Project title:	Lettuce and baby leaf salads: Investigation into control measures for Silver Y moth and caterpillars
Project number:	FV 440
Project leader:	Rosemary Collier, University of Warwick
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Location of project:	Warwick Crop Centre and commercial growers
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The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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

Trials have indicated several insecticides with efficacy against silver Y moth, some of which are novel products. A novel 'remote' monitoring system which uses a small camera located inside a pheromone trap to record moth captures daily shows promise as a method for monitoring the arrival of migrant lepidopterous pests of salad and vegetable crops.

Background

Damage caused by the Silver Y moth and other caterpillar species can result in unacceptable leaf damage in outdoor baby leaf and lettuce crops, where there is zero tolerance for either the presence of, or visible damage from, these pests. Loss of active ingredients has left the industry with a limited list of insecticides which are not effective and all have long harvest intervals. This is resulting in poor control of these pests in UK crops. The overall aim of Project FV 440 is to provide growers of lettuce and baby leaf salad crops with the tools (decision-support and control methods) to improve overall control of silver Y moth and other pest caterpillars.

Summary

The focus of this project is on novel control agents (insecticides and bioinsecticides) and on the use of monitoring approaches to improve the identification of potential problems and aid decision-making with regard to treatment timing.

Trials to measure the efficacy of the chosen treatment regimes (Objectives 1, 2, 3, 4)
Live adult silver Y moths were captured in light traps to produce eggs to set up cultures in the laboratory/greenhouse to infest insecticide and bioinsecticide efficacy trials. Robinson light traps were purchased and set up in Cambridgeshire and at Wellesbourne (4 traps in total). These were run throughout the summer period and checked daily when operating. Small numbers of moths were captured but there were sufficient to start breeding cultures at Warwick Crop Centre and ADAS Boxworth. The moths were allowed to go through several generations to build up numbers.

Three field trials were undertaken in 2015 to evaluate insecticides and bioinsecticides against silver Y moth (2 trials) and diamond-back moth (1 trial). All trials were infested with the target pest insects. Please note that some of the named insecticides do not have approval for application to brassica and/or lettuce crops.

A trial was undertaken at Warwick Crop Centre, Wellesbourne to evaluate insecticides applied as foliar sprays to whole head lettuce (cv Challenge) transplanted on 11 August. There were 7 treatments (6 bioinsecticides and 1 insecticide) x 4 replicates including an insecticide-free control. Small- to medium-sized caterpillars were selected from the laboratory culture and 10 plants per plot were inoculated (6 caterpillars per plant) on 23-24 September. All spray treatments were applied using a knapsack sprayer fitted with 02F110 nozzles in 300 l/ha water on 24 September. The plants were assessed for damage due to caterpillar feeding on a 0-5 scale on 28 September. Inoculated plants were sampled destructively as many of the living caterpillars had eaten into the lettuce. There was a statistically-significant effect of treatment on the numbers of dead caterpillars ($p<0.01$) and the numbers of live caterpillars ($p<0.001$). The coded insecticide HDCI 090 was the most effective treatment in both respects. All of the other treatments were bioinsecticides and did not provide significant levels of control. There were no overall statistically-significant effects of treatment on the mean damage score.

A second trial on silver Y moth was undertaken at Stockbridge Technology Centre using babyleaf lettuce (cv Solavia). There were 7 treatments (all insecticides) x 4 replicates including an insecticide-free control. Caterpillars were received from Warwick Crop Centre on the morning of 29 September and were used immediately to infest the plots. Thirty caterpillars were placed in the central rows of each plot, and left to settle for at least four hours. On the afternoon of 29 September, plots were treated with product, or a water control, by application at 3 bar pressure using an Oxford Precision Sprayer and F01 110 flat fan nozzles. Relatively low numbers of caterpillars were recovered (less than 50% of those released). With the exception of emamectin benzoate, all insecticide treatments resulted in greater mortality of caterpillars than the water-only control and this was a statistically significant effect both 2 and 9-10 days after treatment.

A third trial was undertaken at Warwick crop centre to compare foliar spray treatments (6 treatments and untreated control) for control of diamond-back moth. Brussels sprout plants (cv Faunus F1) were transplanted on 23 June. In the absence of a natural infestation the decision was made to infest the plots artificially. Over the period 4 -24 September, 7 plants were inoculated on 2 occasions each with eggs and caterpillars from the culture maintained at Warwick Crop Centre. All spray treatments were applied using a knapsack sprayer fitted with 02F110 nozzles in 400 l/ha water on 25 September. The plants were assessed for damage due to caterpillar feeding (numbers of feeding holes) and the numbers of caterpillars were counted on 1 October. However, the numbers of caterpillars recovered during assessment of the plots were too low (<1 per plant) for meaningful analysis of the data. As the field trial on diamond-back moth in 2015 was unsuccessful due to low recovery of caterpillars, laboratory tests were planned and the first replicate has been completed.

Monitoring activity of adult moths (Objective 5)

A network of pheromone traps was established in England and Scotland to monitor silver Y moth, diamond-back moth and turnip moth. The traps were supplied by Trapview (www.trapview.com) and the network was supported and managed by Colin Carter of Landseer. A total of 30 traps were set up in May-June 2015 and consisted of 17 traps for silver Y moth, 10 traps for diamond-back moth and 2 traps for turnip moth plus an 'experimental' trap used for trap development. The traps were hosted by growers of salad and brassica crops. Each trap contained a pheromone lure for the appropriate species, a sticky base to capture the moths and a small camera which photographed the sticky base once each day. The camera was powered by a solar cell. The image was downloaded onto the website managed by Trapview and the images of the captures by all the traps were visible to all the trap hosts. Generally there were two 'replicate' traps in each area. 'Ordinary' funnel pheromone traps were run in parallel to the 'Trapview traps' with at least one at each site. The lures in all traps were replaced at the recommended intervals and the sticky bases were replaced as and when necessary. The data from the Trapview traps were downloaded from the Trapview site and checked and corrected by reviewing the images. Data from the other traps were sent to Warwick Crop Centre at the end of the season.

Silver Y moths were captured in the Trapview traps between May and October with the periods of most intense activity in mid-June and mid-July (Figure 1). The data require further analysis but there is no evidence that moths were captured earlier at sites that were further south or further east, for example.

A relatively large number of funnel traps were deployed in crops of lettuce grown by G's in Cambridge and Norfolk. This was to obtain more detailed information on silver Y moth activity both from using traps and by monitoring crops. The main period of activity was between mid-June and mid-July and a maximum of 36 moths was captured in one week.

There was considerable variation between locations in the pattern of moth activity represented by trap captures. The captures of silver Y moths by Trapview traps were compared with captures by funnel pheromone traps. Overall the patterns of activity were similar but not identical. The data require more detailed analysis but the differences in the pattern of captures may be simply a reflection of background variation from trap to trap, as capture of moths is essentially a random process.   There was evidence that, at least in some locations, captures by the Trapview traps were considerably smaller than by the funnel traps.

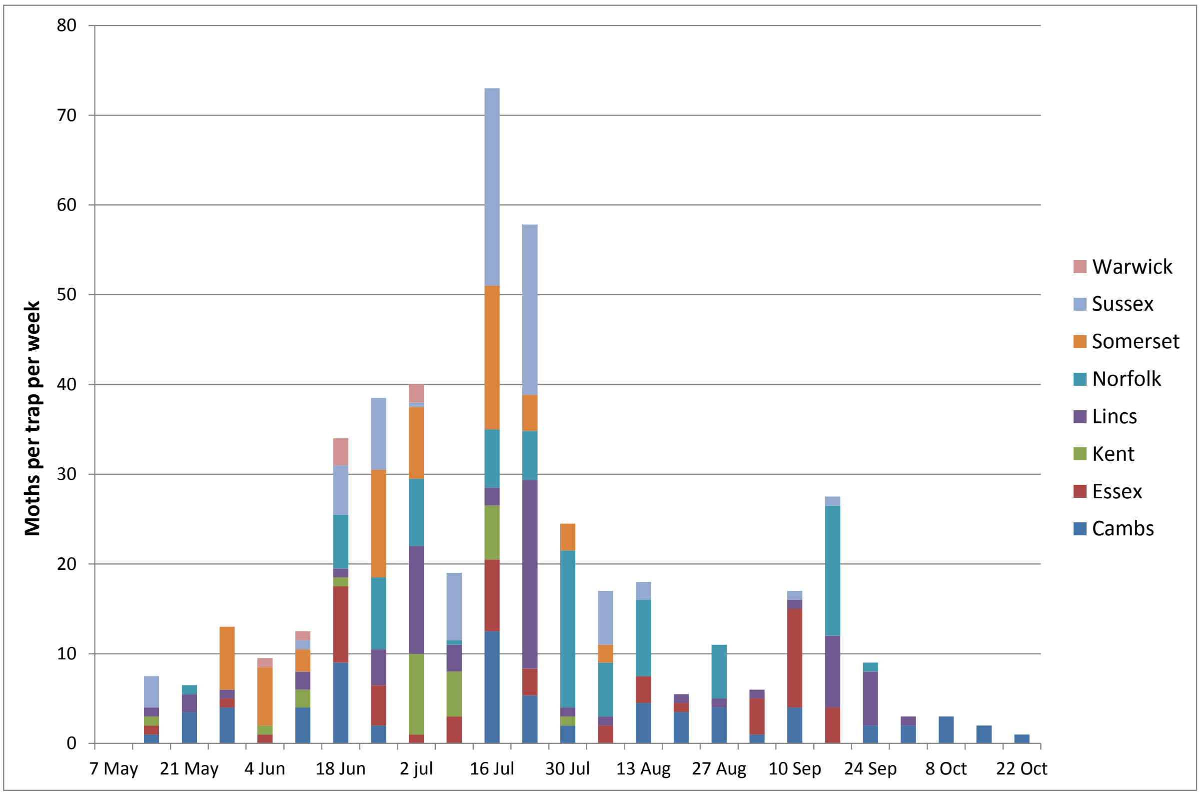

Figure 1. Captures of silver Y moths by Trapview traps in 2015 – sorted by county.

Relationship between captures by pheromone traps and infestation of crops by caterpillars

Captures of silver Y moths in 2015 were relatively low overall and so infestations in lettuce crops were not severe. However, where available, crop walking data were compared with trap captures to determine how much ‘warning’ they might provide and whether there were indications that a threshold might be developed. In Lincolnshire, caterpillars and damage were observed in July, with the first caterpillar seen in Week 27 (first week of July), which coincided with the period of greatest moth activity.   For the crops grown by G’s in Cambridgeshire and Norfolk respectively, peak numbers of caterpillars were observed in mid-July which seemed to tie in most closely with an influx of moths in the traps around 23 June.

Relationship between the timing of moth captures and the detection of caterpillars in crops

In order to try and understand the relationship between the timing of moth captures and the detection of caterpillars in crops, published data on development of the different stages of silver Y moth at different temperatures were summarised. From these data, the estimated threshold temperatures for the egg, larval and pupal stages were 7.6, 9.2 and 7.7°C respectively. Using the estimates of development time at 13 and 18°C, egg development required approximately 60 day-degrees above 7.7°C.

As an example, four sets of weather data collected for the AHDB Pest Bulletin in 2015 were used to estimate the daily day-degrees above 7.7ºC between mid-June and mid-August. Overall, the largest numbers of moths were captured from 13 June until towards the end of July. Using the day-degree sum for egg hatch of approximately 60 day-degrees above 7.7°C indicated that, for example, eggs laid on 14 June in Kent would hatch approximately 9 days later.

Diamond-back moth

Very low numbers of diamond-back moths were captured in the Trapview traps. Data from ordinary (Delta) pheromone traps is so far only available from the sites at Warwick and in Fife. Captures were very low in both locations and too low to undertake any meaningful analysis of the data. As for the silver Y moth, published data on the development times of diamond back moth at a range of temperatures were summarised. At a temperature of 16ºC, egg development took 6.4 days and a complete generation took approximately 33 days.

Turnip moth

Two Trapview traps were run at G's and it was possible to compare the catches from these traps with the data from 13 funnel traps. Not all of the funnel traps were run over the full period, but even so they give a clear indication of the pattern of activity, with two distinct adult generations. The Trapview traps captured relatively low numbers of moths compared with some of the funnel traps.

Performance of the Trapview traps

The Trapview traps are still in the development phase and there were a few problems with them which can be improved on in 2016. The surface of the sticky inserts was not sufficiently sticky to hold some of the silver Y moths firmly (and the same may be true for turnip moths) and there was evidence that the moths had moved around and sometimes escaped from the trap. It seemed that once a few moths had been captured the performance of the traps declined – possibly because the available area for capturing moths had decreased. The camera is relatively heavy and in some cases the trap became distorted, which affected the view of the sticky surface. On some days the signal was insufficient for the image to be downloaded to the Trapview web site.

Historical data

Some of the grower participants, particularly G's, have historical records on silver Y moth abundance and this information has been collated and forwarded to Warwick Crop Centre for further summary and analysis.

Other approaches to monitoring and control (Objectives 5 and 6).

Other information on movement of adult silver Y moths is available from Rothamsted Research. This consists firstly of the captures made by the network of light traps run by the Rothamsted Insect Survey. A summary of captures by these traps over the last 50 years showed that there is considerable variation in overall abundance from year to year. Rothamsted Research also have considerable expertise in relation to the impact of weather conditions, particularly wind on the trajectories of migrating moths and they will be using this expertise to interpret some of the trapping data collected in 2015. It may also be possible to use the light trap data and historical pheromone trap data to explore the relationship between pheromone catches and light trap catches.

Financial Benefits

The benefits of a successful outcome to the project will be improved quality of crops marketed and fewer crop losses and rejections.

Action Points

There are no specific action points from this project at present but it has highlighted the importance of monitoring moth activity to indicate periods when crops may be particularly at risk from infestation.

SCIENCE SECTION

Introduction

Damage caused by the Silver Y moth and other caterpillar species can result in unacceptable leaf damage in outdoor baby leaf and lettuce crops where there is zero tolerance for either the presence of, or visible damage from, these pests. Loss of active ingredients has left the industry with a limited list of insecticides which are not effective and all have long harvest intervals. This is resulting in poor control of these pests in UK crops. There are potentially a number of damaging species including silver Y moth and turnip moth (cutworm) which have a range of hosts and also the brassica specialists such as diamond-back moth that may infest baby leaf crops.

Silver Y moth

Caterpillars of the silver Y moth (*Autographa gamma*) have a fairly wide range of host plants including beet, potato, maize, brassica, and legumes, but are particularly damaging to lettuce and related crops. The silver Y moth is a migrant species and infestations usually first arise as a result of immigration by moths in May and June.

The migration patterns of the silver Y moth have been studied in the UK in the context of increasing our understanding of insect migration activity (Chapman *et al.*, 2012). Spring migrants use fast-moving airstreams, 200–1,000 m above the ground, to travel 300 km northward per night to colonize temporary summer-breeding grounds in northern Europe, from their winter-breeding grounds in North Africa and the Middle East. Radar tracking was used to estimate the annual abundance of immigrating moths during the period 2000–2009. Three years (2000, 2003, and 2006) had high immigrant migrations in spring, corresponding to an estimated 225–240 million adult moths immigrating into the whole of the UK, whereas in the other 7 years the UK received roughly one-ninth that number (10–40 million immigrants). Other outbreak years in the last century have included 1946 and 1996 (documented by the Dorset Moth Group and others).

In the autumn (August and September), silver Y moths return to their winter breeding grounds and Chapman *et al.* (2012) estimated that 80% of emigrants reach regions in the Mediterranean Basin suitable for winter breeding. They also estimated that summer breeding in the UK results in a four-fold increase in the abundance of the subsequent generation of adults, all of which emigrate southward in the autumn. As a result they concluded that the persistence of this species is dependent on summer breeding in high-latitude regions such as the UK, because there is insufficient fresh vegetation to support them in the Mediterranean Basin during the summer months. The information used in the paper by Chapman *et al.* (2012) was obtained from the Rothamsted Insect Survey light trap network as well as by radar tracking.

Monitoring silver y moth

Moth enthusiasts usually monitor silver Y moths using light traps, whilst pheromone traps are more practical for use by growers. The pheromone traps use synthetic female sex pheromone to attract male moths and the assumption is made that the female moths are laying eggs on host plants at the time that the male moths are captured. The precise timing of the arrival of silver Y moth in spring/summer appears to vary from year to year, as does the overall pattern of trap captures (HDC Projects FV 163, FV 163a, FV 192, PC 132), although peaks in abundance, probably representing a new influx of immigrant moths, often occur at a similar time at locations within a region (FV 163a). Crops in the south and east seem to be most at risk from infestation. Within a locality, pheromone traps sited in different locations may catch different numbers of moths (D. Norman, personal communication), although in other cases catch sizes may be very similar (e.g. traps deployed in brassica crops in south Lincolnshire in 2000 (FV 163a)).

It is possible to find silver Y moth eggs and caterpillars on plants during crop walking. However, the eggs are small and laid singly, and can be hard to find. The small caterpillars are green and are often relatively inconspicuous on foliage.

Action thresholds

Attempts have been made to relate the numbers of silver Y moths captured in pheromone traps to the numbers of eggs/caterpillars found on plants. This has been done in the UK for peas (FV 192) and vegetable brassicas (FV 163a) respectively. For peas, it was estimated that a threshold catch was reached when the cumulative catch by the first pod stage (gs 204) exceeded 50 moths. For brassicas, the conclusion was that this was not a very ‘susceptible’ host crop because although moth numbers were often relatively high, none of the 50 site/generation combinations for which there was pheromone trap/caterpillar data had more than 1 caterpillar per plant at the peak. In the case of vegetable brassicas this ‘relatively low’ level of infestation is unlikely to cause problems in most instances, whereas such a situation would be more problematic on lettuce and baby leaf.

Control

Control of silver Y moth with different insecticides was not investigated in the previous HDC projects FV 192, PC 132 and FV 163a. Insecticides and bioinsecticides (two *Bt* products) were evaluated against some pest species of caterpillar in FV 163 but populations of silver Y moth caterpillars were too low for this species to be targeted.

In the more recent SCEPTRE project (CP 077), laboratory tests at Warwick Crop Centre in 2013 evaluated the efficacy of conventional insecticides and biopesticides against silver Y moth caterpillars. To obtain the caterpillars, female moths were captured in a light trap at Warwick Crop Centre and caged with lettuce plants in the Insect Rearing Unit so that they laid eggs which hatched subsequently producing caterpillars.

The three coded conventional insecticides tested in the SCEPTRE project showed excellent activity against silver Y moth when applied as foliar sprays (100% control) (Table 1.1). In a small unfunded trial, two coded conventional insecticides were applied as drench treatments to the peat blocks containing the lettuce plants and both provided 100% control, indicating systemic activity. There was evidence of some persistence with both methods of application with all the products tested. Four coded bioinsecticides showed varying levels of control of silver Y moth caterpillars (Table 1.2). Please note that some of the named insecticides do not have approval for application to brassica and/or lettuce crops.

Table 1.1 Data from SCEPTRE project on control of silver Y moth caterpillars with coded insecticides

SCEPTRE Code	Mean % caterpillars surviving		Mean number of feeding holes	
	Fresh residue	Aged residue (7 days)	Fresh residue	Aged residue (7 days)
Untreated	66	70	58.5	Plants dead
Cyazypyr (SI2013-50)	0	0	0.9	0.7
Spinosad (SI2013-140)	0	0	4.1	2.8
Emamectin benzoate (SI2013-48)	0	0	3.1	2.7

Other caterpillar pests of lettuce

Lettuce and related crops may also be infested by caterpillars of the turnip moth (*Agrotis segetum*) (cutworms) and occasionally by species of Tortrix moth. The turnip moth is a sporadic pest of lettuce. The name derives from the habit of the older caterpillars of feeding underground, damaging plant roots and stems, sometimes so badly that the plant topples.

The adult moths lay eggs on plants or on pieces of litter and debris in the soil, usually from the end of May or early June. These hatch in around 8-24 days, depending on temperature. The young caterpillars seek out and feed on the aerial parts of plants. In a further 10-20 days, again depending on temperature, the caterpillars go through their second moult, becoming “third instar” caterpillars. It is at this point that they adopt the cutworm habit, becoming subterranean and feeding on roots etc.

Unhatched turnip moth eggs and the older, subterranean cutworms are largely invulnerable to the effects of the weather and insecticides. The two early caterpillar instars differ, however. If there is substantial rainfall (defined as 10 mm or more of rain falling in showers of moderate intensity over a 24-hour period) whilst these caterpillars are feeding above ground then this causes high mortality among them. They are also vulnerable to insecticides and irrigation whilst feeding on the foliage.

Table 1.2 Data from SCEPTRE project on control of silver Y moth caterpillars with coded bioinsecticides.

SCEPTRE Code	Mean % caterpillars surviving		Mean number of feeding holes	
	Angular	Back transformed means	Log	Back transformed means
Untreated	60.1	75.2	4.511	91.1
Nemasys-C SI2013-94	33.7	30.8	3.769	43.3
Azadirachtin (SI2013-130)	18.2	9.8	3.222	25.1
SI2013-51	37.7	37.5	3.831	46.1
Lepinox Plus SI2013-68	2.7	0.2	2.284	9.8
F value	20.31	75.2	17.95	
P –value	<0.001		<0.001	
Replicate no.	10		10	
d.f.	45		45	
s.e.d.	6.78		0.277	
l.s.d.	13.65		0.558	

The cutworm model is a computer program that uses weather data to predict the rate of development of turnip moth eggs and caterpillars. It also predicts the level of rain-induced mortality among the early-instar caterpillars. The cutworm model published by Bowden *et al* (1983) has been programmed into the MORPH decision-support software and is also available from ADAS as a service. The model is run from when moths are first caught in pheromone traps. Once eggs are predicted to start to hatch then rainfall becomes important for the forecast. Rainfall events have major effects on the survival of young cutworms (from when they hatch until they reach the third instar (third caterpillar stage – achieved through moults)) and this forms the basis of the forecast i.e. if a heavy rainfall event occurs when a particular cohort of young cutworms is present then it is assumed that they will be killed. For irrigated crops, the risk of cutworm damage is reduced as substantial irrigation has the same effect on cutworm survival as heavy rainfall.

Unlike silver Y moth, turnip moths overwinter in the UK and the timing of emergence is predictable using a simple day-degree forecast developed at Warwick Crop Centre. As with silver Y moth, turnip moths can be captured in light traps or with pheromone traps. There are no thresholds that relate numbers of moths captured in pheromone traps to infestation levels in crops. As with silver Y moth it is very hard to find eggs and small caterpillars whilst crop walking. Turnip moth caterpillars can be controlled with insecticides but once they become subterranean it is much harder to contact them. There has not been any recent work on the efficacy of insecticides and bioinsecticides against this pest.

Brassica specialists

Potentially this could cover several species but probably diamond-back moth (*Plutella xylostella*) and the small and large white butterflies (*Pieris brassicae, Pieris rapae*) present the greatest risk.

Diamond-back moth is similar to silver Y moth in that it does not overwinter very successfully in the UK and so major infestations early in the year are usually the result of migration across the Channel from continental Europe and further south. As with silver Y moth there have been particular outbreak years and often both species are abundant in a particular year (as in 1996).

Monitoring and action thresholds

Diamond-back moth can be monitored using pheromone traps whilst butterflies are monitored using yellow sticky traps or water traps. The use of traps to monitor caterpillar pests of brassica crops was investigated in HDC projects FV 163 and 163a and the potential use of thresholds (both using pheromone traps and through crop walking) was explored in some detail in these projects. Pheromone traps can certainly be useful to indicate when large numbers of moths are entering crops, since female diamond-back moths will lay eggs at the same time that the traps are capturing male moths; and subsequent development is rapid so spray timing is critical. However, the relationship between the numbers of diamond-back moths captured in pheromone traps and the numbers of caterpillars found subsequently on plants in insecticide-free plots was not particularly consistent. Adult trapping data for the small white butterfly appeared to be extremely variable and is probably an unreliable indicator. Egg counts may provide a more reliable indication for this species. Some tentative guidelines were produced with regard to 'threshold' trap captures – but these will not be completely reliable.

Control

Control of brassica specialists was also investigated in FV 163, but the range of products available has changed considerably since then. Brassica caterpillars have been some of the targets for evaluation of coded insecticides and bioinsecticides in the recent SCEPTRE project and data for trials at Warwick Crop Centre in 2013 are shown in Figures 1.1 and 1.2. There are new insecticides and bioinsecticides that are potentially effective.

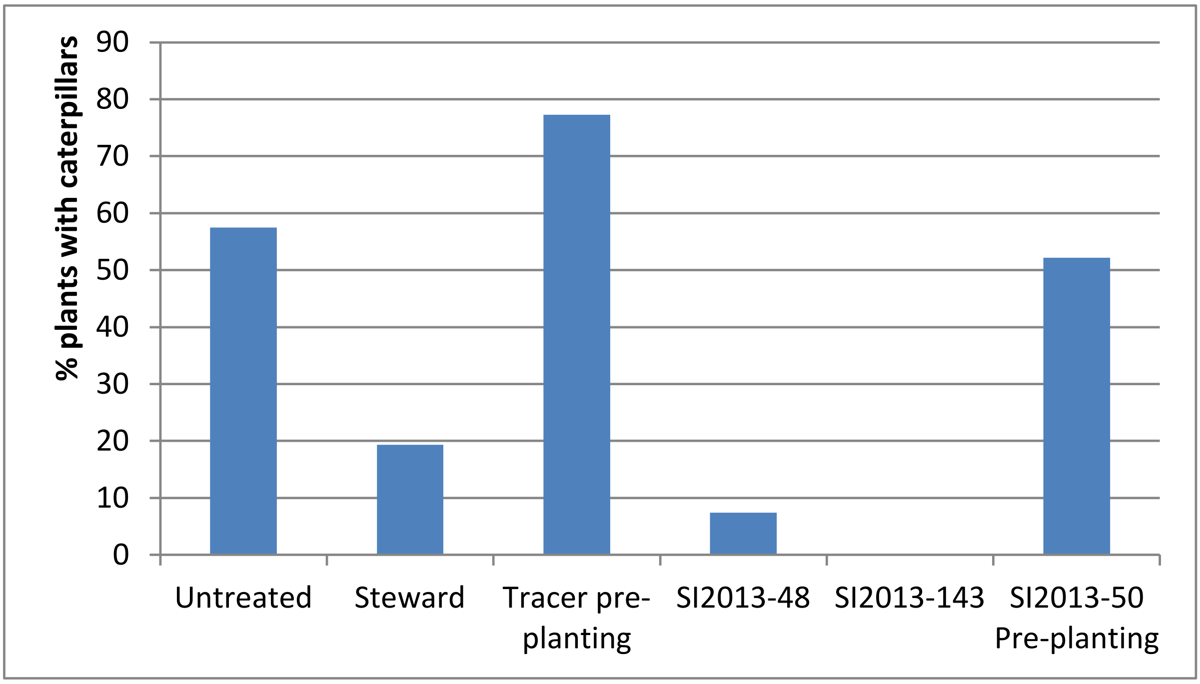

Figure 1.1 SCEPTRE project - caterpillar control on Brussels sprout – insecticides - majority of insects were small white butterfly (*Pieris rapae*). N.B SI2013-BRU-48 is emamectin; SI2013-BRU-50 is cyazypyr.

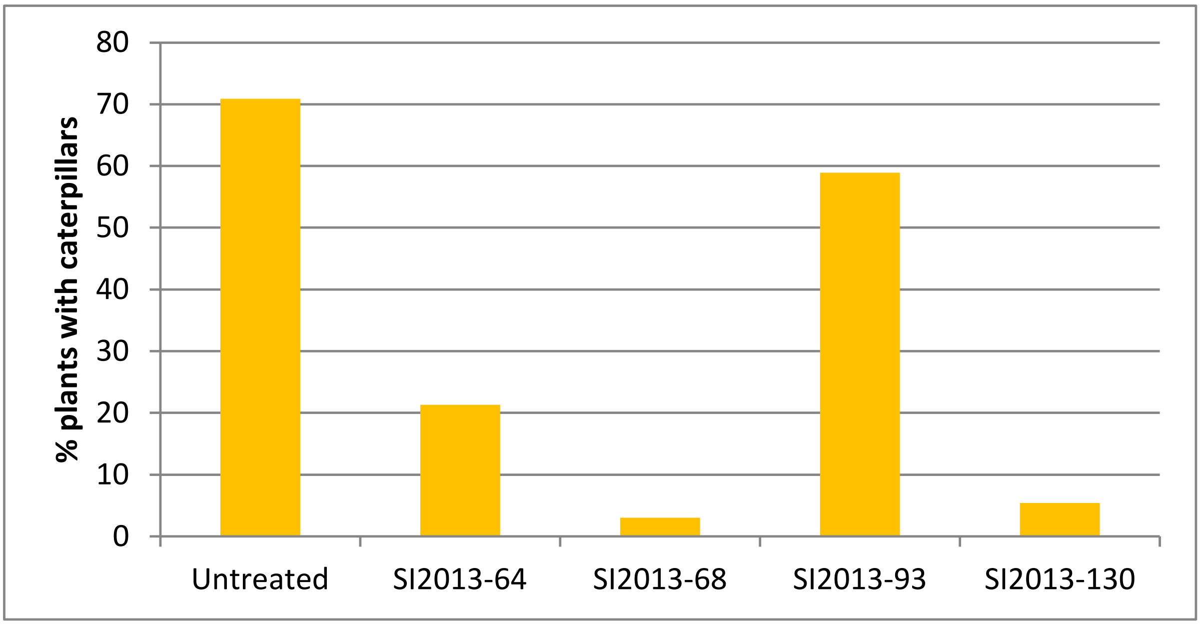

Figure 1.2 SCEPTRE project - caterpillar control on Brussels sprout – bio-insecticides - majority of insects were small white butterfly (*Pieris rapae*). N.B SI2013-130 is Azidirachtin.

Novel methods of management/control – all species

A scan of published research using the search term *Autographa gamma* revealed 317 publications in the Web of Knowledge database. The majority of these are concerned with migration and pheromones. Other aspects that might be of interest in the context of this species were the response of moths to plant volatiles (when seeking nectar) and biological control with egg parasitoids.

For diamond-back moth in particular, a whole range of alternative methods of control have been investigated, including trap cropping, intercropping, biological control by releasing predators or parasitoids or by increasing numbers of natural enemies by enhancing the local environment. All of these approaches have limitations and most may not be appropriate for baby leaf crops. Exclusion methods (crop covers) may be effective, depending on pest species and how they are deployed, but are not always practical or economically viable for commercial crops.

Mass trapping using pheromone traps has been suggested as a possible approach to control of adult moths. However, before mass trapping of males with a female sex pheromone might be considered, it would be important to know exactly where and when the moths mate, as mass trapping at the egg-laying site might be ‘too late’ if the moths had mated before females arrived at the crop. 'Confusion' techniques using pheromones might be another approach to control, by releasing such large amounts of pheromone into the locality that male moths are unable to find female moths and mate with them. However, again this relies on 'catching' the moths before they have mated. 'Lure and kill' has been suggested as a further development of the use of pheromone traps but again it would be important to assess the 'value' of killing male moths as for mass trapping above. If an effective attractant for female moths could be identified, some of these approaches might be more successful. Other approaches that merit consideration would be more targeted use of irrigation to control cutworm caterpillars (and possibly silver Y moth caterpillars), although it would be worth assessing previous Danish research before planning future studies, and the performance of introduced or naturally-occurring natural enemies. However, level of control and speed of kill would be a consideration, especially close to harvest. This might also apply to biopesticides that do not kill very rapidly.

The focus of this project is on novel control agents (insecticides and bioinsecticides) and on the use of monitoring approaches to improve the identification of potential problems and aid decision-making with regard to treatment timing.

The objectives of the project are to:

1. Liaise with agrochemical companies and crop protection specialists to identify experimental conventional pesticides which may show efficacy in controlling caterpillars.
2. Consider the use of novel, approved or near market, biological control products which could be beneficial in reducing the risk of pesticide residues.
3. Gather accurate and detailed data during thorough assessments which will be statistically robust.
4. Carry out suitable, randomized and replicated, field trials to measure the efficacy of the chosen treatment regimes.
5. Develop a risk-based spray-decision-making system linked to trapping of moths and measure its efficacy, via field trials, against normal pest control practice.
6. Investigate other monitoring and control mechanisms which may be effective and make recommendations for how they might be developed through future research.
7. Engage and communicate with growers and other members of the industry.

Experimental

Trials to measure the efficacy of the chosen treatment regimes (Objectives 1,2,3,4)

Collection of silver Y moths

Live adult silver Y moths were captured to produce eggs which were used to set up cultures in the laboratory/greenhouse to infest efficacy trials. Robinson light traps were purchased and set up in Cambridgeshire (run by ADAS, Boxworth) and at Wellesbourne (4 traps in total).

Traps at Wellesbourne

These were run throughout the summer period and checked daily when operating (Figure 2.1). Small numbers of moths were captured but there were sufficient to start breeding cultures. All stages were kept in Bugdorm® cages (30 x 3 x 30 cm) in controlled environment rooms (18-20°C) in the Insect Rearing Unit. The female moths were allowed to lay eggs on potted lettuce plants and the larvae were also maintained on potted lettuce plants. The culture was allowed to go through several generations to build up numbers.

Figure 2.1. One of the Robinson light traps located at Warwick Crop Centre, Wellesbourne.

Traps at Boxworth

Light traps were used at ADAS Boxworth and in a private garden in Boxworth, Cambridgeshire to trap moths between 27 May and 16 July. Only low numbers of Silver Y moths were trapped amongst the many other species including various hawk moths. Silver Y were trapped in the private garden which contained different flowering plants and trees and at various location at ADAS Boxworth where there were flowering weeds e.g. dandelion and also flowering ornamental crops used in various trials. Silver Y moths were also caught with a net at ADAS Boxworth on flowering *Buddleia* and *Choisya*.

The first eggs from a Silver Y female were collected on 16 July and a culture was established in a ventilated Perspex insect rearing cage in a controlled temperature laboratory maintained at 21°C and with natural daylength at ADAS Boxworth. Flowers such as *Buddleia,* chrysanthemum, thistle, poppy, ragwort and nettle were supplied as a food source for the adult moths but these were then substituted with providing honey on a yellow 'feeding wall' which was more successful. The feeding wall consisted of a yellow plastic sticky trap placed in a polythene bag to protect the moths from the glue. Honey was smeared onto the polythene bag which was then fixed to the inside of the Perspex rearing cage (Figure 2.2).

Lettuce leaves were provided in the rearing cage in a white plastic tray for the moths to lay eggs on. The first eggs were recorded on 16 July, caterpillars and pupae from 23 July and new generation adults from 31 July. Leaves with eggs were transferred to a separate cage until the caterpillars were large enough to handle without damaging them. Caterpillars were then transferred to ventilated plastic boxes lined with tissue paper and with lettuce leaves as a food source. The boxes were cleaned every other day and any pupae removed and placed in the adult cage to allow them to emerge.

Caterpillars were sent to STC for Trial 2 on 21 September 2015.

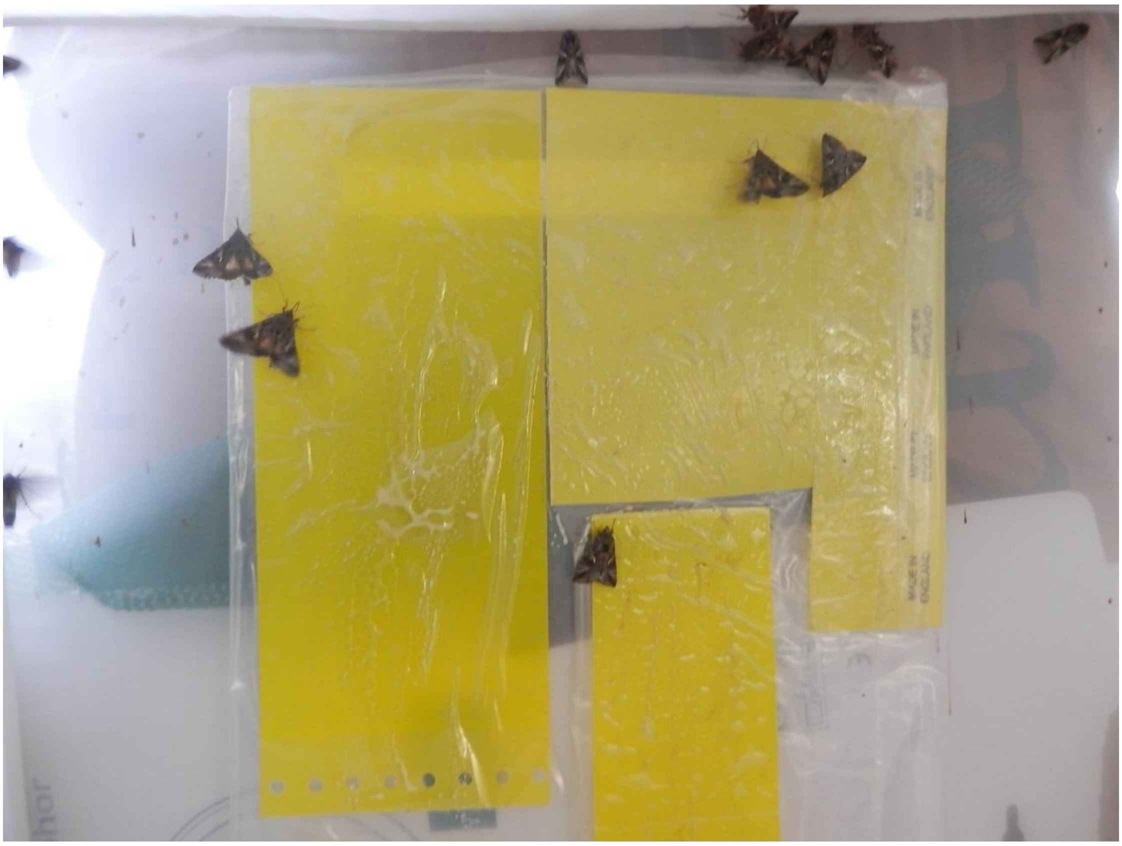

Figure 2.2. Adult Silver Y moths on the ‘feeding wall’ in the rearing cage at ADAS Boxworth.

Field trials

Three field trials were undertaken in 2015 to evaluate insecticides and bioinsecticides against silver Y moth (2 trials) and diamond-back moth (1 trial). All trials were infested with the target pest insects. Please note that some of the named insecticides do not have approval for application to brassica and/or lettuce crops.

Trial 1 Efficacy of insecticides and bioinsecticides against silver Y moth on whole head lettuce.

Materials and methods

The trial was undertaken to compare foliar spray treatments (5 treatments and untreated control). Lettuce seeds (cv Challenge) were sown in P84 trays on 14 July and maintained in a glasshouse until transplanting. The trial was laid out as an augmented Latin square design for 5 replicates of 6 treatments and was transplanted on 11 August. Each plot was 2.8 m x 1 bed and consisted of 4 rows x 9 plants at spacings of 35 cm between rows and 35 cm between plants. The trial was covered with netting to exclude birds and mammals. Small- to medium-sized caterpillars were selected from the laboratory culture at Warwick Crop Centre and counted into pots containing a piece of untreated lettuce leaf. Ten plants per plot were inoculated (6 caterpillars per plant) on 23-24 September by tipping the lettuce leaves with caterpillars attached into the centre of a lettuce. All spray treatments (Table 2.1) were applied using a knapsack sprayer fitted with 02F110 nozzles in 300 l/ha water on 24 September. With the exception of HDCI 090, all the products were bioinsecticides.

The plants were assessed for damage due to caterpillar feeding on a 0-5 scale (0 = no damage, 1 = <5 holes, 2 =<10 holes, 3 = <20 holes and 5 = >20 holes) on 28 September (4 days after spraying). The numbers of caterpillars (live and dead) were counted on 30 September. Inoculated plants were sampled destructively as many of the living caterpillars had eaten into the lettuce. The key events of the trial are listed in Table 2.2.

Table 2.1 Treatments used in Trial 1

Code	Active ingredient	Product	Rate	Approved for use
1	Untreated control			
2	HDC1 100		As specified by supplier	No
3	Azadirachtin		As specified by supplier	No
4		Lepinox Plus	As specified by supplier	Yes
5	HDCI 089		As specified by supplier	No
6	HDCI 090		As specified by supplier	No

Table 2.2 Key events in Trial 1

Date	Event
14-Jul	Seeds sown in P84 trays
11-Aug	Trial transplanted
23-Sep	Caterpillar inoculation started
24-Sep	Caterpillar inoculation completed
24-Sep	Spray treatments applied
28-Sep	Plants damage assessed
30-Sep	Caterpillars counted

Results

The data were analysed using Analysis of Variance. For the analysis of the numbers of live and dead caterpillars remaining 4 days after treatment there was a statistically-significant effect of treatment on the numbers of dead caterpillars ($p<0.01$) and the numbers of live caterpillars ($p<0.001$) (Table 2.3; Figure 2.2). The insecticide HDCI 090 was the most effective treatment in both respects.

Table 2.3 Trial 1 - the mean numbers of dead and live silver Y moth caterpillars 4 days after treatment.

Treatments	**Mean numbers of dead caterpillars**	**Mean numbers of live caterpillars**
Untreated control	0	8.2
HDCI 100	0.2	13.6
Azadirachtin	0.8	11.8
Lepinox Plus	0.4	13.8
HDCI 089	1	11.8
HDCI 090	4.8	4.2
P-value	0.009784	0.000211
LSD (5%) (two-sided)	2.659147	3.926835
LSD (5%) (one-sided)	2.204317	3.255175

For the analysis of the mean damage score there were no overall statistically-significant effects of treatment (p=0.090) (Figure 2.4).

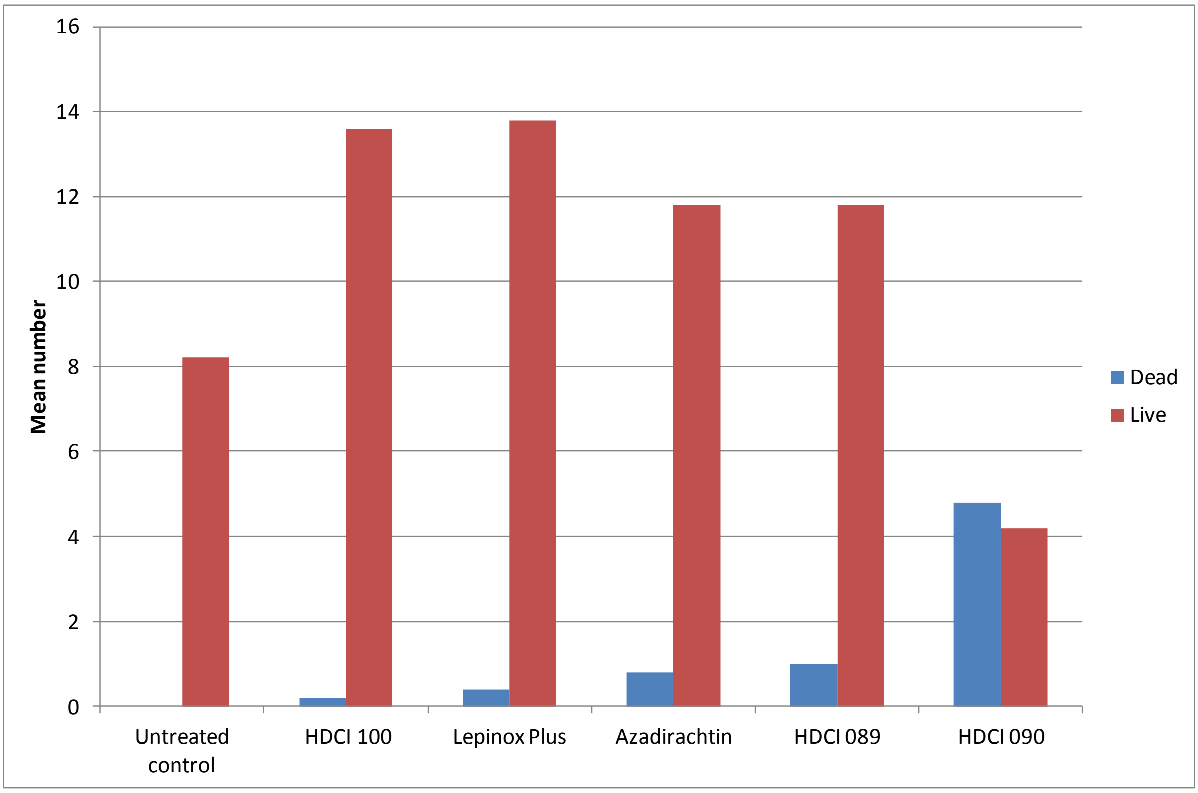

Figure 2.3. Trial 1 - the mean numbers of dead and live silver Y moth caterpillars 4 days after treatment.

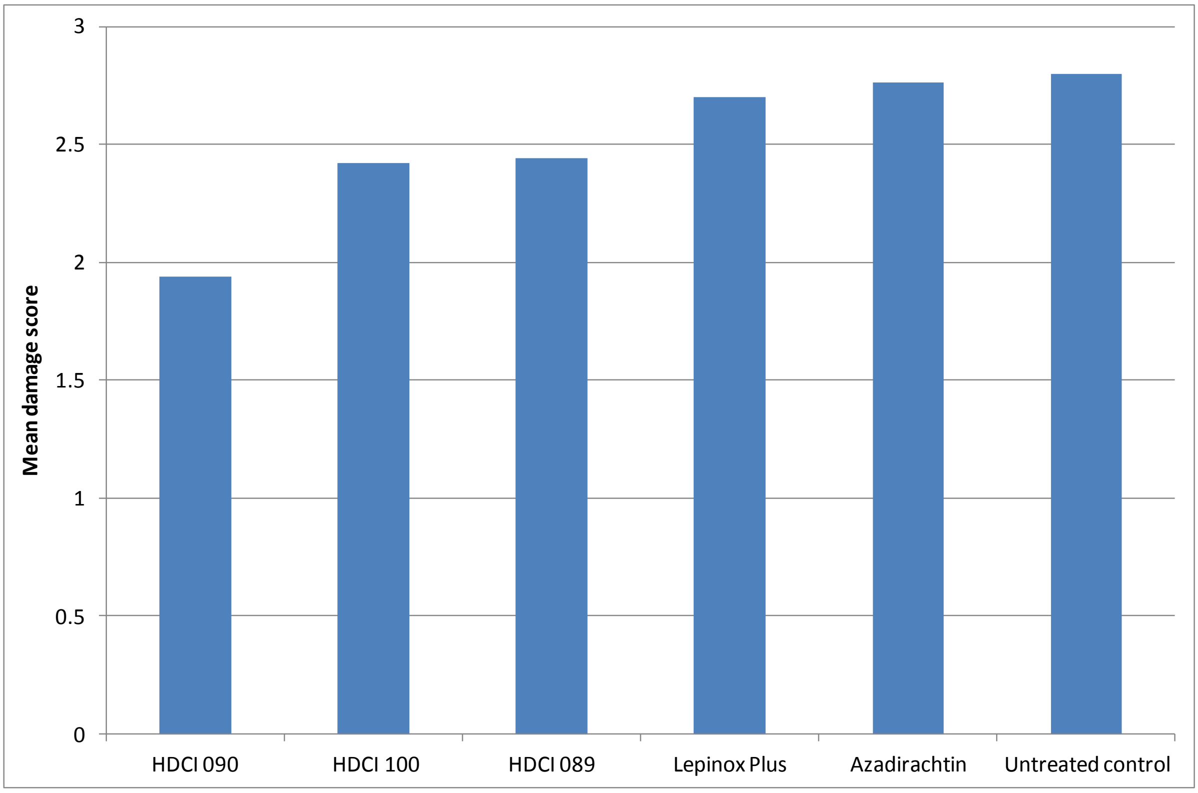

Figure 2.4. Trial 1 – the mean damage score due to feeding by silver Y moth caterpillars 4 days after treatment.

Trial 2 Efficacy of insecticides and bioinsecticides on silver Y moth in baby leaf lettuce

Materials and methods

The trial was conducted outdoors, under unprotected conditions, though the study site was surrounded by an electrified rabbit fence. Twenty-eight plots, measuring 3.6m metres long and 1.2m wide, were sown with baby leaf lettuce, *Lactuca sativa* var. Solavia RZ, at a rate of approximately 278 seeds per m^2 and 8 rows per plot (as advised by STC's Operations Manager), on 6 August 2015. Each plot was separated by 90 cm of bare soil to prevent spray drift between plots and treatments, with plots arranged according to a randomised block design.

Caterpillars were received from Warwick Crop Centre on the morning of 29 September 2015, and were immediately used to infest the plots. Thirty caterpillars were placed in the central rows of each plot, and left to settle for at least four hours.

On the afternoon of 29 September 2015, plots were treated with product, or a water control, by application at 3 bar pressure using an Oxford Precision Sprayer and F01 110 flat fan nozzles fitted to 3 outlets of a 4 outlet boom spray bar (the 4^{th} outlet being blanked off). Table 2.4 summarises treatments and application rates; water rate was 300L/ha on account of plant size.

Table 2.4. Treatments used in Trial 3.

Code	Active ingredient	Product	Rate	Approved for use
1	Untreated control			
2	Lambda-cyhalothrin	Warrior	0.75 l/ha	Yes
3	Indoxacarb		0.085 l/ha	
4	Cyazypyr		As specified by supplier	No
5	HDCI 096		As specified by supplier	No
6	Emamectin benzoate		As specified by supplier	No
7	Cyantraniliprole		As specified by supplier	No

Two visual assessments for live caterpillars were made of the plots following treatment, with observations for phytotoxicity made at the same time.

The first, non-destructive visual assessment was taken two days after treatment (1 October 2015). Each plant in a plot was examined for presence of live caterpillars, and the total number of live caterpillars found in each plot was recorded. The number of dead individuals was also recorded. Finally, the soil surface around the base of the plants was examined for caterpillars.

The second visual assessment was taken on the ninth and tenth days after treatment (8 and 9 October 2015). This assessment was taken destructively – each plant in the plot was uprooted and examined, to obtain a more accurate estimate of the numbers of caterpillars present. As per the first assessment, the total number of live caterpillars in each plot was recorded, and the number of dead individuals was also recorded.

Results

Raw data were transformed to percentage caterpillars recovered in each plot. These data were then analysed by one-way ANOVA having confirmed that assumptions for parametric testing were met. Normality was checked using the Anderson-Darling test and homoscedasticity checked by the Levene's test. The data for two days after treatment did not require transformation prior to ANOVA, though data collected 9-10 days after treatment needed to be arcsin square-root transformed to fit test assumptions for both normality and homoscedasticity. Where a significant effect of treatment was detected, post-hoc testing for pairwise differences between means was conducted via the Tukey's test. Data for 2 days after treatment and 9-10 days after treatment were analysed separately.

Relatively low numbers of caterpillars were recovered (less than 50% of those released). All treatments led to lower numbers of caterpillars versus the control, with the exception of emamectin benzoate. For the data collected two days after treatment there was a significant effect of treatment ($F_{(6,20)} = 8.65$; $P = 0.000$), with a difference also found between treatments 9-10 days after treatment ($F_{(6,20)} = 17.92$; $P = 0.000$). Pairwise differences between treatment means ($P < 0.05$) are shown in Figures 2.5 and 2.6. No evidence of phytotoxicity was observed.

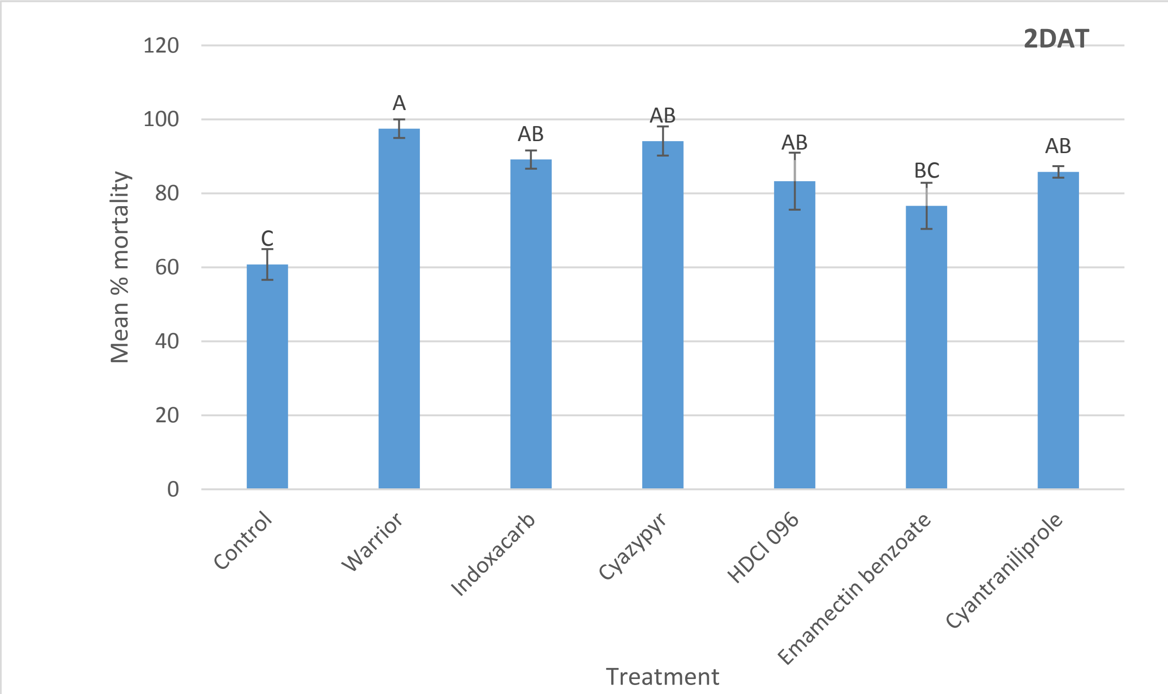

Figure 2.5. Mean percentage mortality of silver Y moth caterpillars 2 days (2DAT) after treatment. Means are displayed with ± SEs, where n = 4 for all means, except HDCI 096, where n = 3. Means not sharing a common letter are significantly different (P<0.05).

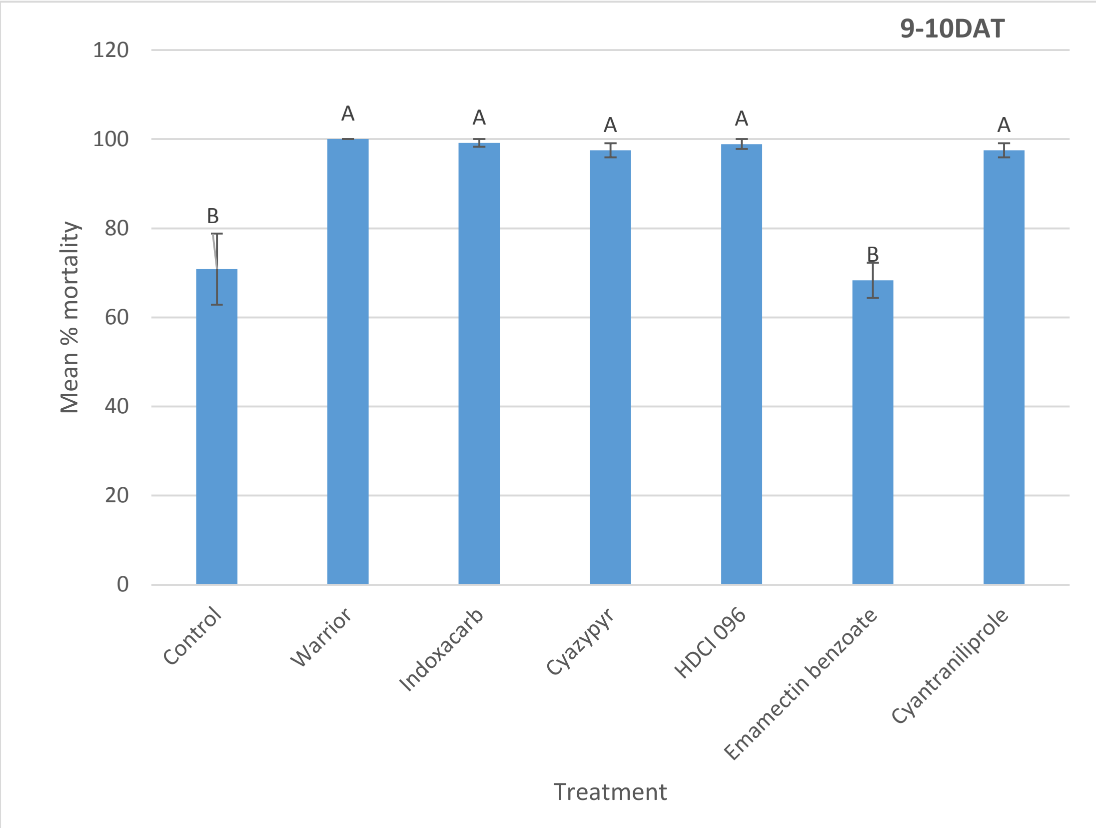

Figure 2.6. Mean percentage mortality of silver Y moth caterpillars 9-10 days after treatment. Means are displayed with ± SEs, where n = 4 for all means, except HDCI 096, where n = 3. Means not sharing a common letter are significantly different (P<0.05).

Trial 3 Efficacy of insecticides and bioinsecticides on diamond-back moth

Materials and methods

The trial was undertaken to compare foliar spray treatments (6 treatments and untreated control) (Table 2.5). Brussels sprout seeds (cv Faunus F1) were sown in 308 Hassy trays on 12 May and maintained in a glasshouse until transplanting. The trial was laid out as a Youden Rectangle for 4 replicates of 7 treatments and was transplanted on 23 June. Each plot was 3.5 m x 1 bed and consisted of 3 rows x 8 plants at spacings of 50 cm between rows and 50 cm between plants. The trial was covered with netting to exclude birds and mammals. In the absence of a natural infestation the trial was inoculated with diamond-back moths from the continuous culture maintained within the Insect Rearing Unit at Warwick Crop Centre.

Adult moths were allowed to lay eggs for 3 days on pot-grown Brussels sprout plants. Portions of leaves were selected which contained approximately 6 eggs or very small caterpillars. This task was made more difficult by the moths' habit of laying eggs in preference on the plastic pots so portions of pot were also selected as appropriate. The selected leaf/pot pieces were attached to marked plants with paper clips. Over the period 4 -24 September 7 plants/plot were inoculated on 2 occasions each. All spray treatments (Table 3) were applied using a knapsack sprayer fitted with 02F110 nozzles in 400 l/ha water on 25 September. Please note that some of the named insecticides do not have approval for application to brassica and/or lettuce crops.

The plants were assessed for damage due to caterpillar feeding (numbers of feeding holes on inoculated leaves) and the numbers of caterpillars (live and pupae) were counted on 1 October. The key events of the trial are listed in Table 2.6.

Table 2.5 Treatments used in Trial 3.

Code	**Active ingredient**	**Product**	**Rate**	**Approved for use**
1	Untreated control			
2	Cyazypyr		As specified by supplier	Only as a drench, not as foliar spray
3	Azadirachtin		As specified by supplier	No
4	HDCI-096		As specified by supplier	No
5	Emamectin benzoate		As specified by supplier	No
6	HDCI 100		As specified by supplier	No
7		Lepinox Plus	As specified by supplier	Yes

Table 2.6 Key events in Trial 3

Date	**Event**
12-May	Seeds sown in 308 Hassy trays
23-Jun	Trial transplanted
4-Sep	Caterpillar inoculation started
24-Sep	Caterpillar inoculation completed
25-Sep	Spray treatments applied
28-Sep	Plants damage assessed and caterpillars counted

Results
The numbers of caterpillars recovered during assessment of the plots per treatment were too low (<1 per plant) for meaningful analysis of the data.

Trial 4 Efficacy of insecticides and bioinsecticides on diamond-back moth

As the field trial on diamond-back moth in 2015 was unsuccessful due to low recovery of caterpillars, laboratory tests were planned and the first replicate has been completed. The treatments were the same as those used in Trial 3 with the addition of a new formulation of Tracer. The trial was conducted within the Insect Rearing Unit at Warwick Crop Centre.

Twenty pot-grown Brussel sprout plants were placed in a cage with adult diamond-back moths. The moths were allowed to lay eggs for three days before the plants were removed to another cage. Caterpillars were allowed to develop for 7 days and medium sized caterpillars were transferred to fresh plants (6 plants per treatment and 5 caterpillars per plant). The caterpillars were allowed to establish for a further day before spraying.

Plants were taken outside and removed from cages before spraying. The treatments (Table 2.7) were applied using a knapsack sprayer fitted with 02F110 nozzles in 300 l/ha water. The plants were returned to their cages and kept at 20^{o}C for two days before the numbers of feeding holes and the numbers of live caterpillars were assessed.

Table 2.7 Treatments used in Trial 4.

Code	Active ingredient	Product	Rate	Approved for use
1	Untreated control			
2	Spinosad	Tracer		Yes
3	Cyazypyr		As specified by supplier	Not as foliar spray
4	Azadirachtin		As specified by supplier	No
5	HDCI-096		As specified by supplier	No
6	Emamectin benzoate		As specified by supplier	No
7	HDCI 100		As specified by supplier	No
8		Lepinox Plus	As specified by supplier	Yes

Results

Figures 2.7 and 2.8 show the percentage live caterpillars recovered (based on the numbers used to infest the plants at the start of the trial) and the mean number of feeding holes per plant from the first replicate of the laboratory test. Further replicates are planned.

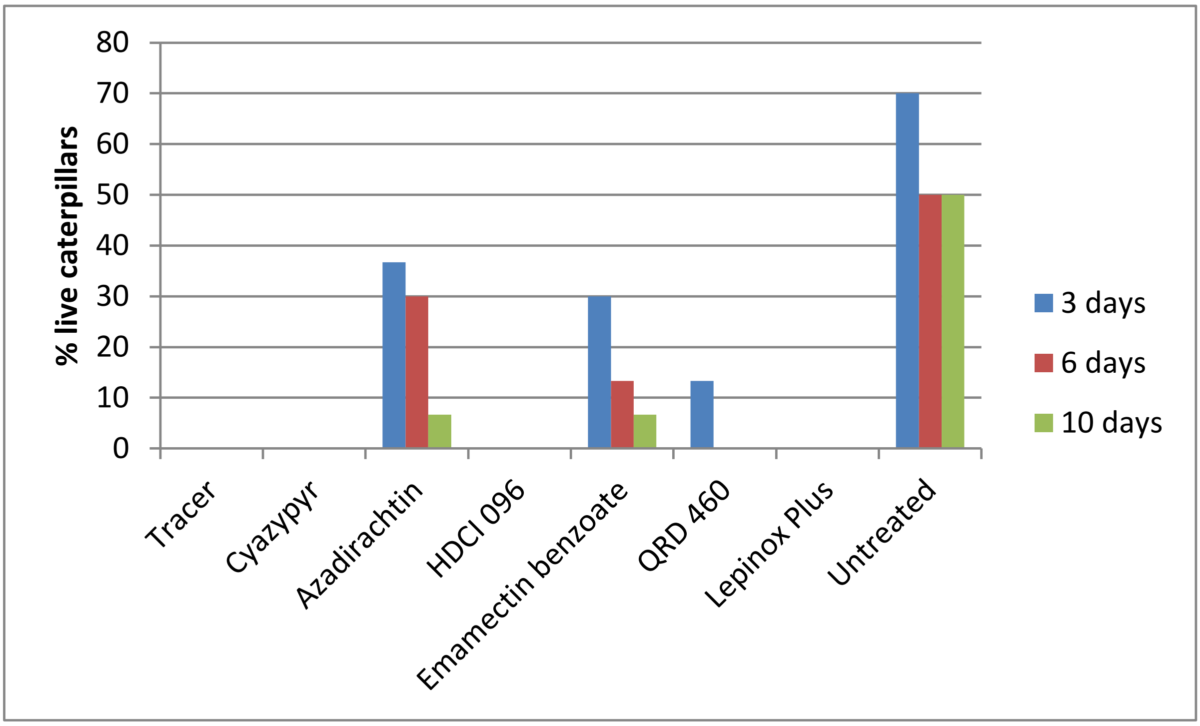

Figure 2.7. Percentage live caterpillars 3, 6 and 10 days after treatment. First replicate of laboratory tests.

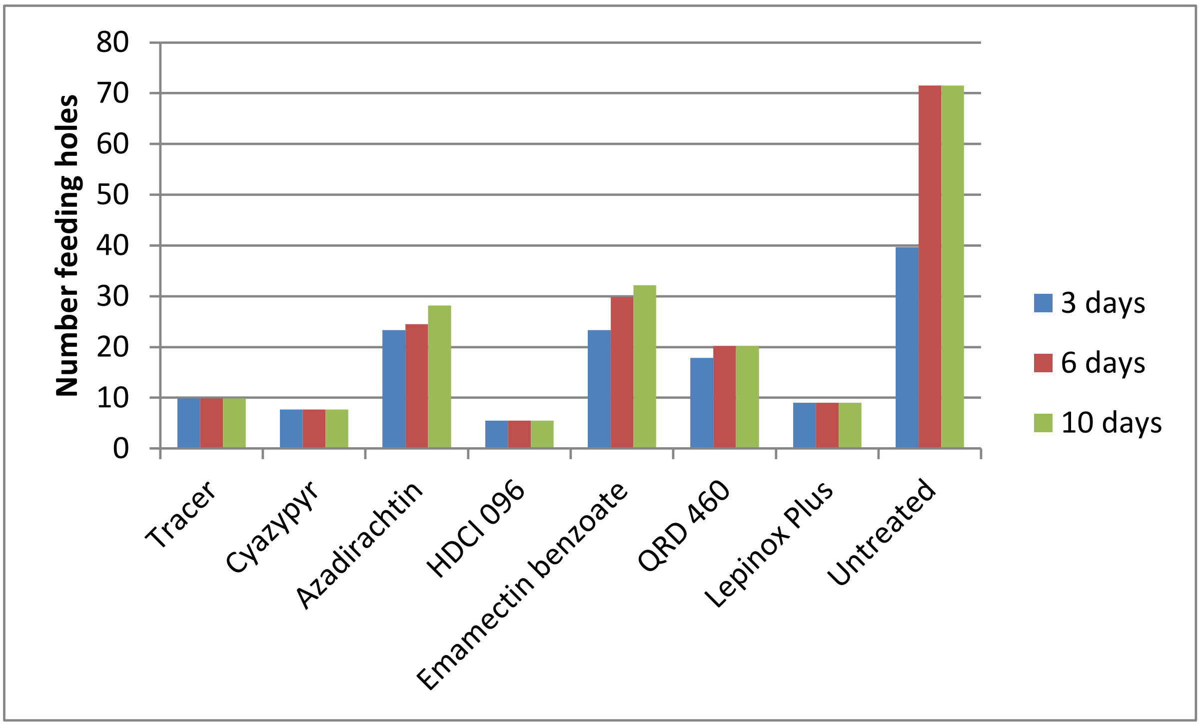

Figure 2.8. Mean number of feeding holes per plant 3, 6 and 10 days after treatment. First replicate of laboratory tests.

Monitoring activity of adult moths (Objective 5)

A network of pheromone traps was established in England and Scotland to monitor silver Y moth, diamond-back moth and turnip moth. The traps were supplied by Trapview (www.trapview.com) and the network was supported and managed by Colin Carter of Landseer. A total of 30 traps were set up in May-June 2015 and consisted of 17 traps for silver Y moth, 10 traps for diamond-back moth and 2 traps for turnip moth plus an 'experimental' trap used for trap development. The traps were hosted by growers of salad and brassica crops (Table 3.1).

Table 3.1 Locations of Trapview traps in 2015.

G's	Barway - Ely	Turnip	Cutworm
G's	Norfolk	Turnip	Cutworm
WCC	Warwick	Salads	DBM
KS Coles	South West	Swede	DBM
KS Coles	South West	Swede	DBM
Polybell Organic	Doncaster	Brassica	DBM
Saul Farms	Leverton, Lincs	Brassica	DBM
Angflor	Frating, Essex	Brassica	DBM
Kettle Produce	Scotland	Brassica	DBM
Kettle Produce	Scotland	Brassica	DBM
Philpott	Kent	Brassica	DBM
Philpott	Kent	Brassica	DBM
G's	Norfolk	Salads	Silver Y
G's	Norfolk	Salads	Silver Y
G's	Barway - Ely	Salads	Silver Y
G's	Cambs	Salads	Silver Y
G's	Norfolk	Salads	Silver Y
G's	Cambs	Salads	Silver Y
G's	TLC - Sussex	Salads	Silver Y
G's	TLC - Sussex	Salads	Silver Y
Intercrop	Sandwich - Kent	Salads	Silver Y
Intercrop	Sandwich - Kent	Salads	Silver Y
Intercrop	Worth - Kent	Salads	Silver Y
WCC	Warwick	Salads	Silver Y
JEPCO	Gedney - East	Salads	Silver Y
JEPCO	Gedney - East	Salads	Silver Y
KS Coles	South West	Peas	Silver Y
KS Coles	South West	Peas	Silver Y
Anglia Salads	Essex	Salads	Silver Y
Anglia Salads	Essex	Salads	Silver Y

One of the traps is shown in Figures 3.1 and 3.2. Each trap contained a pheromone lure for the appropriate species, a sticky base to capture the moths and a small camera which photographed the sticky base once each day. The camera was powered by a solar cell. The image was downloaded onto the website managed by Trapview and the images of the captures by all the traps (Figure 3.3) were visible to all the trap hosts. Generally there were two 'replicate' traps in each area. 'Ordinary' pheromone traps were run in parallel to the 'Trapview traps' with at least one at each site. The lures were replaced at the recommended intervals and the sticky bases were replaced as and when necessary. The data from the Trapview traps were downloaded from the Trapview site and checked and corrected using the images. Data from the other traps were sent to Warwick Crop Centre at the end of the season.

Figure 3.1. Trapview pheromone trap

Figure 3.2. Close up of ‘Trapview’ pheromone trap

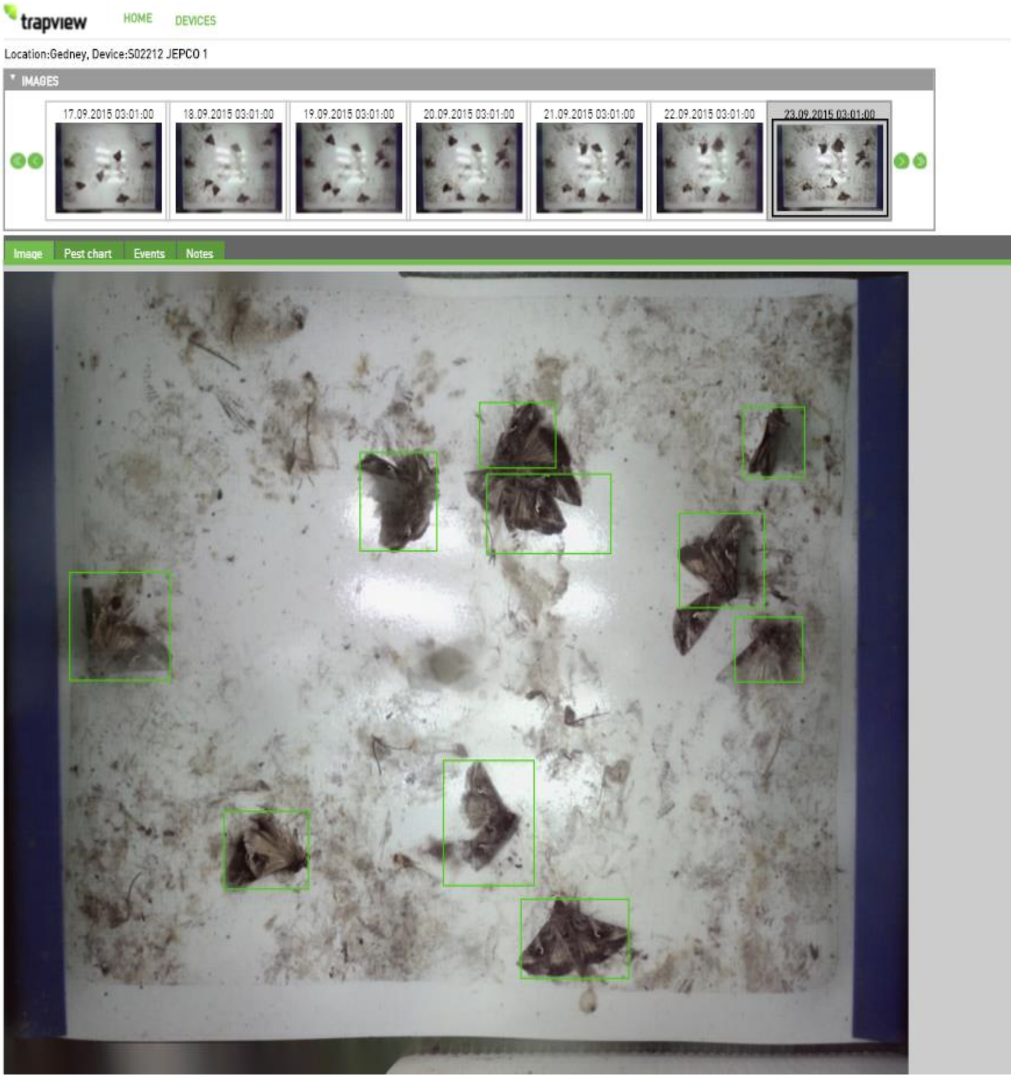

Figure 3.3. Image of silver Y moths captured in Trapview trap from Trapview website

Results

Silver Y moth

Captures by all of the Trapview traps are summarised by county in Figure 3.4. Not all of the traps were fully operational in May but the figures show that moths were captured between May and October with periods of more intense activity in mid-June and mid-July. The data require further analysis once captures for 2016 are complete, but there is no evidence that moths were captured earlier at sites that were further south or further east, for example.

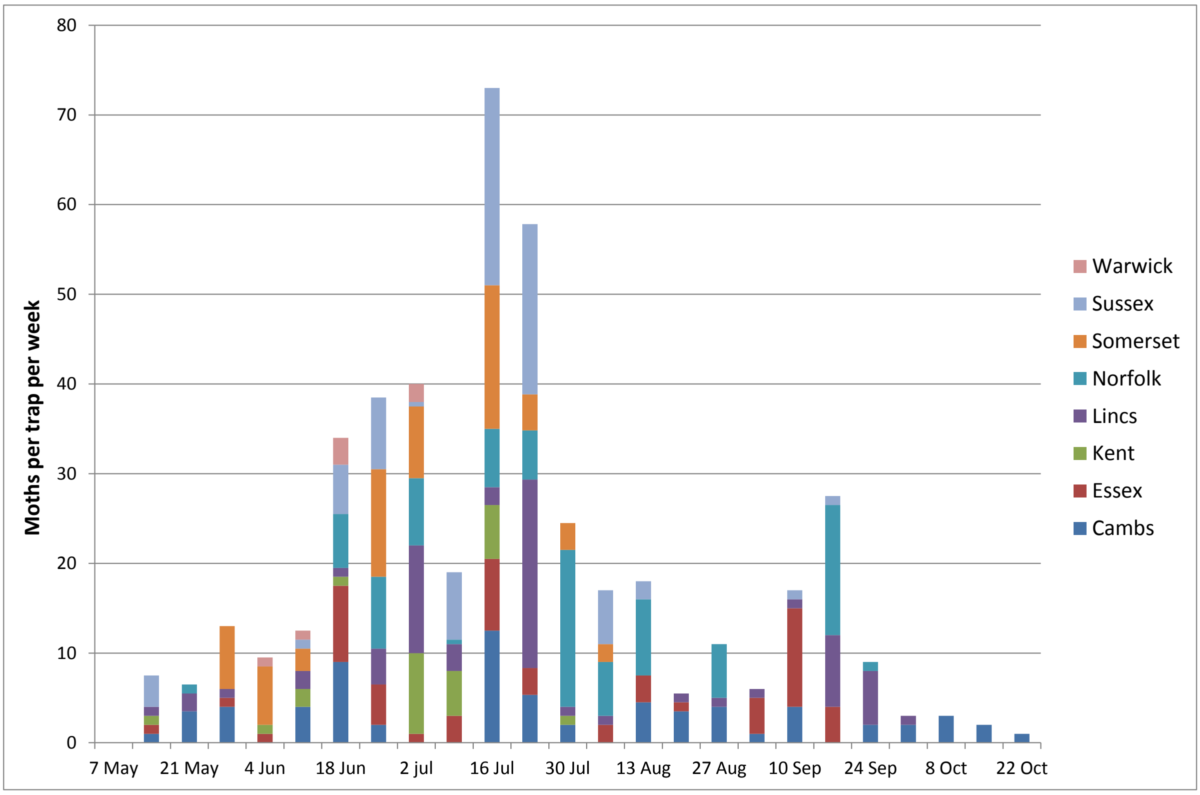

Figure 3.4. Captures of silver Y moths by Trapview traps in 2015 (moths per trap per week in each region.

A relatively large number of traps were deployed in crops of lettuce grown by G's. This was to obtain more detailed information on silver Y moth activity both from using traps and by monitoring crops. Some of the data collected is summarised below.

Figure 3.5 shows the numbers of moths captured per trap per week in the 'ordinary' funnel pheromone traps in 13 locations at G's in 2015. The main period of activity was between mid-June and mid-July and a maximum of 36 moths was captured in one week. There was considerable variation between locations in the pattern of moth activity as represented by trap captures.

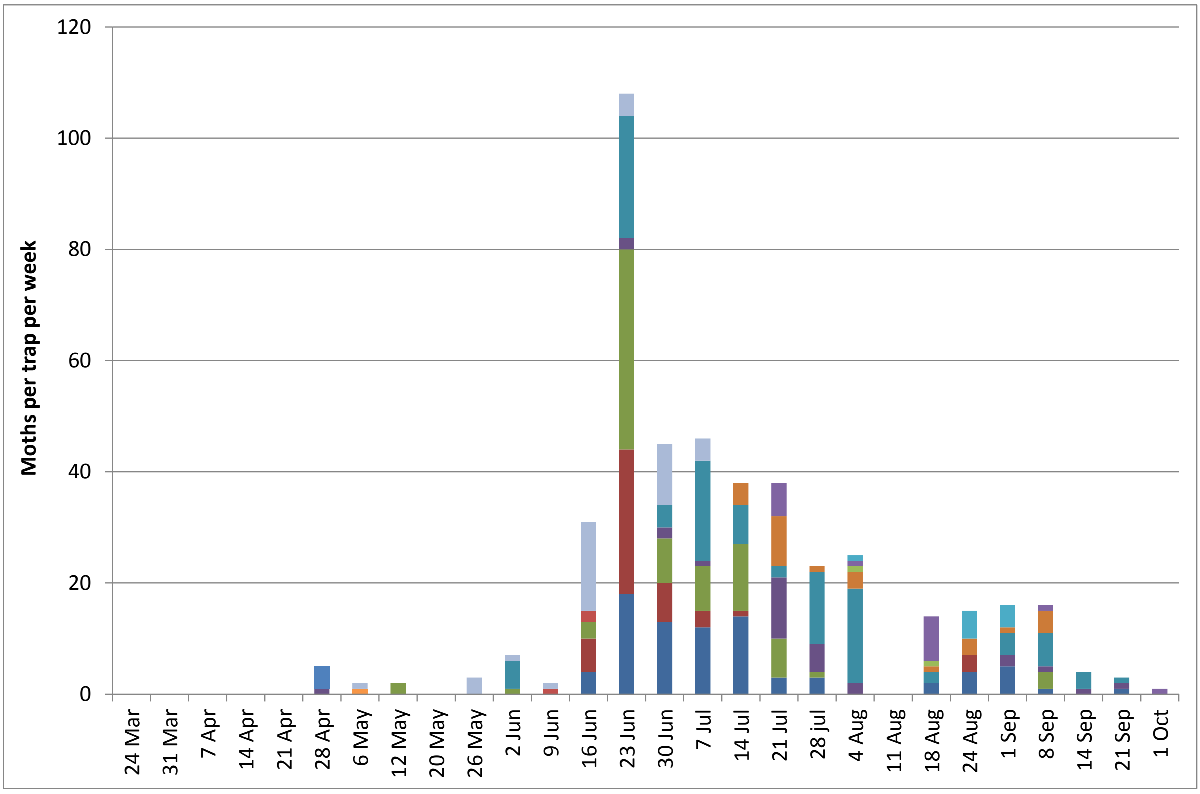

Figure 3.5. Captures of silver Y moths by 13 funnel traps in G's crops in 2015.

Figures 3.6 and 3.7 compare the captures of silver Y moths at G's by Trapview traps with captures by funnel pheromone traps. The data are compared for the crops within a county – so either the traps in crops in Cambridgeshire or those in Norfolk. There were 3 Trapview traps and 4 ordinary traps in each county. Overall the patterns of activity were similar, but not identical. The data require more detailed analysis of the variation within a location (once captures for 2016 are complete) but the differences in the pattern of captures may be simply a reflection of background variation between traps – as the capture of moths by the traps is essentially a random process.

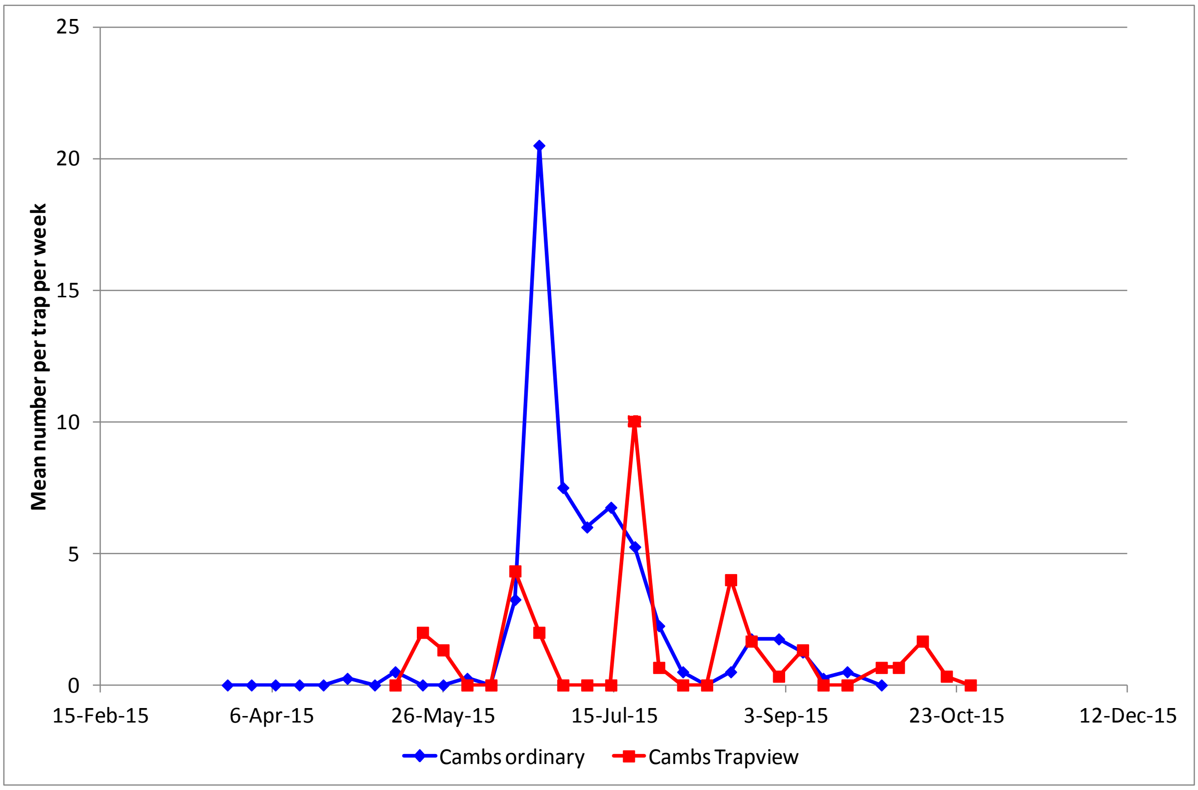

Figure 3.6. Captures of silver Y moths by Trapview traps and funnel traps in G's crops in Cambridgeshire 2015.

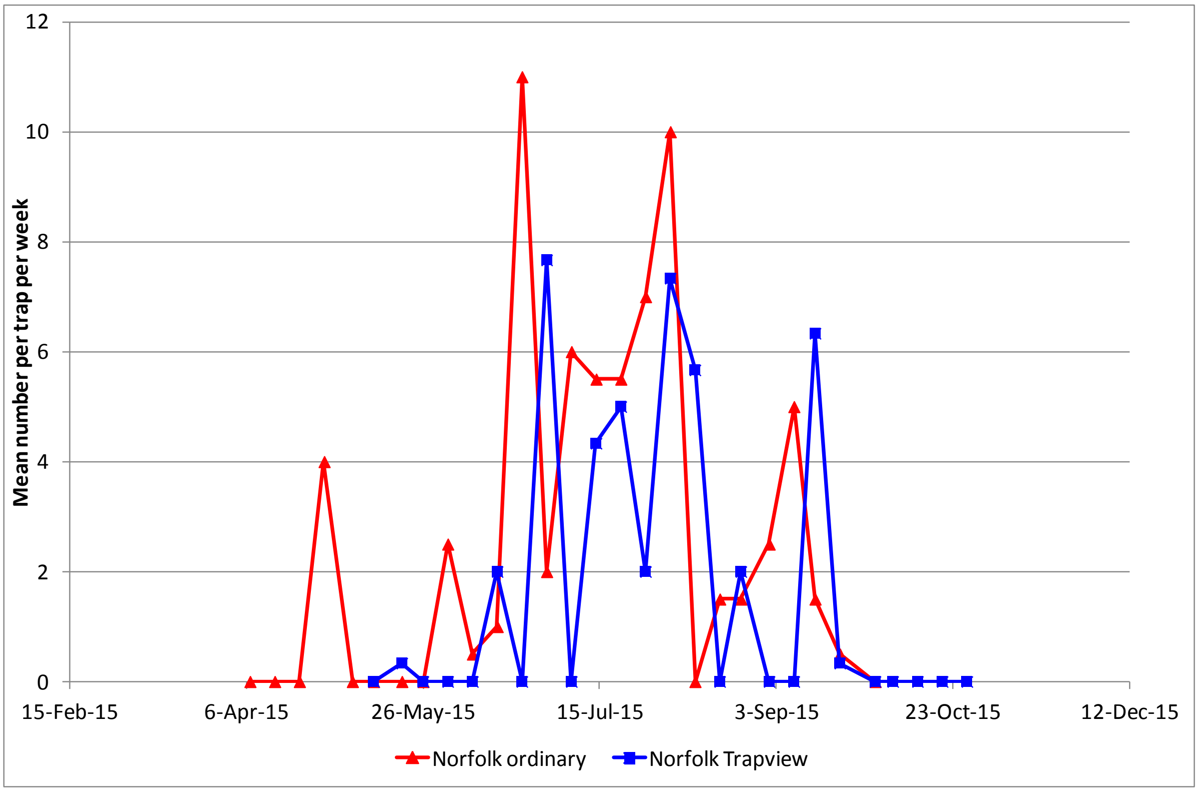

Figure 3.7. Captures of silver Y moths by Trapview traps and funnel traps in G's crops in Norfolk 2015.

Figure 3.8 shows the captures of silver Y moths by the Trapview and funnel traps in Essex. Again the pattern of captures was similar between the two trap types, but not identical.

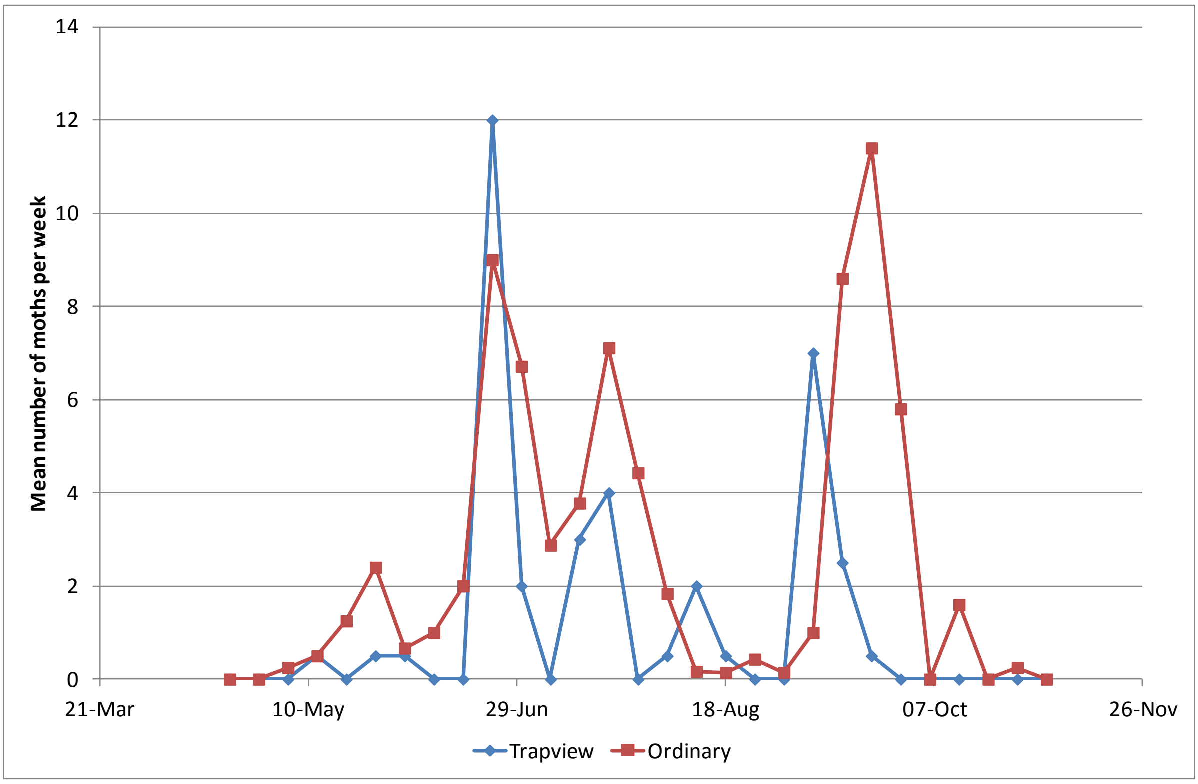

Figure 3.8. Captures of silver Y moths by Trapview traps and funnel traps in Essex in 2015.

Figures 3.9 and 3.10 show the captures of silver Y moths by Trapview and funnel traps in Lincolnshire at two locations. Again the pattern of captures was similar between the two trap types but not identical. Captures by the Trapview traps were considerably lower than by the funnel traps.

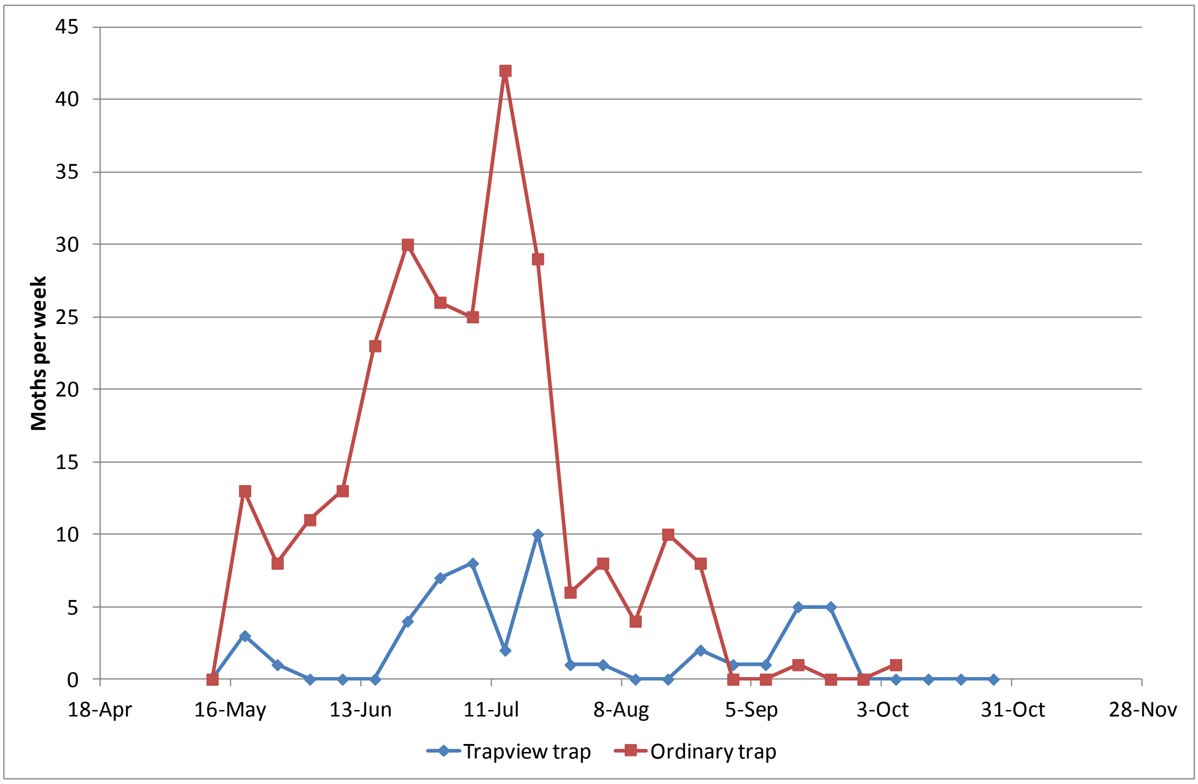

Figure 3.9. Captures of silver Y moths by Trapview traps and funnel traps in Lincolnshire in 2015.

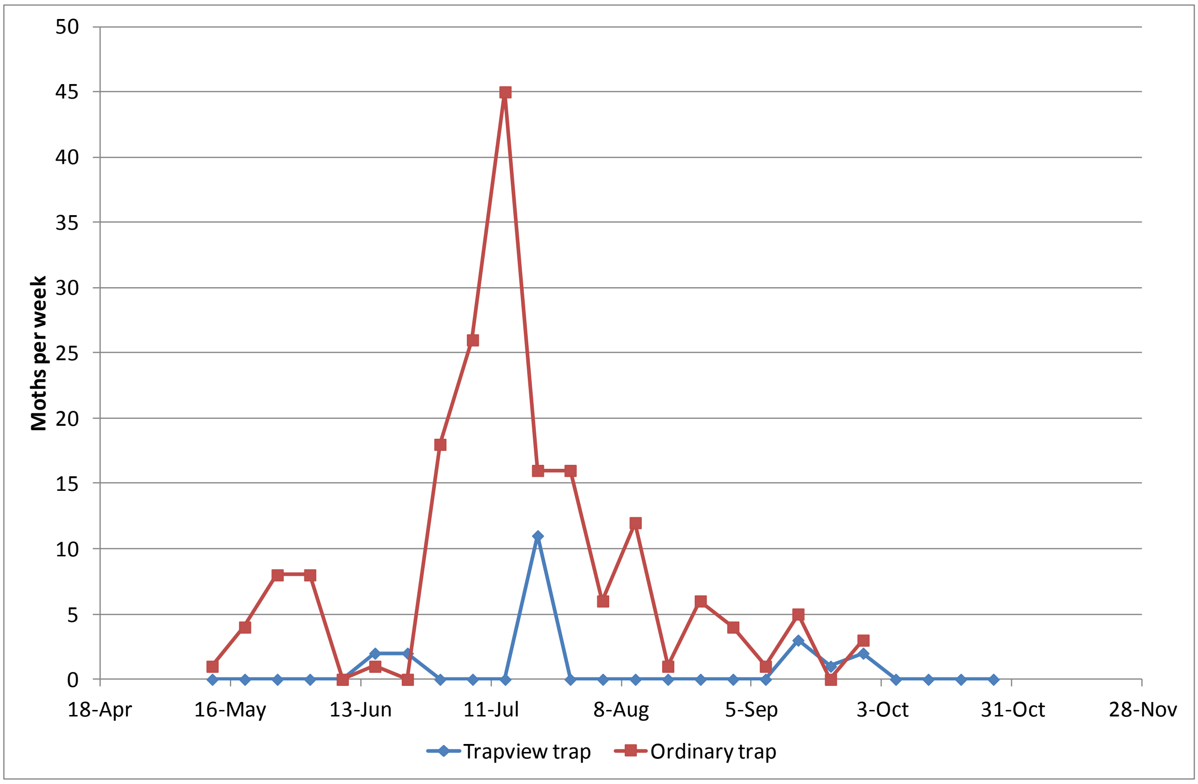

Figure 3.10. Captures of silver Y moths by Trapview traps and funnel traps in Lincolnshire in 2015.

No Trapview traps were used to monitor silver Y moth in Scotland. However, funnel pheromone traps were run at 4 locations and the captures are summarised in Figure 3.11. Overall, captures were low and nothing was captured in one of the traps. However, moths were present from mid-June until late August.

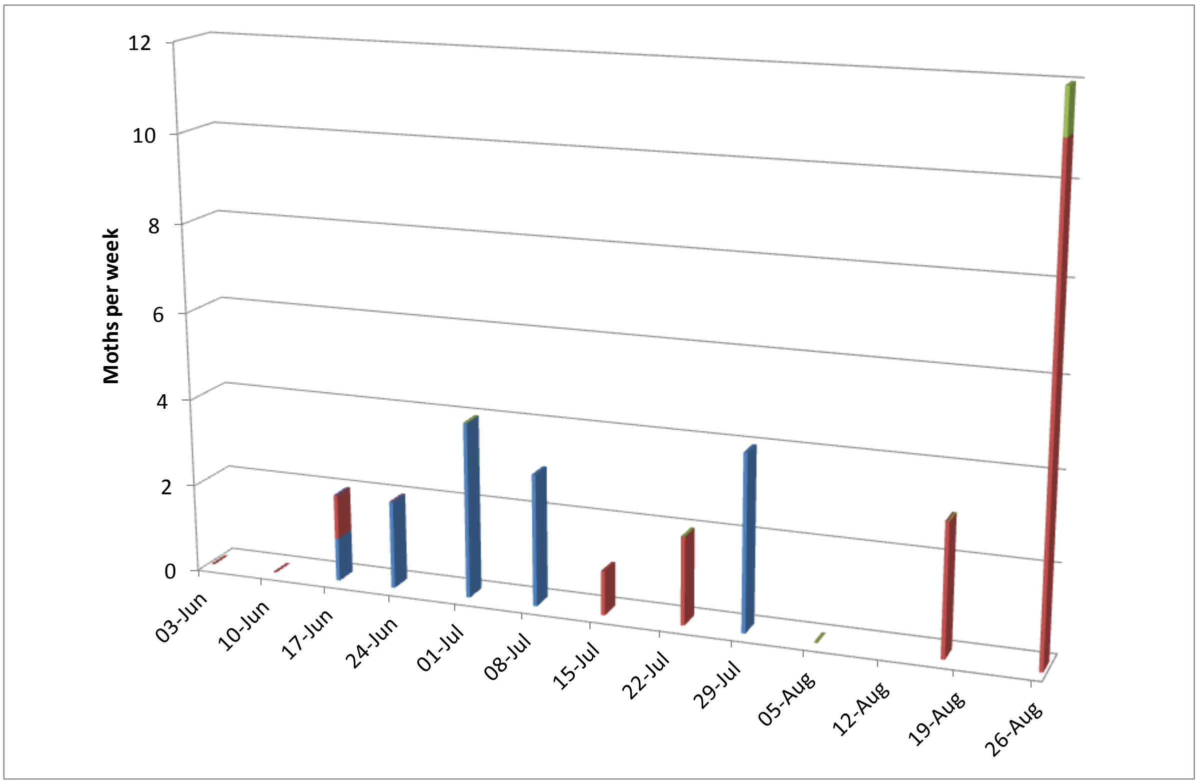

Figure 3.11. Captures of silver Y moths by funnel traps in Scotland in 2015.

Performance of the Trapview traps used to capture silver Y moth

Colin Carter helped the trap hosts to set up their traps and provided ongoing support for the trap network. He monitored the traps using the Trapview website and contacted the hosts when there were problems. He also recorded lure changes. The traps are still in the development phase and there were a few problems with them which the company hopes to improve on in 2016. The surface of the sticky inserts was not sufficiently sticky to hold some of the silver Y moths firmly and there was evidence that they had moved around and sometimes escaped from the trap. It seemed that once a few moths had been captured then the performance of the traps declined – possibly because the available area for capturing moths had decreased. The camera is relatively heavy and in some cases the trap became distorted, which affected the view of the sticky surface. On some days the signal was insufficient for the image to be sent to the Trapview web site.

Relationship between captures by pheromone traps and infestation of crops by caterpillars

Captures of silver Y moths in 2015 were relatively low and so infestations in lettuce crops were not severe. However, where available, crop walking data were compared with trap captures to determine how much 'warning' they might provide and whether there were indications that a threshold might be developed. In Lincolnshire, caterpillars and damage were observed in July, with the first caterpillar seen in week 27 (first week of July) which coincided with the period of greatest moth activity (Figures 3.9 and 3.10).

Crop walking data collected at G's are summarised and compared with trap captures by ordinary pheromone traps in Figures 3.12 and 3.13 for the crops in Cambridgeshire and Norfolk respectively. Peak numbers of caterpillars were observed in mid-July which seemed to tie in most closely with the influx of moths around 23 June.

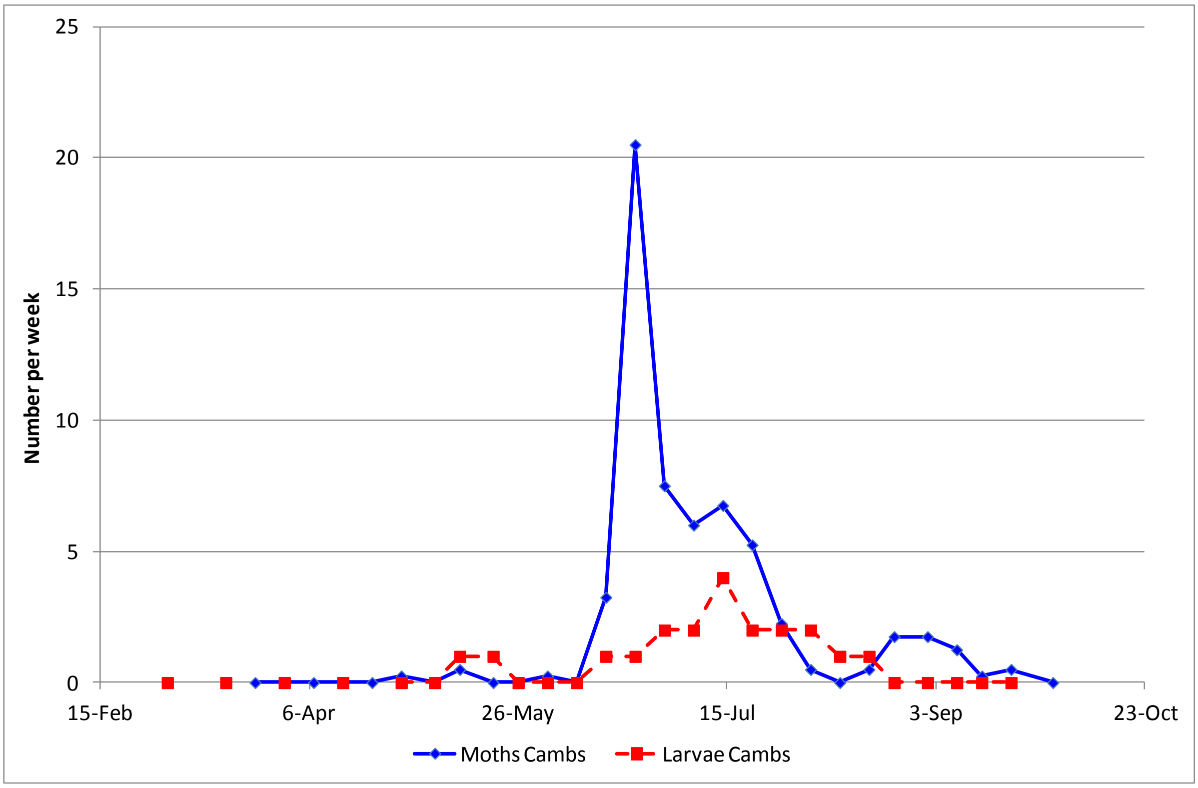

Figure 3.12. Captures of silver Y moths compared with crop walking records on the presence of caterpillars in G's crops in Cambridgeshire in 2015.

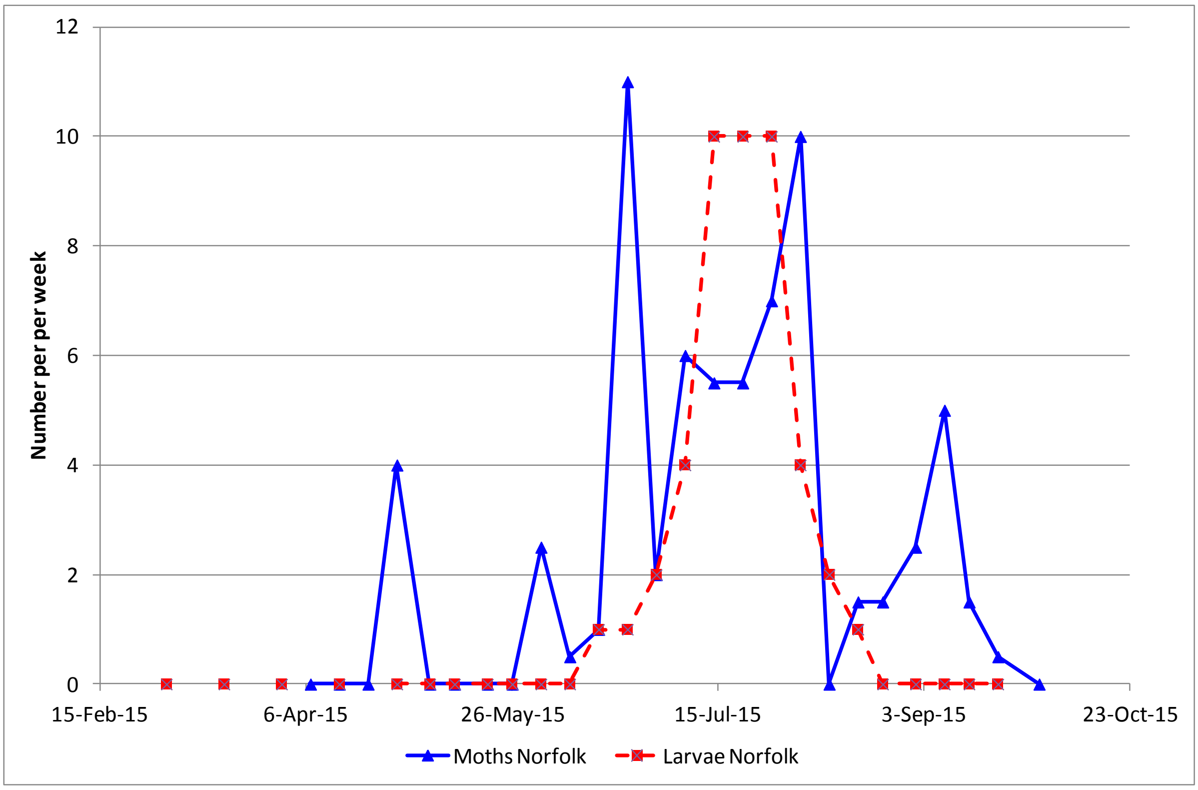

Figure 3.13. Captures of silver Y moths compared with crop walking records on the presence of caterpillars in G's crops in Norfolk in 2015.

Relationship between the timing of moth captures and the detection of caterpillars in crops

In order to try and understand the relationship between the timing of moth captures and the detection of caterpillars in crops, data on development of the different stages of silver Y moth at different temperatures (Hill and Gatehouse, 1992; Saito, 2007) were summarised. Table 3.2 shows the durations of the different stages at a range of temperatures.

Table 3.2. Durations of the egg, larval and pupal stages of development of the silver Y moth at a range of temperatures. Data from Saito (2007)[1] and Hill & Gatehouse (1992)[2].

	Development time in days		
Temperature °C	**Egg[1]**	**Larva[2]**	**Pupa[2]**
13	11	51	31
16		34	19
18	6		
19		23	13
22		21	10
23	4		
25		16	8
28	3		

Figure 3.14 shows the relationship between the rate of development (100/time) and temperature for each stage. From the lines fitted in Figure 3.14 it is possible to estimate the low temperature threshold for each stage and from this to estimate the day-degree requirement for each stage. The estimated threshold temperatures for the egg, larval and pupal stages are 7.6, 9.2 and 7.7°C respectively. Using the estimates of development time at 13 and 18°C, egg development required approximately 60 day-degrees above 7.7°C.

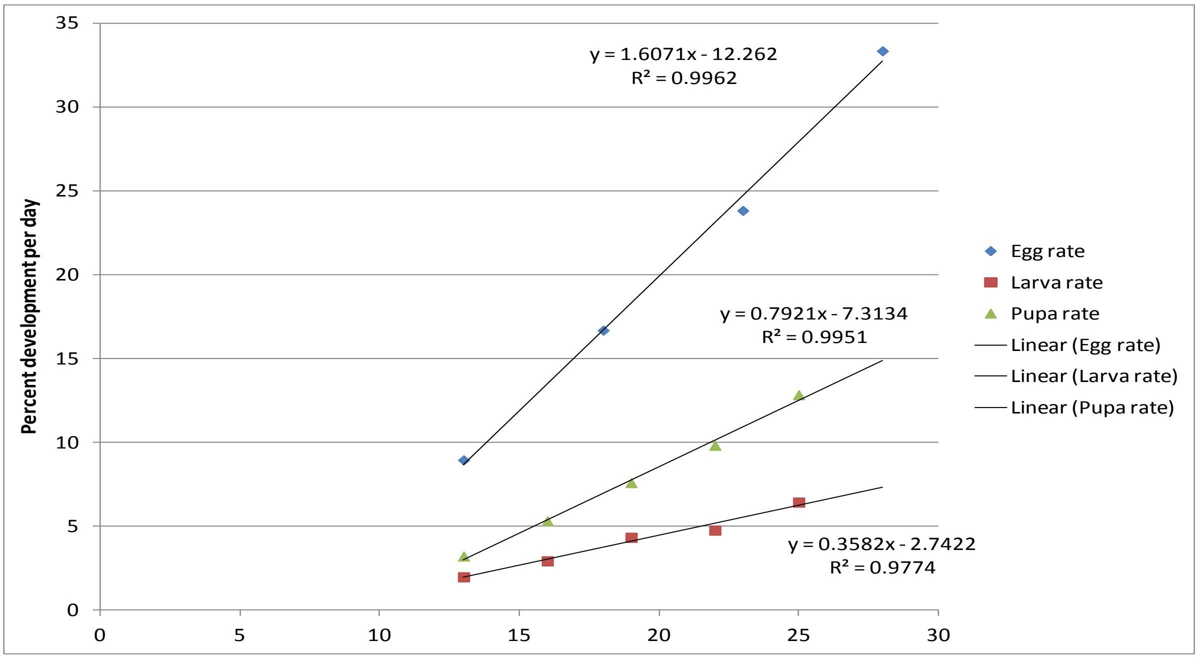

Figure 3.15. Relationship between the rate of development (100/time) and temperature for each stage of development of the silver Y moth. Data from Hill & Gatehouse (1992) with the exception of the egg stage which is from Saito (2007).

As an example, four sets of weather data collected for the AHDB Pest Bulletin in 2015 were used to estimate the daily day-degrees above 7.7°C between mid-June and mid-August (Table 3.3). Overall, the largest numbers of moths were captured from 13 June until towards the end of July. Using the day-degree sum for egg hatch of approximately 60 day-degrees above 7.7°C indicated that, for example, eggs laid on 14 June would hatch approximately 9 days later in Kent.

Table 3.3 Daily day-degrees between 13 June and 15 August in 4 locations. Weather data from AHDB Pest Bulletin project. The day-degree sum for silver Y moth eggs to hatch is approximately 60 day-degrees above 7.7°C. So, for example, eggs laid on 14 June would hatch approximately 9 days later in Kent (6 + 5 + 5 + 10 + 9 + 7 + 8 + 8 + 6) = 60 day-degrees.

	Kent	Suffolk	Norfolk	South Lincolnshire
13/06/2015	8	7	5	4
14/06/2015	6	6	4	4
15/06/2015	5	4	3	4
16/06/2015	5	5	6	8
17/06/2015	10	10	8	9
18/06/2015	9	7	5	6
19/06/2015	7	6	5	5
20/06/2015	8	7	6	7
21/06/2015	8	9	7	7
22/06/2015	6	6	3	4
23/06/2015	6	5	3	4
24/06/2015	8	8	7	8
25/06/2015	9	9	9	10
26/06/2015	10	10	9	10
27/06/2015	10	11	9	10
28/06/2015	9	9	8	9
29/06/2015	10	9	10	10
30/06/2015	10	10	11	13
01/07/2015	15	15	15	16
02/07/2015	12	14	14	13

	Kent	Suffolk	Norfolk	South Lincolnshire
03/07/2015	10	10	8	9
04/07/2015	14	15	14	12
05/07/2015	8	9	9	9
06/07/2015	9	9	9	8
07/07/2015	9	11	9	9
08/07/2015	8	8	5	7
09/07/2015	7	6	5	7
10/07/2015	8	10	9	10
11/07/2015	12	13	11	11
12/07/2015	9	10	9	10
13/07/2015	10	10	9	9
14/07/2015	11	11	9	10
15/07/2015	11	11	8	9
16/07/2015	10	8	7	7
17/07/2015	12	12	10	11
18/07/2015	9	10	8	9
19/07/2015	9	11	8	8
20/07/2015	10	10	9	9
21/07/2015	11	12	11	10
22/07/2015	10	11	8	8
23/07/2015	8	8	6	7
24/07/2015	7	7	6	6
25/07/2015	7	6	5	6
26/07/2015	6	6	4	4
27/07/2015	9	9	7	7

	Kent	Suffolk	Norfolk	South Lincolnshire
28/07/2015	8	8	6	7
29/07/2015	6	6	4	5
30/07/2015	6	5	4	4
31/07/2015	6	6	5	6
01/08/2015	7	8	8	7
02/08/2015	8	8	9	10
03/08/2015	12	13	11	12
04/08/2015	10	10	9	9
05/08/2015	9	9	8	9
06/08/2015	9	10	9	10
07/08/2015	9	9	8	7
08/08/2015	9	9	8	11
09/08/2015	10	11	10	10
10/08/2015	11	11	10	12
11/08/2015	10	9	8	8
12/08/2015	10	9	8	8
13/08/2015	11	11	8	8
14/08/2015	12	12	11	7
15/08/2015	10	9	7	7

Diamond-back moth

Very low numbers of diamond-back moths were captured in the Trapview traps (Figure 3.16). Data from ordinary (Delta) pheromone traps is so far only available from the sites at Warwick and in Fife. Captures were very low in both locations and too low to undertake any meaningful analysis of the data.

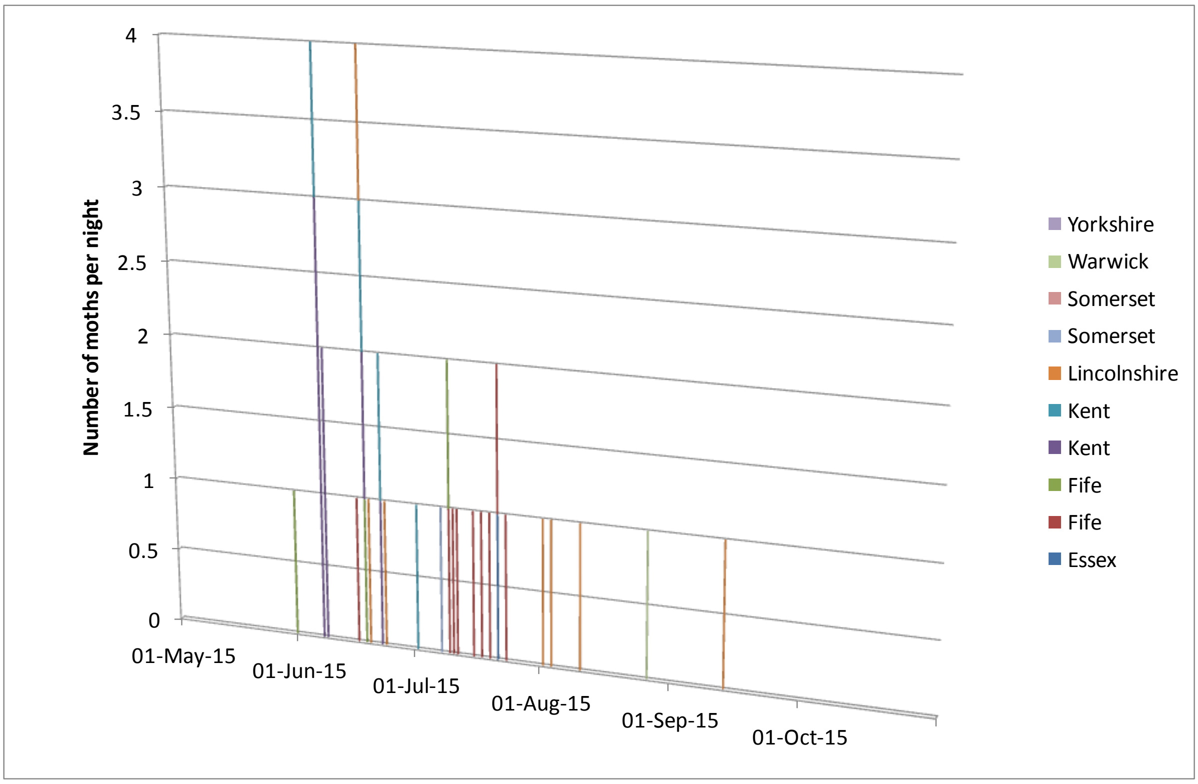

Figure 3.16. The numbers of diamond-back moths captured in 10 Trapview traps in 2015.

As for the silver Y moth, data on development times of diamond back moth (Liu et al., 2001) were plotted and are shown in Figure 3.17.

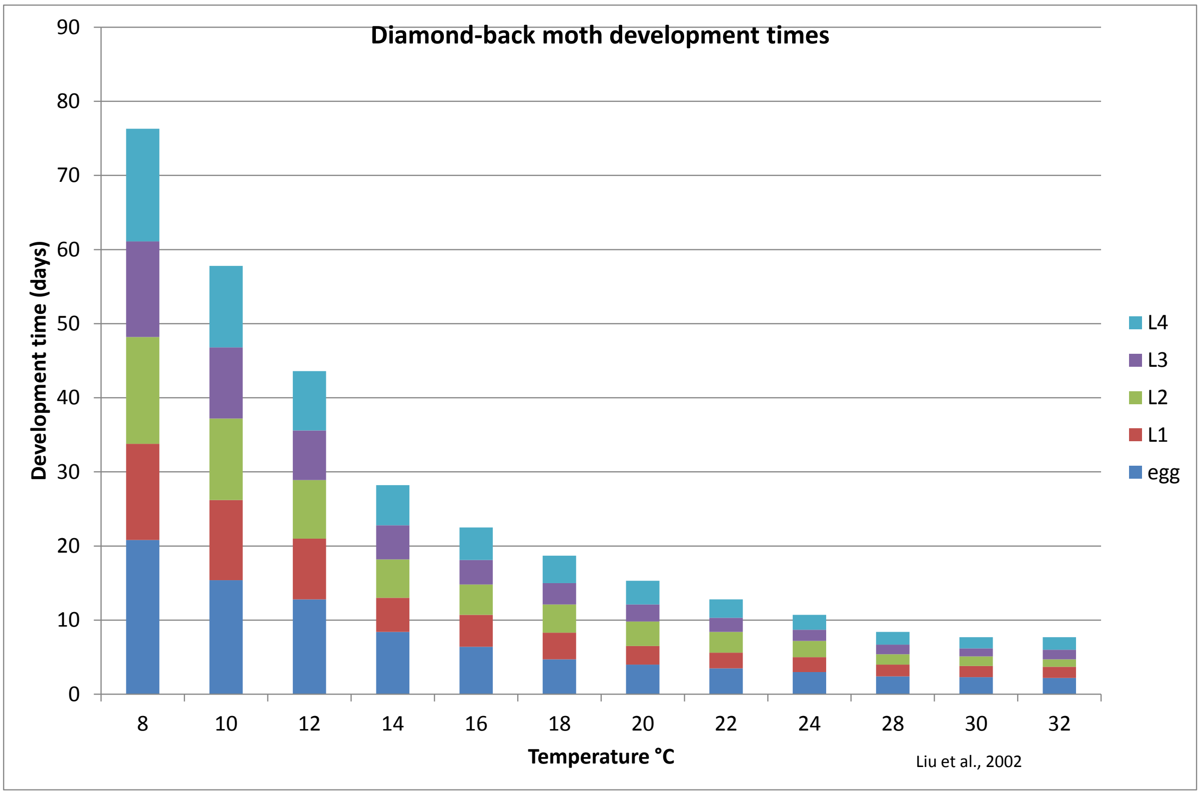

Figure 3.17. Development times for diamond-back moth eggs and larvae (Liu et al., 2001).

At a temperature of 16°C, egg development took 6.4 days and a complete generation took approximately 33 days.

Turnip moth

Two Trapview traps were run at G's and it was possible to compare the catches from these traps with the data from 13 funnel traps (Figure 3.17). Not all of the funnel traps were run over the full period, but even so they give a clear indication of the pattern of activity - with two distinct adult generations. The data from the two Trapview traps are at the front of the graph in blue and red and captured relatively low numbers of moths compared with some of the funnel traps.

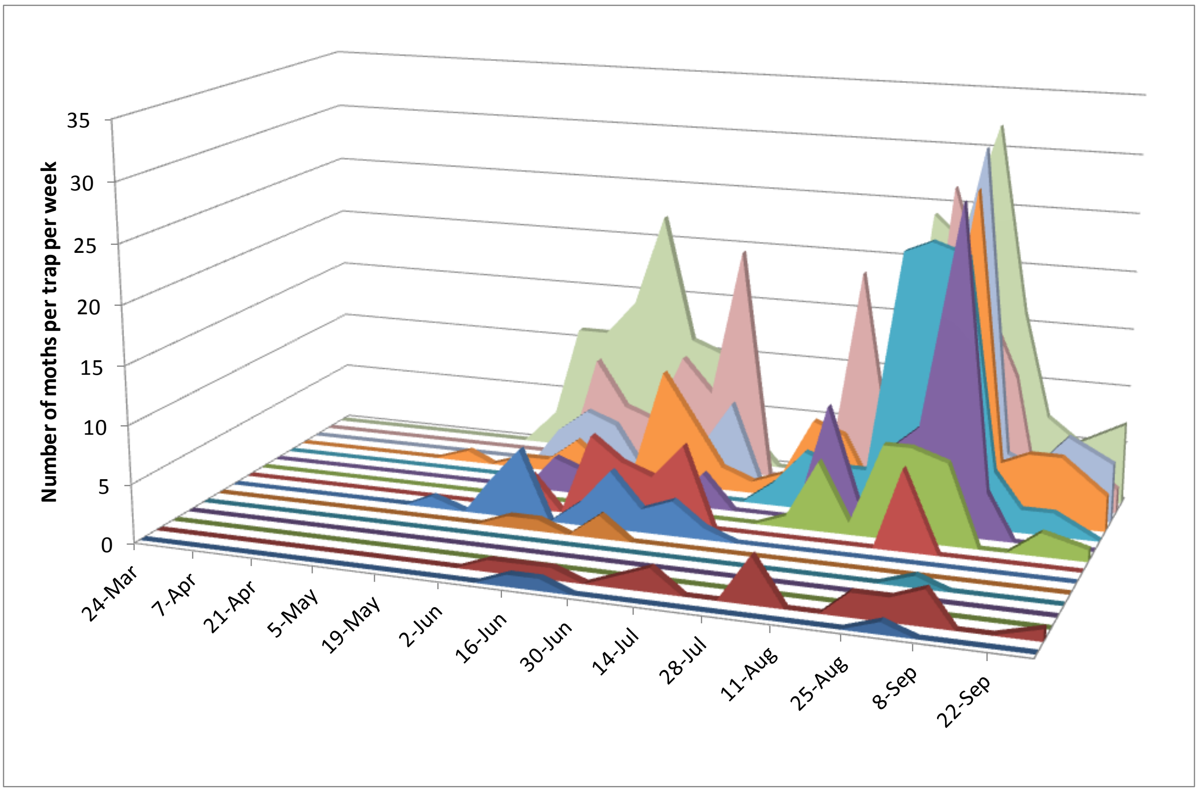

Figure 3.17. The numbers of turnip moths captured in 2 Trapview traps and 13 ordinary traps in 2015 in Cambridgeshire and Norfolk. The data from the two Trapview traps are at the front of the graph in blue and red.

Historical data

Some of the grower participants, particularly G's, have historical records on silver Y moth and this information has been collated and forwarded to Warwick Crop Centre for further summary and analysis.

Other approaches to monitoring and control (Objectives 5 and 6).

Other information on movement of adult silver Y moths is available from Rothamsted Research. This consists firstly of the captures made by the network of light traps run by the Rothamsted Insect Survey. Figure 4.1 summarises captures by these traps over the last 50 years and shows that there is considerable variation in overall abundance from year to year.

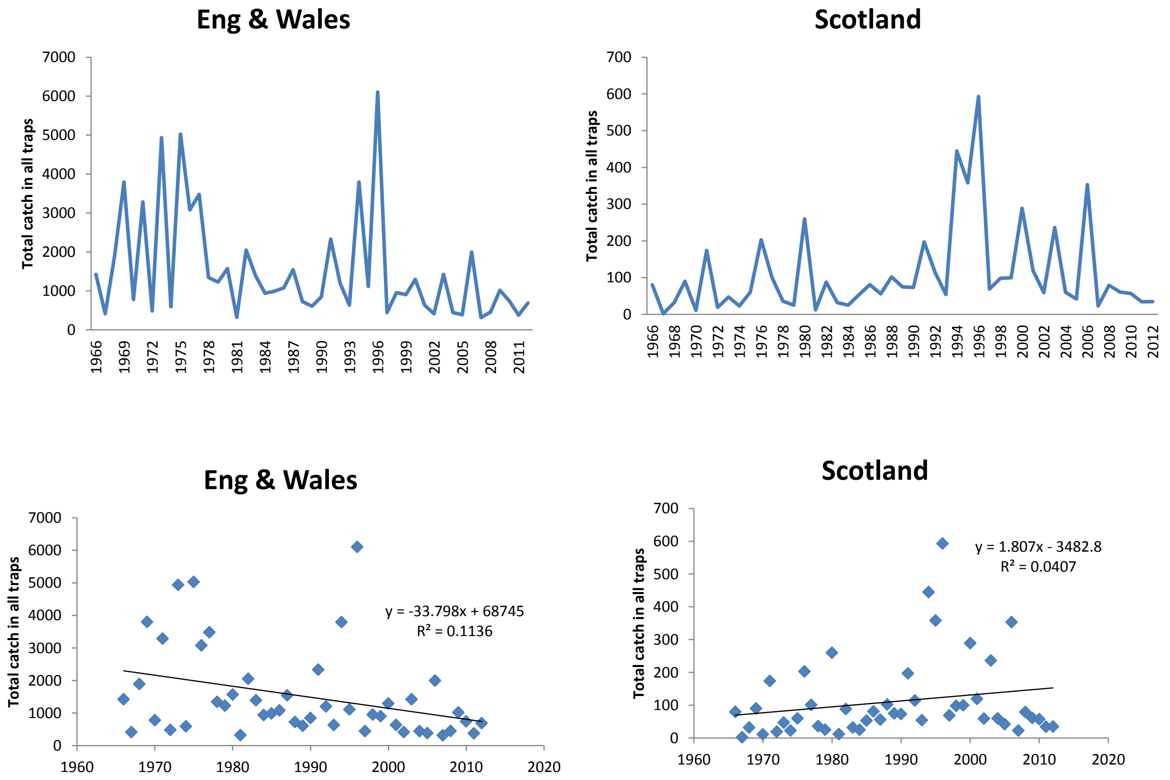

Figure 4.1. Summary of the captures of silver Y moth made by the network of light traps run by the Rothamsted Insect Survey.

Rothamsted Research also have considerable expertise in relation to the impact of weather conditions, particularly wind on the trajectories of migrating moths and they will be using this expertise to interpret some of the trapping data collected in 2015. Questions to explore include a period of possible non-sexual activity of migrants which could explain the delay sometimes seen between catches and first caterpillar damage and the relationship between pheromone catches and light trap catches. It is possible that pheromone traps only catch sexually active male moths while light traps capture them all.

Discussion

The trials to evaluate insecticides and bioinsecticides indicated some new insecticides with efficacy against silver Y moth. Unfortunately none of the bioinsecticides tested were effective, although Azadirachtin (SI2013-130) and another coded bioinsecticide showed efficacy in a laboratory trial in the SCEPTRE project (Table 1.2). Unfortunately no useful data were obtained from the field trial on diamond-back moth and discussion at the consortium meeting indicated that laboratory and greenhouse trials might be the best way forward, and a laboratory trial is now underway (replicated in time).

Unfortunately for the project, migrant moths were not abundant in 2015 and the diamond-back moth was particularly scarce. As a result it was not possible to infer much about diamond-back moth from the trapping data. However, captures of silver Y moth and the resident species, turnip moth, were sufficient to provide useful information about the utility of the monitoring system and also about the pattern of activity at a range of locations. These data require further analysis and can also be compared with the historical data sets provided by G's in particular. It may also be possible to obtain further information from the Rothamsted Insect Survey in relation to their network of light traps.

The emphasis in 2016 needs to be on collecting further data on activity of all three species and particularly to obtain as much data on caterpillar infestations in nearby commercial crops as possible to develop the 'relationship' between pheromone captures of male moths and caterpillars in the crop.

Summary of plans for Year 2

- Information that can be obtained from historical data – growers and Rothamsted Research
- Interpretation of silver Y moth trapping data from 2015 – Rothamsted Research
- Trapping and crop walking data collection with an emphasis on obtaining as much crop walking data as possible - all
- Further efficacy trials – Warwick, STC, ADAS
- Objective 5 Develop a risk-based spray-decision-making system linked to trapping of moths and measure its efficacy, via field trials, against normal pest control practice.
- Objective 6 Investigate other monitoring and control mechanisms which may be effective and make recommendations for how they might be developed through future research.
- Objective 7 Engage and communicate with growers and other members of the industry

Conclusions

- A novel 'remote' monitoring system which uses a small camera located inside a pheromone trap to record moth captures daily shows promise as a method for monitoring the arrival of migrant lepidopterous pests of salad and vegetable crops.
- Trials have indicated several insecticides with efficacy against silver Y moth, some of which are novel products.

Knowledge and Technology Transfer

A workshop for the consortium was held at PGRO on 11th February 2016.

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References

Bowden *et al.* (1983). A survey of cutworm attacks in England and Wales, and a descriptive population model for *Agrotis segetum* (Lepidoptera: Noctuidae). Annals of Applied Biology 102 29-47.

Chapman *et al.* (2012). Seasonal migration to high latitudes results in major reproductive benefits in an insect. PNAS 109, 14924–14929.

Hill, J.K. & Gatehouse, A.G. (1992). Effects of temperature and photoperiod on development and pre-reproductive period of the silver Y moth *Autographa gamma* (Lepidoptera: Noctuidae). Bulletin of Entomological Research 82, 335-341.

Liu S.S., Chen, F-Z & Zalucki, M.P. (2002). Development and Survival of the Diamondback Moth (Lepidoptera: Plutellidae) at constant and alternating temperatures. Environmental Entomology 31(2): 221-231.

Saito, O. (2007). Diapause-like prolongation of larval duration under short-day photoperiod and low temperature conditions in the silver Y moth, *Autographa gamma* Linnaeus (Lepidopter: Noctuidae). Applied Entomology and Zoology 42 (3). 391-395.

