2010	Hallmark + Equity	Syngenta + Dow	100 ml + 1500 ml	lambda cyhalothrin + chlorpyrifos	EC 100 g/l + EC 480 g/l	pyrethroid + organophosphate
7	2010	Pyrethrum	Agropharm	20 ml/5 l water*	pyrethrins	SC 50 g/l	natural pyrethrins
8	2010/11	Steward	DuPont	170 g	indoxacarb	WG 300 g/l	oxadiazine
9	2011	Steward	DuPont	250 g	indoxacarb	WG 300 g/l	oxadiazine
10	2011	Toppel	SBM	250 ml	cypermethrin	EC 100 g/l	pyrethroid

* Pyrethrum label rate allows application to all soft fruit at a rate of 20 ml/5 l water.

Table 4. Approved use (on-label and EAMUs) of insecticide products on different crops and cropping situations – November 2011

Product	Active ingredient	Crop	Label or EAMU	Situation		Max individual dose	Max total dose	Max no. sprays	Harvest interval (days)
				Out-door	Prot-ected				
Calypso	thiacloprid	Raspberry	EAMU	Yes	Yes	250 ml/ha	750 ml/ha	-	3
Calypso	thiacloprid	Strawberry	EAMU	Yes	Yes	250 ml/ha	500 ml/ha	-	3
Calypso	thiacloprid	Ornamentals	EAMU	Yes	No	375 ml/ha	-	2	-
Chess	pymetrozine	Raspberry & Strawberry	EAMU	No	Yes	400 g/ha	1200 g/ha	-	3
Chess	pymetrozine	Ornamentals	EAMU	No	Yes	60 g/ 100 l water	-	3	-
Chess	pymetrozine	Ornamentals	Label	Yes	Yes	20 g/ 100 l water	-	4	-
Equity	chlorpyrifos	Raspberry	Label	Yes	Yes	1500 ml/ha	3000 ml/ha	-	7
Equity	chlorpyrifos	Strawberry	Label	Yes	Yes	1500 ml/ha	-	2	7
Gazelle	acetamiprid	Raspberry & Strawberry	EAMU	Yes	Yes	500 g/ha	-	2	365
Gazelle	acetamiprid	Ornamentals	Label	Yes	No	250 g/ha	-	2	-
Hallmark	lambda cyhalothrin	Raspberry	EAMU	Yes	No	75 ml/ha	150 ml/ha	4	28
Hallmark	lambda cyhalothrin	Strawberry	EAMU	Yes	No	125 ml/ha	250 ml/ha	4	3
Hallmark	lambda cyhalothrin	Strawberry	EAMU	No	Yes	75 ml/ha	150 ml/ha	4	3
Hallmark	lambda cyhalothrin	Ornamental	EAMU	Yes	No	90 ml/ha	270 ml/ha	4	-
Hallmark	lambda-cyhalothrin	Ornamental	EAMU	No	Yes	50 ml/ha	-	3	-
Pyrethrum	pyrethrins	Raspberry, Strawberry & Ornamentals	Label	Yes	No	20 ml/ 5 l water	1100 ml/ha	-	-
Pyrethrum	pyrethrins	Raspberry, Strawberry & Ornamentals	Label	No	Yes	20 ml/ 5 l water	2400 ml/ha	-	-
Steward	indoxacarb	Raspberry & Strawberry	EAMU	Yes	No	250 g/ha	-	3	365
Steward	indoxacarb	Raspberry &	EAMU	No	Yes	12.5 g/	-	6	365

Product	Active ingredient	Crop	Label or EAMU	Situation		Max individual dose	Max total dose	Max no. sprays	Harvest interval (days)
				Out-door	Prot-ected				
		Strawberry				100 l water			
Steward	indoxacarb	Ornamentals	EAMU	Yes	No	250 g/ha	-	3	-
Steward	indoxacarb	Ornamentals	Label	No	Yes	12.5 g/ 100 l water	-	6	-
Toppel	cypermethrin	Ornamentals	Label	Yes	No	250 ml/ha	-	-	-
Toppel	cypermethrin	Ornamentals	Label	No	Yes	62 ml/ 100 l water	-	-	-

A dash (-) means not approved for use. The approval status of pesticides is subject to change. Consult the relevant label or EAMU before using a product.

Insecticide treatments were applied in the evening, between 7.30 and 9.00 pm on 23 June 2010, and between 7.30 and 10.00 pm on 14 June 2011. Evening insecticide applications are currently recommended to ensure that adult weevils are either directly contacted with the spray or come into contact with residues before they dry. Insecticide treatments were applied using a knapsack sprayer which had been calibrated previously, so that the equivalent of 700 l of water/ha was applied. This is typical of the water volumes generally used by soft fruit and nursery stock growers for vine weevil control. The sprayer was washed out thoroughly between treatments and a shield was used between cages when applying treatments to prevent drift. The temperature at the time of spraying was approximately 25°C in 2010 and 18°C in 2011. Plants in control cages were treated with water only. Each cage was thoroughly sprayed with the appropriate volume, making sure that the sides and floor of the cage were evenly treated. At the time of application, most weevils were located inside the refuges, under the plant pots, or on the compost surface.

Temperature was recorded using a TinyTag logger placed within the canopy of a *Euonymus* plant pot in one of the untreated cages; daily minimum and maximum temperatures were recorded.

Assessments

Seven days (eight days in 2011) after the treatments were applied all cages were thoroughly searched for vine weevils. The compost, refuges and plants and pots were all thoroughly checked for weevils in each cage. Weevils were classified as; alive, moribund (i.e. still alive but not showing coordinated movement) or dead. Weevils that were still alive or moribund were placed in clean ventilated plastic boxes together with fresh clean

Euonymus leaves as a food source. These boxes were placed in a laboratory away from direct sunlight. A second assessment was completed after a further seven days, again recording the weevils as alive, moribund or dead.

Laboratory experiments

Experimental units

Small plastic pots (110 mm diameter and 50 mm deep) were used for the two laboratory experiments. Each pot had a layer of compost 20 mm deep, a piece of corrugated cardboard acting as a refuge for the weevils and a small piece of damp tissue paper as a source of moisture. *Euonymus* leaves (free from any pesticide residues) were placed in each pot to act as food for the weevils. The lid of each pot was perforated to allow ventilation. A total of five weevils were placed into each pot after treatment application (see below).

Experimental design and statistical analysis

A total of 21 pots in the *direct contact* experiment were arranged in a randomized block design with three replicates each of seven treatments (Figure 2). Similarly, a total of 27 pots in the *residue* experiment were arranged in a randomized block design with three replicates each of nine treatments. Both experiments were completed in a controlled temperature (21°C) laboratory at ADAS Boxworth in 2011. The data were analysed using a generalized linear model, which calculated the proportion of weevils alive, moribund or dead after seven and 14 days. The data were logit transformed before the analysis of variance was completed. This method corrected for any non-normality in the data.

Figure 2. Direct contact experiment arranged in randomized block design.

Treatments

The treatments and rates applied in the *direct contact* experiment are shown in Table 5 and the *residue* experiment in Table 6. In both experiments treatments were chosen in conjunction with Dr Paul Sopp, industry representative.

Table 5. Insecticide treatments used in direct contact experiment in 2011

Treatment number	Product	Rate/ha	Active ingredient	Formulation	Chemical group
1	Water	-	-	-	-
2	Hallmark	50 ml	lambda cyhalothrin	EC 100 g/l	pyrethroid
3	Hallmark	100 ml	lambda cyhalothrin	EC 100 g/l	pyrethroid
4	Hallmark	150 ml	lambda cyhalothrin	EC 100 g/l	pyrethroid
5	Steward	125 g	indoxacarb	WG 300 g/l	oxadiazine
6	Steward	250 g	indoxacarb	WG 300 g/l	oxadiazine
7	Steward	375 g	indoxacarb	WG 300 g/l	oxadiazine

Table 6. Insecticide treatments used in residue experiment in 2011

Treatment number	Product	Rate/ha	Weevils introduced after (h)	Active ingredient	Formulation	Chemical group
1	Water	-	0	-	-	-
2	Water	-	12	-	-	-
3	Water	-	24	-	-	-
4	Hallmark	100 ml	0	lambda cyhalothrin	EC 100 g/l	pyrethroid
5	Hallmark	100 ml	12	lambda cyhalothrin	EC 100 g/l	pyrethroid
6	Hallmark	100 ml	24	lambda cyhalothrin	EC 100 g/l	pyrethroid
7	Steward	250 g	0	indoxacarb	WG 300 g/l	oxadiazine
8	Steward	250 g	12	indoxacarb	WG 300 g/l	oxadiazine
9	Steward	250 g	24	indoxacarb	WG 300 g/l	oxadiazine

Insecticide treatments in both experiments were applied in the evening, between 7.00 and 8.00 pm, on 31 August 2011. Insecticide treatments were applied using a garden mister, which had been calibrated previously, so that the equivalent of 700 l of water/ha was applied to the floor and sides of each pot. The sprayer was washed out thoroughly between treatments. The temperature at the time of spraying was approximately 21°C.

In the *direct contact* experiment five weevils were placed into a clean empty pot of the same size and design as those prepared with compost, *Euonymus* leaves etc. The pot was then sprayed using the garden mister with one of the insecticide treatments or the water control. By ensuring that the base and sides of the pot were evenly sprayed at a rate equivalent to 700 l of water/ha, the weevils were subject to direct contact with the spray. Once sprayed the weevils were transferred to one of the previously prepared pots.

In the *residue* experiment each of the pots prepared with compost, *Euonymus* leaves etc was sprayed with one of the insecticide treatments or water controls as previously described. Five weevils were then introduced into these pots 0, 12 or 24 hours after spray application.

Results

Semi-field experiments

The proportion of the introduced population of weevils recovered from cages was 83% in 2010 and 88% in 2011. The fact that 100% recovery was not achieved in either experiment reflects the difficulty in recovering weevils from a more complex environment. Therefore, results on weevil mortality are expressed as a proportion of total weevils recovered.

Due to the high levels of mortality in the control treatment recorded in 2010, care should be taken with the interpretation of results for the insecticide treatments tested and in comparing results from 2010 with those from 2011, where mortality in the control was low. Therefore, two analyses of the data are presented. In the first analysis (Table 7) mean weevil mortality is considered. In the second analysis (Table 8) mean weevil mortality for each treatment is adjusted for the control mortality using Abbotts Formula:

$$\text{Adjusted mortality of product} = \frac{\text{(\% mortality of product - \% mortality of control)}}{\text{(100 - \% mortality of control)}} * 100$$

Table 7. Mean weevil mortality recorded in 2010 and 2011

Treatment no.	Product	Rate (ml or g/ha) used	Mean % mortality after treatment			
			2010		2011	
			7 days	14 Days	8 days	15 days
1	Control	N/A	50 (7)	55 (7)	0 (0)	7 (3)
2	Calypso	250	59 (6)	**90 (4)**	**22 (5)**	**31 (6)**
3	Chess	400	-	-	**57 (6)**	**60 (6)**
4	Gazelle	250	32 (6)	52 (6)		
5	Hallmark	100	**77 (5)**	**100 (0)**	0 (0)	4 (2)
6	Hallmark + Equity	100 + 1500	**100 (0)**	**100 (0)**	-	-
7	Pyrethrum	20 ml/5 l water	42 (7)	70 (7)	-	-
8	Steward	170	**69 (5)**	**93 (3)**	**32 (5)**	**35 (6)**
9	Steward	250	-	-	**70 (6)**	**73 (6)**
10	Toppel	250	-	-	3 (2)	16 (5)
Significance (df = 6), P =			< 0.001	< 0.001	< 0.001	< 0.001

Figures in bold are significantly different from the untreated (P<0.05) in that column. Figures in brackets are the standard errors for each treatment. A dash (-) means not tested.

Mean weevil mortality – in 2010, treatment significantly affected adult weevil mortality at seven (P<0.001) and 14 days (P<0.001) after the sprays were applied. Hallmark, Hallmark + Equity or Steward (170 g/ha) significantly increased adult weevil mortality compared to the untreated control at each assessment. Calypso significantly increased mortality after 14 days. In 2011, treatment significantly affected adult weevil mortality eight (P<0.001) and 15 days (P<0.001) after the sprays were applied. Significantly higher levels of weevil mortality were recorded for Calypso 250 ml/ha, Chess at 400g/ha or Steward at both 170 g/ha and 250 g/ha eight and 15 days after treatment application.

Table 8. Mean weevil mortality recorded in 2010 and 2011 adjusted for control mortality

Treatment no.	Product	Rate (ml or g/ha) used	Mean % mortality after treatment:			
			2010		2011	
			7 days	14 days	8 days	15 days
1	Control	N/A	N/A	N/A	N/A	N/A
2	Calypso	250	23	67	21	25
3	Chess	400	-	-	**58**	**60**
4	Gazelle	250	-51	-22		
5	Hallmark	100	45	**100**	0	-4
6	Hallmark + Equity	100 + 1500	100	**100**	-	-
7	Pyrethrum	20 ml/5 l water	-42	3	-	-
8	Steward	170	45	**91**	32	26
9	Steward	250	-	-	**70**	**71**
10	Toppel	250	-	-	5	15
Significance (df = 10), P =			n.s.	0.019	0.004	0.034
SED			51.24	35.00	14.60	20.33

Figures in bold are significantly different from zero (P<0.05). A dash (-) means not tested

Mean weevil mortality adjusted for control mortality - by analysing the data after adjusting for control mortality fewer of the treatments tested were found to have significantly increased mortality of vine weevil adults. In 2010 there was no treatment effect after seven days due to the variability of the data. After 14 days there was a significant treatment effect (P = 0.019). Three of the treatments, Hallmark, Hallmark + Equity or Steward (170 g/ha) were found to have significantly increased vine weevil mortality. Mortality in the Calypso treatment was 67% but this was not significantly different from 0% mortality, again due to the variability of the data. Gazelle and Pyrethrum were ineffective.

In 2011, there was a significant treatment effect after eight (P = 0.004) and 15 days (P = 0.034). Two of the treatments, Chess or Steward (250 g/ha), were found to significantly increase vine weevil mortality at both assessment dates. Calypso, Hallmark, Steward at 170 g/ha and Toppel were ineffective.

By adjusting weevil mortality using Abbotts Formula it is apparent that with the exception of Hallmark + Equity there was a large increase in adult weevil mortality between the first and second assessments in 2010 but not in 2011. Indeed, levels of mortality for Calypso or Steward (170 g/ha) at the first assessment are very similar in both experiments. However, at the second assessment levels of mortality are two to three times higher for these treatments in 2010 than in 2011. For Hallmark the difference between 2010 and 2011 is even more striking with high levels of mortality in 2010 but apparently no effect in 2011.

In 2010, there was a large decrease in the number of moribund weevils between the two assessments for the control, Calypso, Hallmark or Steward (170 g/ha) treatments (Table 9). In the control treatment most of the weevils recorded as moribund after seven days were recorded as alive after 14 days. In the Calypso, Hallmark or Steward (170 g/ha) treatments most of the weevils recorded as moribund after seven days were recorded as dead after 14 days. In the Gazelle treatment the number of moribund weevils was high both seven and 14 days after the treatment was applied, possibly indicating a slow mode of action for this product. In 2011, only six weevils were recorded as being moribund eight days after treatment application.

In 2010, the start of the experiment coincided with a period of hot weather. In order to mitigate the effects of the hot weather green shading mesh was put in place in the roof of the tunnel over the cages, and the sides and ends were opened as much as possible to allow ventilation. However, despite these steps the TinyTag datalogger placed in a plant pot inside one of the cages still recorded mean daily temperatures in excess of 30°C and maximums in excess of 37°C before the first assessment (Figure 3). In 2011 the experiment coincided with a period of cooler weather. The TinyTag datalogger placed inside one of the cages did not record mean daily temperatures above 30°C before the first assessment.

Table 9. Mean numbers of moribund weevils recorded in 2010 and 2011

Treatment no.	Product	Rate (ml or g/ha) used	Mean % moribund after treatment:			
			2010		2011	
			7 days	14 days	8 days	15 days
1	Control	N/A	25	2	0	0
2	Calypso	250	26	4	0	0
3	Chess	400	-	-	3	0
4	Gazelle	250	39	34		
5	Hallmark	100	23	0	0	0
6	Hallmark + Equity	100 + 1500	0	0	-	-
7	Pyrethrum	20 ml/5 l water	6	5	-	-
8	Steward	170	14	0	3	0
9	Steward	250	-	-	2	0
10	Toppel	250	-	-	1	0
Significance (df = 6), P =			< 0.001	< 0.001	n.s.	n.s.

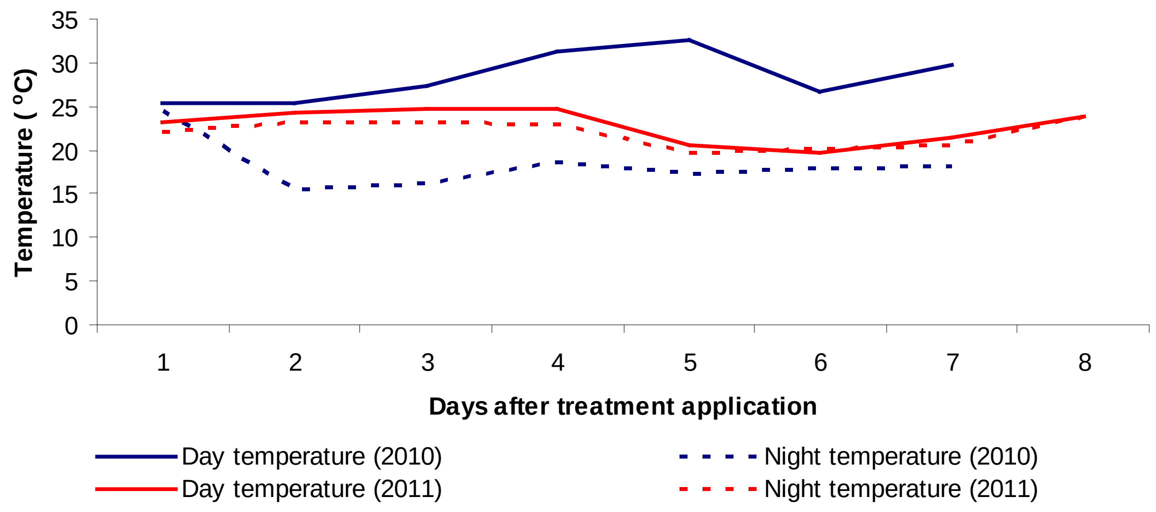

Figure 3. Mean day (9am to 9pm) and night (9pm to 9am) temperatures within a mesh cage during the experiments completed in June 2010 at ADAS Rosemaund and June 2011 at ADAS Boxworth

Laboratory experiments

Weevil mortality data collected from the *direct contact* experiment are presented in Table 10 and for the *residue* experiment in Table 11. Numbers of weevils recorded as alive, moribund or dead after seven or 14 days were not significantly affected by treatment in the *direct contact* experiment. Indeed, levels of mortality were low for both Hallmark and Steward, even at higher than approved rates. This indicates that direct contact may not be important in determining the efficacy of these two products. Numbers of dead weevils in the *residue* experiment were significantly affected by product seven days (P<0.05) after the treatments were applied but not 14 days after treatment application. However, although vine weevil mortality was highest in the Hallmark treatments, this was not significantly different from the untreated control. The number of moribund weevils was also significantly affected by product (P<0.001). Here, Hallmark was found to increase numbers of moribund weevils significantly compared to both Steward and the untreated control. This effect was also seen 14 days after the treatments were applied. In addition, weevil mortality was significantly affected by an interaction (P<0.05) between product and the time after application that weevils were exposed to residues.

Table 10. Mean numbers live, moribund and dead weevils resulting from direct contact with different rates of Hallmark or Steward

Treatment no.	Product	Rate/ha	7 days after treatment application			14 days after treatment application		
			Mean % alive	Mean % moribund	Mean % dead	Mean % alive	Mean % moribund	Mean % dead
1	Water	-	100 (0)	0 (0)	0 (0)	100 (0)	0 (0)	0 (0)
2	Hallmark	50 ml	87 (6)	7 (6)	7 (6)	80 (10)	7 (6)	13 (8)
3	Hallmark	100 ml	73 (7)	7 (6)	20 (9)	73 (11)	0 (0)	27 (10)
4	Hallmark	150 ml	87 (6)	0 (0)	13 (8)	67 (12)	20 (10)	13 (8)
5	Steward	125 g	87 (6)	0 (0)	13 (8)	80 (10)	7 (6)	13 (8)
6	Steward	250 g	100 (0)	0 (0)	0 (0)	93 (6)	7 (6)	0 (0)
7	Steward	375 g	87 (6)	7 (6)	7 (6)	67 (12)	27 (11)	7 (6)
Significance (df = 6), P =			n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Figures in brackets are the standard errors for each treatment. Note that rounding up may lead to values greater than 100%.

Table 11. Mean numbers of live, moribund and dead weevils resulting from contact with Hallmark or Steward residues

Treatment no.	Product	Weevils introduced after (h)	7 days after treatment application			14 days after treatment application		
			Mean % alive	Mean % moribund	Mean % dead	Mean % alive	Mean % moribund	Mean % dead
1	Water	0	93 (6)	0 (0)	7 (6)	87 (9)	7 (6)	7 (6)
2	Water	12	87 (8)	0 (0)	13 (9)	87 (9)	0 (0)	13 (9)
3	Water	24	100 (0)	0 (0)	0 (0)	87 (9)	13 (9)	0 (0)
4	Hallmark	0	60 (12)	20 (9)	20 (10)	53 (12)	27 (11)	20 (10)
5	Hallmark	12	53 (12)	47 (11)	0 (0)	60 (12)	33 (12)	7 (6)
6	Hallmark	24	33 (11)	47 (11)	20 (10)	20 (9)	47 (12)	33 (11)*
7	Steward	0	100 (0)	0 (0)	0 (0)	80 (10)	20 (10)	0 (0)
8	Steward	12	100 (0)	0 (0)	0 (0)	93 (6)	7 (6)	0 (0)
9	Steward	24	100 (0)	0 (0)	0 (0)	53 (12)	27 (11)	20 (10)
Significance (product) (df = 2), P =			< 0.001	< 0.001	0.012	< 0.001	n.s.	n.s.
Significance (time) (df = 2), P =			n.s.	n.s.	n.s.	0.005	0.025	n.s.

Figures in brackets are the standard errors for each treatment. Note that rounding up may lead to values greater than 100%. * Significant interaction between product and weevil introduction (P = 0.030).

A feature of both the *direct contact* and *residue* experiments was the sub-lethal effects of the insecticide treatments on adult vine weevil behaviour. Moribund individuals are usually described as being unable to make coordinated movements. However here, several individuals were seen to walk either without the use of their back legs or to hold the body high off the ground. In both experiments weevils walking in this way were recorded as moribund. In addition, weevils treated with Steward were seen to produce a liquid, possibly regurgitation, from the mouth (Figure 4). It is not known what effects these sub-lethal effects may have on weevil survival or fecundity.

Figure 4. Adult vine weevil previously treated with Steward producing a liquid from the mouth.

Discussion

The semi-field experiments completed in 2010 and 2011 provided a realistic environment in which to assess the efficacy of a range of insecticide products. However, the disadvantage of this approach was less than 100% recovery of weevils from the mesh cages. Despite this, overall losses of weevils were relatively low; 17% in 2010 and 12% in 2011.

A high level of control mortality was recorded in 2010 but not in 2011. It seems likely that this difference was due to the higher temperatures experienced in 2010 compared with those in 2011. Indeed the temperatures recorded in 2010 may be an underestimate as the TinyTag was shaded and so soil temperatures are likely to have been even higher.

Vine weevils are thought to originate from Europe and are found throughout temperate areas. Temperature is considered to strongly determine the range of this pest. The upper temperature threshold for adult vine weevil is not known but oviposition is believed to stop at temperatures above 26°C (Evenhuis, 1978). Despite this it remains a fact that vine weevil is a serious pest of crops grown under protection where very high temperatures may be recorded. This is possible as weevils seek out refuges protected from these extreme daytime temperatures, although temperatures within these refuges have to-date not been recorded.

An alternative possibility for the adult weevil mortality in 2010 is that some of the insects were infected by a unicellular parasitic fungus (*Nosema* sp.), which is very common in some populations. This organism either kills or weakens the adults, lowering their reproductive capacity and allowing other infections by entomopathogenic fungi such as *Metarhizium* to occur (Denny and Bruck, 2008).

Due to the high levels of control mortality in 2010 care should be taken in interpreting the results from this experiment. However, the result for Hallmark in the 2010 semi-field experiment does appear to be consistent with the results from the first HDC-funded project, which evaluated insecticides against adult vine weevil (HNS 61, 1997). HNS 61 showed that pyrethroid insecticides were slow acting with weevils classed as moribund seven days after spraying.

In this SF/HNS 112 study, Hallmark killed 77% of weevils after seven days (data before Abbotts Formula was used), and gave complete control within 14 days in 2010. The addition of an organophosphate insecticide (chlorpyrifos) as a tank mix with Hallmark increased the speed of control, and led to 100% mortality within seven days. However, the semi-field experiment completed in 2011 did not find Hallmark to be effective. Hallmark is a widely used pyrethroid in many crops, and is approved for use on outdoor raspberry, protected and outdoor strawberry and ornamental crops such as nursery stock. Chlorpyrifos (Equity) has approval for use on strawberry and cane fruit crops such as raspberry. Full details of the conditions of approval for all insecticides used in this project are given in Table 4.

Neither Toppel (cypermethrin) (tested in 2011), nor natural pyrethrum (tested in 2010) significantly increased mortality of adult vine weevil. In the case of natural pyrethrum this may be due to the very short persistence of this product.

Hallmark (a pyrethroid insecticide) was effective in 2010 but not in 2011. It is unclear why Hallmark was effective in only one of the semi-field experiments completed. Results from the *direct contact* and *residue* experiments indicate that good coverage of foliage, soil etc may be an important factor in determining control of adult vine weevil. Direct contact with Hallmark did not significantly increase weevil mortality compared with the untreated control, even if higher than approved rates of this product were used. In the *residue* experiment Hallmark did not significantly increase weevil mortality but did increase the number of moribund weevils. More work is required to determine whether moribund weevils subsequently die or if they are capable of reproducing. Insecticide resistance cannot be excluded as a possible explanation for the Hallmark results recorded in the 2011 semi-field experiment and the controlled conditions experiments.

Steward (indoxacarb) is a relatively new insecticide in the oxadiazine group, which is approved for control of caterpillar pests on ornamentals as well as protected strawberry and raspberry crops. Results from both 2010 and 2011 demonstrate the potential of this product against vine weevil adults. However currently, Steward has a 12 month harvest interval when used in soft fruit crops, which effectively limits its use to non-fruiting plantations. Also, when used on crops grown under protection the maximum rate is 12.5 g/100 l water, which was not tested in this study and so the efficacy of this rate against adult vine weevil is not known.

Chess (pymetrozine) was the second most effective product tested in 2011. Pymetrozine (Plenum) has recently been approved for use against pollen beetle in oilseed rape. Although pymetrozine works systemically against aphid pests it is believed to work through direct contact against pollen beetle. Both Steward and Chess are relatively safe to beneficial insects and mites, and so would be suited for use within IPM systems (Dinter and Wiles, 2000; Sechser et al., 2002). Pyrethroid insecticides such as Hallmark are incompatible with IPM systems, and in fact are known to cause mortality of native predators of vine weevil, such as carabid beetles (Crook and Solomon, 1996).

Neonicotinoid products such as Calypso (thiacloprid) and Gazelle (acetamiprid) are widely used in soft fruit for the control of aphids, capsids and other pests. Results from this study suggest that when used against vine weevil they are less effective. In 2010, Calypso produced significantly higher levels of weevil mortality than the control only after 14 days (this effect was not seen when data was corrected for control mortality). In 2011 the level of mortality was relatively low (25 and 31% respectively). Gazelle was only tested in 2010 and here levels of mortality were not significantly different from the control. Calypso has approval for all cane fruit and strawberries, and also other bush fruit such as blackcurrants, whereas Gazelle is only approved for non-cropping soft fruit such as crops in propagation. Both products are approved for use on ornamental crops.

The semi-field experiment completed in 2011 was completed under relatively cool conditions while the *direct contact* and *residue* experiments were completed at a constant 21°C. This contrasts with the 2010 semi-field experiment, which was completed during a period of hot weather and temperatures in the cages reached 37°C. It is possible then that the efficacy of Hallmark was in part determined by the additional stress provided by the high temperatures in 2010.

More generally the level and timing (with the exception of Hallmark + Equity) of mortality across all treatments differed between 2010 and 2011, and this in turn may have been influenced by temperature differences in the two experiments. The high temperatures in 2010 led to high levels of control mortality within seven days of the sprays being applied. For the insecticide treatments (except Hallmark + Equity) tested in 2010 weevils died throughout the 14 days of the experiment. In 2011 control mortality was low and nearly all of the mortality in the insecticide treatments occurred within eight days. It seems likely then that a combination of insecticide treatment and high temperatures in 2010 led to large numbers of weevils dying more than a week after the sprays were applied. In 2011 the weevils were not stressed by high temperatures and so may have been better able to survive any long-term effects of the insecticide treatments.

Adult vine weevils are nocturnal, and so it is currently recommended that sprays are applied in the evening and, depending on the habitat involved, using large volumes of water (up 1,000 l/ha in some vigorous crops). However, results from the laboratory residue experiment suggest that evening applications of Hallmark may not be required if weevils recorded as moribund subsequently die or are unable to lay eggs. This is because residues of Hallmark up to 24 hours old significantly increased numbers of moribund weevils, whilst direct contact with this product did not increase numbers of dead or moribund weevils. Further work under semi-field and field conditions would be required to confirm this result but this would be advantageous to growers who would avoid overtime costs associated with evening insecticide applications.

The timing of application is also important because, if treatment is delayed beyond mid- to late July, weevils may already have laid eggs, leading to further larval damage later in the season. Thus, thorough and timely application of adult weevil control sprays is extremely important.

Conclusions

- In 2010, Hallmark alone applied at 100 ml/ha gave 100% mortality of adult vine weevils in small scale cage trials, but took 14 days to achieve this level of kill. In 2011, Hallmark was not effective under similar but cooler conditions.
- Addition of Equity (1500 ml/ha) as a tank mix with Hallmark in 2010 resulted in 100% mortality within seven days.
- Steward at 170 g/ha in 2010 and also at 250 g/ha in 2011 produced encouraging results. This product is compatible with IPM programmes and further work may be warranted.
- Weevils treated with Steward produced a liquid, possibly regurgitation, from the mouth for at least seven days after the sprays were applied. In addition, weevils treated with either Steward or Hallmark had difficulty walking for at least two weeks after the treatments were applied. These sub-lethal effects could help to reduce vine weevil populations and warrant further investigation.
- Chess at 400 g/ha is also compatible with IPM programmes and was effective in 2011 trials.
- Calypso applied at 250 ml/ha was effective, but only after 14 days in 2010. In 2011 this product increased vine weevil mortality but only by relatively low levels.
- Gazelle (250 ml/ha) or pyrethrum (20 ml/5 l water) did not significantly increase vine weevil mortality.
- Environmental conditions appear to be important in determining insecticide efficacy against adult vine weevil.
- Hallmark residues up to 24 hours old significantly increased numbers of moribund weevils recorded under controlled conditions. If moribund weevils subsequently die or do not lay eggs then it may not be necessary to restrict insecticide application to the evening, as currently recommended in order to treat active weevils.

Potential further work

- Establish the relationship between adult vine weevil populations and damage caused by larvae feeding on plant roots.

- Determine what impact sub-lethal effects of insecticide applications have on adult vine weevil survival and fecundity.

- Investigate potential interactions between temperature and insecticide efficacy against adult vine weevil.

- Determine if insecticide resistance is present in vine weevil populations.
- Compare efficacy of daytime and evening insecticide applications for control of adult vine weevil.
- Investigate the efficacy of single and multiple insecticide applications for control of adult vine weevil.

Knowledge and technology transfer

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Appendix 1. Raw data – ADAS Rosemaund 2010 – Semi-field.

	7 Day Assessment			14 Day Assessment		
Treatment	**Alive**	**Moribund**	**Dead**	**Alive**	**Moribund**	**Dead**
Pyrethrum (20ml/5l water)	11	0	2	8	0	5
Hallmark (100ml/ha)	0	0	18	0	0	18
Water (Control)	0	6	9	5	0	10
Calypso (250ml/ha)	4	0	21	1	3	21
Gazelle (250ml/ha)	0	15	7	0	8	14
Hallmark (100ml/ha + Equity (1500ml/ha)	0	0	22	0	0	22
Steward (170g/ha)	0	0	23	0	0	23
Steward (170g/ha)	14	1	18	6	0	27
Water (Control)	13	0	6	12	1	6
Hallmark (100ml/ha)	0	0	22	0	0	22
Hallmark (100ml/ha + Equity (1500ml/ha)	0	0	25	0	0	25
Calypso (250ml/ha)	0	16	6	0	0	22
Pyrethrum (20ml/5l water)	0	1	14	0	0	15
Gazelle (250ml/ha)	0	11	11	4	8	10
Steward (170g/ha)	0	10	15	0	0	25
Pyrethrum (20ml/5l water)	14	2	3	3	3	13
Gazelle (250ml/ha)	18	0	3	5	6	10
Water (Control)	1	6	10	5	0	12
Calypso (250ml/ha)	6	1	13	3	0	17
Hallmark (100ml/ha)	0	15	7	0	0	22
Hallmark (100ml/ha + Equity (1500ml/ha)	0	0	16	0	0	16

Appendix 2. Raw data – ADAS Boxworth 2011 – Semi-field.

	8 Day Assessment			15 Day Assessment		
Treatment	**Alive**	**Moribund**	**Dead**	**Alive**	**Moribund**	**Dead**
Water (Control)	18	0	0	18	0	0
Hallmark (100 ml/ha)	26	0	0	25	0	1
Toppel (250 ml/ha)	22	0	1	20	0	3
Steward (170g/ha)	15	2	8	17	0	8
Steward (250g/ha)	8	0	15	7	0	16
Chess (400 g/ha)	8	0	15	8	0	15
Calypso (250 ml/ha)	18	0	5	15	0	8
Water (Control)	18	0	0	18	0	0
Hallmark (100 ml/ha)	25	0	0	23	0	2
Toppel (250 ml/ha)	24	1	0	23	0	2
Steward (170g/ha)	9	0	16	7	0	18
Steward (250g/ha)	3	1	15	3	0	16
Chess (400 g/ha)	16	0	9	16	0	9
Calypso (250 ml/ha)	18	0	2	17	0	3
Water (Control)	20	0	0	16	0	4
Hallmark (100 ml/ha)	23	0	0	23	0	0
Toppel (250 ml/ha)	9	0	1	6	0	4
Steward (170g/ha)	24	0	0	24	0	0
Steward (250g/ha)	7	0	14	7	0	14
Chess (400 g/ha)	4	2	16	4	0	18
Calypso (250 ml/ha)	15	0	7	13	0	9

Appendix 3. Raw data – ADAS Boxworth 2011 – Direct Contact Experiment.

	7 Day Assessment			14 Day Assessment		
Treatment	Alive	Moribund	Dead	Alive	Moribund	Dead
7	5	0	0	2	3	0
5	5	0	0	4	0	1
1	5	0	0	5	0	0
3	5	0	0	5	0	0
4	5	0	0	4	1	0
6	5	0	0	5	0	0
2	5	0	0	5	0	0
3	5	0	0	5	0	0
4	4	0	1	3	1	1
2	4	1	0	3	1	1
6	5	0	0	5	0	0
1	5	0	0	5	0	0
7	5	0	0	5	0	0
5	4	0	1	4	1	0
6	5	0	0	4	1	0
2	4	0	1	4	0	1
4	4	0	1	3	1	1
3	1	1	3	1	0	4
7	3	1	1	3	1	1
5	4	0	1	4	0	1
1	5	0	0	5	0	0

Appendix 4. Raw data – ADAS Boxworth 2011 – Residue Experiment.

	7 Day Assessment			14 Day Assessment		
Treatment	Alive	Moribund	Dead	Alive	Moribund	Dead
5	2	3	0	5	0	0
3	5	0	0	5	0	0
8	5	0	0	5	0	0
4	5	0	0	4	0	0
2	5	0	0	5	0	0
7	5	0	0	5	0	0
6	3	1	1	2	2	1
1	5	0	0	5	0	0
9	5	0	0	3	2	0
1	4	0	1	3	1	1
5	1	4	0	2	2	1
9	5	0	0	2	1	2
7	5	0	0	3	2	0
6	0	5	0	0	3	2
3	5	0	0	3	2	0
2	4	0	1	4	0	1
4	3	1	1	3	1	1
8	5	0	0	5	0	0
3	5	0	0	5	0	0
8	5	0	0	4	1	0
5	5	0	0	2	3	0
4	1	2	2	1	2	2
1	5	0	0	5	0	0
2	4	0	1	4	0	1
9	5	0	0	3	1	1
7	5	0	0	4	1	0
6	2	1	2	1	2	2