Project title:	Brassicas: Improving control of whitefly
Project number:	FV 406a
Project leader:	Rosemary Collier and Simon Springate
Report:	Final
Previous report:	February 2015
Key staff:	Andrew Jukes Marian Elliott Simon Springate Andrew Mead
Location of project:	Warwick Crop Centre University of Greenwich Elsoms Seeds
Industry Representative:	Andy Blair
Date project commenced:	1 March 2014
Date project completed (or expected completion date):	28 February 2016

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.

Signature .... Date ....

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GROWER SUMMARY

Headline

Movento was the most effective and persistent insecticide treatment for whitefly control and was particularly effective when applied in July and August, coinciding with soon after the start of the second and third generations of whitefly. Foliar sprays of HDCI 073, HDCI 075, HDCI 085 and HDCI 086 also provided control, but were not as persistent, as did Sanokote seed treatment or crop covers applied in the early stages of growth.

Background

Whitefly (*Aleyrodes proletella*) is becoming increasingly difficult to control on kale and Brussels sprout in particular. The overall aim of the current project is to improve understanding of the biology and ecology of cabbage whitefly to help growers minimise the development of whitefly infestations and control unacceptable infestations effectively. It focuses particularly on the assessment of novel methods of control and on the timing of the most promising of these together with existing treatments. The specific objectives of the project are described in the Summary. Objectives 1, 3 and 4 were undertaken at Warwick Crop Centre and Objective 2 was undertaken by staff of the Natural Resources Institute (University of Greenwich), Syngenta Bioline, Allium & Brassica Agronomy Ltd., Elsoms Seeds and Warwick Crop Centre in Year 2.

Summary

Objective 1: Investigate additional treatments for whitefly control.

The aim of this objective was to evaluate new products to determine whether they would be effective as part of a programme to control whitefly. Trials were undertaken in 2014 and 2015 (details in Table A). There were two pre-planting treatments – Sanokote (imidacloprid) seed treatment in 2014 and a module drench of HDCI 085 in 2015. As a biopesticide, HDCI 074 was applied more frequently than the other treatments.

Table A Trial details in 2014 and 2015

	Planting date	Treatment date	Assessment dates
2014	13 May	All - 20 Aug, 12 Sep HDCI 074 - 27 Aug, 3 Sep	7 Aug (Sanokote only), 19 Aug (Sanokote only), 22 Oct
2015	28 May	16 Jul, 12 Aug	16 Jul (HDCI 085 drench only) 7 Aug, 9 Sep, 2 Oct

Lower numbers of egg circles, leaves infested with larvae and adults were found on the plants treated with Sanokote throughout the trial in 2014, but these differences were statistically significant on the first assessment date (7 August) only. When all treatments were compared on 22 October 2014 (29 days after the last spray application), the numbers of egg circles, larvae and adults were reduced by Movento, HDCI 075 and HDCI 073, whilst the biopesticide HDCI 074 reduced the numbers of larvae. In 2015, the HDCI 085 drench treatment had little or no effect on any whitefly life stage. On 7 August 2015, 22 days after first spray application, all of the spray treatments had reduced the numbers of all whitefly life stages compared with the untreated control. Movento reduced egg numbers and numbers of leaves with larvae compared with all other treatments. HDCI 085 was the next best treatment reducing egg numbers and numbers of leaves with larvae compared with all other treatments except Movento. Additionally, when considering eggs and larvae, HDCI 075 was more effective than all other treatments except Movento and HDCI 085. Differences in adult numbers were smaller but Movento reduced numbers compared with the drench treatment, HDCI 073 and HDCI 086. On 9 September 2015, 28 days after second spray application, levels of control appeared to have diminished. Only Movento reduced numbers of all whitefly life stages compared with the untreated control. HDCI 085 and HDCI 075 both reduced the numbers of leaves with larvae but not the numbers of eggs or adults. On 2 October 2015, 51 days after second spray application, only Movento reduced the numbers of all whitefly life stages compared with the untreated control. No other treatments reduced numbers of eggs or leaves with larvae but HDCI 085, HDCI 075 and HDCI073 had all reduced numbers of adults. Data for the mean number of leaves with whitefly larvae on the main assessment dates in 2015 are shown Figure A.

Objective 2: To investigate the efficacy of parasitoid release and crop covers, alone and in combination, in suppressing whitefly infestations.

The aim in 2014 was to field test the impact of parasitoid releases on whitefly infestations on kale and to explore the effect of covering the crop during the early stages of growth. A production system for the parasitoid wasp *Encarsia tricolor* was established at Syngenta Bioline to provide insects for field release in a trial in Lincolnshire. Unfortunately the parasitoid production collapsed and so part of the trial was re-focused. However, the netting covers significantly disrupted whitefly infestation. This part of the project was continued in 2015 by dividing the rearing process between University of Greenwich and the University of Warwick. Simon Springate produced vials of adult parasitoids at approximately weekly intervals and these were introduced onto kale plants infested with cabbage whitefly which were maintained in a polytunnel at Warwick Crop Centre. Production at Warwick Crop Centre was inconsistent and compounded by regular infestations of *Myzus persicae* which interfered with both whitefly production and parasitoid rearing. However, despite these problems, each plot was inoculated with an average of 244 parasitoid pupae overall. When the parasitoid pupae had developed in the whitefly larvae (seen as blackened pupae), the pupae were counted and the plants were removed to 10 'isolated' field plots, infested naturally with whitefly, which were separated into 5 pairs based on their location. One plot from each pair was inoculated with plants supporting the parasitoids and one plot was untreated. Unfortunately there were no treatment differences on any assessment date. Paired plots were very similar, the largest differences occurring between different locations. Small numbers of parasitized whitefly larvae were observed, predominantly on the last assessment date in one location.

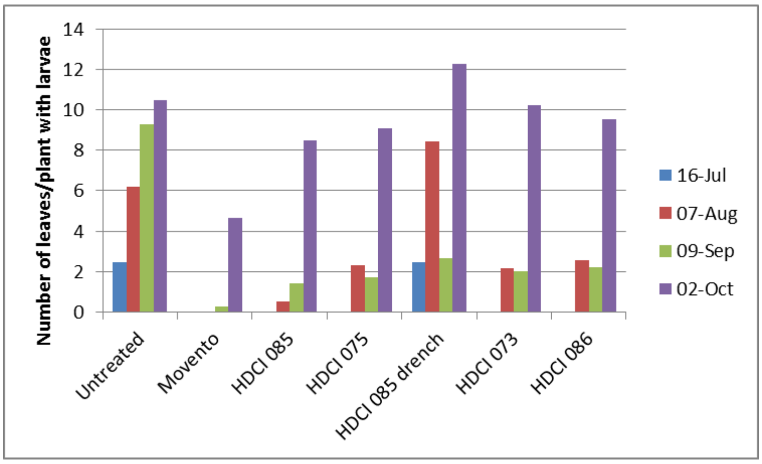

Figure A Mean number of leaves with whitefly larvae per plant on four occasions in 2015.

Objective 3: Investigate the most effective way to use Movento and other effective insecticides in terms of the interval between treatments.

The aim of Trial 3.1 in 2014 was to investigate the persistence of Movento, Sanokote (imidacloprid) and HDCI 075. The plants (kale) were transplanted on 21 May and sprayed on 20 August. Assessments were made on 7 and 19 August (Sanokote and untreated control only) and on 17 September and 23 October. There were always more whitefly in the untreated control plots than in those treated with Sanokote, but the differences were statistically significant on 19 August only. On 17 September (28 days after spraying), both spray treatments had reduced the numbers of whitefly egg circles, larvae and adults compared with the untreated control. By 23 October (64 days after spraying) there were no differences between treatments in the numbers of adults, but larval numbers were reduced by all treatments and Movento appeared to be having a continued effect on egg numbers.

In 2015 a field trial (Trial 3.2) using kale was transplanted on 28 May. Some of the treatments were grown from seed treated with Sanokote (imidacloprid – for continuity with 2014) (Figure B). Spray treatments with Movento were applied after the start of either the second, third or fourth whitefly generations as indicated by monitoring by Spencer Collins on other plots as part of his PhD project (CP 091). For two treatments, crop covers (0.8mm mesh) were used from transplanting to exclude whitefly adults and were removed at the start of either the second (16 July) or third (12 August) generations. On 8 July (pre-spray) the infestation was relatively low but the Sanokote seed treatment reduced numbers of eggs and adults compared with the untreated control. On 6 August (after Generation 2 spray) all of the sprayed treatments and the covered treatments reduced all whitefly life stages compared with the untreated control. On 11 September (after Generation 3 spray) all treatments except 'Movento 3 + 4' (which had only the Generation 3 spray) reduced the numbers of leaves with larvae. Additionally, both Sanokote treatments and the Movento treatment sprayed at Generations 2 and 3 reduced egg numbers and both Sanokote treatments reduced adults. On 12 October (after Generation 4 spray) both Sanokote treatments and the Movento treatment sprayed at Generations 2 and 4 reduced the numbers of all life stages of the whitefly compared with the untreated control. Movento applied at Generations 2 and 3 reduced eggs and adults. The two covering treatments both reduced the numbers of adults compared with untreated control.

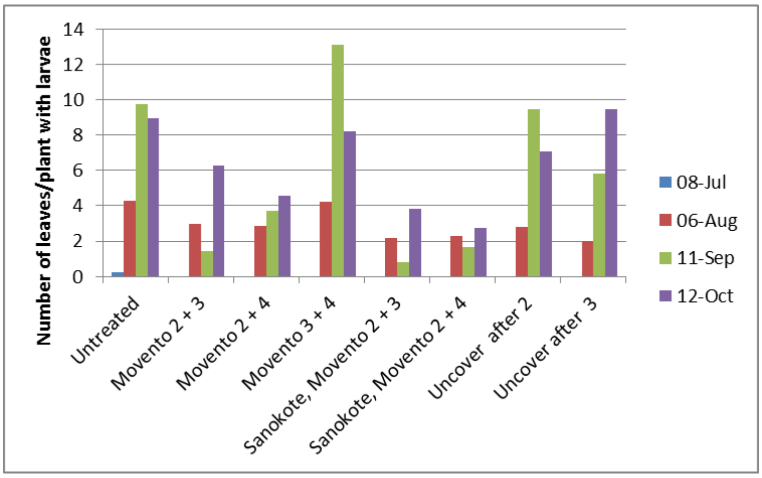

Figure B Mean numbers of leaves with larvae per plant in Trial 3.2**.**

Objective 4: Investigate the most effective overall treatment strategy for whitefly control

This objective was addressed in 2014 with a field trial using kale transplanted on 21 May (Trial 4.1). For each of the four insecticide treatments, a single spray of Movento was applied soon after the start of either the first, second, third or fourth generations as indicated by monitoring undertaken by Spencer Collins. The sprays were applied on 9 June, 17 July, 20 August or 12 September. The plots sprayed on 17 July had lower numbers of egg circles than the untreated control on all 3 assessment dates, lower numbers of larvae on the first two assessment dates and lower numbers of adults on the last two assessment dates. The plots sprayed on 20 August had lower numbers of larvae and adults on the last assessment date. Overall, a single spray applied either on 17 July or 20 August appeared to reduce the infestation more effectively than sprays on 9 June or 12 September.

The aim of Trial 4.2 in 2015 was to investigate the efficacy of different insecticides applied as two sprays in a four spray programme based on Movento (Figure C). The Movento sprays were applied as the two middle treatments in the programme based on the results obtained in 2014. Kale plants were transplanted on 28 May. There was an untreated control treatment and in the other treatments two sprays of Movento were applied soon after the start of the second and third generations as indicated by monitoring. The other insecticides were applied at the start of the first and fourth generations. The sprays were applied on 29 June, 16 July, 12 August and 18 September. On 15 July (after the first spray) treatment differences were only significant for larvae, with HDCI 073 reducing the numbers of leaves with larvae compared with the untreated control. HDCI 085 also reduced larval numbers but this was not quite significant. On 7 August (after one Movento spray), 8 September (after 2 Movento sprays) and 9 October (after the final coded spray) all treatments reduced the numbers of all life stages compared with the untreated control. There were no significant differences between the treatment programmes.

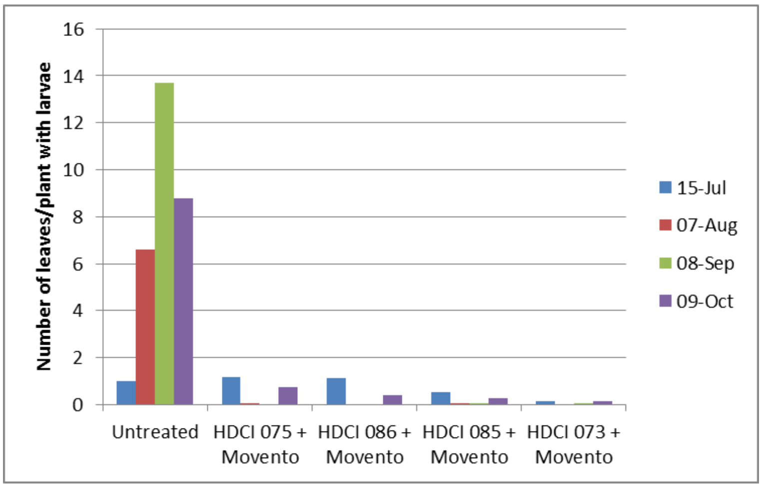

Figure C Mean number of leaves with larvae per plant on four assessment occasions.

Financial Benefits

In recent years the cabbage whitefly has caused considerable reductions to the quality and marketable yield of Brussels sprout and kale crops in particular. As control options are currently limited, additional options and information on how to use current control options more effectively will be very valuable to the industry.

Action Points

- Application of netting covers for a restricted period following planting can disrupt whitefly colonisation and population growth without impacts on plant growth.
- Growers should try to use the considerable efficacy and relative persistence of Movento to best effect in their spray programmes. Movento was particularly effective when applied in July and August, after the start of the second and third generations of whitefly.
- Sanokote seed treatment with imidacloprid can suppress the development of whitefly infestations, particularly early in the season. It might be expected that Phytodrip treatment with the neonicitinoid thiamethoxam would perform similarly to imidacloprid, although it has not been tested directly.
- Some novel insecticides offer whitefly control and could be used (subject to approval) to augment control with Movento.

SCIENCE SECTION

Introduction

Whitefly (*Aleyrodes proletella*) is becoming increasingly difficult to control on kale and Brussels sprout in particular. It is not clear why this is the case, although outbreaks appear to be more severe in hot, dry years (2003, 2006 and 2010). Research on the basic biology and ecology of cabbage whitefly was undertaken in the late 1930s and this provides very useful background information. More recently, there has been research on the overwintering status of cabbage whitefly (females overwinter in a state of ovarian diapause) and on development times on, and preferences for, different cultivars of susceptible brassica crops.

Most recently, research in the UK has focused on insecticidal control (data obtained in other AHDB Horticulture projects targeted at control of aphids on brassica crops) and a PhD project at the University of Greenwich (Simon Springate – supervised by Professor John Colvin) investigated the increasing importance of cabbage whitefly as a pest, and potential methods for its control. Populations of whitefly were tested for resistance to certain insecticides and it was shown that certain whitefly populations are resistant to pyrethroid insecticides. The potential for native predators, in particular a species of ladybird and parasitic wasps (*Encarsia* spp.), to control whitefly was also investigated.

There are a number of possible insecticide treatments to control whitefly. In AHDB Horticulture trials focused on brassica aphids some of these insecticides suppressed whitefly infestations and a novel insecticide also looked interesting. However, we still did not really understand how to put together a spray programme to suppress whitefly. There were also questions about the best ways to apply spray treatments to maximise control.

AHDB Horticulture then developed a portfolio of work to address whitefly control on brassica crops and to date this has involved 4 projects:

FV 399 - The aim of the project was to evaluate insecticide spray programmes and application strategies that might improve control of brassica whitefly. This was addressed through 1) field trials, 2) pot trials and 3) spray application tests in a wind tunnel. In the field trials, all treatments were applied at fortnightly intervals, when the infestation was already quite high and Movento was the most effective insecticide product. The most effective programmes began with Movento and the most effective strategy was to separate the two Movento applications included rather than apply them consecutively. In the wind tunnel study, boommounted nozzle configurations did not give adequate under-leaf coverage of sprays regardless of nozzle type, application volume or forward speed. Dropleg spraying systems improved coverage on the undersides of leaves on Brussels sprout, but not on kale.

FV 406 – the aim of the project was to field test the impact of releasing parasitoid wasps (*Encarsia tricolor*) and explore the impact of early insecticide applications. Early insecticide application based on monitoring proved as effective as periodic application in controlling whiteflies on kale. Two applications of a coded product were comparable to existing systemic products. Release of parasitoid wasps provided control levels equivalent to insecticides at the point of release.

CP 091 - this was an AHDB Horticulture Studentship (Spencer Collins) on the biology of cabbage whitefly. The overall aim of the project was to improve understanding of the biology and ecology of cabbage whitefly to help growers to minimise the development of whitefly infestations and to control unacceptable infestations effectively.

The aim of FV 406a was to evaluate the components of programmes (insecticidal, biological and physical) that might improve control of brassica whitefly. It focused particularly on the assessment of novel components and on the timing of the most promising of these and existing treatments. This is firstly with regard to the development of whitefly infestations on susceptible crops (which was based on the most recent findings of CP 091) and secondly, in relation to the efficacy and persistence of different treatments. In FV 399, all treatments were applied at fortnightly intervals. However, with Movento at least, it may be feasible and more 'cost-effective' to increase the interval between treatments. There are also coded products under development, some of which have shown potential for whitefly control in previous trials (FV 399, FV 406 and others), and these were included in the project.

In terms of other methods of control, the project considered the commercial scale production of large numbers of parasitoids and subsequent testing of timed releases in a replicated field trial. Plastic mesh crop covers or fleeces can exclude specific pests if placed over the crop before the pest becomes active (Finch & Collier, 2000). The advantages of employing covers in brassica crops have been shown to be significant against a range of pests, including *A. proletella*, (Ester *et al*., 1994; Saucke *et al*., 2003, 2004; Schultz *et al*., 2010) though long-term covering may be impractical and may negatively impact on plant growth and quality. Shorter periods of covering after planting may be sufficient to disrupt initial colonisation and maintain local populations below economically damaging levels. The use of crop covers should enable us to understand whether effective early suppression (total exclusion) of whitefly contributes significantly to a reduction in later infestation levels.

The specific objectives of project FV 406a were to:

1. Investigate additional insecticide treatments for whitefly control.
2. Investigate the efficacy of parasitoid release and crop covers, alone and in combination, in suppressing whitefly infestations.
3. Investigate the most effective way to use Movento and other effective insecticides in terms of the interval between treatments.
4. Investigate the most effective overall treatment strategy for whitefly control.

The work was undertaken by staff of the Warwick Crop Centre (University of Warwick), Natural Resources Institute (University of Greenwich), Syngenta Bioline, Allium & Brassica Agronomy Ltd. and Elsoms Seeds.

Experimental

For clarity this section covers each of the four objectives in sequence:

Objective 1: Investigate additional treatments for whitefly control.

The aim of this objective was to evaluate new products to determine whether they would be effective as part of a programme to control whitefly.

Trial 1.1 - 2014

Materials and methods

This objective was addressed in 2014 with a replicated plot trial. There were 7 treatments including an untreated control and each treatment was replicated 4 times. There was one sowing-time treatment (Sanokote – Gaucho (imidacloprid)) and the other treatments were applied as foliar sprays to an established infestation. The crop was kale (cv Reflex) and this was sown on 23 April and transplanted on 13 May. The plots were 3.5 m x 1 bed (3 plants wide). All plants were treated with Dursban WG prior to transplanting to protect against cabbage root fly larvae. Treatments were applied on: 20 August (all treatments), 27 August (HDCI 074 only), 3 September (HDCI 074 only) and 12 September (all treatments). All spray treatments were applied in 400 l/ha water using a knapsack sprayer fitted with 3 x 02F110 nozzles. The treatments are shown in Table 1.1.

Table 1.1 Treatments applied in field trial to investigate additional insecticide and biopesticide treatments for whitefly control.

	Product	a.i.	Rate	Adjuvant
1	Untreated			
2	Sanokote	Imidacloprid	140g a.i./100,000 seeds	
3	Movento	Spirotetramat	0.50 l/ha	
4	HDCI 075 (insecticide)		As recommended by manufacturer	Phase II
5	HDCI 076 (insecticide)		As recommended by manufacturer	Phase II
6	HDCI 073 (insecticide)		As recommended by manufacturer	Phase II
7	HDCI 074 (bio-insecticide)		As recommended by manufacturer	

Assessments

Assessments of the Sanokote (imidacloprid) treatment and the untreated control for comparison were made on 2 occasions (7 August, 19 August) and all plots were assessed on 22 October which was 40 days after the last spray was applied. Assessments were made of:

- Number of egg-circles per plant
- Number of leaves with larvae per plant
- Number of adults per plant on a scale of 0-4 where 1 = 1-10, 2 = 11-100, 3 = 101-500 and 4 = >500

The data for eggs and larvae were square-root transformed before statistical analysis.

Results

The size of the whitefly infestation increased throughout the trial. Table 1.2 shows the mean numbers of egg circles, leaves with larvae and adult scores on 7 and 19 August when only the untreated control and the Sanokote (imidacloprid) treatment were compared. There were statistically significant differences ($p<0.05$) (t-test on transformed data) in the numbers of egg circles, leaves with larvae and adult scores on 7 August but not on 19 August.

Table 1.2 Mean numbers of egg circles, leaves with larvae and adult scores per plant on 7 and 19 August. * denotes p<0.05.

		Untreated	Sanokote (imidacloprid)	P(T<=t) one-tail	P(T<=t) two-tail
07-Aug	Egg circles	48.8	10.4	0.038*	0.076
	Larvae	2.1	0.2	0.012*	0.025*
	Adults	2.0	1.0	0.022*	0.043*
19-Aug	Egg circles	93.2	22.6	0.156	0.312
	Larvae	2.3	1.0	0.270	0.541
	Adults	1.3	1.0	0.287	0.575

Table 1.3 and Figures 1.1, 1.2 and 1.3 show the mean numbers of egg circles, leaves with larvae and adult scores respectively on 22 October. There were statistically-significant differences between treatments for all 3 life stages. The numbers of egg circles, larvae and adults were reduced by Movento, HDCI 075 and HDCI 073 compared with the untreated control. Sanokote (imidacloprid) reduced the number of egg circles and HDCI 074 reduced the numbers of larvae compared with the untreated control.

Table 1.3 Mean numbers of egg circles, leaves with larvae and adult scores on 22 October (40 days after the last spray was applied). Values followed by * are significantly different from the untreated control (p<0.05).

	Egg circles		Larvae		Adults	
	Sqrt-trans per plot	Back-trans per plant	Sqrt-trans per plot	Back-trans per plant	Per plot	Per plant
Untreated	66.0	725.6	9.4	14.9	22.5	3.8
Sanokote (imidacloprid)	44.7*	333.4	8.4	11.8	18.5	3.1
Movento	17.3*	50.2	0.6*	0.1	11*	1.8
HDCI 075	48.3*	388.7	6.6*	7.4	17.8*	3.0
HDCI 076	62.7	655.6	8.4	11.7	21	3.5
HDCI 073	25.5*	108.6	2.0*	0.7	13.3*	2.2
HDCI 074	65.5	715.2	7.3*	8.9	20.8	3.5
df	21		21		21	
p	<0.001		<0.001		<0.001	
LSD two-tailed	17.746		1.266		4.890	
LSD one-tailed	14.68399		1.047123		4.046	

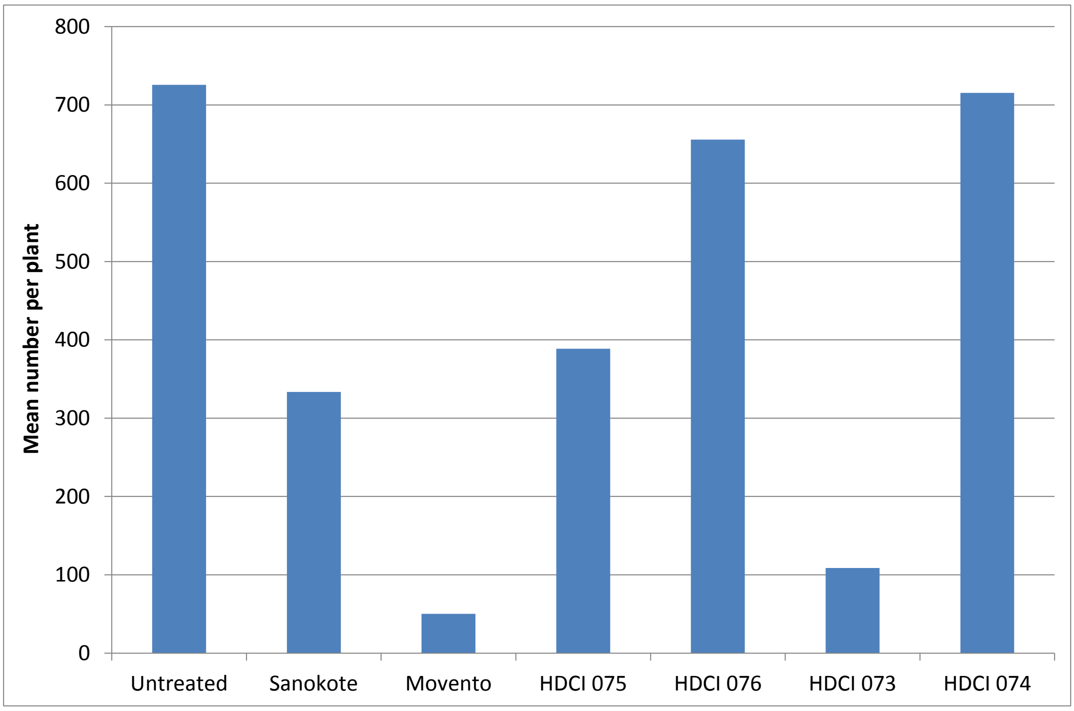

Figure 1.1 Mean number of whitefly egg circles per plant on 22 October 2014 (40 days after the last spray was applied).

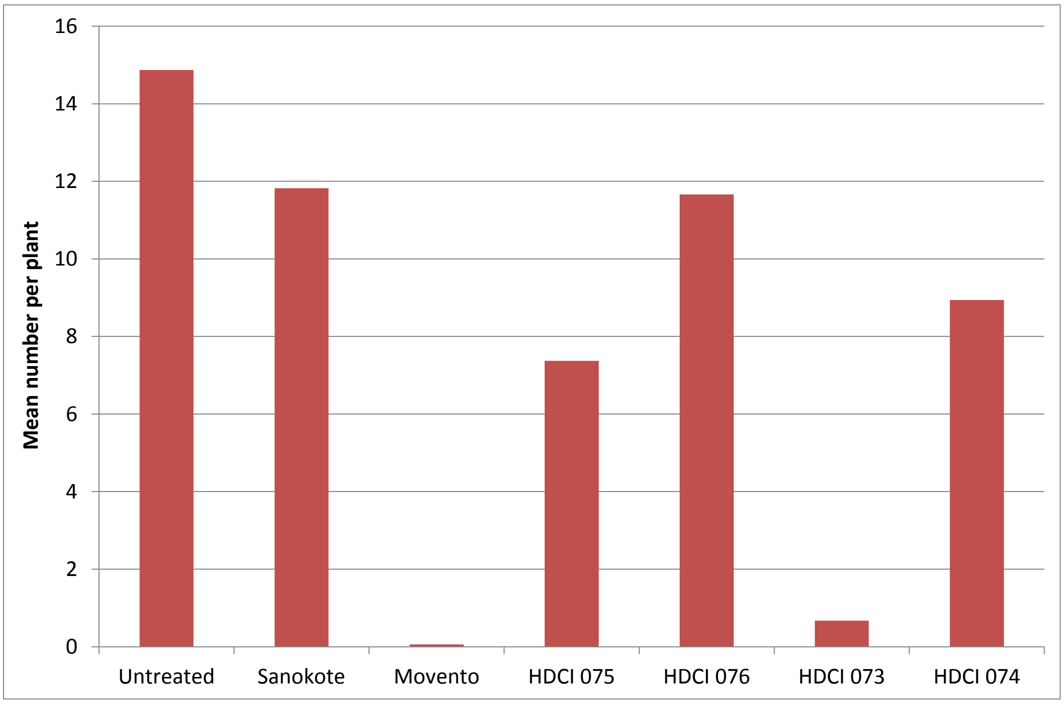

Figure 1.2 Mean number of leaves with whitefly larvae per plant on 22 October 2014. (40 days after the last spray was applied)

Figure 1.3 Mean whitefly adult score per plant on 22 October 2014. (40 days after the last spray was applied)

Figures 1.4, 1.5 and 1.6 show respectively the mean numbers of egg circles, leaves with larvae and adult score for all the Sanokote (imidacloprid) treatments. There were lower numbers of whitefly on all the plots treated with Sanokote (imidacloprid) on all occasions, but as indicated above, these differences were mainly only statistically-significant at the first assessment on 7 August.

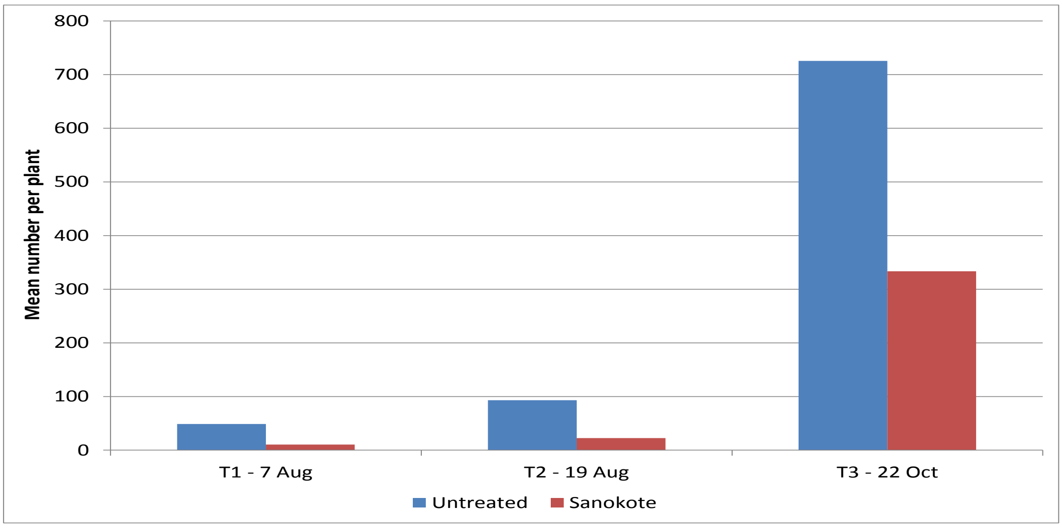

Figure 1.4 Mean numbers of egg circles per plant for all the Sanokote (imidacloprid) treatments.

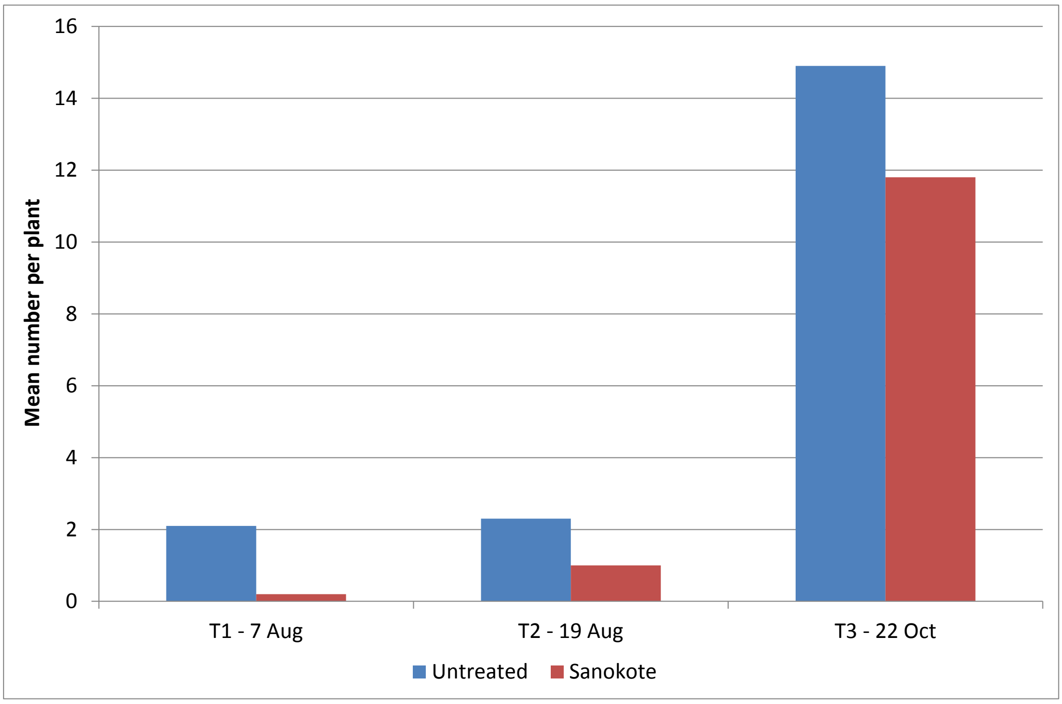

Figure 1.5 Mean numbers of leaves with larvae per plant for all the Sanokote (imidacloprid) treatments.

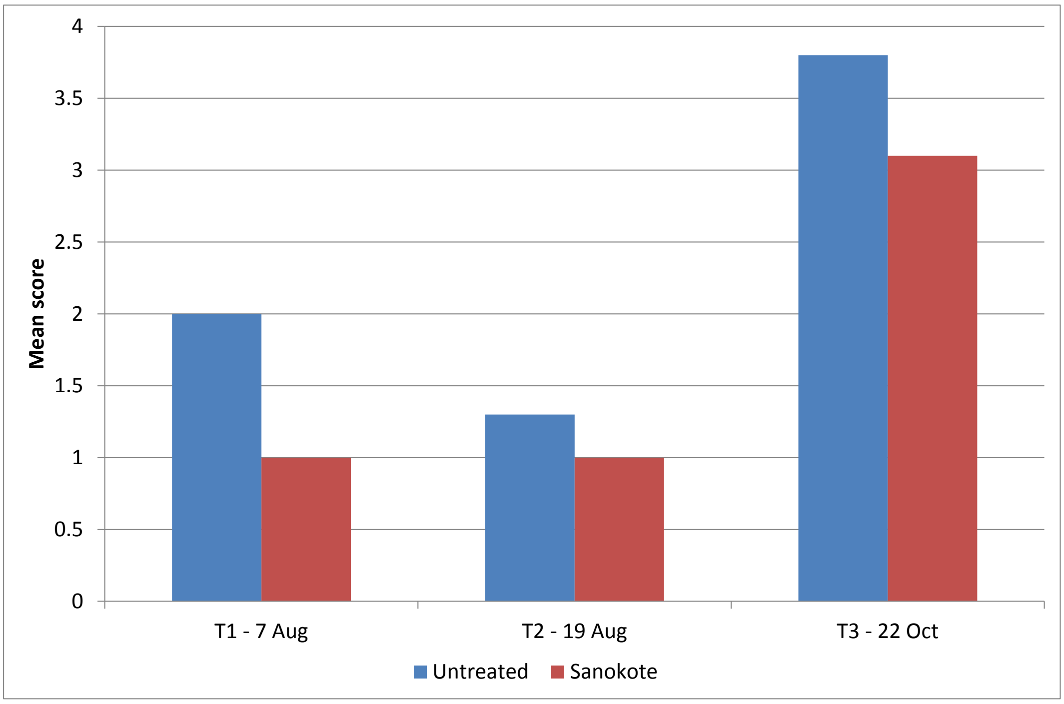

Figure 1.6 Mean adult score per plant for all the Sanokote (imidacloprid) treatments.

Trial 1.2 2015

Materials and methods

This objective was addressed in 2015 with a further replicated plot trial. There were 7 treatments including an untreated control and each treatment was replicated 4 times. There was one module drench treatment and the other treatments were applied as foliar sprays to an established infestation. The crop was kale (cv Winterbor) and this was sown on 10 April and transplanted on 28 May. The plots were 3.5 m x 1 bed (3 plants wide). The treatments are shown in Table 1.4. The drench treatment was applied in 1 ml/module using a laboratory pipette on 27 May (1 day before transplanting). All of the other plants were treated with Dursban WG to protect against cabbage root fly larvae. All spray treatments were applied in 300 l/ha water using a knapsack sprayer fitted with 3 x 02F110 nozzles. The spray treatments were applied on 16 July and 12 August 2015.

Table 1.4 Treatments applied in field trial to investigate additional insecticide treatments for whitefly control.

	Product	a.i.	Rate	Adjuvant
1	Untreated			
2	Movento	Spirotetramat	0.50 l/ha	None
3	HDCI 085			Phase II
4	HDCI 075		As recommended by manufacturer	Phase II
5	HDCI 085 drench		As recommended by manufacturer	None
6	HDCI 073		As recommended by manufacturer	Phase II
7	HDCI 086		As recommended by manufacturer	Phase II

Assessments

Assessments of the drench treatment and the untreated control for comparison were made on 16 July and all plots were assessed on 7 August, 9 September and 2 October. Assessments were made of:

- Number of egg-circles per plant
- Number of leaves with larvae per plant
- Number of adults per plant on a scale of 0-4 where 1 = 1-10, 2 = 11-100, 3 = 101-500 and 4 = >500

The data for eggs and larvae were log transformed before statistical analysis. The data were subjected to Analysis of Variance using the Genstat programme.

Results

The size of the whitefly infestation increased throughout the trial. The untreated and HDCI 085 drench-treated plots were assessed immediately before the first spray applications. The HDCI 085 treatment had little or no effect on any whitefly life stage (Table 1.5).

Table 1.5 Mean numbers of egg circles, leaves with larvae and adult scores on 16 July.

Treatment	**Egg circles**		**Larvae**		**Adults**
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	4.006	54.43	1.078	2.44	1.750
HDCI 085 drench	3.968	52.40	1.079	2.44	1.875
F-Value	0.01		0.00		0.57
P-Value	0.935		0.990		0.477
SED	0.443		0.088		0.165
5% LSD	1.083		0.215		0.404
df	6		6		6

On 7 August, 22 days after first spray application, all of the spray treatments had reduced all whitefly life stages compared with the untreated control ($p<0.05$) (Table 1.6, Figures 1.7-1.9). When comparing treatments, Movento reduced egg numbers and numbers of leaves with larvae compared with all other treatments. HDCI 085 was the next best treatment reducing egg numbers and numbers of leaves with larvae compared with all other treatments except Movento ($p<0.05$). Additionally, when considering eggs and larvae, HDCI 075 was more effective than all other treatments except Movento and HDCI 085 ($p<0.05$). Differences in adult numbers were smaller but Movento reduced numbers compared with the drench treatment, HDCI 073 and HDCI 086 ($p<0.05$).

On 9 September, 28 days after second spray application, generally levels of control appeared to have diminished (Table 1.7, Figures 1.7 – 1.9). Only Movento reduced all whitefly life stages compared with the untreated control ($p<0.05$).. HDCI 085 and HDCI 075 both reduced numbers of leaves with larvae but not numbers of eggs or adults ($p<0.05$)..

On 2 October, 51 days after second spray application, only Movento reduced all whitefly life stages compared with the untreated control ($p<0.05$). (Table 1.8, Figures 1.7 – 1.9). No other treatments reduced numbers of eggs or leaves with larvae ($p<0.05$), but HDCI 085, HDCI 075 and HDCI073 had all reduced numbers of adults ($p<0.05$)..

Table 1.6 Mean numbers of egg circles, leaves with larvae and adult scores on 7 August. Values followed by * are significantly different from the untreated control (p<0.05).

Treatment	Egg circles		Larvae		Adults
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	4.673	106.50	1.904	6.21	2.64
Movento	1.801*	5.55	-0.754*	-0.03	1.09*
HDCI 085	3.112*	21.96	0.036*	0.54	1.45*
HDCI 075	3.055*	20.73	1.030*	2.30	1.36*
HDCI 085 drench	5.287	197.26	2.187	8.41	2.79
HDCI 073	3.792*	43.87	0.972*	2.14	1.92*
HDCI 086	3.839*	45.96	1.119*	2.56	1.79*
F-Value	31.32		22.56		11.54
P-Value	<0.001		<0.001		<0.001
SED	0.289		0.303		0.268
5% LSD	0.630		0.660		0.585
df	12		12		12

Table 1.7 Mean numbers of egg circles, leaves with larvae and adult scores on 9 September (28 days after the second spray application). Values followed by * are significantly different from the untreated control (p<0.05).

Treatment	Egg circles		Larvae		Adults
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	4.996	147.3	2.282	9.30	2.51
Movento	4.095*	59.6	-0.278*	0.26	1.92*
HDCI 085	4.406	81.4	1.403*	3.57	2.09
HDCI 075	4.925	137.2	1.722*	5.10	2.54
HDCI 085 drench	5.223	185.0	2.660	13.80	3.10
HDCI 073	4.863	128.9	1.995	6.85	2.36
HDCI 086	4.833	125.1	2.222	8.73	2.52
F-Value	3.70		67.84		6.15
P-Value	0.026		<0.001		0.004
SED	0.282		0.166		0.215
5% LSD	0.613		0.362		0.469
df	12		12		12

Table 1.8 Mean numbers of egg circles, leaves with larvae and adult scores on 2 October (51 days after second spray application). Values followed by * are significantly different from the untreated control (p<0.05).

Treatment	Egg circles		Larvae		Adults
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	4.957	141.6	2.394	10.46	3.03
Movento	3.450*	31.0	1.637*	4.64	2.20*
HDCI 085	4.180	64.9	2.196	8.49	2.34*
HDCI 075	4.359	77.7	2.262	9.10	2.46*
HDCI 085 drench	5.362	212.6	2.545	12.24	3.13
HDCI 073	4.449	85.0	2.373	10.23	2.48*
HDCI 086	4.719	111.5	2.307	9.54	2.74
F-Value	4.97		9.47		4.71
P-Value	0.009		<0.001		0.011
SED	0.387		0.133		0.229
5% LSD	0.842		0.290		0.499
df	12		12		12

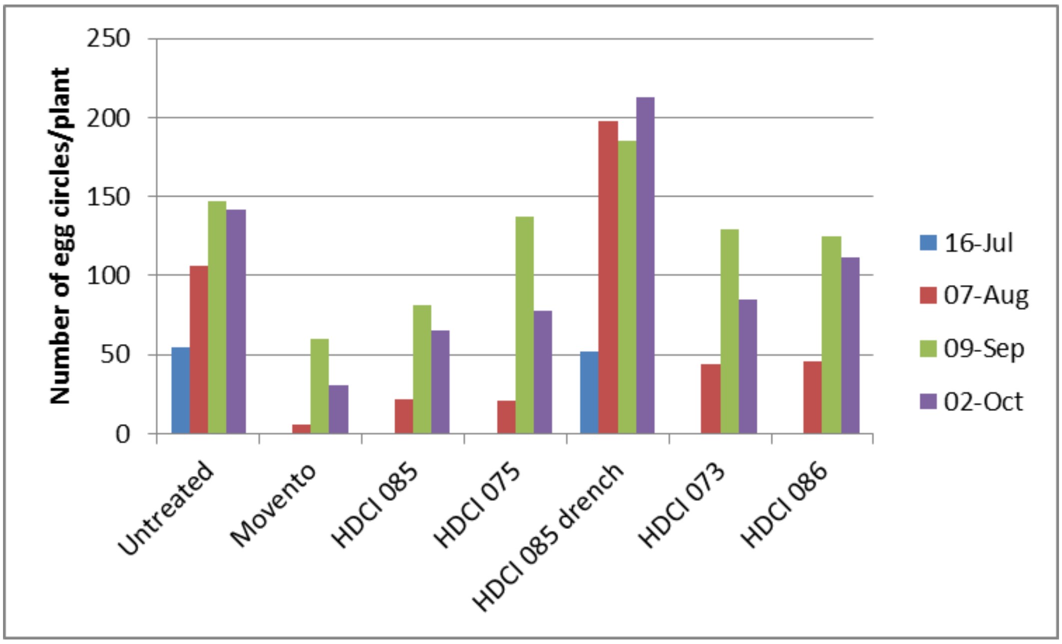

Figure 1.7 Mean number of whitefly egg circles per plant on 4 occasions in 2015.

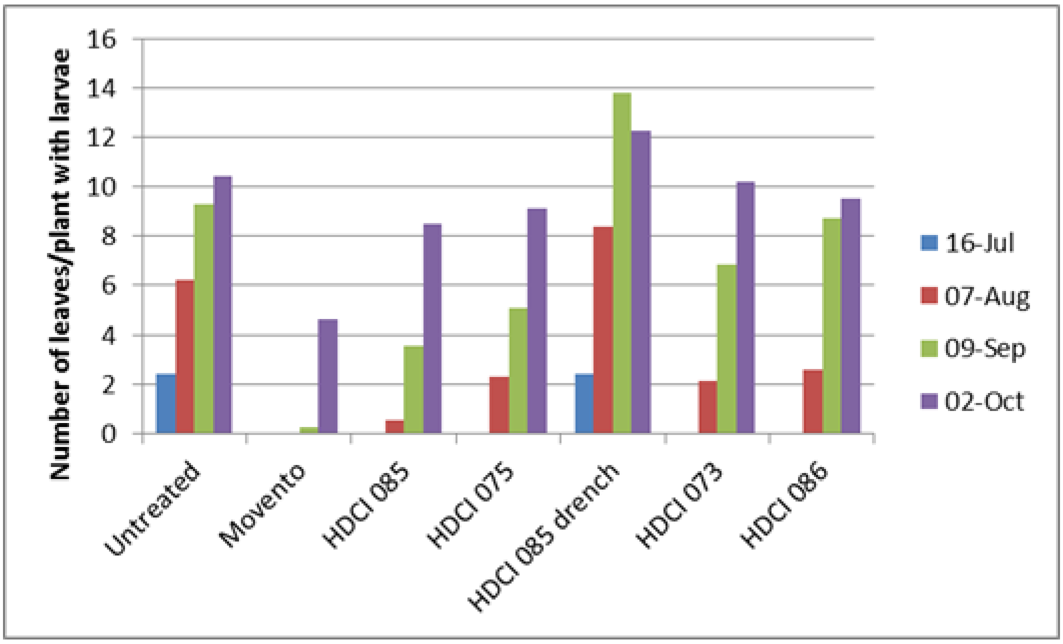

Figure 1.8 Mean number of leaves with whitefly larvae per plant on 4 occasions in 2015.

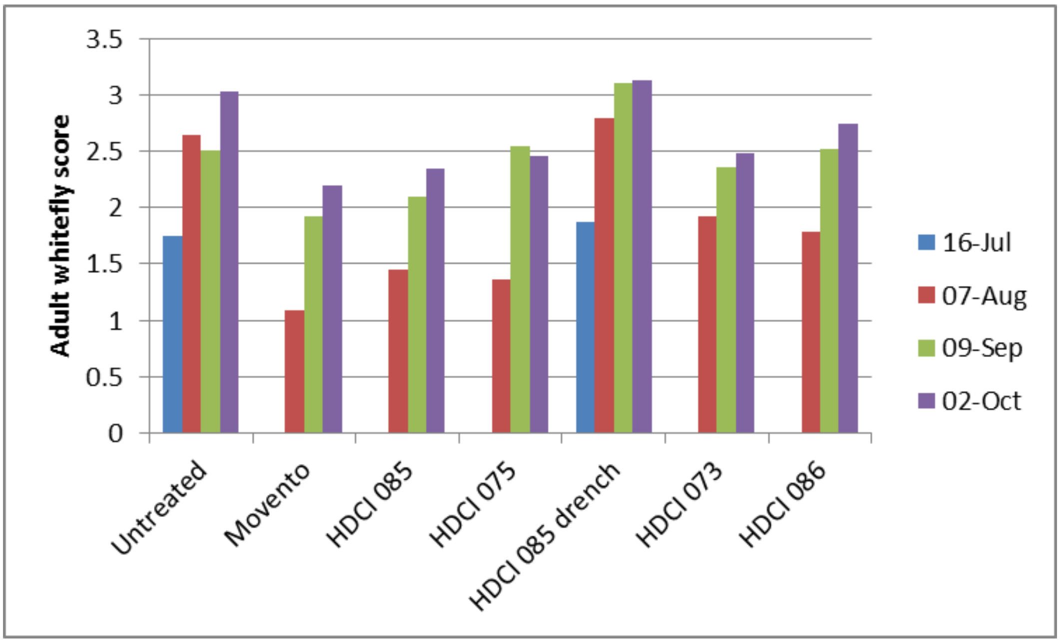

Figure 1.9 Mean whitefly adult score per plant on 4 occasions in 2015.

Objective 2: Investigate the efficacy of parasitoid release and crop covers, alone and in combination, in suppressing whitefly infestations.

Trial 2.1 - 2014

Materials and Methods

Parasitoid rearing

Parasitoids from cultures at NRI were supplied over several months to Syngenta Bioline to establish a production line on glasshouse whitefly, *Trialeurodes vaporariorum*. The intent was to develop a system that could (a) reliably supply sufficient numbers for an effective field trial (b) serve as a test of the commercial viability of such a production. While in FV 406, parasitoids were released as adults, the intention in this trial was to harvest and supply parasitoids as pupae, as is the case in commercial production of other species, and to utilize or adapt existing container designs to field release in brassicas.

After the trial had been set-up, a series of setbacks occurred in the production which prevented the delivery of the required insects. Consequently, those treatments intended to include parasitoids were replaced with a Movento application in late September, in order to gain useful data for the project overall.

Field Trial

Kale plants (cv. “Reflex”) were planted at the 3-4 leaf stage at Elsoms Seeds Ltd. research site outside Spalding, Lincs. on the 2 July 2014. The main trial consisted of 16 plots of 286 plants (13 rows of 22 plants) with ~50cm spacing between plants in a 4 x 4 grid arrangement. In addition, 4 smaller plots of 81 plants (9 rows of 9 plants) were planted in a line 15m from the main trial for the demonstration and comparison of insecticide options for visitors. Lengthwise paths were 1.2m wide, widthwise paths were 2m wide. Following herbicide application, netting was applied to half the trial plots on the 7 July.

Field trial treatments are listed in Table 2.1. Each treatment was applied to 4 plots, assigned randomly. The function of the revised trial was to compare the whitefly control provided by late Movento application before active growth may have ceased (B), 4 weeks of netting coverage after planting only (C), and a combination of these two approaches (D). The efficacy of covering crops with plastic meshes to exclude pests has been shown previously (see above) but such an approach may not be practical for large growers and may have impacts on growth, yield and quality over time. However, excluding whiteflies for some short period may be sufficient to disrupt establishment for one generation and consequently reduce the contamination at harvest substantially. If covers are only present when plants are small, subsequent growth may not be affected.

Demonstration plots

Three insecticide applications were planned but slow development of the infestation and poor spraying conditions in October led to the third stage in the programmes not being applied. Application rates for the trial and demonstration treatments are described in Table 2.2.

Table 2.1 Experimental treatments applied in the trial and demonstration plots

	Trial		Demonstration
A.	**Untreated**	1.	**Untreated**
B.	**Late Movento**	2.	**Movento / Biscaya**
C.	**Net only (4 weeks)**	3.	**Movento / -**
D.	**Net / Movento**	4.	**HDCI 073 / -**

Table 2.2 Insecticide rates used in the field trial

Product	Active ingredient	Application rate	Water volume
Movento	Spirotetramat	0.50 l/ha	
HDCI 073	Coded insecticide	As recommended by manufacturer (with Codacide at 2.5 l/ha)	300 l/ha
Biscaya	Thiacloprid	0.40 l/ha	

An AZO knapsack sprayer powered by compressed air with VP02F conventional nozzles was used for spray application, operated by trained personnel. Insecticide was applied under dry conditions. Treatments were applied on: 4 September (Movento on demo 2 and 3, HDCI 073 on demo 4) and 22 September (Movento on trial B and D, Biscaya on demo 2).

On the relevant plots, plants were covered with a single piece of plastic insect-proof netting (0.77mm holes) and the edges secured with soil (Fig. 2.1).

Figure 2.1 Netting covering experimental kale plots

While some distortion was evident in plants close to the edges of netted plots, this had no obvious long-term impact on the vertical growth of plants, their shape or the total number of leaves.

Monitoring

Following netting removal, twenty plants per trial plot were randomly selected and monitored every four weeks. The number of adult whiteflies, egg circles and leaves bearing nymphs were counted on each plant. As whitefly numbers were relatively low, absolute counts are presented. The same measurements were made on 10 plants per demonstration plot. As high levels of Diamondback Moth (*Plutella xylostella*) were evident following planting, the number of larvae per plant was also recorded in August following netting removal.

Analysis

Data was subjected to square root transformation prior to analysis. All analyses were carried out using R 3.0.2 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Whitefly population levels on this site have historically been high in previous trials (FV 399 and FV 406). However, the anticipated pest migration did not occur rapidly in 2014 though commercial thresholds were eventually reached. Plots were monitored weekly but it was not till the 29 August that whitefly were observed on >90% of plants in uncovered plots. Delayed planting and slow establishment limited the number of whitefly generations that could be influenced by the treatments but significant impacts were still observed.

Tables 2.3 – 2.5 show a summary of the analysis for the main trial with Figures 2.2 - 2.4 presenting mean data in graphical form. Figures 2.5 – 2.7 present similar data for the demonstration plots.

Adults

Netting proved highly effective in reducing whitefly infestation by up to 95% compared to untreated controls at the time of removal in August. While this level of suppression was not maintained in subsequent months, the reduction of netting alone remained significant, still being greater than 70% on average by 17 November. A single Movento application in late September against this low infestation had a substantial effect by 15 October, becoming greater over time as mortality of larvae reduced the recruitment of adults. The combination of netting and Movento was significantly more effective than the other treatments by 17 November.

Table 2.3 Mean adult whitefly counts per plant in each treatment on different dates. Values followed by * are significantly different from the untreated control (p<0.05).

	Trans	Back-trans	Trans	Back-trans	Trans	Back-trans	Trans	Back-trans
	13-Aug		17-Sep		15-Oct		17-Nov	
Untreated	1.44	2.07	2.85	8.12	9.46	89.44	9.79	95.88
Late Movento	1.35	1.83	2.80	7.85	8.16*	66.59	7.32*	53.58
Net only	0.12*	0.01	0.87*	0.76	1.87*	3.49	4.60*	21.14
Net / Movento	0.11*	0.01	0.83*	0.69	1.60*	2.56	2.53*	6.42
df	9		9		9		9	
F	126.90		70.31		245.4		146.5	
P	<0.001		<0.001		<0.001		<0.001	
LSD	0.245		0.509		0.985		0.488	

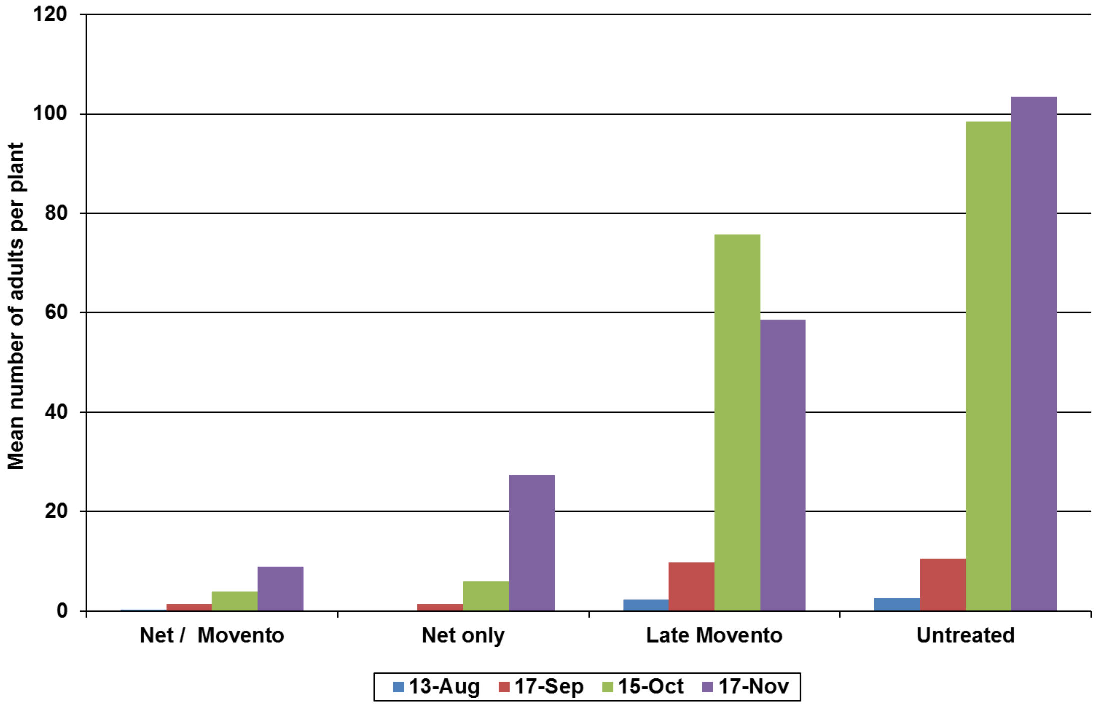

Figure 2.2 Mean number of adult whitefly per plant (treatments ranked by level of control on 17 November).

Eggs

In line with adult numbers, egg circles were also significantly reduced in netted plots in August and September. Late Movento application significantly reduced egg-laying to a similar degree as netting treatments by 15 October, though the number of circles was decreasing by this time on all plots. While these reductions compared to the untreated control were still present on 17 November, the Net treatments showed significantly lower values.

Table 2.5 Mean whitefly egg circle counts per plant in each treatment on different dates. Values followed by * are significantly different from the untreated control (p<0.05).

	Trans	Back-trans	Trans	Back-trans	Trans	Back-trans	Trans	Back-trans
	13-Aug		17-Sep		15-Oct		17-Nov	
Untreated	2.07	4.28	4.74	22.44	2.02	4.08	1.22	1.49
Late Movento	1.73	2.98	4.63	21.46	0.91*	0.82	0.76*	0.57
Net only	0.22*	0.05	1.99*	3.98	0.78*	0.62	0.38*	0.14
Net / Movento	0.19*	0.04	1.98*	3.92	0.59*	0.34	0.22*	0.05
df	9		9		9		9	
F	99.65		65.09		30.06		24.63	
P	<0.001		<0.001		<0.001		<0.001	
LSD	0.371		0.725		0.442		0.168	

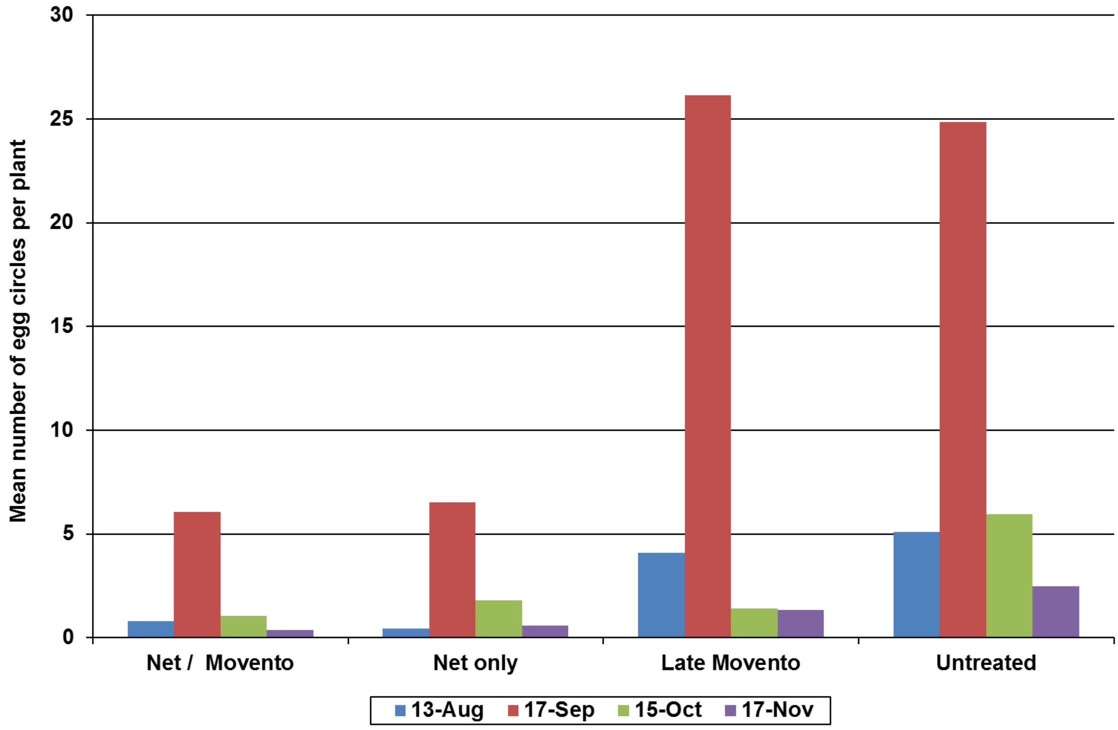

Figure 2.3 Mean number of egg circles per plant (treatments ranked by level of control on 17 November).

Larvae

There were no significant differences in levels of larval contamination after netting removal in August, though these were rarely present. By 17 September, the impact of reduced oviposition seen in the netting treatments was evident in the significant reduction in larvae relative to the untreated plots. After Movento treatment in late September, those plots to which it was applied showed significantly fewer leaves with larvae than their equivalents on 15 October and 17 November; the Net / Movento treatment was lower than that with Net only, as was the Movento only treatment compared to the untreated control. Netting alone and the single Movento treatment produced similar results, though the Movento average was non-significantly lower.

Table 2.6 Mean number of leaves with larvae per plant in each treatment on different dates. Values followed by * are significantly different from the untreated control (p<0.05).

	Trans	Back-trans	Trans	Back-trans	Trans	Back-trans	Trans	Back-trans
	13-Aug		17-Sep		15-Oct		17-Nov	
Untreated	0.038	0.001	2.236	5.000	2.885	8.323	1.651	2.726
Late Movento	0.038	0.001	2.227	4.960	2.050*	4.203	0.941*	0.885
Net only	0.025	0.001	0.455*	0.207	1.518*	2.304	0.783*	0.613
Net / Movento	0.000	0.000	0.445*	0.198	1.119*	1.252	0.383*	0.147
df	9		9		9		9	
F	1.02		209.20		57.20		31.75	
P	0.383		<0.001		<0.001		<0.001	
LSD	0.066		0.266		0.378		0.176	

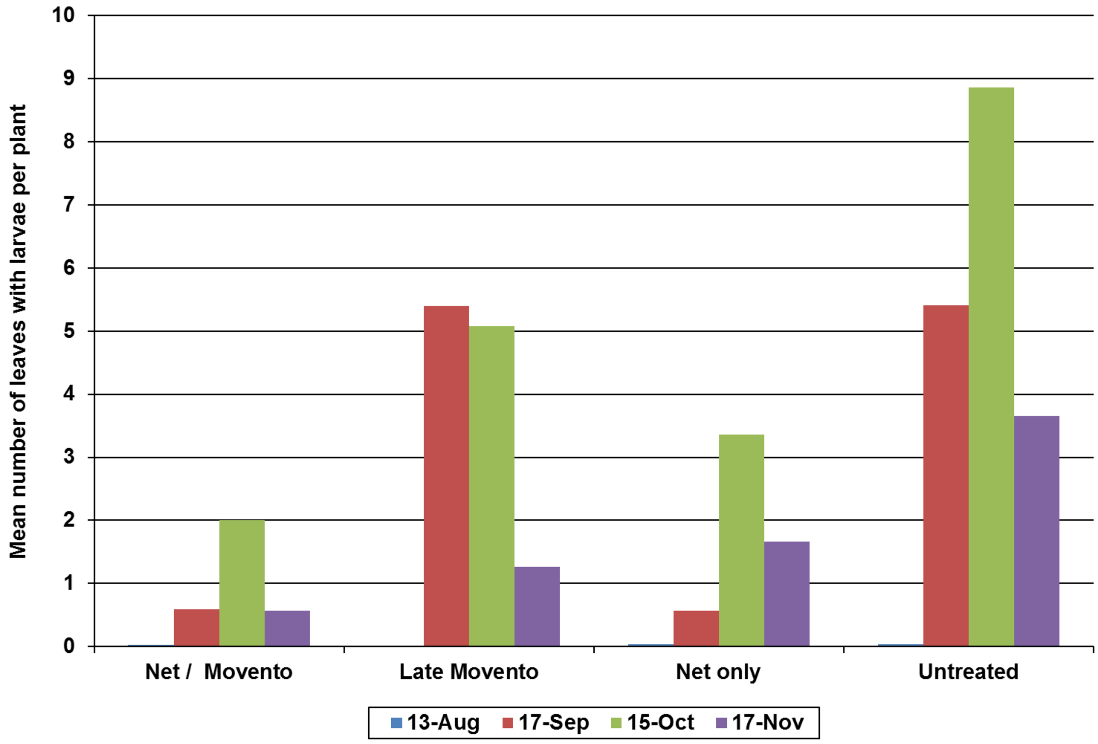

Figure 2.4 Mean number of leaves with larvae per plant (treatments ranked by level of control on 17 November).

Diamondback Moth

As previously mentioned, Diamondback Moth numbers were high in 2014 around the time of planting. Once netting was removed in August there was no difference in infestation levels between treatments (mean ± SE: 3.7 ± 0.2 larvae per plant, $F_{3,316} = 0.377$, $P = 0.769$) though larvae seemed more evenly distributed across the plots in those treatments without nets. This suggests that adults reached the trial plants rapidly in the few days between planting and covering. There was substantial damage to lower leaves on the most heavily infested plants at this time. However, though another generation of adults was produced, many larvae were found to have died at a late stage of development. Analysis of samples by an NRI pathologist did not identify fungal or protozoan pathogens in cadavers. While these moths persisted in the trial, their numbers did not recover and little damage was observed on younger leaves.

Demonstration plots

While the demonstration plots were unreplicated and therefore susceptible to local variations, some data is included for comparison with other trial results (Figure 2.5-2.7). Whitefly numbers were higher on the demonstration plots than on the main plots, possibly due to their position on the site relative to potential sources of migrating adults. However, the lack of replication limited the statistical significance of many differences. With the exception of a reduction in leaves with larvae in the Movento only treatment on 17 September, there was no substantial effect of the first insecticide application. Both treatments beginning with Movento showed significantly reduced levels of all metrics compared to the other two treatments on the 15 October and 17 November. The number of leaves infested with larvae was lower in the Movento / Biscaya treatment compared to that with Movento only on 17 November. The single application of HDCI 073 proved ineffective for all metrics throughout the trial.

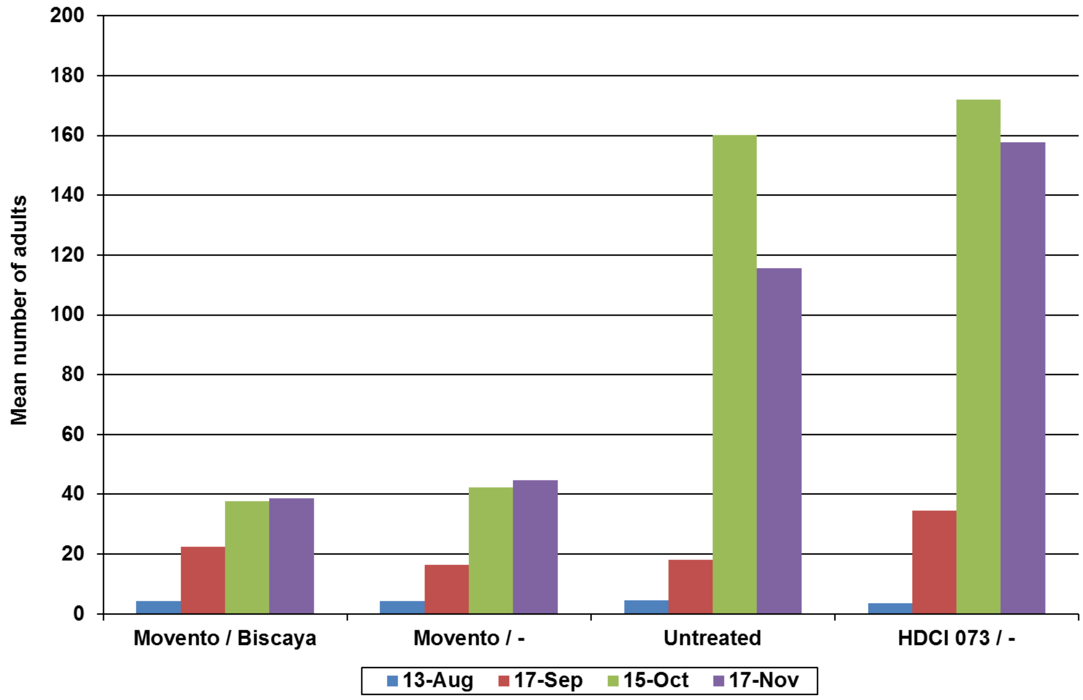

Figure 2.5 Mean number of adult whitefly per plant (treatments ranked by level of control on 17 November).

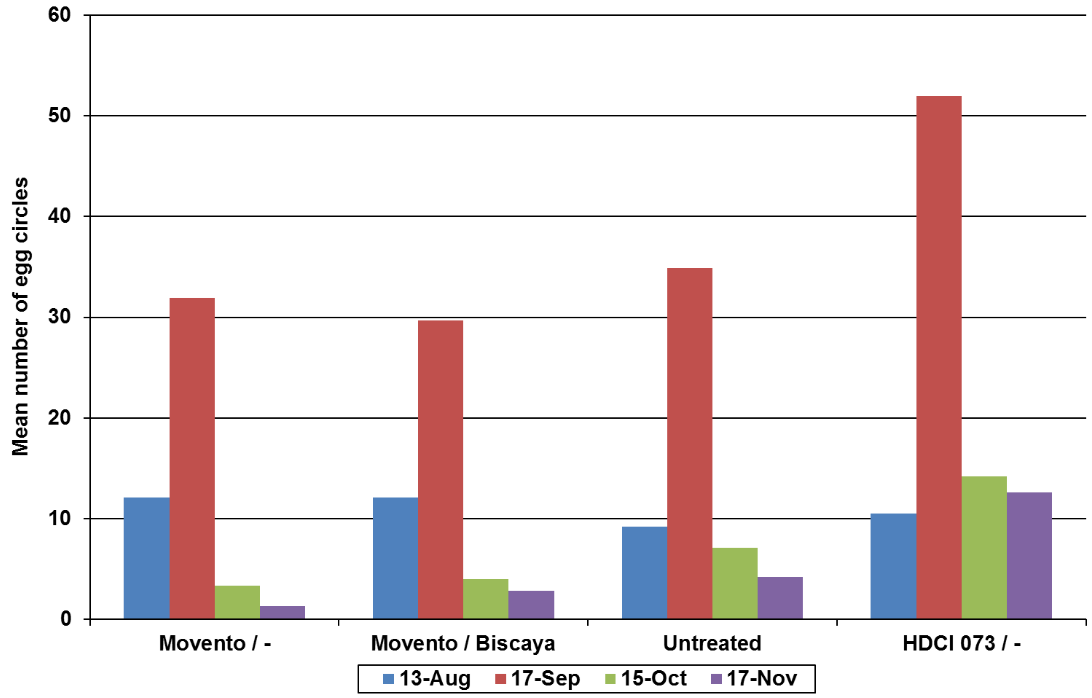

Figure 2.6 Mean number of egg circles per plant (treatments ranked by level of control on 17 November).

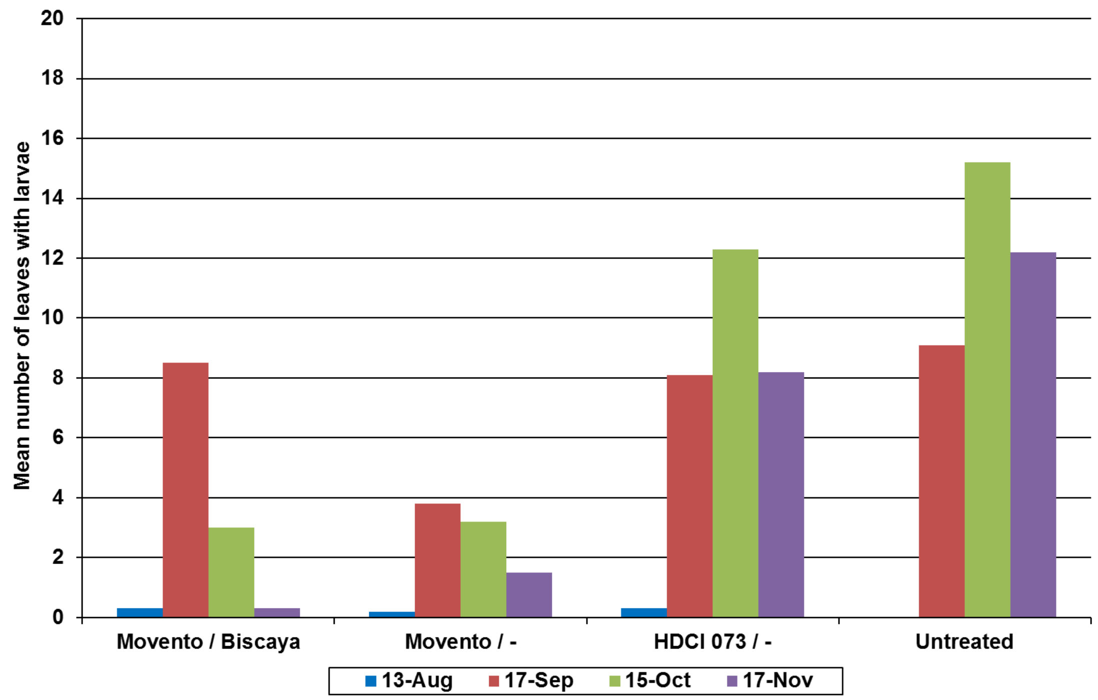

Figure 2.7 Mean number of leaves with larvae per plant (treatments ranked by level of control on 17 November).

Trial 2.2 - 2015

Materials and Methods

As the commercial rearing method was unsuccessful in 2014 this part of the project was continued by dividing the rearing process between University of Greenwich and University of Warwick. Simon Springate produced vials of adult parasitoids at approximately weekly intervals and these were introduced onto kale plants infested with cabbage whitefly which were maintained in a polytunnel at Warwick Crop Centre (University of Warwick). The culture was not maintained in the Insect Rearing Unit at Wellesbourne because of the risk of contaminating the cultures of cabbage whitefly with parasitoids. When the parasitoids pupae had developed in the whitefly larvae (seen as blackened pupae), the pupae were counted and the kale plants were removed to field plots that were infested naturally with cabbage whitefly.

Kale (cv Winterbor) was sown on 10 April and transplanted on 8 June. The plots were 3 m x 2 beds (3 plants across each bed). There were 10 'isolated' field plots which were separated into 5 pairs based on their location. There were four plots in Pump Ground, two in Long Meadow West, two in Long Meadow Centre and two in Cottage Field. One plot from each pair was inoculated with parasitoids (by placing the plants with parasitoids within it) and one plot was untreated. Whitefly infestation was assessed on 23 July, 12 August, 10 September and 14 November. Assessments were made of:

- Number of egg-circles per plant
- Number of leaves with larvae per plant
- Number of adults per plant on a scale of 0-4 where 1 = 1-10, 2 = 11-100, 3 = 101-500 and 4 = >500
- Number of parasitized pupae

The data for eggs and larvae were log transformed before statistical analysis. The data were subjected to Analysis of Variance using the Genstat programme.

Results

The size of the whitefly infestation increased throughout the trial. Details of parasitoid releases are given in Table 2.7. Production was inconsistent and compounded by regular infestations of *Myzus persicae* which interfered with both whitefly production and parasitoid rearing. However, despite these problems, each plot was inoculated with an average of 244 parasitoid pupae overall.

Table 2.7 Inoculation details for isolated plot parasitoid trial.

Date		Number of parasitoid pupae				
Plant inoculation	Field inoculation	Pump Ground E	Pump Ground W	Long Meadow Centre	Long Meadow West	Cottage field
10-Jul	29-Jul	37	162	45	48	50
14-Jul	03-Aug	62	78	24	10	15
27-Jul	14-Aug	18	3	0	0	0
31-Jul	18-Aug	0	0	0	0	0
5-Aug	24-Aug	43	0	20	26	27
12-Aug	01-Sep	23	0	0	7	0
17-Aug	07-Sep	0	26	10	0	25
24-Aug	14-Sep	0	17	0	40	26
02-Sep	21-Sep	85	39	10	15	20
09-Sep	28-Sep	20	20	25	26	7
16-Sep	05-Oct	35	25	5	10	34
Total number of parasitoid pupae		**323**	**370**	**139**	**182**	**204**

Results from the statistical analysis of assessments by treatment (with or without parasitoids) are presented in Tables 2.8 - 2.11. There were no treatment differences for any life stage of the whitefly on any assessment date. The data are also presented in Figures 2.8 – 2.10 as individual plots. Paired plots were very similar, the largest differences occurring between different locations.

Small numbers of parasitized whitefly larvae were observed (Figure 2.11), predominantly on the last assessment date in Long Meadow West but there appeared to be little or no impact on whitefly numbers.

Table 2.8 Mean numbers of egg circles, leaves with larvae and adult scores on 23 July.

Treatment	**Egg circles**		**Larvae**		**Adults**
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	2.928	18.2	1.421	3.64	2.07
Parasitoid	2.941	18.4	1.467	3.84	2.00
F-Value	0.00		1.34		1.00
P-Value	0.950		0.312		0.374
SED	0.197		0.040		0.067
5% LSD	0.546		0.111		0.185
df	4		4		4

Table 2.9 Mean numbers of egg circles, leaves with larvae and adult scores on 12 August.

Treatment	Egg circles		Larvae		Adults
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	4.557	94.8	1.561	4.26	2.600
Parasitoid	4.476	87.4	1.566	4.29	2.567
F-Value	0.34		0.00		0.17
P-Value	0.593		0.952		0.704
SED	0.139		0.072		0.082
5% LSD	0.385		0.200		0.227
df	4		4		4

Table 2.10 Mean numbers of egg circles, leaves with larvae and adult scores on 10 September.

Treatment	Egg circles		Larvae		Adults
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	5.506	245.6	1.977	6.722	3.067
Parasitoid	5.536	253.3	1.963	6.622	2.967
F-Value	0.18		0.13		2.25
P-Value	0.696		0.732		0.208
SED	0.073		0.038		0.067
5% LSD	0.204		0.105		0.185
df	4		4		4

Table 2.11 Mean numbers of egg circles, leaves with larvae and adult scores on 14 November.

Treatment	Egg circles		Larvae		Adults
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	5.815	334.6	2.090	7.588	2.933
Parasitoid	5.871	354.2	2.070	7.427	2.967
F-Value	0.68		0.10		0.29
P-Value	0.457		0.773		0.621
SED	0.069		0.065		0.062
5% LSD	0.192		0.180		0.173
df	4		4		4

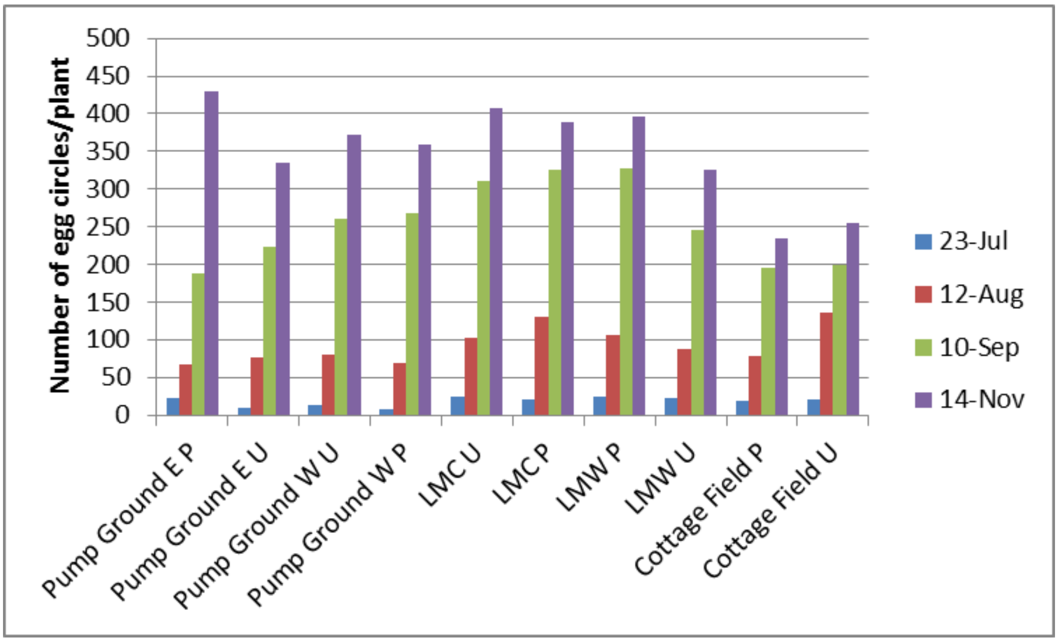

Figure 2.8 Mean number of egg circles per plant (P = parasitoids added; U = untreated)

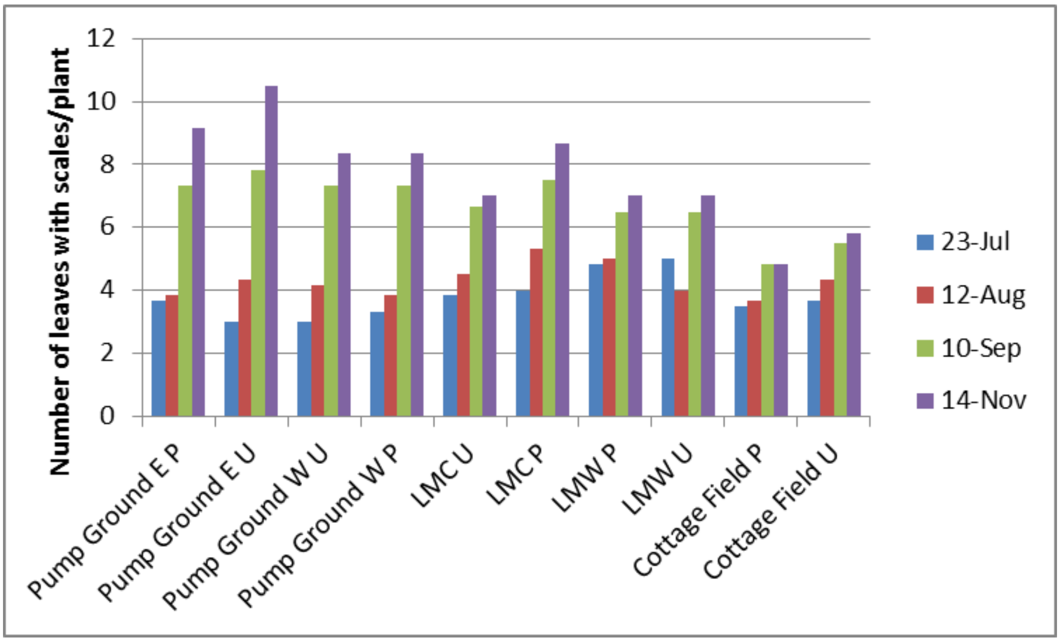

Figure 2.9 Mean number of leaves with larvae per plant (P = parasitoids added; U = untreated)

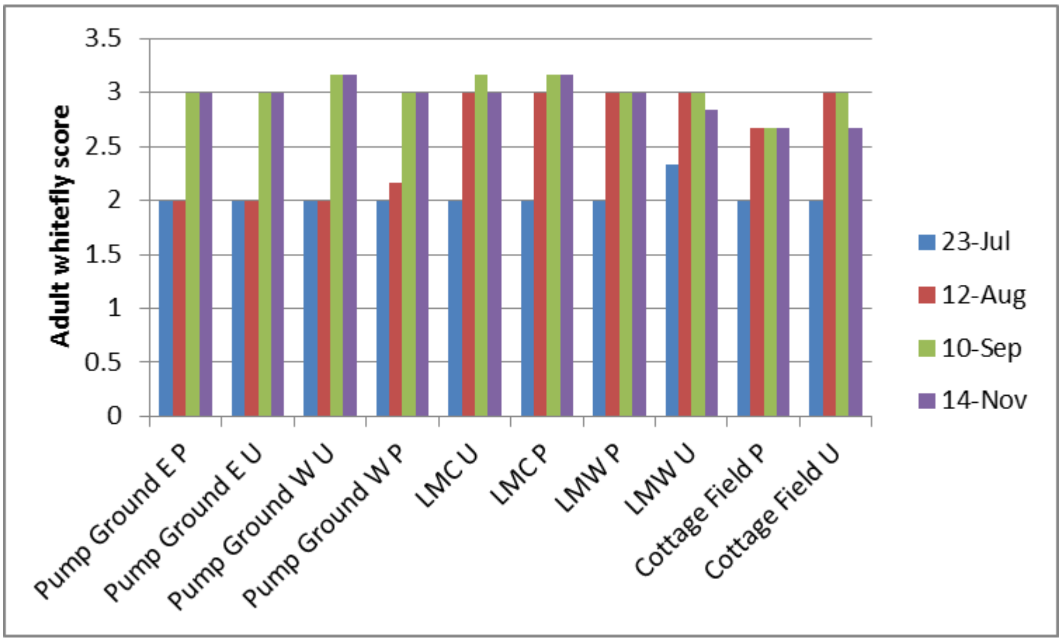

Figure 2.10 Mean adult score per plant (P = parasitoids added; U = untreated)

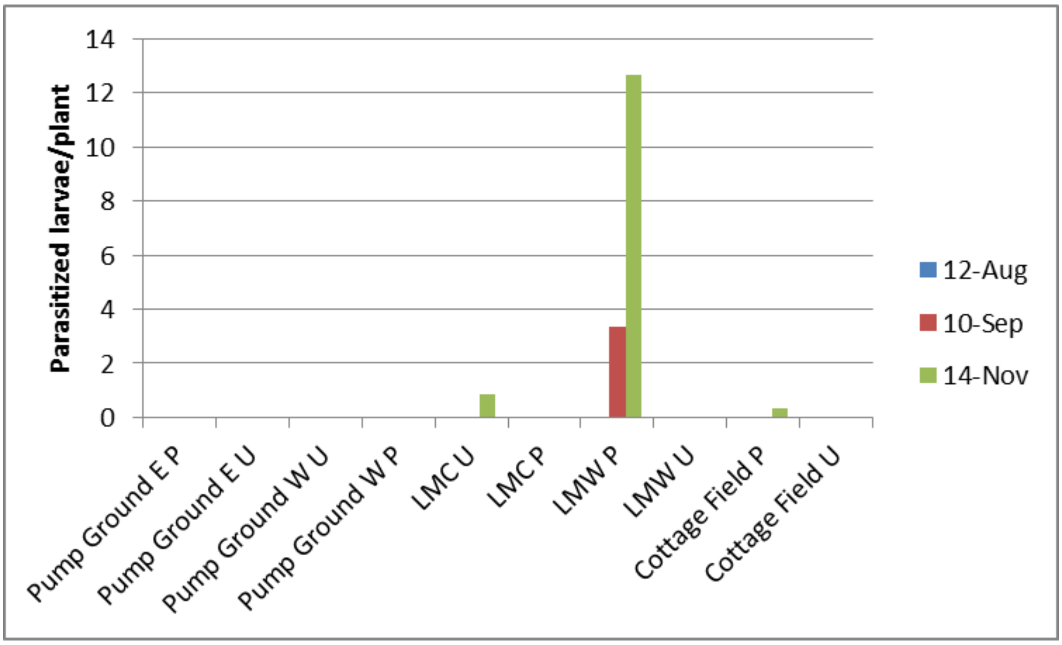

Figure 2.11 Mean number of parasitized larvae per plant (P = parasitoids added; U = untreated)

Objective 3: Investigate the most effective way to use Movento and other effective insecticides in terms of the interval between treatments.

Trial 3.1 - 2014

Materials and Methods

The aim of this trial was to investigate the persistence of three treatments and an untreated control. The treatments were Movento, Sanokote (imidacloprid) and HDCI 075 (Table 3.1). The plants were sown on 23 April and transplanted on 21 May and sprayed on 20 August. All spray treatments were applied in 400 l/ha water using a knapsack sprayer fitted with 3 x 02F110 nozzles.

Table 3.1 Treatments applied in field trial to investigate persistence of insecticide treatments for whitefly control.

	Product	a.i.	Rate	Adjuvant
1	Untreated			
2	Sanokote	Imidacloprid	140g a.i./100,000 seeds	
3	Movento	Spirotetramat	0.50 l/ha	
4	HDCI 075 (insecticide)		As recommended by manufacturer	Phase II

Assessments

Assessments were made on 7 August, 19 August (Sanokote (imidacloprid) and untreated control only) and on 17 September and 23 October. Assessments were made of:

- Number of egg-circles per plant
- Number of leaves with larvae per plant
- Number of adults per plant on a scale of 0-4 where 1 = 1-10, 2 = 11-100, 3 = 101-500 and 4 = >500

The data on eggs and larvae were square-root transformed prior to analysis.

Table 3.2 shows the mean number of egg circles, leaves with larvae and adult score in plots treated with Sanokote (imidacloprid) pre-planting and in the untreated control plots. There were always more whitefly in the untreated control plots but the differences were statistically-significant on 19 August only.

Table 3.2 Mean number of egg circles, leaves with larvae and adult score per plant in plots treated with Sanokote (imidacloprid) pre-planting and in the untreated control plots.

		Untreated	**Sanokote (imidacloprid)**	**P(T<=t) one-tail**	**P(T<=t) two-tail**
07-Aug	Egg circles	70.7	52.7	0.375	0.749
	Larvae	2.2	1.4	0.2375	0.474
	Adults	2.1	1.7	0.229	0.459
19-Aug	Egg circles	354.4	91.9	0.003*	0.006*
	Larvae	8.1	4.0	0.036*	0.072
	Adults	2.3	1.5	0.020*	0.040*

Tables 3.3 – 3.4 and Figures 3.1 - 3.3 show the mean numbers of egg circles, leaves with larvae and adult score on 17 September and 23 October. On 17 September, all three treatments had reduced the number of whitefly egg circles, larvae and adults compared with the untreated control. By 23 October there were no difference between treatments in the numbers of adults, but larval numbers were reduced by all four treatments and Movento appeared still to be having an effect on egg numbers.

Table 3.3 Mean numbers of egg circles, leaves with larvae and adult score on 17 September.

Treatment	Egg circles		Larvae		Adults	
	Per plot sqrt	Per plant back-trans	Per plot sqrt	Per plant back-trans	Per plot	Per plant
Untreated	65.6	717.2	11.3	21.3	21.5	3.6
Sanokote (imidacloprid)	33.9*	191.9	9.6*	15.3	16.3*	2.7
Movento	23.1*	88.8	7.7*	9.9	13.8*	2.3
HDCI 075	41.3*	284.1	9.4*	14.8	17.3*	2.9
df	12		12		12	
P	0.002		<0.001		<0.001	
SED	8.499		0.391		1.311	
LSD two-tailed	18.518		0.851		2.856	
LSD one-tailed	15.148		0.6968		2.337	

Table 3.4 Mean numbers of egg circles, leaves with larvae and adult score on 23 October.

Treatment	Egg circles		Larvae		Adults	
Untreated	79.3	6285.4	11.5	131.2	24	4.0
Sanokote (imidacloprid)	70.2	4926.6	10.3*	105.7	23	3.8
Movento	63.4*	4023.5	3.2*	10.1	22.3	3.7
HDCI 075	78	6081.8	10.5*	109.6	23.5	3.9
df	12		12		12	
P	0.066		<0.001		0.47	
SED	5.918		0.558		1.113	
LSD two-tailed	12.895		1.2025		2.426	
LSD one-tailed	10.5485		0.9835		1.984	

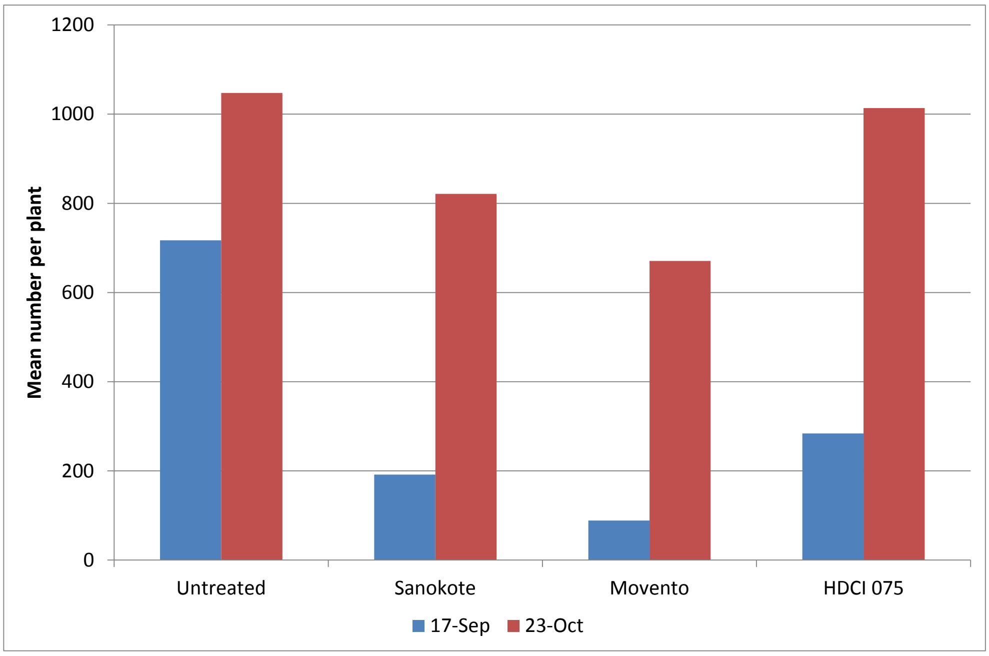

Figure 3.1 Mean numbers of egg circles per plant on 17 September and 23 October.

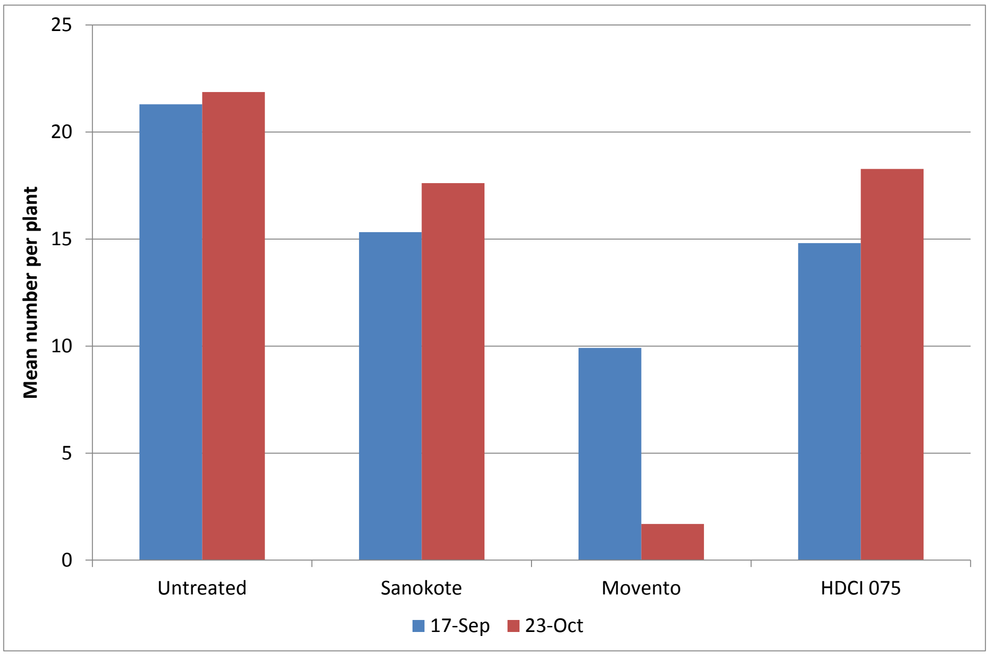

Figure 3.2 Mean numbers of leaves with larvae per plant on 17 September and 23 October.

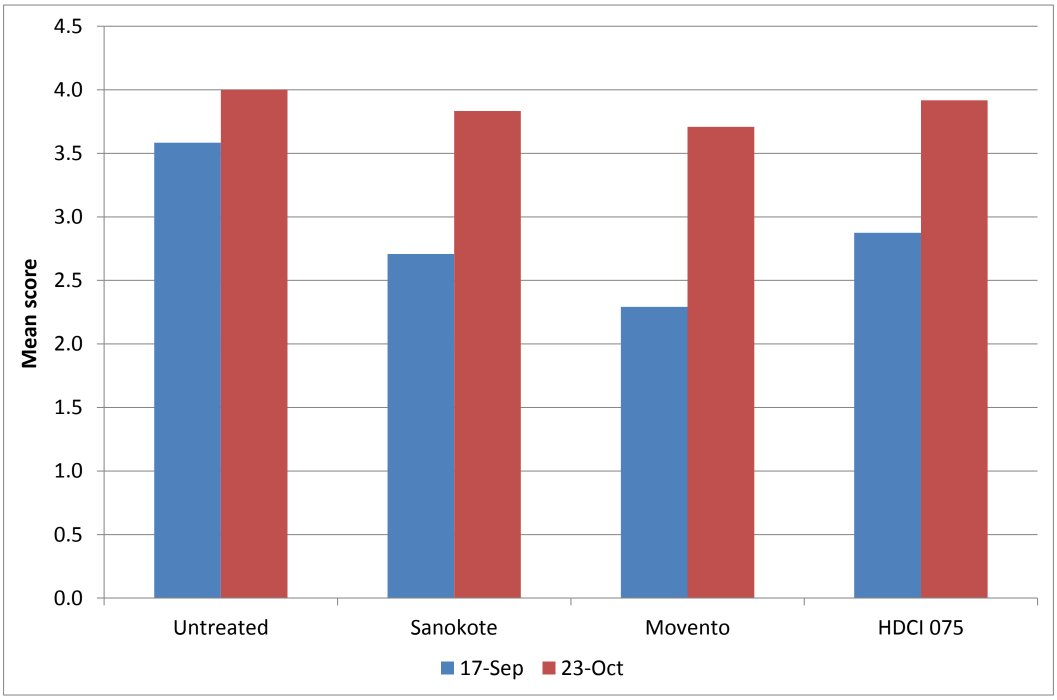

Figure 3.3 Mean adult score per plant on 17 September and 23 October.

Figures 3.4 - 3.6 show the mean number of egg circles, leaves with larvae and adult score respectively for all the Sanokote (imidacloprid) treatments. The size of the infestation increased over time, but the plots treated with Sanokote (imidacloprid) always had lower numbers of whitefly compared with the untreated control – although this difference was not always statistically significant (Tables 3.1 and 3.2).

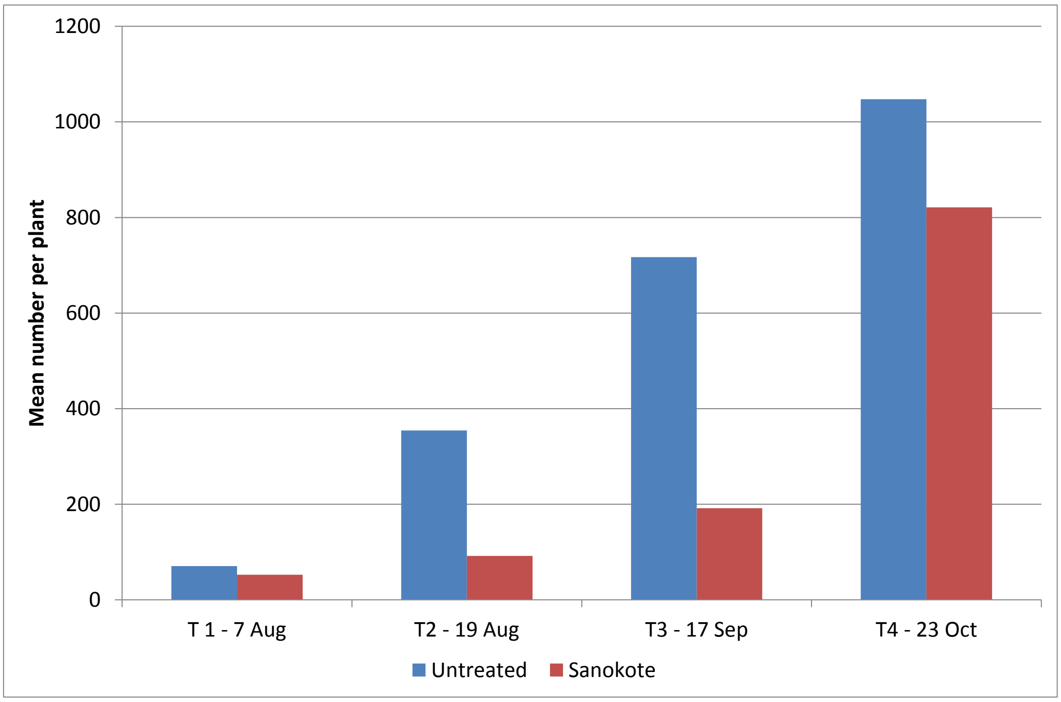

Figure 3.4 Mean numbers of egg circles per plant for all the Sanokote (imidacloprid) treatments.

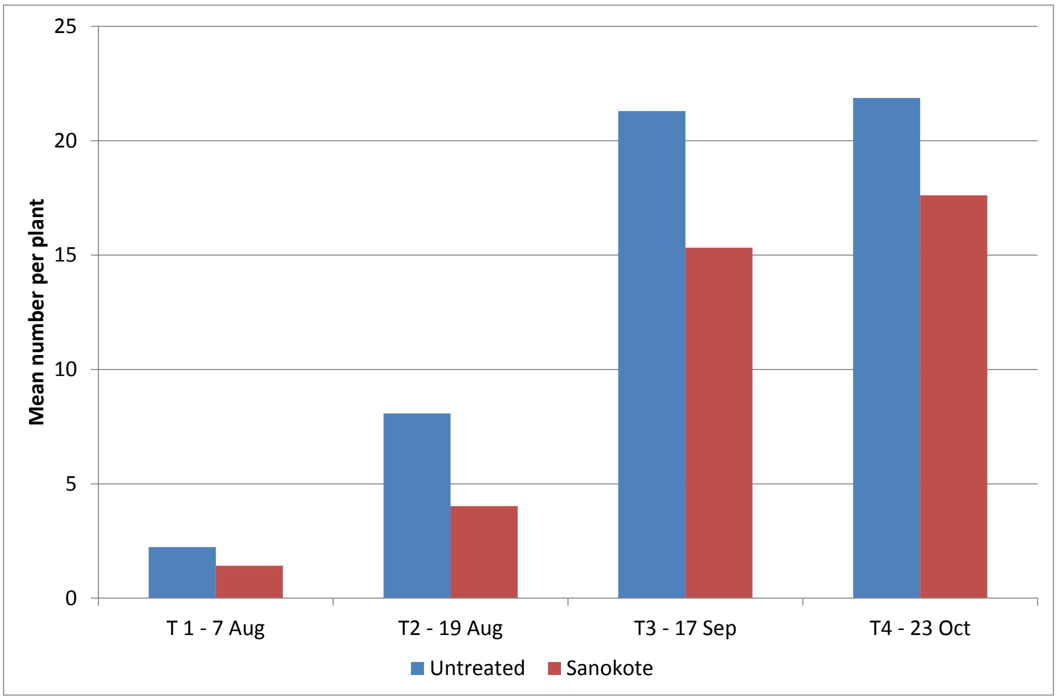

Figure 3.5 Mean numbers of leaves with larvae per plant for all the Sanokote (imidacloprid) treatments.

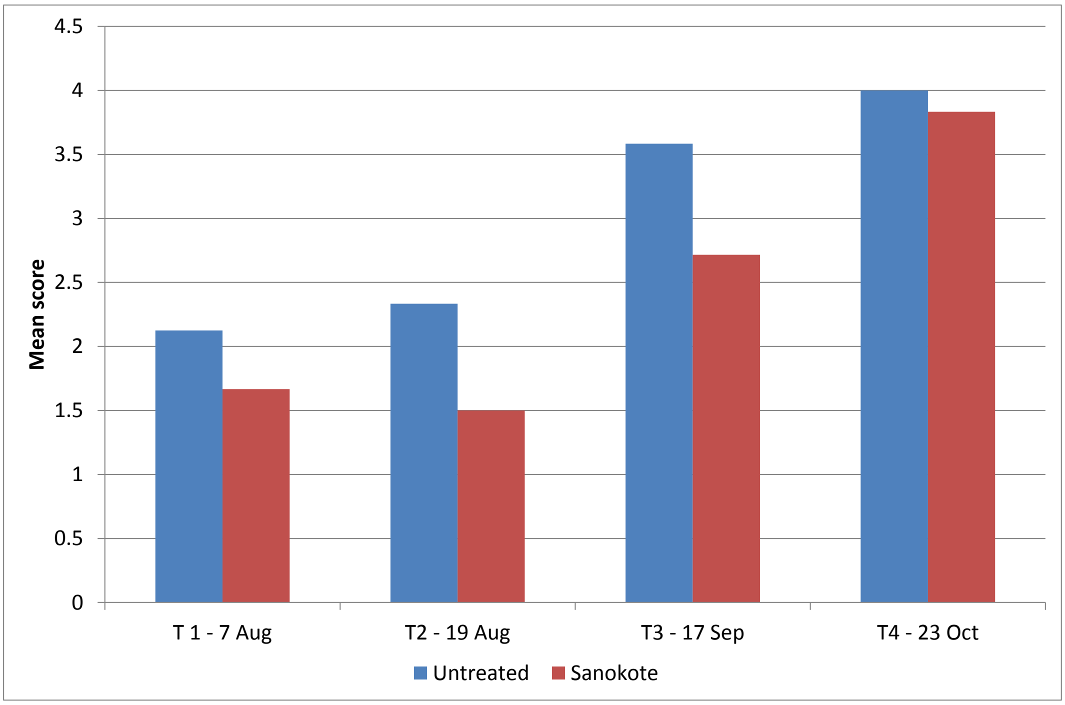

Figure 3.6 Mean adult score per plant for all the Sanokote (imidacloprid) (imidacloprid) treatments.

Trial 3.2 - 2015

Materials and methods

Objective 3 was also addressed in 2015 with a field trial on plots of kale (cv Winterbor). The seed was sown on 10 April and the plants were transplanted on 28 May. All plants were treated with Dursban WG to protect against cabbage root fly larvae. There were 4 replicates of 8 treatments including an untreated control, arranged in a randomized block design and the plots were 3.5 m x 1 bed (3 plants). A natural infestation was allowed to develop.

There was an untreated control treatment and in treatments 2-6 two sprays of Movento (0.5 l/ha) were applied. All spray treatments were applied in 300 l/ha water using a knapsack sprayer fitted with 3 x 02F110 nozzles and were applied after the start of either the second, third or fourth generations as indicated by the monitoring on other plots undertaken by Spencer Collins as part of his PhD project (CP 091). Treatments 5 and 6 were sown with dummy pills treated with imidacloprid (Sanokote treatment) – imidacloprid was used to provide continuity with the trial undertaken in 2014. For treatments 7 and 8 crop covers (0.8mm mesh) were used from transplanting to exclude whitefly adults and were removed at the start of either the second (16 July) or third (12 August) generations.

The treatments are summarised in Table 3.5.

Table 3.5 Treatments used in a trial evaluating the best times to apply Movento treatments.

		Whitefly generation		
Code	**Sowing**	**2nd**	**3rd**	**4th**
1	Untreated			
2		Movento	Movento	
3		Movento		Movento
4			Movento	Movento
5	Sanokote	Movento	Movento	
6	Sanokote	Movento		Movento
7	Cover	Uncover		
8	Cover		Uncover	

Figure 3.7 shows the numbers of whitefly on a monitoring plot of kale in 2015. The dates of the emergence of adults of each generation and the dates of spray applications are shown in Table 3.6.

Table 3.6 Timing of whitefly generations and spray application dates in 2015.

White fly generation	Start of emergence	Spray date	Difference in days
First	15 May		
Second	26 June	16 July	20
Third	8 August	12 August	4
Fourth	15 September	18 September	3

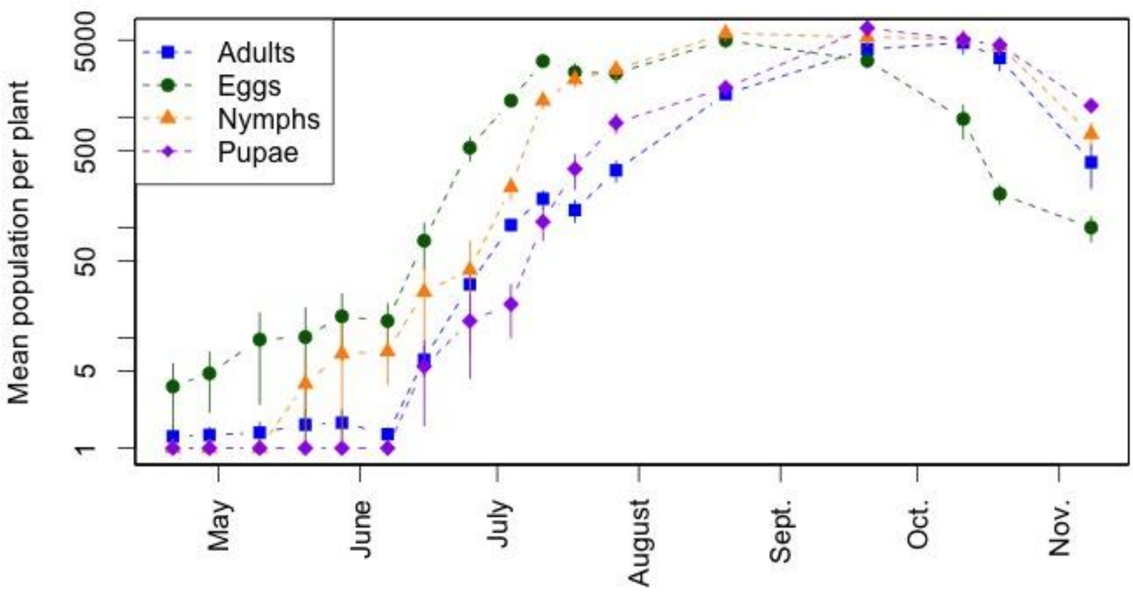

Figure 3.7 Numbers of whitefly on a monitoring plot of kale in 2015 (data from CP 091).

Assessments

The plots were assessed on 8 July (untreated control and Sanokote only), 6 August, 11 September and 12 October. Assessments were made of:

- Number of egg-circles per plant
- Number of leaves with larvae per plant
- Number of adults per plant on a scale of 0-4 where 1 = 1-10, 2 = 11-100, 3 = 101-500 and 4 = >500

The data for eggs and larvae were log transformed before statistical analysis. The data was subjected to Analysis of Variance using the Genstat programme.

Results

The size of the whitefly infestation increased throughout the trial. The results of assessments made post-spraying are shown in Tables 3.7 – 3.10 and Figures 3.8 – 3.10.

On 8 July (pre-spray) the infestation was relatively low but the Sanokote seed treatment reduced numbers of eggs and adult whiteflies compared with the untreated control ($p<0.05$).

On 6 August (after Generation 2 spray) all of the sprayed treatments (T2, T3, T5 and T6) and the covered treatments (T7 and T8) reduced all whitefly life stages compared with the untreated control ($p<0.05$).

On 11 September (After Generation 3 spray) all treatments except T4 (which had only the Generation 3 spray) reduced the numbers of leaves with larvae ($p<0.05$). Additionally, both Sanokote treatments (T5 and T6) and the Movento treatment sprayed at generations 2 and 3 (T2) reduced egg numbers and both Sanokote treatments reduced adults ($p<0.05$).

On 12 October (After Generation 4 spray) both Sanokote treatments (T5 and T6) and the Movento treatment sprayed at generations 2 and 4 (T3) reduced all life stages of the whitefly compared with the untreated ($p<0.05$). Movento at generation 2 and 3 (T2) reduced eggs and adults ($p<0.05$). The two previously covered treatments (T7 and T8) both reduced the numbers of adults compared with untreated ($p<0.05$).

Table 3.7 Mean numbers of egg circles, leaves with larvae and adult scores on 8 July.

Treatment	Egg circles		Larvae		Adults
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	4.47	86.69	-0.337	0.21	2.083
Sanokote (T5)	2.97	18.91	-0.693	0.00	1.208
F-Value	19.26		4.02		42.68
P-Value	0.005		0.092		<0.001
SED	0.342		0.177		0.134
5% LSD	0.838		0.434		0.328
df	6		6		6

Table 3.8. Mean numbers of egg circles, leaves with larvae and adult scores on 6 August. Values followed by * are significantly different from the untreated control (p<0.05).

Code	Treatment	Egg circles		Larvae		Adults
		Log-trans	Back-trans	Log-trans	Back-trans	
1	Untreated	4.059	57.4	1.561	4.26	2.50
2	Movento 2 + 3	2.966*	18.9	1.250*	2.99	2.00*
3	Movento 2 + 4	3.061*	20.9	1.219*	2.88	2.00*
4	Movento 3 + 4	4.205	66.5	1.557	4.24	2.67
5	Sanokote Movento 2 + 3	2.764*	15.4	0.978*	2.16	2.00*
6	Sanokote Movento 2 + 4	2.770*	15.5	1.014*	2.26	2.00*
7	Uncover 2	2.919*	18.0	1.194*	2.80	2.00*
8	Uncover 3	2.095*	7.6	0.906*	1.98	1.54*
	F-Value	12.53		10.61		4.79
	P-Value	<0.001		<0.001		0.003
	SED	0.279		0.108		0.224
	5% LSD	0.587		0.226		0.471
	df	18		18		18

Table 3.9 Mean numbers of egg circles, leaves with larvae and adult scores on 11 September. Values followed by * are significantly different from the untreated control (p<0.05).

Code	Treatment	Egg circles		Larvae		Adults
		Log-trans	Back-trans	Log-trans	Back-trans	
1	Untreated	5.411	223.3	2.328	9.75	2.88
2	Movento 2 + 3	4.431*	83.5	0.653*	1.42	2.21
3	Movento 2 + 4	4.978	144.7	1.437*	3.71	2.29
4	Movento 3 + 4	5.688	294.7	2.611	13.11	3.17
5	Sanokote Movento 2 + 3	3.860*	47.0	0.268*	0.81	1.75*
6	Sanokote Movento 2 + 4	4.029*	55.7	0.759*	1.64	2.08*
7	Uncover 2	5.175	176.2	2.300	9.48	2.63
8	Uncover 3	5.152	172.2	1.844	5.82	2.54
	F-Value	5.68		15.63		3.88
	P-Value	0.001		<0.001		0.010
	SED	0.392		0.316		0.326
	5% LSD	0.824		0.664		0.685
	df	18		18		18

Table 3.10 Mean numbers of egg circles, leaves with larvae and adult scores on 12 October. Values followed by * are significantly different from the untreated control (p<0.05).

Code	Treatment	Egg circles		Larvae		Adults
		Log-trans	Back-trans	Log-trans	Back-trans	
1	Untreated	5.91	367.1	2.248	8.97	3.58
2	Movento 2 + 3	4.33*	75.7	1.909	6.25	2.38*
3	Movento 2 + 4	4.56*	95.1	1.617*	4.54	2.54*
4	Movento 3 + 4	6.00	403.9	2.161	8.18	3.67
5	Sanokote Movento 2 + 3	4.25*	69.7	1.467*	3.84	2.17*
6	Sanokote Movento 2 + 4	3.59*	35.8	1.171*	2.73	1.96*
7	Uncover 2	5.27	194.5	2.022	7.06	2.71*
8	Uncover 3	4.82	124.0	2.297	9.45	2.50*
	F-Value	6.23		4.87		6.20
	P-Value	<0.001		0.003		<0.001
	SED	0.475		0.260		0.354
	5% LSD	0.998		0.545		0.743
	df	18		18		18

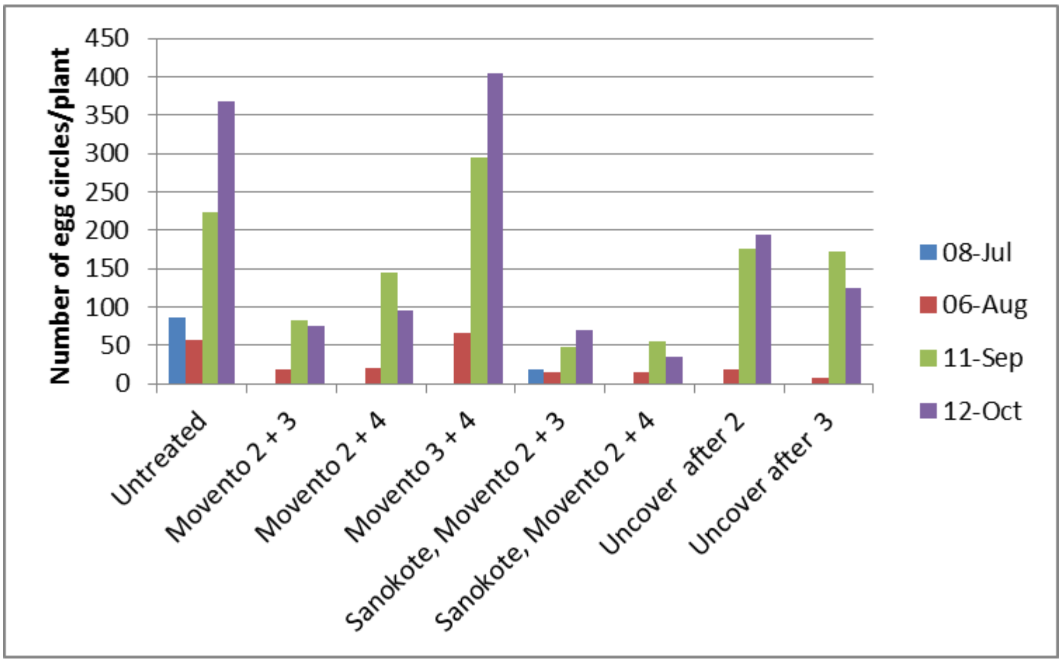

Figure 3.8 Mean numbers of egg circles per plant.

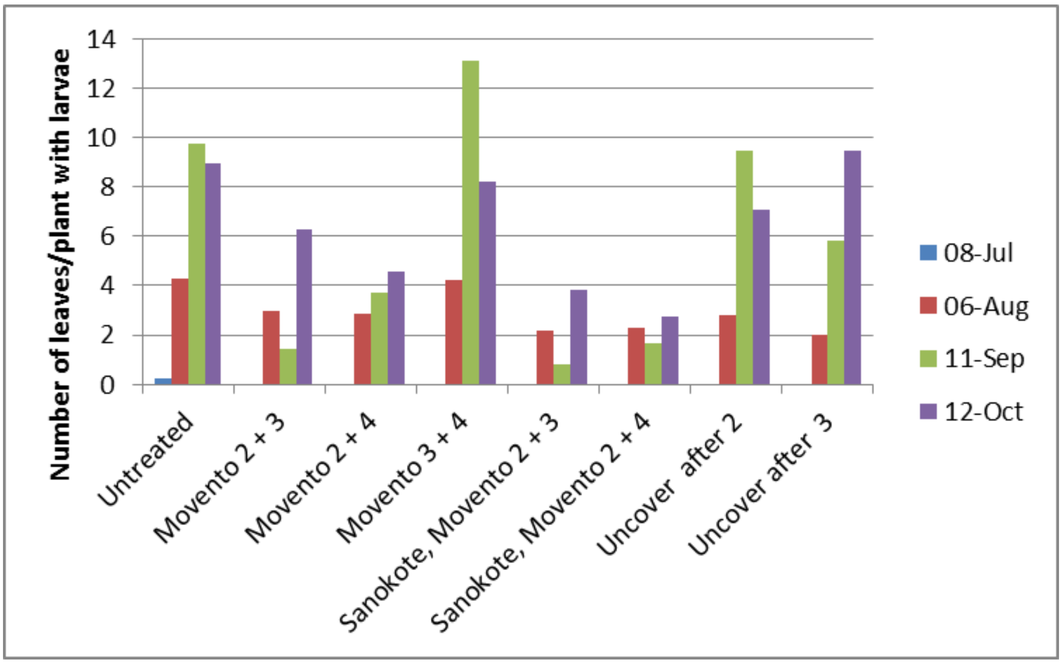

Figure 3.9 Mean numbers of leaves with larvae per plant**.**

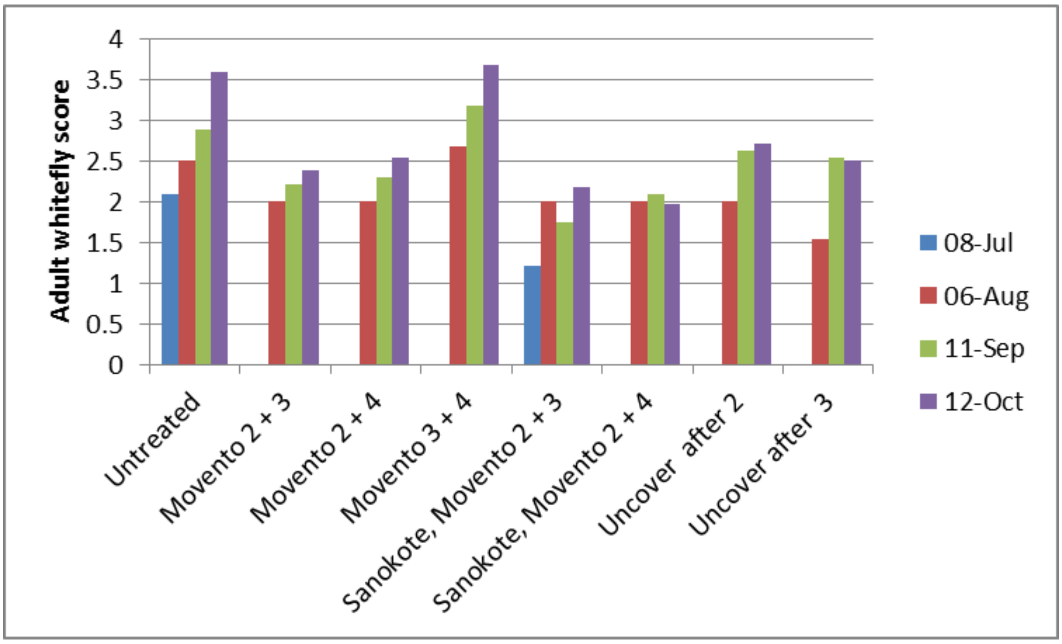

Figure 3.10 Mean adult score per plant.

Objective 4: Investigate the most effective overall treatment strategy for whitefly control

Trial 4.1 - 2014

Materials and methods

This objective was addressed in 2014 with a field trial on field plots of kale (cv Reflex). The kale seed was sown on 23 April and the plants were transplanted on 21 May. There were 4 replicates of 5 treatments including an untreated control, arranged in a randomized block design and the plots were 3.5 m x 1 bed (3 plants). A natural infestation was allowed to develop.

For each of the four insecticide treatments, the aim was to apply a single spray of Movento (0.5 l/ha) after the start of either the first, second, third or fourth generations as indicated by the monitoring on other plots undertaken by Spencer Collins as part of his PhD project (CP 091). All spray treatments were applied in 400 l/ha water using a knapsack sprayer fitted with 3 x 02F110 nozzles. Figure 4.1 shows the numbers of whitefly on a monitoring plot of kale in 2014. The dates of the emergence of adults of each generation and the dates of spray application are shown in Table 4.1.

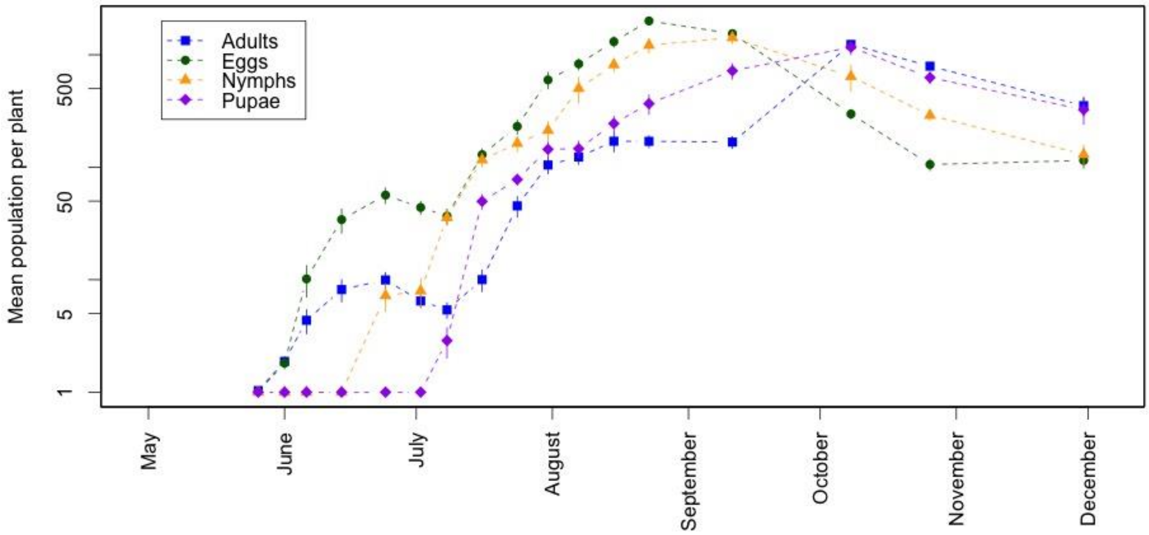

Figure 4.1 Mean numbers of whitefly per plant on kale at Wellesbourne in 2014. Data provided by Spencer Collins.

Table 4.1 Timing of whitefly generations and spray application dates in 2014.

White fly generation	Start of emergence	Spray date	Difference in days
First	29 May	9 June	11
Second	9 July	17 July	8
Third	7 August	20 August	13
Fourth	12 September	12 September	0

Assessments

The plots were assessed on 30 July 5 September and 26 September. Assessments were made of:

- Number of egg-circles per plant
- Number of leaves with larvae per plant
- Number of adults per plant on a scale of 0-4 where 1 = 1-10, 2 = 11-100, 3 = 101-500 and 4 = >500

The data on eggs and larvae were square-root transformed prior to statistical analysis.

Results

Tables 4.2 – 4.4 and Figures 4.2 - 4.4 show the mean numbers of egg circles, leaves with larvae and adult score on 3 occasions following application of a single spray of Movento on different application dates timed to coincide with the start of each generation of whitefly at Wellesbourne.

The plots sprayed on 17 July had lower numbers of egg circles than the untreated control on all 3 assessment dates, lower numbers of larvae on the first two assessment dates and lower numbers of adults on the last two assessment dates. The plots sprayed on 20 August had lower numbers of larvae and adults on the last assessment date. Overall, a single spray applied either on 17 July or 20 August appeared to reduce the infestation more effectively that sprays on 9 June or 12 September.

Table 4.2 Mean numbers of egg circles, leaves with larvae and adult score on 30 July. Values followed by * are significantly different from the untreated control ($p<0.05$).

Treatment	**Egg circles**		**Larvae**		**Adults**	
	Per plot sqrt	Per plant Back-trans	Per plot sqrt	Per plant Back-trans	Per plot	Per plant
Untreated control	7.2	8.6	1.7	0.5	3.7	0.6
Sprayed 9 June	7.5	9.3	1.9	0.6	6.8	1.1
Sprayed 17 July	1.2*	0.2	0.0*	0.0	3.2	0.5
Sprayed 20 August	7.7	10.0	1.1	0.2	5.9	1.0
Sprayed 12 September	9.5	15.2	1.5	0.4	6.5	1.1
P-Value	0.028		0.314		0.656	
SED	2.335		0.944		2.094	
LSD (5%) (two-sided)	4.977		2.012		4.462	
LSD (5%) (one-sided)	4.093		1.655		3.670	

Table 4.3 Mean numbers of egg circles, leaves with larvae and adult score on 5 September. Values followed by * are significantly different from the untreated control (p<0.05).

Treatment	Egg circles		Larvae		Adults	
	Per plot sqrt	Per plant Back-trans	Per plot sqrt	Per plant Back-trans	Per plot	Per plant
Untreated control	38.5	247.5	7.3	8.8	10.5	1.8
Sprayed 9 June	42.6	302.4	9.4	14.6	11	1.8
Sprayed 17 July	14.9*	37.1	2.8*	1.3	6	1.0
Sprayed 20 August	18.1	54.7	6.6	7.2	7	1.2
Sprayed 12 September	43.0	308.5	7.9	10.3	10.75	1.8
P-Value	0.110		0.003		0.301	
SED	12.943		1.385		2.885	
LSD (5%) (two-sided)	27.587		2.951		6.150	
LSD (5%) (one-sided)	22.689		2.427		5.058	

Table 4.4 Mean numbers of egg circles, leaves with larvae and adult score on 26 September. Values followed by * are significantly different from the untreated control (p<0.05).

Treatment	Egg circles		Larvae		Adults	
	Per plot sqrt	Per plant Back-trans	Per plot sqrt	Per plant Back-trans	Per plot	Per plant
Untreated control	47.9	381.7	9.2	14.2	19	3.2
Sprayed 9 June	49.9	415.7	10.4	17.9	19.8	3.3
Sprayed 17 July	20.8*	72.2	7.4	9.1	11.8	2.0
Sprayed 20 August	23.9	95.1	4.6*	3.5	13.5	2.3
Sprayed 12 September	43.8	319.2	8.8	12.8	18	3.0
P-Value	0.147		0.002		0.076	
SED	13.841		1.139		3.101	
LSD (5%) (two-sided)	29.501		2.428		6.610	
LSD (5%) (one-sided)	24.263		1.997		5.436	

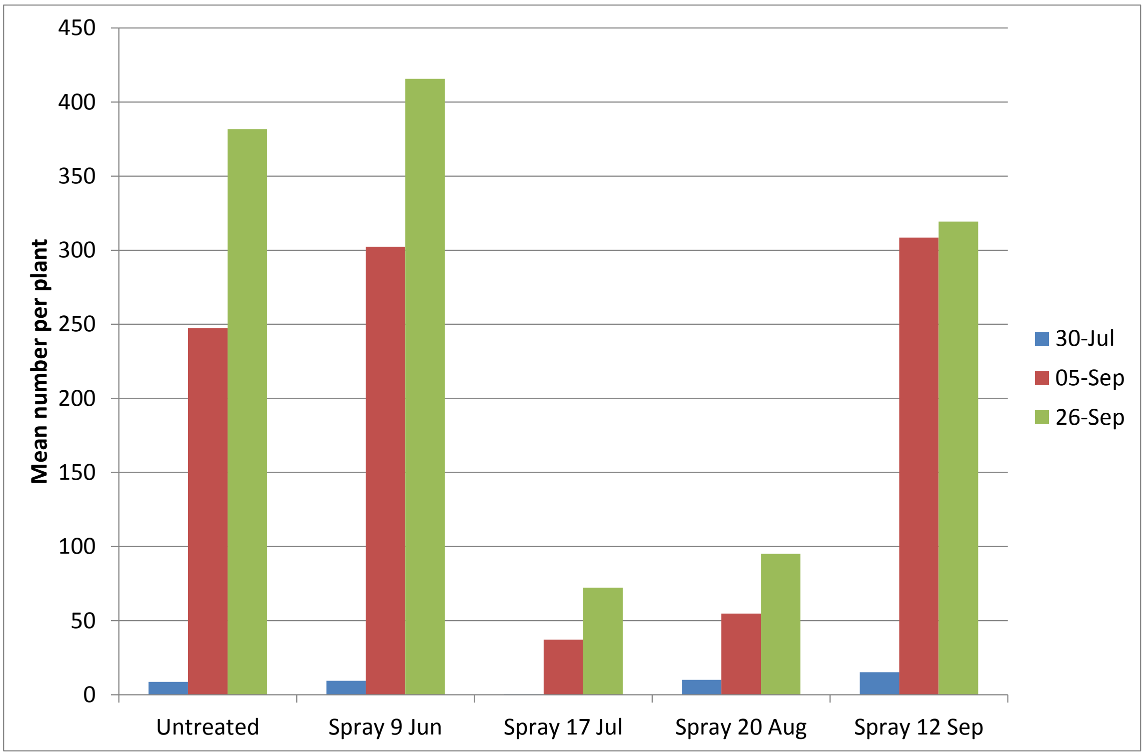

Figure 4.2 Mean number of egg circles per plant on 3 assessment occasions.

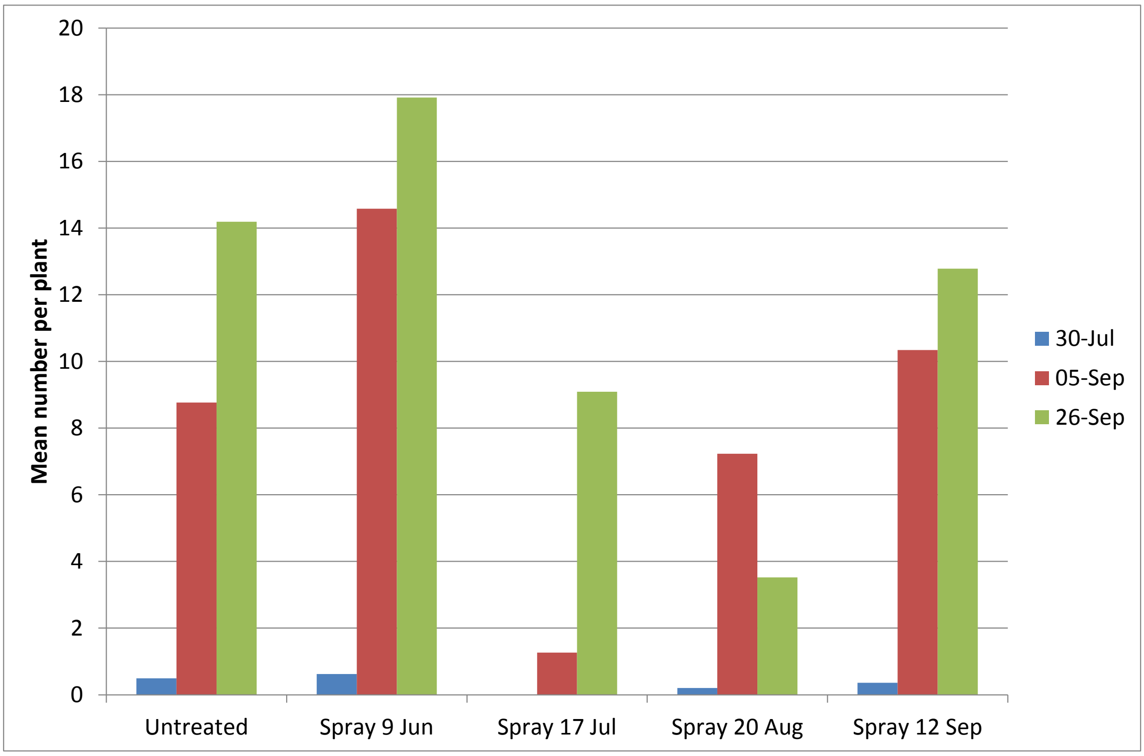

Figure 4.3 Mean number of leaves with larvae per plant on 3 assessment occasions.

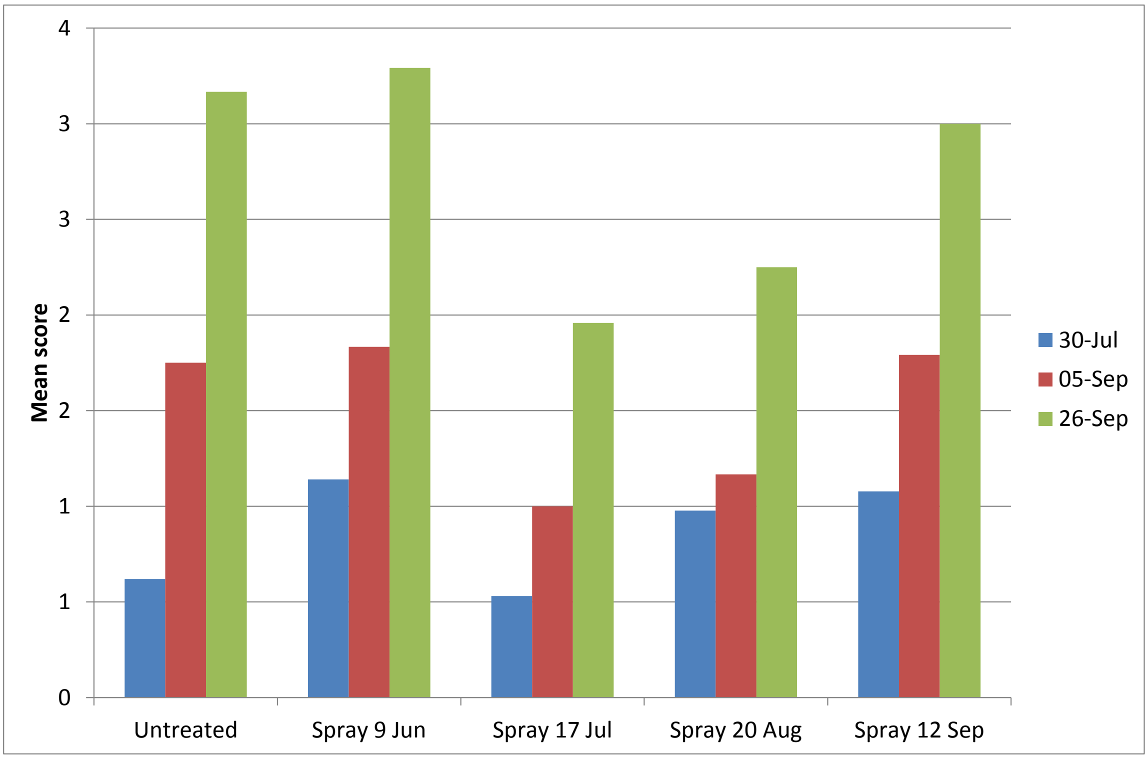

Figure 4.4 Mean adult score per plant on 3 assessment occasions.

Trial 4.2 - 2015

Materials and Methods

The aim of this trial was to investigate the efficacy of different insecticides applied as two sprays in a four spray programme based on Movento. The Movento sprays were applied as the two middle treatments in the programme based on the results obtained in 2014.

Kale seed (cv Winterbor) was sown on 10 April and the plants were transplanted on 28 May. There were 4 replicates of 5 treatments including an untreated control, arranged in a randomized block design and the plots were 3.5 m x 1 bed (3 plants). A natural infestation was allowed to develop.

There was an untreated control treatment and in treatments 2-5 two sprays of Movento (0.5 l/ha) were applied soon after the start of the second and third generations as indicated by the monitoring on other plots undertaken by Spencer Collins as part of his PhD project (CP 091). The other insecticides (Table 4.5) were applied at the start of the first and fourth generations. All spray treatments were applied in 300 l/ha water using a knapsack sprayer fitted with 3 x 02F110 nozzles and were applied with the wetter Phase II (except Movento which required no wetter). The sprays were applied on 29 June, 16 July, 12 August and 18 September.

Table 4.5 Insecticide programmes applied

	Whitefly generation			
	1st	**2nd**	**3rd**	**4th**
1	Untreated			
2	HDCI 075	Movento	Movento	HDCI 075
3	HDCI 086	Movento	Movento	HDCI 086
4	HDCI 085	Movento	Movento	HDCI 085
5	HDCI 073	Movento	Movento	HDCI 073

Assessments

Assessments were made on 26 June (untreated control only), 15 July, 7 August, 8 September and 9 October. Assessments were made of:

- Number of egg-circles per plant
- Number of leaves with larvae per plant
- Number of adults per plant on a scale of 0-4 where 1 = 1-10, 2 = 11-100, 3 = 101-500 and 4 = >500

The data for eggs and larvae were log transformed before statistical analysis. The data was subjected to Analysis of Variance using the Genstat programme.

Results

On 26 June (pre spray) the whitefly infestation was low. On untreated plots the mean numbers of eggs, leaves with larvae and adult whitefly score were 6.17, 0 and 0.88 respectively. The whitefly infestation in the untreated plots then increased throughout the trial.

The results of assessments made post-spraying are shown in Tables 4.6 - 4.9 and Figures 4.5 – 4.7. On 15 July (after the first spray) treatment differences were only significant for larvae with HDCI 073 significantly reducing numbers of leaves with larvae compared with the untreated ($p<0.05$). HDCI 085 also reduced numbers but this was not quite significant. On 7 August (after one Movento spray), 8 September (after 2 Movento sprays) and 9 October (after the final coded spray) all treatments reduced all life stages compared with the untreated ($p<0.05$). There were no significant differences between the treatment programmes.

Table 4.6 Mean numbers of egg circles, leaves with larvae and adult scores on 15 July. Values followed by * are significantly different from the untreated control (p<0.05).

Treatment	Egg circles		Larvae		Adults
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	3.795	44.0	0.410	1.01	1.90
HDCI 075 + Movento	3.831	45.6	0.501	1.15	2.02
HDCI 086 + Movento	3.999	54.1	0.483	1.12	1.99
HDCI 085 + Movento	3.573	35.1	0.028	0.53	1.90
HDCI 073 + Movento	3.766	42.7	-0.416*	0.16	1.74
F-Value	3.63		10.19		3.76
P-Value	0.057		0.003		0.052
SED	0.113		0.175		0.079
5% LSD	0.261		0.403		0.181
df	8		8		8

Table 4.7 Mean numbers of egg circles, leaves with larvae and adult scores on 7 August. Values followed by * are significantly different from the untreated control (p<0.05).

Treatment	Egg circles		Larvae		Adults
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	4.946	140.16	1.960	6.60	2.50
HDCI 075 + Movento	1.052*	2.36	-0.633*	0.03	1.00*
HDCI 086 + Movento	1.272*	3.07	-0.696*	0.00	1.03*
HDCI 085 + Movento	0.870*	1.89	-0.675*	0.01	0.99*
HDCI 073 + Movento	0.810*	1.75	-0.692*	0.00	0.98*
F-Value	138.2		814.3		65.15
P-Value	<0.001		<0.001		<0.001
SED	0.213		0.058		0.118
5% LSD	0.492		0.135		0.271
df	8		8		8

Table 4.8 Mean numbers of egg circles, leaves with larvae and adult scores on 8 September. Values followed by * are significantly different from the untreated control (p<0.05).

Treatment	**Egg circles**		**Larvae**		**Adults**
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	4.90	133.92	2.653	13.70	2.76
HDCI 075 + Movento	2.56*	12.47	-0.704*	0.00	1.69*
HDCI 086 + Movento	2.83*	16.41	-0.695*	0.00	1.52*
HDCI 085 + Movento	2.28*	9.28	-0.675*	0.01	1.26*
HDCI 073 + Movento	2.28*	9.31	-0.622*	0.04	1.02*
F-Value	19.58		1964		18.76
P-Value	<0.001		<0.001		<0.001
SED	0.352		0.048		0.219
5% LSD	0.813		0.110		0.506
df	8		8		8

Table 4.9 Mean numbers of egg circles, leaves with larvae and adult scores on 9 October. Values followed by * are significantly different from the untreated control (p<0.05).

Treatment	**Egg circles**		**Larvae**		**Adults**
	Log-trans	Back-trans	Log-trans	Back-trans	
Untreated	4.72	111.66	2.226	8.76	3.19
HDCI 075 + Movento	2.22*	8.71	0.212*	0.74	1.61*
HDCI 086 + Movento	1.46*	3.81	-0.080*	0.42	1.31*
HDCI 085 + Movento	1.74*	5.18	-0.252*	0.28	1.29*
HDCI 073 + Movento	2.35*	10.04	-0.425*	0.15	1.60*
F-Value	10.27		48.29		10.17
P-Value	0.003		<0.001		0.003
SED	0.571		0.220		0.351
5% LSD	1.316		0.508		0.809
df	8		8		8

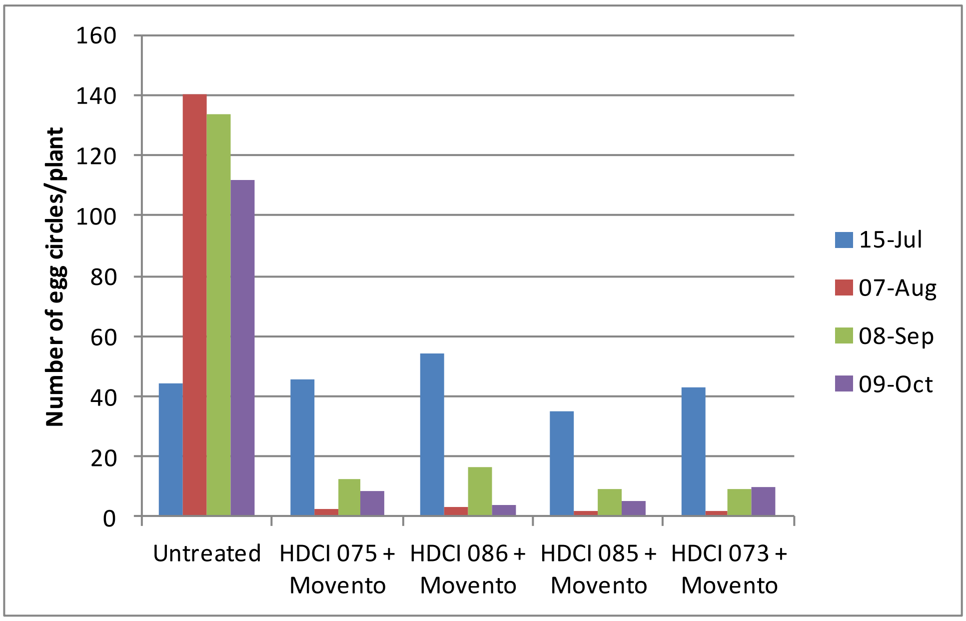

Figure 4.5 Mean number of egg circles per plant on 4 assessment occasions.

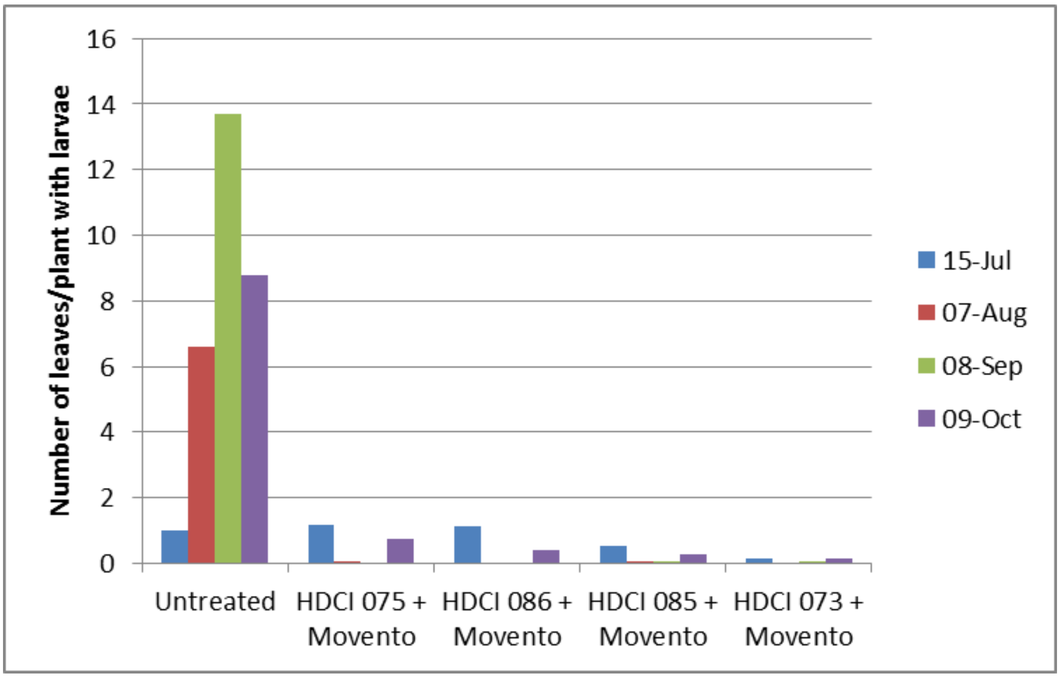

Figure 4.6 Mean number of leaves with larvae per pant on 4 assessment occasions.

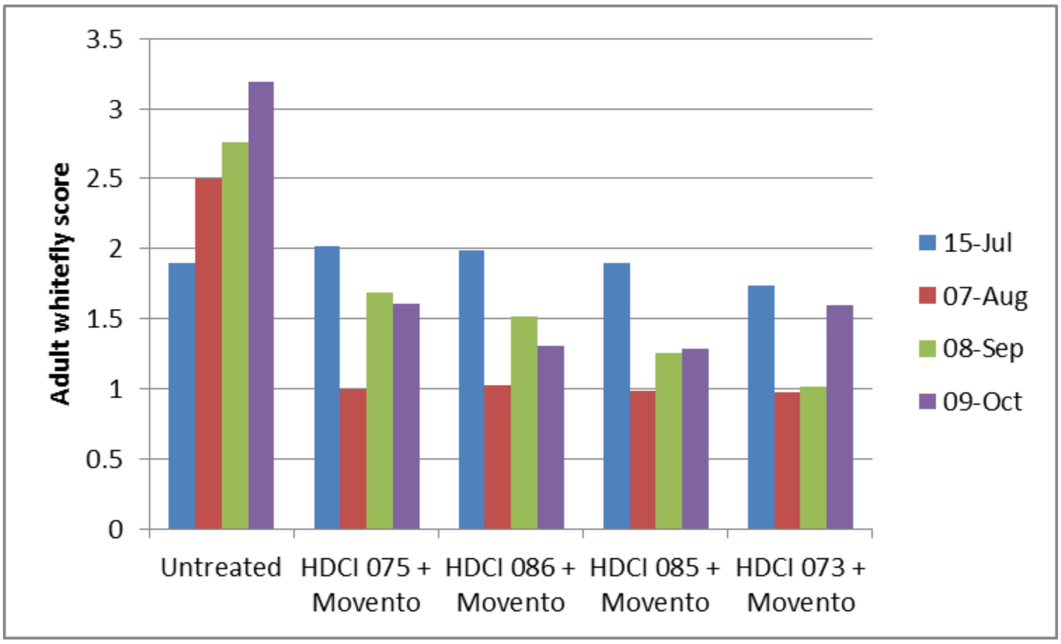

Figure 4.7 Mean adult score per plant on 4 assessment occasions.

Discussion

The overall aim of the current project was to improve understanding of the biology and ecology of cabbage whitefly to help growers minimise the development of whitefly infestations and control unacceptable infestations effectively. It focuses particularly on the assessment of novel methods of control and on the timing of the most promising of these together with existing treatments. Obviously, even with the relatively small number of treatments evaluated, there are a huge number of combinations of sequences and application and assessment timings, of which only a small number could be explored. The intent with the design of the trials undertaken was to try and address some of the key questions, address them in the context of the whitefly life-cycle where possible, and evaluate the outcomes of the trials in a robust way (replication etc.). In addition, the three 'insecticide' trials in 2015 all used the same cultivar of kale, were planted on the same day and sprayed on the same days as appropriate to the objectives of each trial. They were also assessed at similar times – although not on the same days – because of the time required to undertake a full assessment.

Insecticides and biopesticides

The field trials in the two years confirmed the efficacy of Movento (spirotetramat), HDCI 073 and HDCI 075 as foliar sprays (Figures 5.1 and 5.2 show percentage infestation versus the untreated control). In 2015, HDCI 085 and HDCI 086 also showed statistically-significant levels of control. The trials also indicated that Sanokote seed treatment with imidacloprid suppressed the development of whitefly infestations, particularly early in the season, compared with the untreated control. Overall, reductions compared with the untreated control in the numbers of egg circles and larvae were 'greater' than reductions in adults (e.g. Figure 5.1), which probably reflects the mobility of the adults, which may move from plot to plot very readily. The biopesticide HDCI 074 reduced the numbers of larvae.

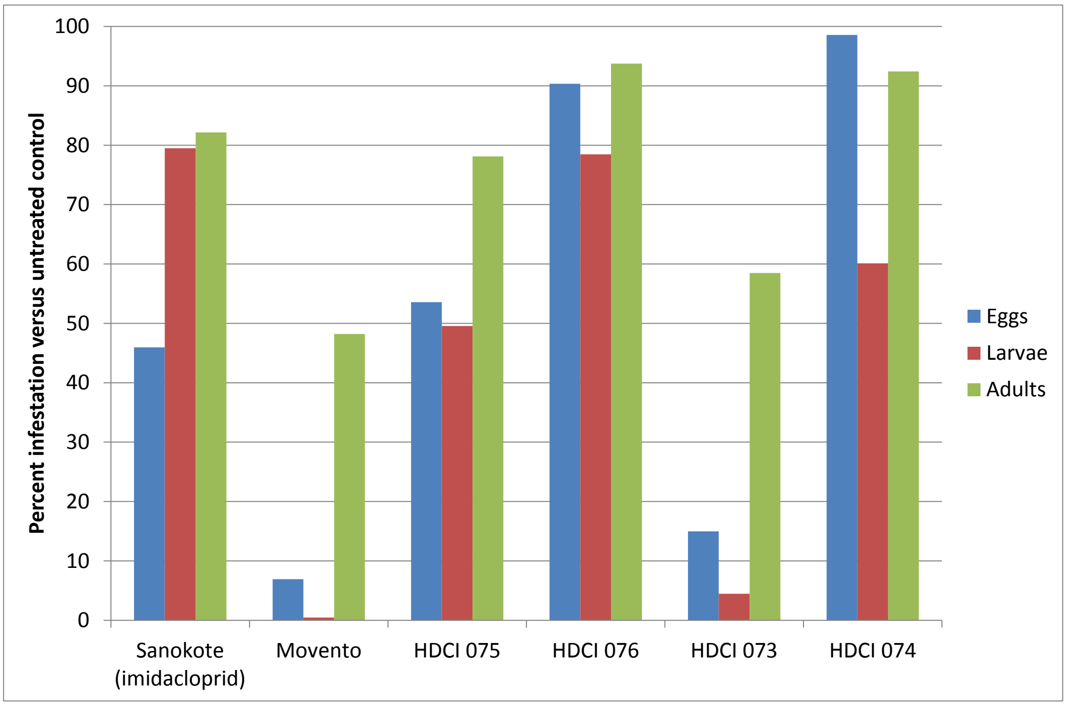

Figure 5.1 Trial 1.1 – percentage infestation on treated plots versus untreated control. Assessment made on 22 October 2014 (38 days after last spray) with the last sprays in the programme applied on 12 September. N.B. 'Eggs' are the number of egg circles and 'larvae' are the number of leaves with larvae.

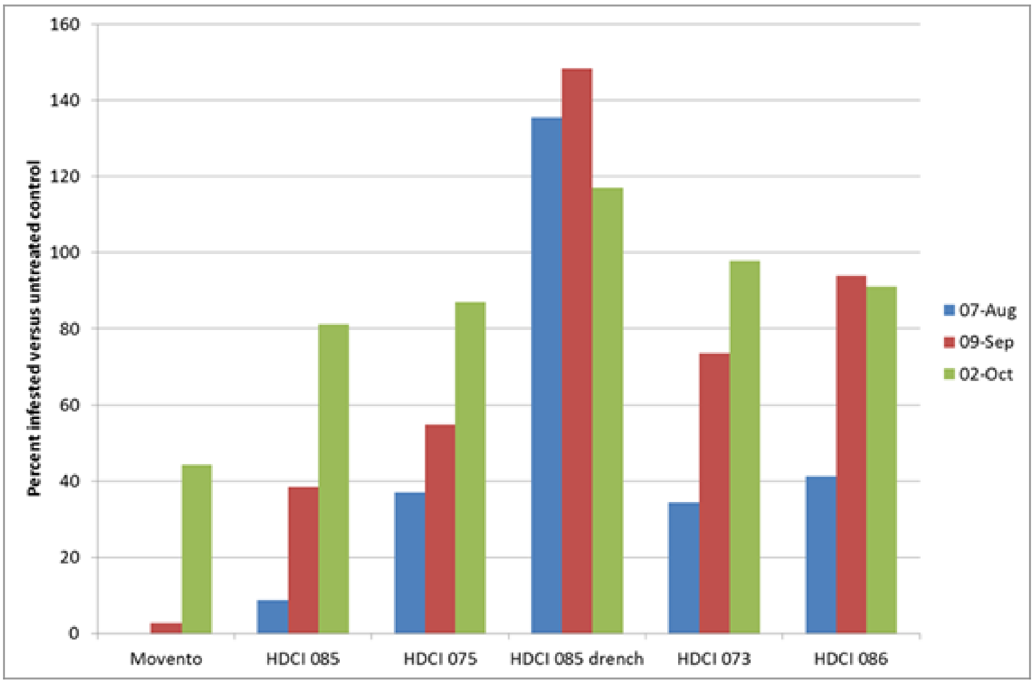

Figure 5.2 Trial 1.2 – percentage infestation on treated plots versus untreated control – number of leaves per plant with larvae - 2015. Treatments were applied on 16 July and 12 August 2015.

Biological control

The failure to produce and subsequently test the parasitoids in the field in 2014 in Trial 2.1 was a substantial disappointment. Despite this, useful data were still extracted from the trial in relation to insecticides and crop covers. In 2015, attempts were made to rear and release parasitoids into open plots at Warwick Crop Centre. Simon Springate produced vials of adult parasitoids at approximately weekly intervals and these were introduced onto kale plants infested with cabbage whitefly which were maintained in a polytunnel at Warwick Crop Centre (University of Warwick). The culture was not maintained in the Insect Rearing Unit at Wellesbourne because of the risk of contaminating the cultures of cabbage whitefly with parasitoids. Production at Warwick Crop Centre was inconsistent and compounded by regular infestations of *Myzus persicae* which interfered with both whitefly production and parasitoid rearing. However, despite these problems, each plot was inoculated with an average of 244 parasitoid pupae overall. Unfortunately there were no treatment differences in the field trial for any life stage of the whitefly on any assessment date. Counts from paired plots were very similar, the largest differences occurring between different locations. Small numbers of parasitized whitefly larvae were observed, predominantly on the last assessment date in Long Meadow West but there appeared to be little or no impact on whitefly numbers. Spencer Collins has monitored whitefly populations at Warwick Crop Centre and elsewhere quite intensively over the last 3 years and encountered very few naturally parasitized larvae.

Crop covers and sowing time treatments

The potential value of short-term netting for exclusion of adult whiteflies was shown in both years, with some effects persisting to the end of the trial. They were more effective in 2014 than in 2015. Obviously the practicalities and costs of using such an approach need to be considered. The sowing time treatments with a neonicotinoid insecticide (imidacloprid), tested in Trials 1.1, 3.1, 3.2 (imidacloprid was used for continuity), showed similar early season effects. These persisted to some degree throughout the trials and could be a more viable alternative on a field scale. It might be expected that Phytodrip treatment with the neonicitinoid thiamethoxam would perform similarly to imidacloprid although it has not been tested directly.

Treatment timing

Treatment timing was investigated in several trials. The application of crop covers in Trial 2.1 between 7 July and 6 August led to a considerable reduction in the size of the subsequent infestation which persisted until the final assessment on 17 November (Figure 5.3).

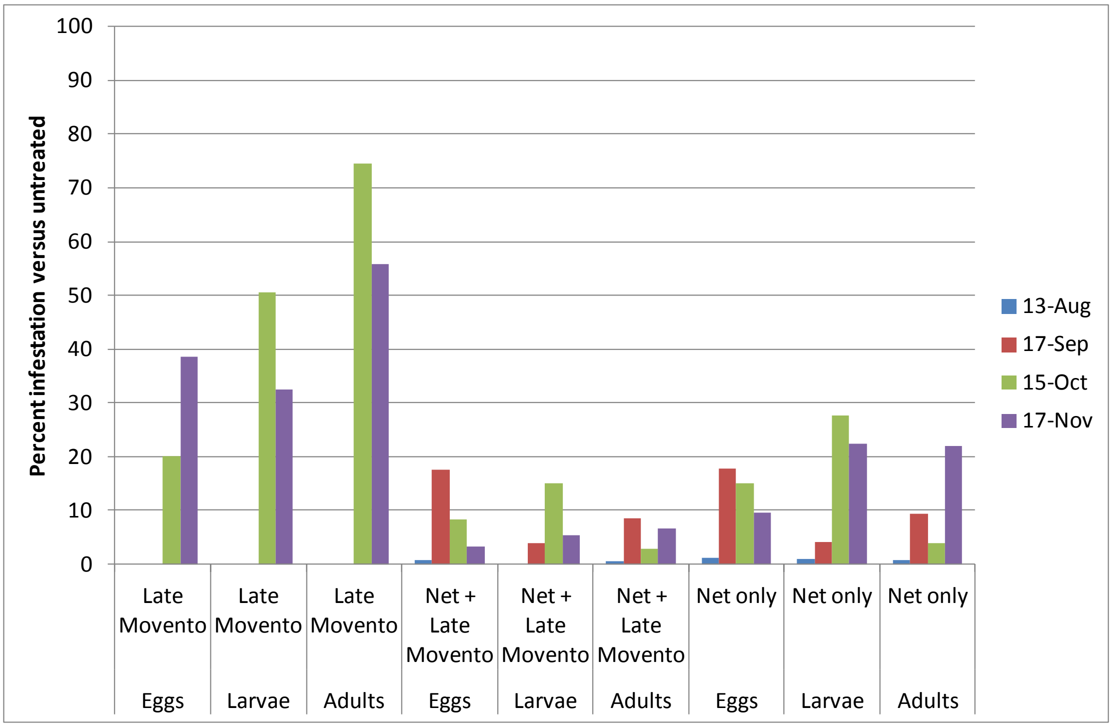

Figure 5.3 Trial 2.1 – percent infestation versus untreated control. Covers in place 7 July – 6 August and late Movento spray applied on 22 September. N.B. 'Eggs' are the number of egg circles and 'larvae' are the number of leaves with larvae.

Similarly, the applications of Movento on either 17 July or 20 August in Trial 4.1 were the most effective treatments at the final assessment on 26 September (Figure 5.4), whereas the spray applied very early (9 June) and the late spray (12 September) had no, or much less, impact. This was reinforced by the results of Trial 3.2 when the programmes where Movento sprays were applied after generations 2 + 3 or 2 + 4 were relatively more effective than the programme where sprays were applied after generations 3 + 4.

From these trials there is evidence that the treatment programme should be focussed in mid-summer, even though the size of the infestation may not be large by then and the crop may still be some time away from harvest and that the Movento sprays should be deployed during this period.

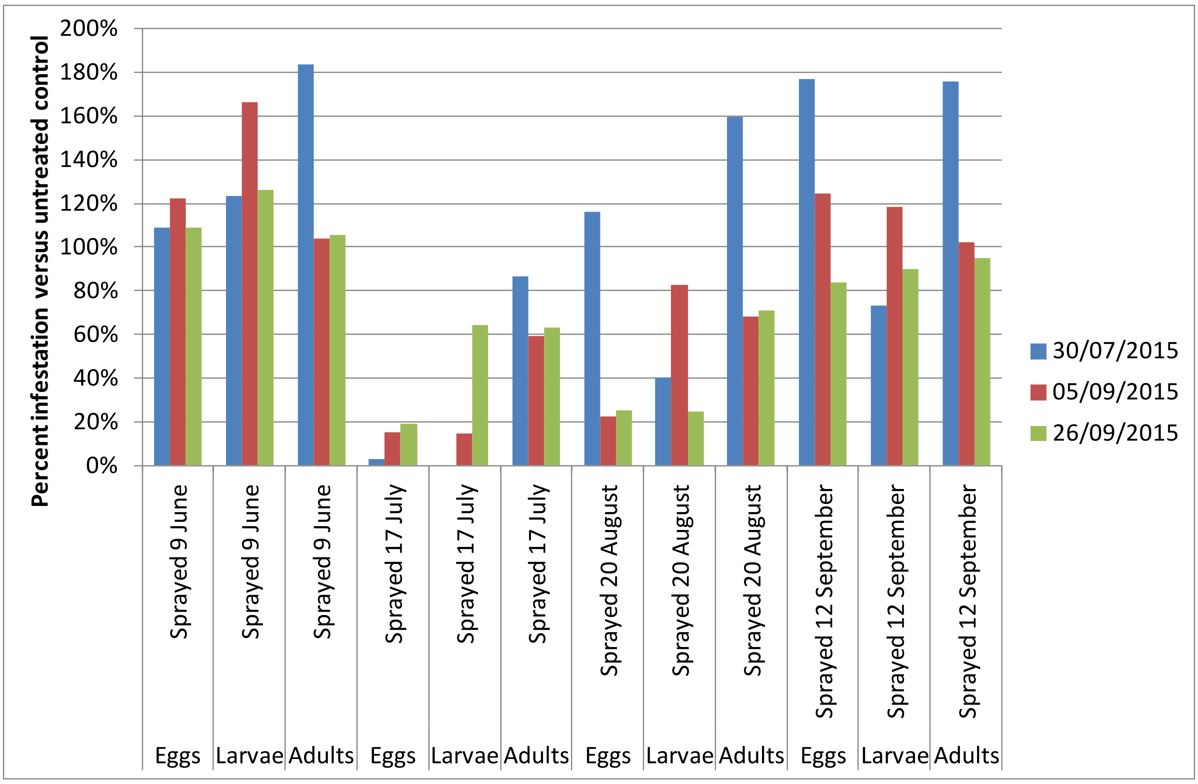

Figure 5.4 Trial 4.1 – percent infestation versus untreated control. N.B. 'Eggs' are the number of egg circles and 'larvae' are the number of leaves with larvae.

Figures 5.5 and 5.6 show the mean numbers of whitefly eggs, larvae (nymphs) and eggs per adult averaged over 5 insecticide-free plots of kale at Wellesbourne in 2014 and 2015. All of these declined considerably during September and October as part of the natural life-cycle. Different insecticide treatments are likely to have varying direct effects on the different life stages of whitefly. For example, as diapausing female insects (which would not lay eggs until the following spring) were developing at the time of late Movento application in Trial 2.1, the effect of this product could only have a limited, if significant, impact on egg-laying. This may explain the limited effect of Movento treatment in Trial 2.1 when comparing the netting treatments, despite a significant reduction in the late Movento only treatment compared to the untreated control. Similarly, Trials 3.2 and 4.1 both indicated that late sprays of Movento were less effective than those applied in July and August. It should also be noted that Movento, which needs to be taken into the plant's system, is potentially less effective when the weather cools in late summer and plant growth is much slower.

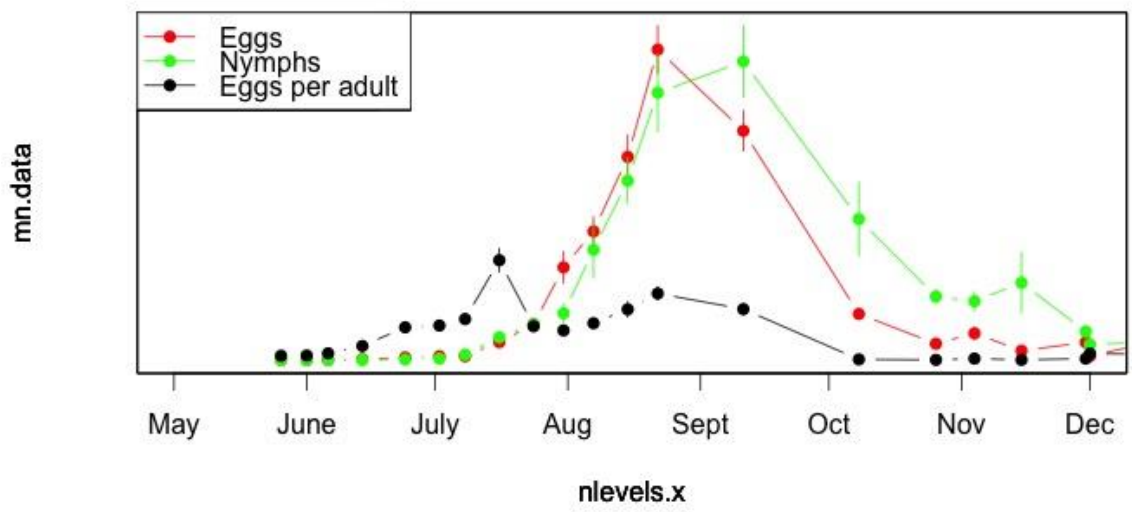

Figure 5.5 Numbers of whitefly eggs, larvae (nymphs) and eggs per adult averaged over 5 plots of kale at Wellesbourne in 2014. Data from CP 091.

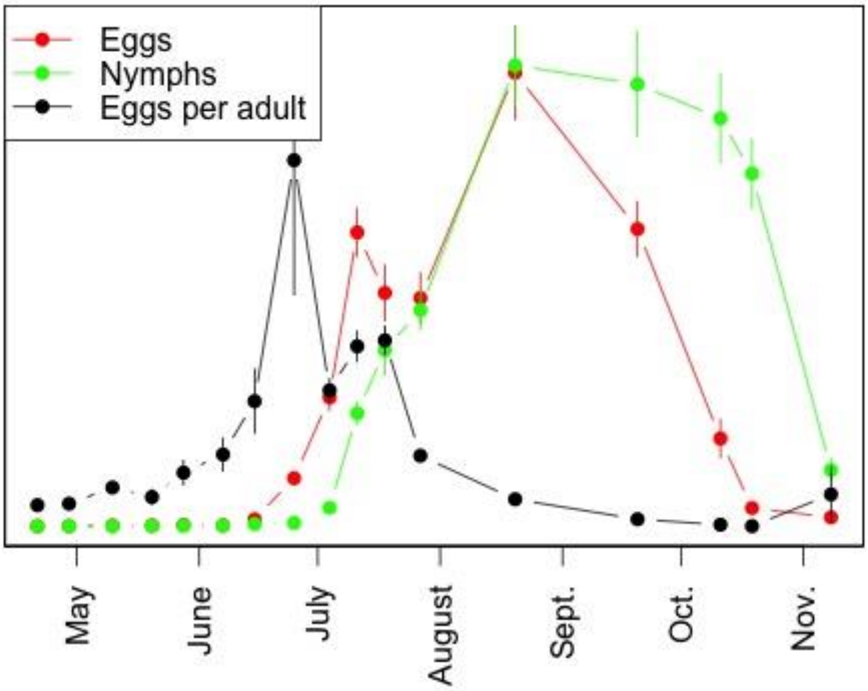

Figure 5.6 Numbers of whitefly eggs, larvae (nymphs) and eggs per adult averaged over 5 plots of kale at Wellesbourne in 2015. Data from CP 091.

Persistence of treatments

In Trial 3.1, the effects of the spray treatments applied on 20 August and of the Sanokote (imidacloprid) treatment applied on 23 April persisted until 17 September (statistically-significant effect) (4 weeks after spraying and 21 weeks after sowing) and the effect of the Movento treatment persisted longer. Similarly, the effects of the treatments applied in Trial 1.1 persisted for 40 days after the last spray was applied (Figure 5.1). In Trial 1.2 (2015) effects persisted for at least 51 days after the second (last) spray of a number of test products. The reduction was greatest with eggs and after treatment with Movento (Figure 5.5). In Trial 3.2 (2015) again the greatest reduction in numbers was seen with eggs and persisted 61 days after the 'Generation 3' spray (Figure 5.6). The 'persistence' is likely to arise from two effects: 1) the continuing (but diminishing) presence of the pesticide - as with the Sanokote treatment and possibly also with Movento and HDCI 073 to a certain extent and 2) the persistence of the effect of a reduction in whitefly numbers at a critical time in the life cycle that cannot be rapidly 'made-up' by the insect. This might particularly be the case if dispersal of adults was insignificant in the period post-treatment.

The three 'insecticide' trials in 2015 all used the same cultivar of kale, were planted on the same day and sprayed on the same days as appropriate to the objectives of each trial. They were also assessed at similar times – although not on the same days – because of the time required to undertake a full assessment. This means that they can be compared informally. Figures 5.7-5.9 show the data from all 3 trials for eggs, larvae and adults respectively. In general, the sizes of the infestations (as illustrated by untreated control treatments) in the three trials were comparable, although the abundance of eggs in particular appeared to be greater in Trial 3.2.

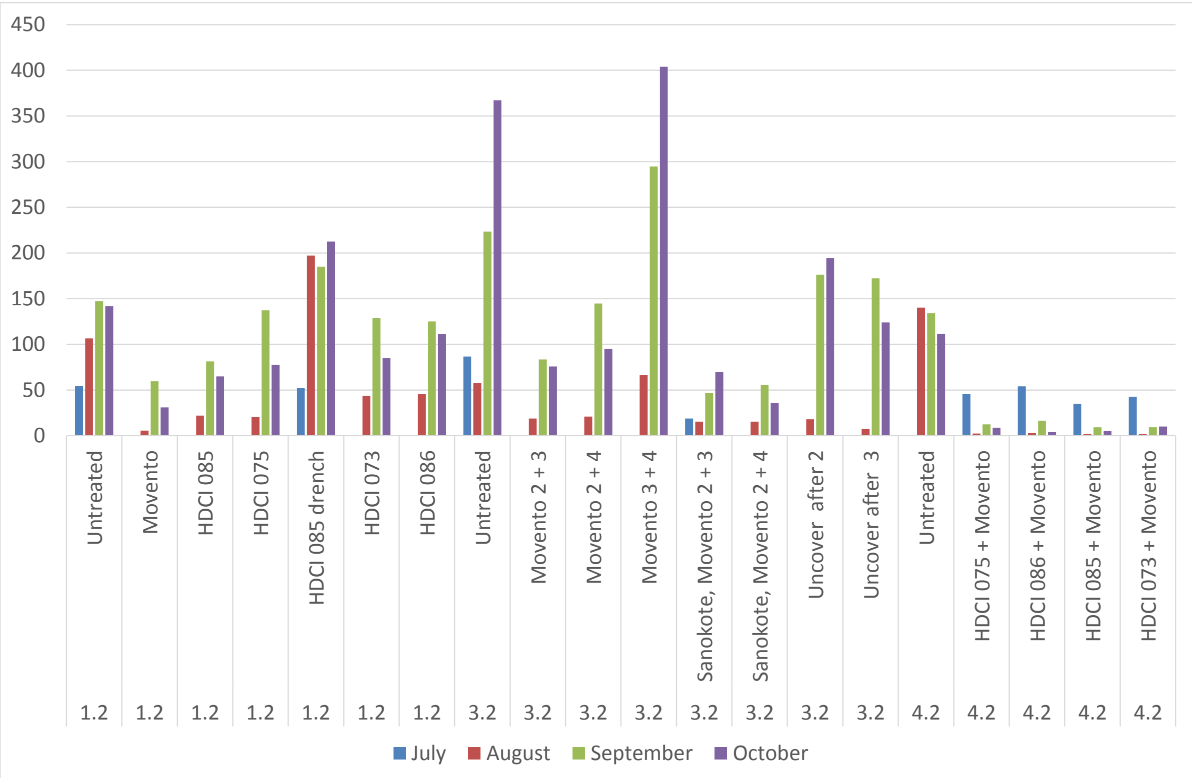

Figure 5.7 Mean number of egg circles per plant – Trials 1.2, 3.2 and 4.2 in 2015.

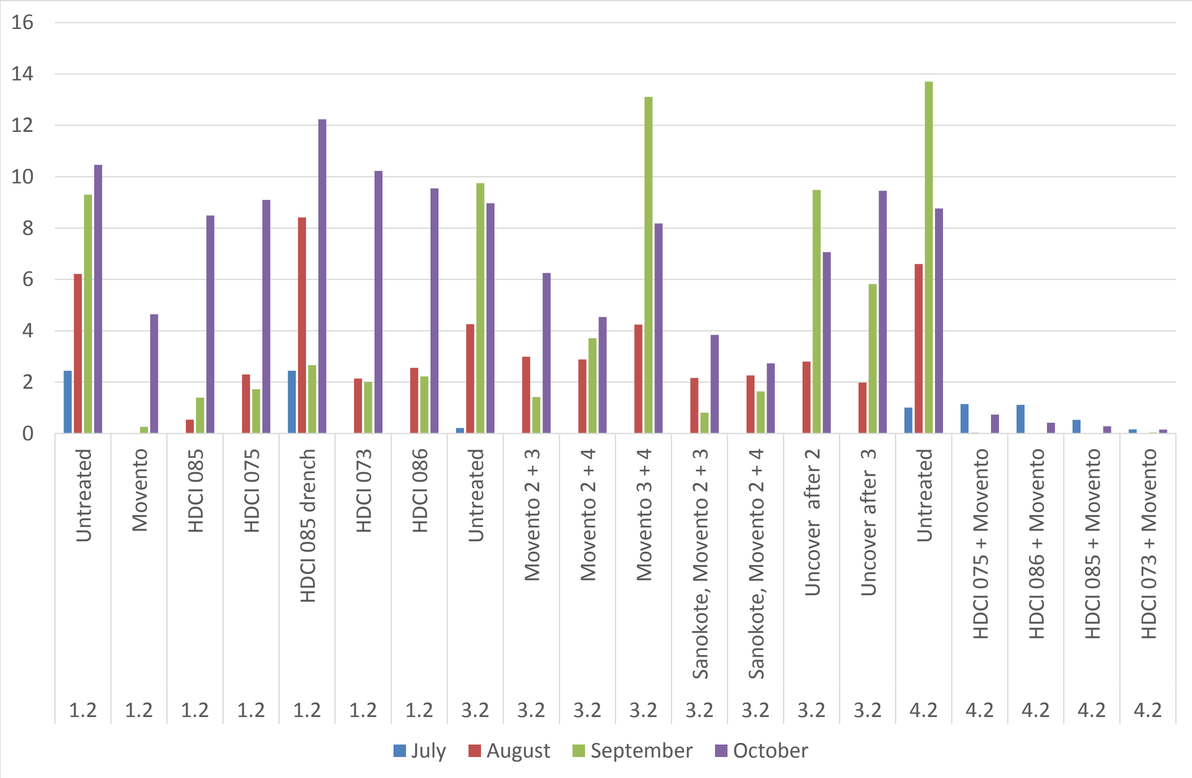

Figure 5.8 Mean number of leaves per plant infested with larvae – Trials 1.2, 3.2 and 4.2 in 2015.

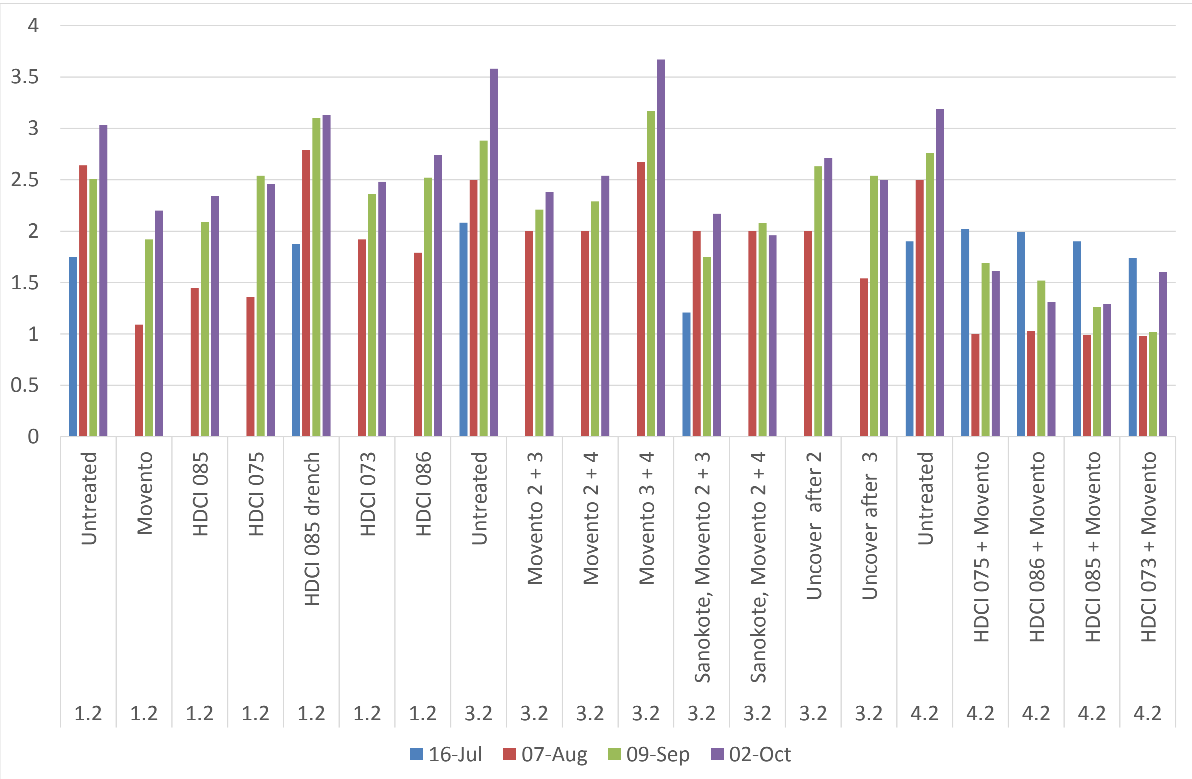

Figure 5.9 Infestation with adults (score) – Trials 1.2, 3.2 and 4.2 in 2015.

Figures 5.10-5.12 compare the percent infestation versus the untreated control for eggs, larvae and adults in Trial 4.2 (programmes of 4 sprays with Movento as the two ‘middle’ treatments) with the percent infestation versus the control for the treatments in Trials 1.2 and 3.2 where only two sprays of Movento were applied – but at the same time as the Movento sprays were applied in Trial 4.2. These graphs indicate the ‘added value’ of the extra treatments at the start and end of the progamme.

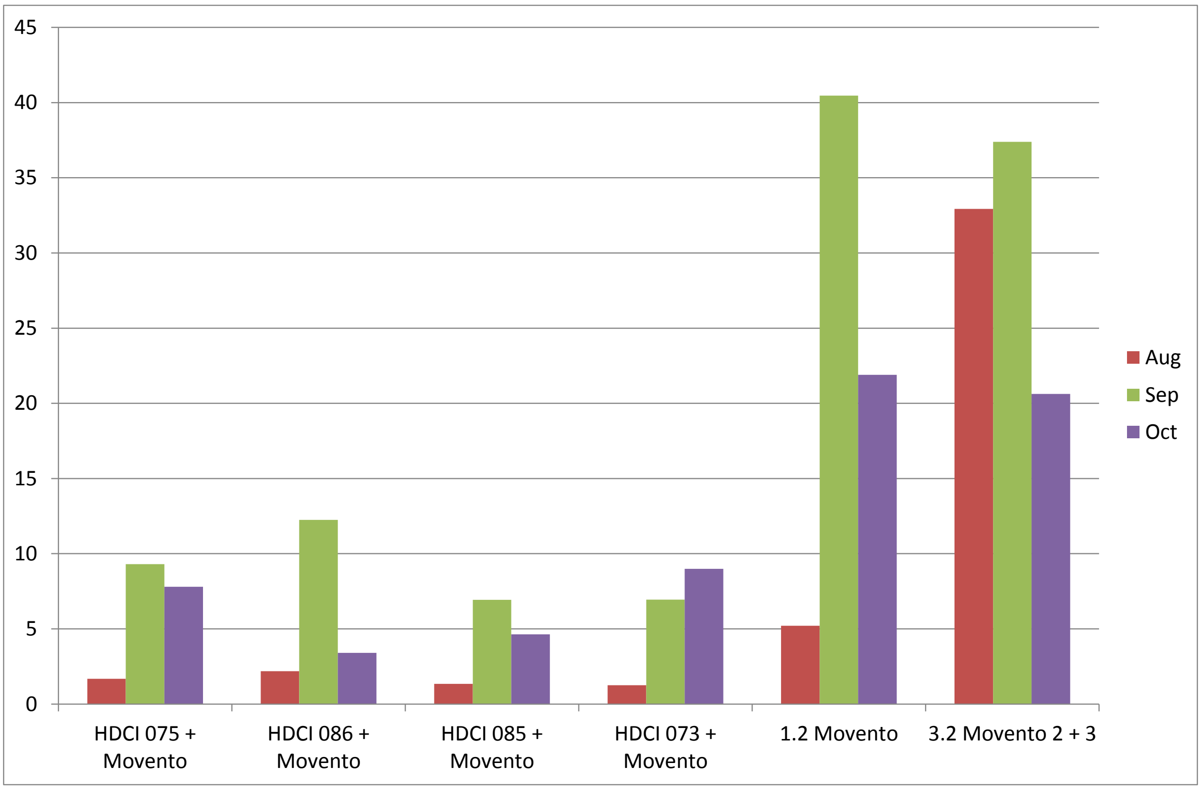

Figure 5.10 Mean number of egg circles per plant – comparison of the percent infestation versus the untreated control in Trial 4.2 (programmes of 4 sprays with Movento as the two ‘middle’ treatments) with the percent infestation versus the control for the treatments in Trials 1.2 and 3.2 where only two sprays of Movento were applied – but at the same time as the Movento sprays were applied in Trial 4.2.

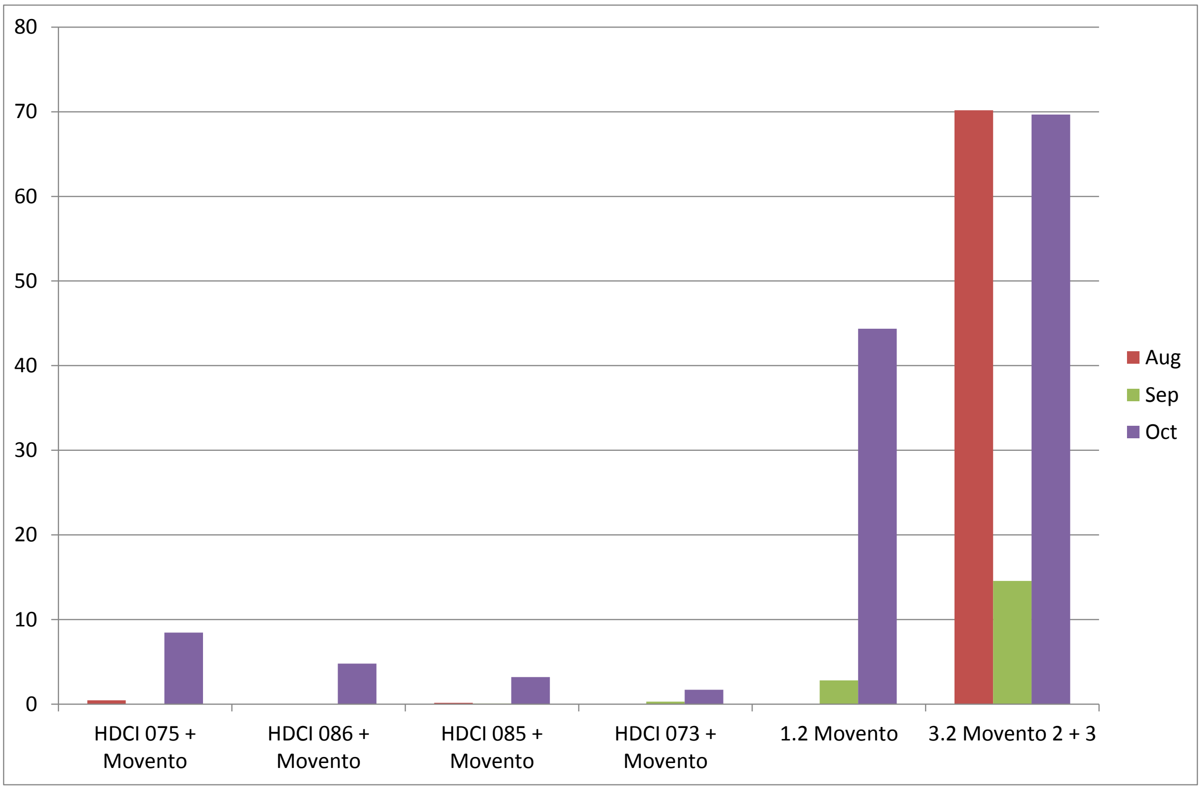

Figure 5.11 Mean number of leaves infested with larvae per plant – comparison of the percent infestation versus the untreated control in Trial 4.2 (programmes of 4 sprays with Movento as the two 'middle' treatments) with the percent infestation versus the control for the treatments in Trials 1.2 and 3.2 where only two sprays of Movento were applied – but at the same time as the Movento sprays were applied in Trial 4.2.

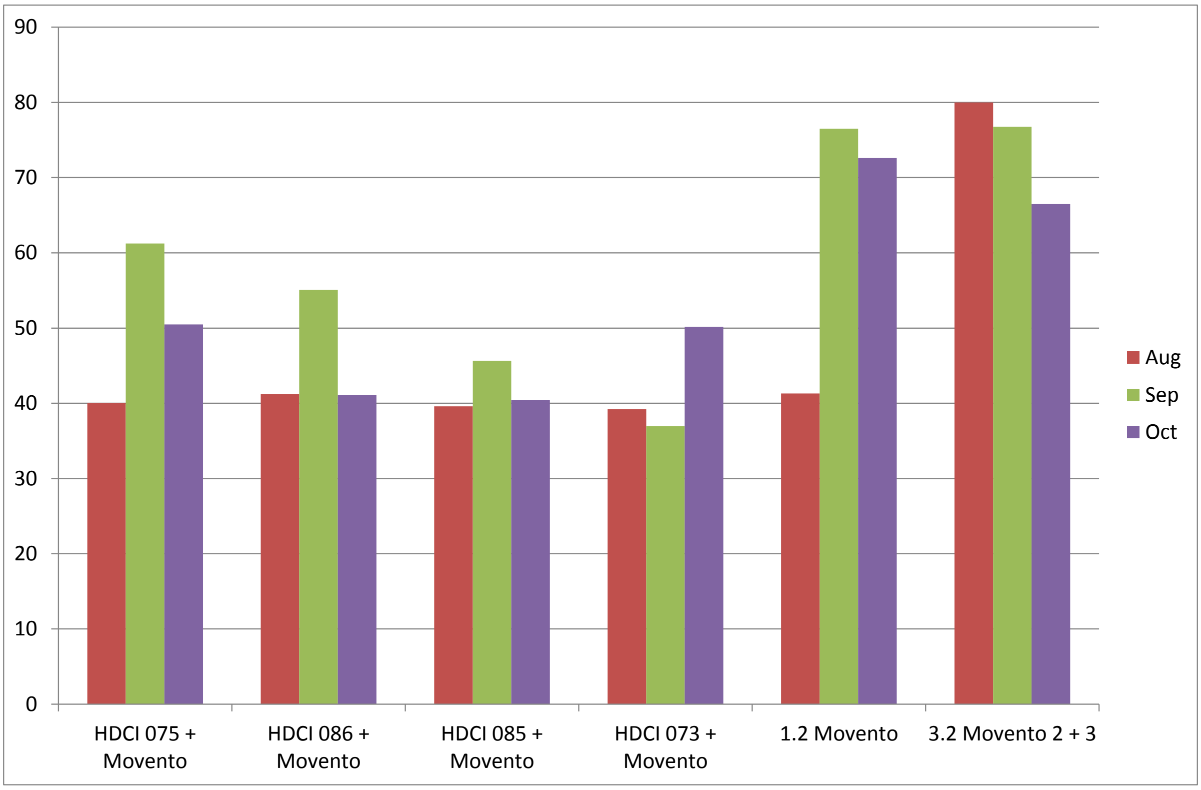

Figure 5.12 Infestation with adults (score) – comparison of the percent infestation versus the untreated control in Trial 4.2 (programmes of 4 sprays with Movento as the two 'middle' treatments) with the percent infestation versus the control for the treatments in Trials 1.2 and 3.2 where only two sprays of Movento were applied – but at the same time as the Movento sprays were applied in Trial 4.2.

Acknowledgements

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References

Ester, A., Van de Zande, J.C. and Frost, A.J.P. (1994). Crop covering to prevent pest damage to field vegetables and the feasibility of pesticide application through polyethylene nets. Proceedings of the Brighton Crop Protection Conference, Pests and Diseases 2:761-766.

Finch, S. and Collier, R.H. (2000). Integrated pest management in field vegetable crops in Northern Europe - with focus on two key pests. Crop Protection 19:817-824.

Saucke, H. and Giessmann, M. (2003). Eignung verschiedener Kulturschutz-Netze und Vliese zur Regulierung der Kohlmottenschildlaus (*Aleyrodes proletella*) in Rosenkohl. In Rau, F. & Buck, H. (eds.), Versuche im niedersächsischen Öko-Gemüsebau - 2002 - Ergebnisse-Analysen-Empfehlungen. Kompetenzzentrum Ökolandbau Niedersachsen GmbH, Visselhövede, Germany. 115-118.

Saucke, H., Schultz, B. and Predatova, M. (2004). Eignung verschiedener Kulturschutz-Netze und Vliese zur Regulierung der Kohlmottenschildlaus (*Aleyrodes proletella*) in Rosenkohl. In Rau, F. & Buck, H. (eds.), Versuche im niedersächsischen Öko-Gemüsebau - 2003 - Ergebnisse-Analysen-Empfehlungen. Kompetenzzentrum Ökolandbau Niedersachsen GmbH, Visselhövede, Germany. 145-149.

Schultz, B., Zimmerman, O., Liebig, N., Wedemeyer, R., Leopold, J., Rademacher, J., Katz, P., Rau, F. and Saucke, H. (2010) Anwendung natürlich vorkommender Gegenspieler der Kohlmottenschildlaus (KMSL) in Kohlgemüse im kombinierten Einsatz mit Kulturschutznetzen. Federal Ministry of Food Agriculture and Consumer Protection (BMELV), Bonn, Germany.

FV 399 - Improving control of Brassica whitefly (Aleyrodes proletella). 2011-2012.
CP 091 - Studentship - Biology of cabbage whitefly (Aleyrodes proletella). 2012-2016.
FV 406 - Brassicas: integrated management of whitefly (Aleyrodes proletella). 2012-2013.