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Project leader:	Rosemary Collier and Simon Springate
Report:	Annual
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Location of project:	Warwick Crop Centre University of Greenwich Elsoms Seeds
Industry Representative:	Andy Blair
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Date project completed (or expected completion date):	28 February 2016

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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CONTENTS

GROWER SUMMARY

Headline

Field trials using a range of approaches to manage cabbage whitefly are beginning to indicate some of the components of an effective treatment programme.

Background

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 provides useful background information. Recent research in the UK has focused on insecticidal control (data obtained in other HDC 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. The HDC has recently been developing a portfolio of work addressing whitefly control on brassica crops and to date this has involved three projects: FV 399 - to evaluate insecticide spray programmes and application strategies that might improve control of brassica whitefly; FV 406 – to field test the impact of releasing parasitoid wasps (*Encarsia tricolor*) and explore the impact of early insecticide applications; CP 091 - an HDC Studentship at Warwick Crop Centre (Spencer Collins) on the biology of cabbage whitefly.

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. and Elsoms Seeds.

Summary

Objective 1: Trial 1 - Investigate additional treatments for whitefly control.

The aim of this replicated plot trial was to determine the relative efficacy of treatments for whitefly control. The crop was kale (cv. Reflex) and this was sown on 23 April and transplanted on 13 May. There was an untreated control, one sowing-time treatment (Sanokote – Gaucho (imidacloprid)) and the other treatments (Movento (spirotetramat), HDCI 075, HDCI 076, HDCI 073 (coded insecticides), HDCI 074 (coded bio-insecticide)) were applied as foliar sprays to an established infestation of whitefly. Treatments (4 replicates) were applied on: 20 August (all treatments), 27 August (HDCI 074 only), 3 September (HDCI 074 only) and 12 September (all treatments). Comparative assessments of the Sanokote (imidacloprid) treatment and the untreated control were made on 2 occasions (7 August, 19 August) and all plots were assessed on 22 October, 40 days after the last spray was applied (Figure 1). The size of the whitefly infestation increased throughout the trial. Lower numbers of egg circles, leaves infested with larvae and adults (score) were found on the plants treated with Sanokote throughout the trial but these differences were statistically significant on the first assessment date (7 August) only. When all treatments were compared on 22 October, there were statistically-significant differences between treatments for all three life stages. Compared with the untreated control, the numbers of egg circles, larvae and adults were reduced by Movento, HDCI 075 and HDCI 073, whilst HDCI 074 reduced the numbers of larvae.

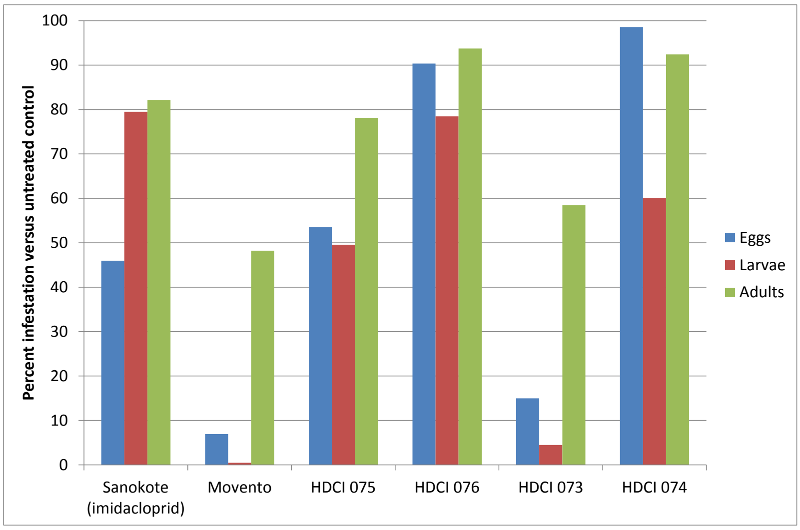

Figure 1. Trial 1 – percentage infestation on treated plots versus untreated control. Assessment made on 22 October and the last sprays in the programme were applied on 12 September (40 days after last spray).

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

The aim was to field test the impact of parasitoid releases on whitefly infestations on kale and to explore the effect of early netting covers. A production system for the parasitoid wasp *Encarsia tricolor* was established at Syngenta Bioline to provide insects for field release. An experimental field trial was carried out in 2014 on 22 x 13 plant kale plots in Lincolnshire. Each treatment was applied to 4 plots (Table 1). In two treatments, netting (0.77mm mesh) was applied soon after planting and removed 4 weeks later. Following the collapse of the parasitoid production, an alternative strategy of late season Movento application was applied to the relevant plots, to contribute to other project objectives. Three demonstration plots (9 x 9 plants) were treated with simplified insecticide programs for comparison (Table 1). An AZO knapsack sprayer powered by compressed air with VP02F conventional nozzles was used for spray application.

Table 1 Experimental treatments applied in the field trial

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 / -**

Whitefly numbers on the trial site were lower than in previous years. Short-term netting covers significantly disrupted whitefly infestation (C and D). Late Movento applications in September also reduced whitefly levels and contamination in October and November, with an additive effect to those plots previously covered by netting (D), making this the most successful treatment in terms of adult whitefly numbers and leaves contaminated with larvae (Figure 2). In the unreplicated demonstration plots, only those treatments including Movento led to significant reductions. While HDCI 073 was highly effective on small plants in FV 406, application to larger plants in the demonstration plot was ineffective, suggesting a need for good coverage when using this product.

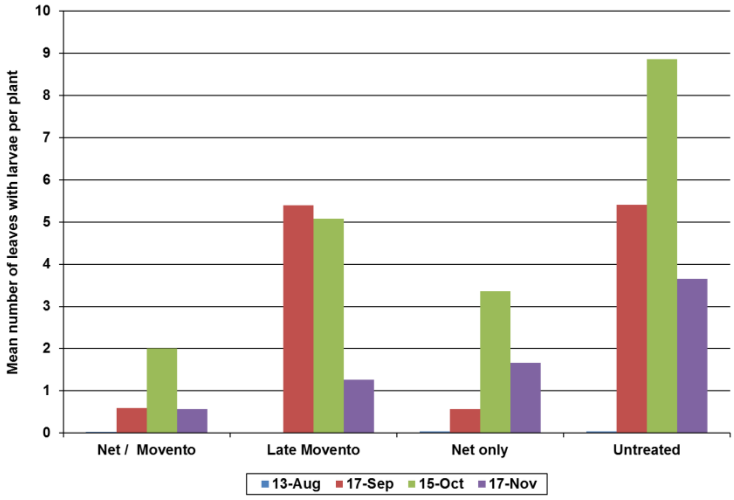

Figure 2 Number of leaves with larvae per plant (treatments ranked by level of control on 17 November).

Objective 3 Trial 3 - Investigate the most effective overall treatment strategy for whitefly control

This objective was addressed with a field trial on field plots of kale (cv. Reflex). The seed was sown on 23 April and the plants were transplanted on 21 May. A natural infestation was allowed to develop. For each of four insecticide treatments, a single spray of Movento was applied soon after the start of either the first, second, third or fourth generations of the field population of whitefly at Wellesbourne, as indicated by the monitoring on other plots undertaken by Spencer Collins as part of project CP 091. The sprays were applied on 9 June, 17 July, 20 August or 12 September. There was also an untreated control.

The plots were assessed on 30 July, 5 and 26 September. 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 (Figure 3). The plots sprayed on 17 July had lower numbers of egg circles than the untreated control on all three assessment dates, lower numbers of larvae on the first two assessment dates and lower numbers of adults on the last two assessment dates ($p<0.05$). The plots sprayed on 20 August had lower numbers of larvae and adults on the last assessment date ($p<005$).

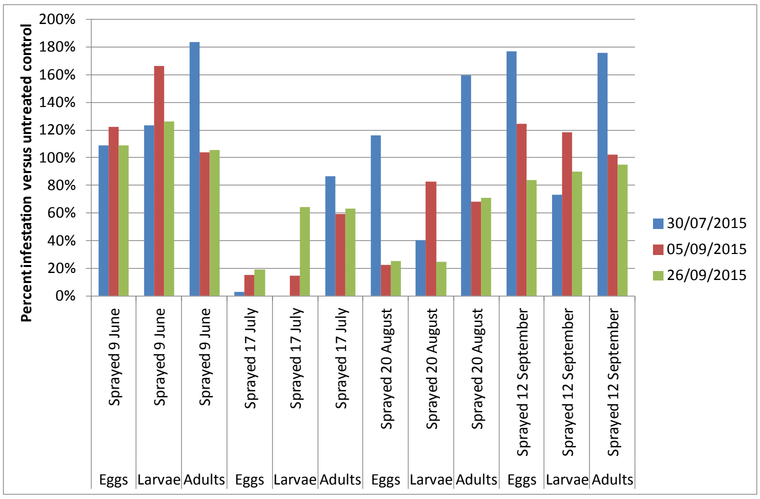

Figure 3 Trial 3 – percent infestation versus the untreated control.

Objective 4: Trial 4 - Investigate the most effective way to use Movento and other effective insecticides in terms of the interval between treatments.

The aim of this trial was to investigate the persistence of three treatments and an untreated control (4 replicates). The treatments were Movento, Sanokote (imidacloprid) and HDCI 075. The plants (cv. Reflex) were sown on 23 April and transplanted on 21 May and sprayed on 20 August. Assessments were made on 7 and 19 August (Sanokote (imidacloprid) 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, both spray treatments had reduced the number of whitefly egg circles, larvae and adults compared with the untreated control. By 23 October there were no differences between treatments in the numbers of adults, but larval numbers were reduced by all four treatments and Movento appeared to be having a continued effect on egg numbers.

Discussion

The field trials confirmed the efficacy of Movento (spirotetramat) and HDCI 073 as foliar sprays for whitefly control and indicated that Sanokote seed treatment with imidacloprid (Gaucho) suppressed the development of whitefly infestations, particularly early in the season. HDCI 075 also showed statistically-significant levels of control with a reasonable amount of persistence. Overall, compared with the untreated control, reductions in numbers of egg circles and larvae were 'greater' than reductions in numbers of adults, which probably reflects the mobility of the adults to a certain extent, as they may move from plot to plot very readily.

The failure to produce and subsequently test the parasitoids in the field was a substantial disappointment and prevented the primary function of the trial in Objective 2 from being achieved. Despite this, useful data were still extracted from the trial in relation to insecticides and crop covers since the potential value of short-term netting for exclusion of adult whiteflies was shown, with the effects persisting to the end of the trial. However, a heavier infesting pest pressure would be required to test other eventualities. Also data from studentship CP 091 may indicate whether such short-term covers would be effective in other cases or if whitefly immigration is less predictable.

Treatment timing was investigated particularly in Trials 2 and 3. The application of crop covers in Trial 2 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 2). Similarly, the applications of Movento on either 17 July or 20 August in Trial 3 were the most effective treatments at the final assessment on 26 September (Figure 3), whereas the spray applied very early (9 June) and the late spray (12 September) had no, or much less, impact. Thus there is evidence that the treatment programme should begin 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.

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

- Short term netting covers following planting can disrupt whitefly colonisation and population growth without impacts on growth. Movento application late in the growing season gives equivalent control and additive benefits in association with covers.
- Growers should try to use the considerable efficacy and relative persistence of Movento to best effect in their spray programmes.
- Sanokote seed treatment with imidacloprid (Gaucho) can suppress the development of whitefly infestations, particularly early in the season.

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 HDC 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 HDC 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.

The HDC has recently been developing a portfolio of work addressing whitefly control on brassica crops and to date this has involved 3 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, boom-mounted 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 - which is an HDC Studentship (Spencer Collins) on the biology of cabbage whitefly and is at the beginning of its second year. The overall aim of the project is 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 this project is to evaluate the components of programmes (insecticidal, biological and physical) that might improve control of brassica whitefly. It focuses 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 will be 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 is also a coded product that is under development and has shown potential for whitefly control in previous trials (FV 399, FV 406 and others) and this will be included in the project.

In terms of other methods of control, the project will consider 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 will 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 the project are 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 overall treatment strategy for whitefly control.
4. Investigate the most effective way to use Movento and other effective insecticides in terms of the interval between treatments.

The work is being 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: Trial 1 - Investigate additional treatments for whitefly control.

Materials and methods

This objective was addressed 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). Treatments were applied on: 20 August (all treatments), 27 August (HDCI 074 only), 3 September (HDCI 074 only) and 12 September (all treatments). 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. 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	

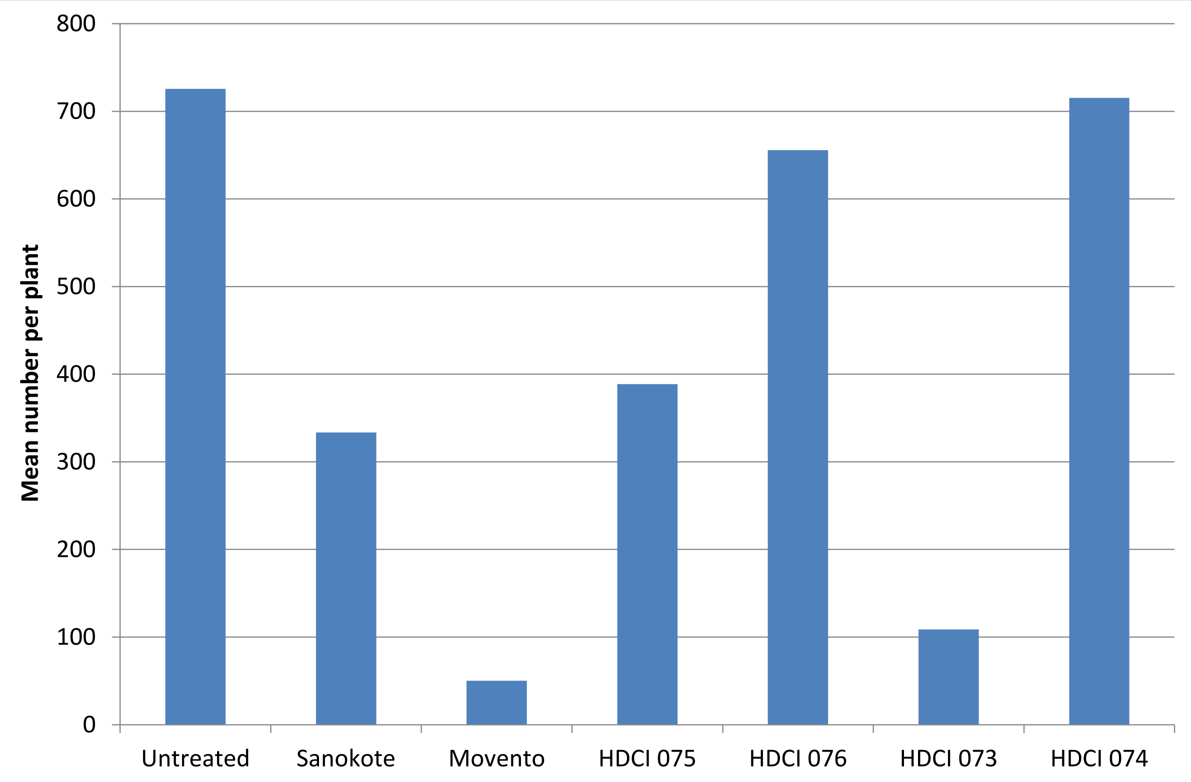

Figure 1.1 Mean number of whitefly egg circles per plant on 22 October 2014.

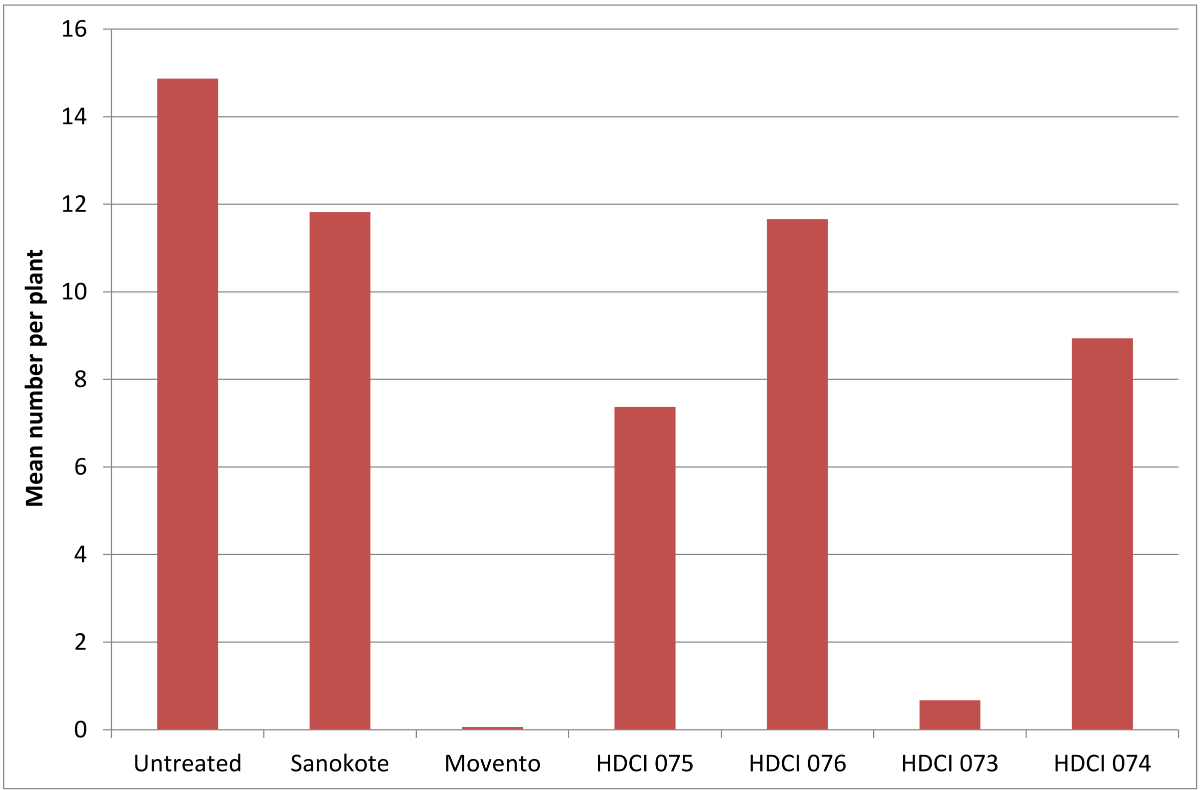

Figure 1.2 Mean number of leaves with whitefly larvae per plant on 22 October 2014.

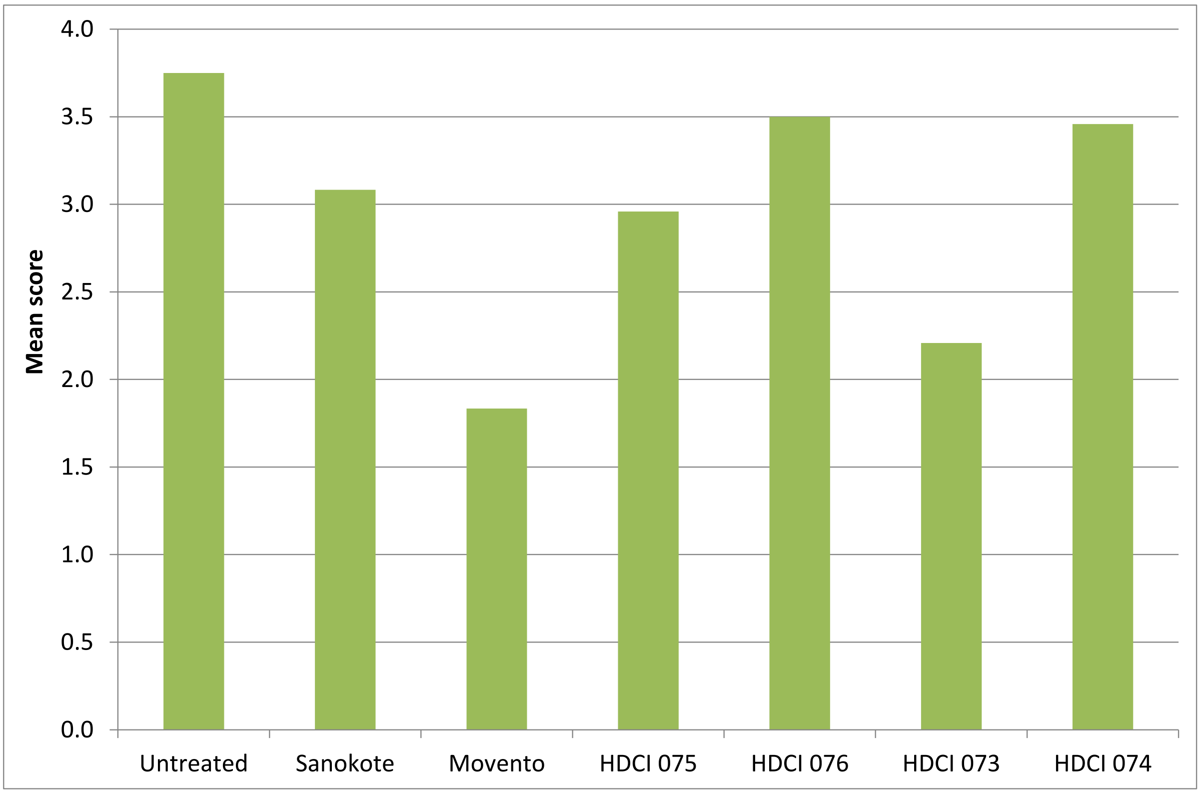

Figure 1.3 Mean whitefly adult score per plant on 22 October 2014.

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.

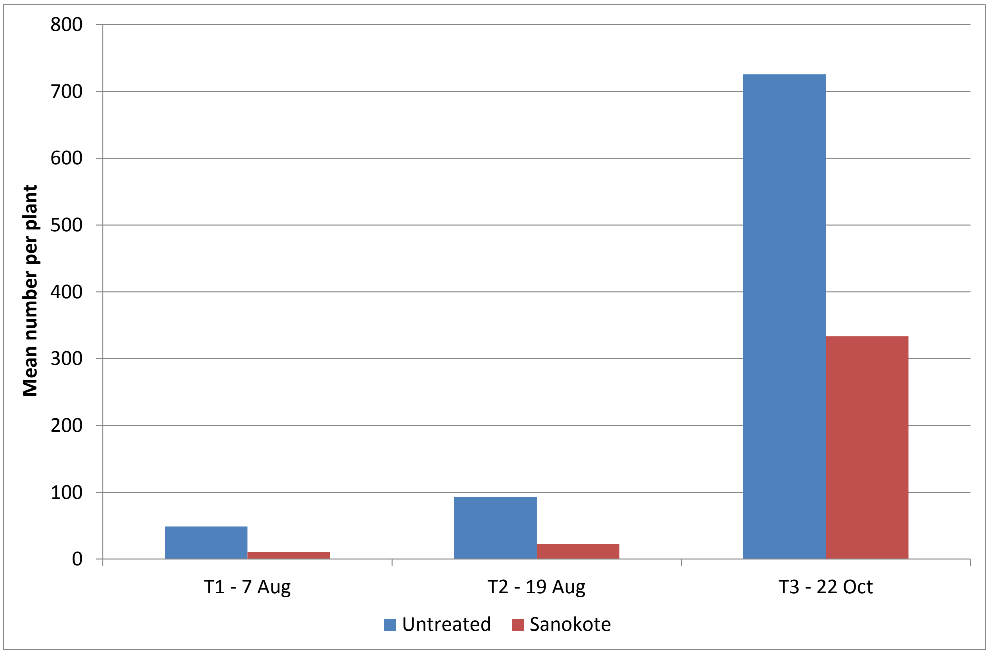

Figure 1.4 Mean numbers of egg circles per plant for all the Sanokote (imidacloprid) treatments.

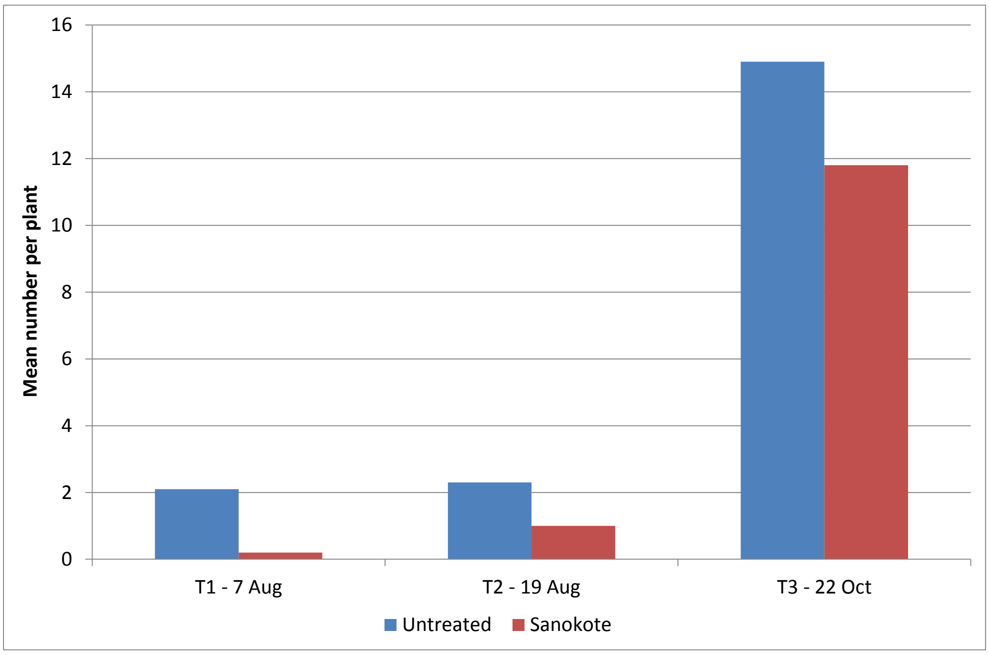

Figure 1.5 Mean numbers of leaves with larvae per plant for all the Sanokote (imidacloprid) treatments.

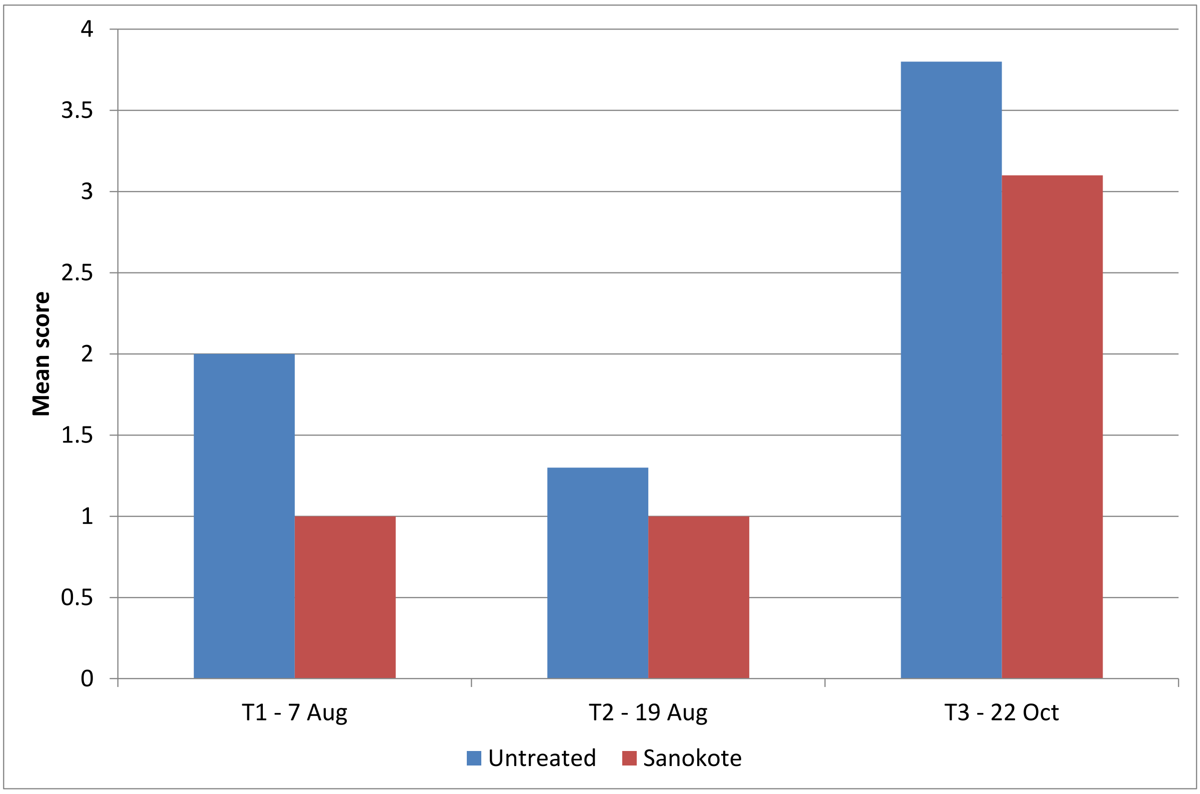

Figure 1.6 Mean adult score per plant for all the Sanokote (imidacloprid) treatments.

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

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	300 l/ha
HDCI 073	Coded insecticide	As recommended by manufacturer (with Codacide at 2.5 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	

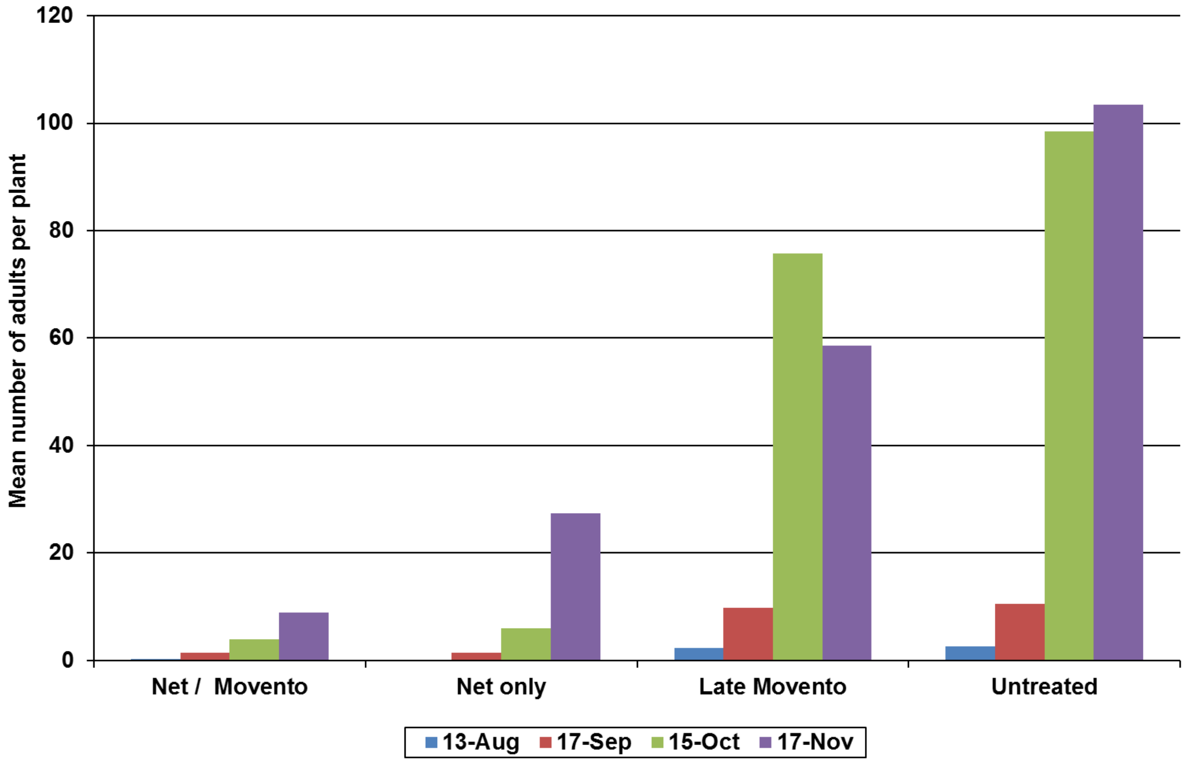

Figure 2.2 Mean number of adult whitefly per plant (treatments ranked by level of control on 17 November).

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	

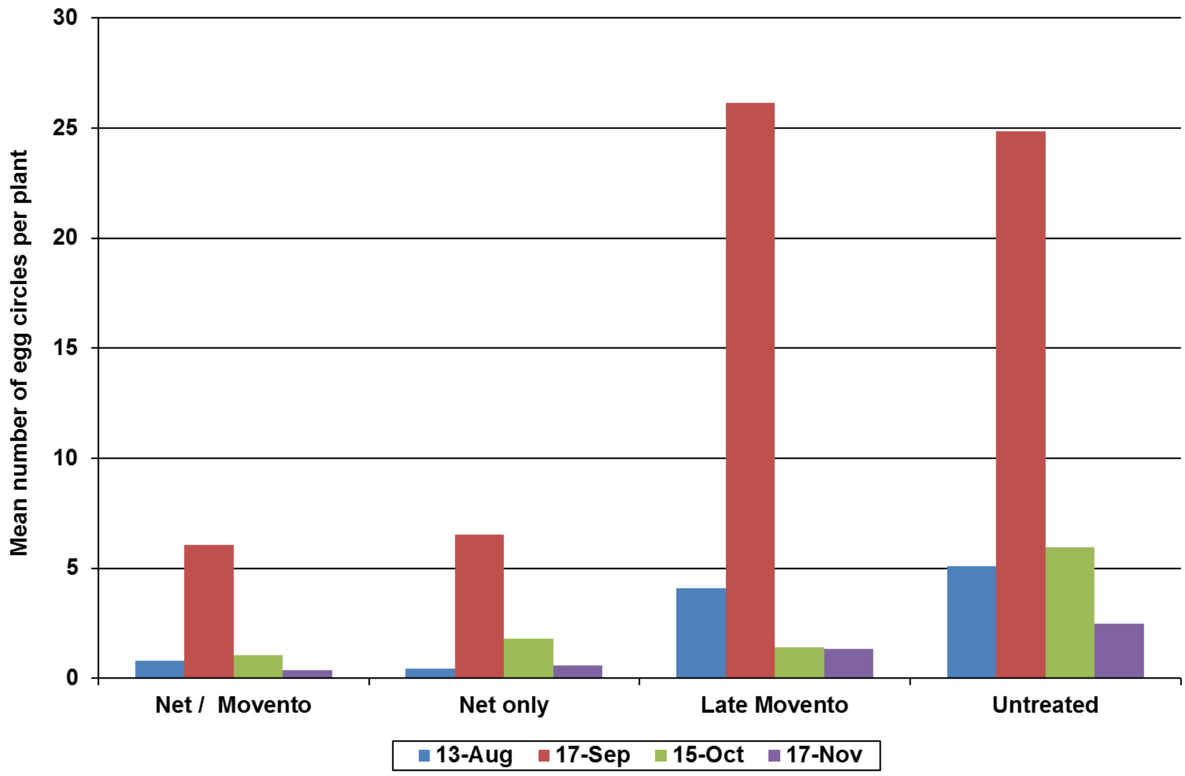

Figure 2.3 Mean number of egg circles per plant (treatments ranked by level of control on 17 November).

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	

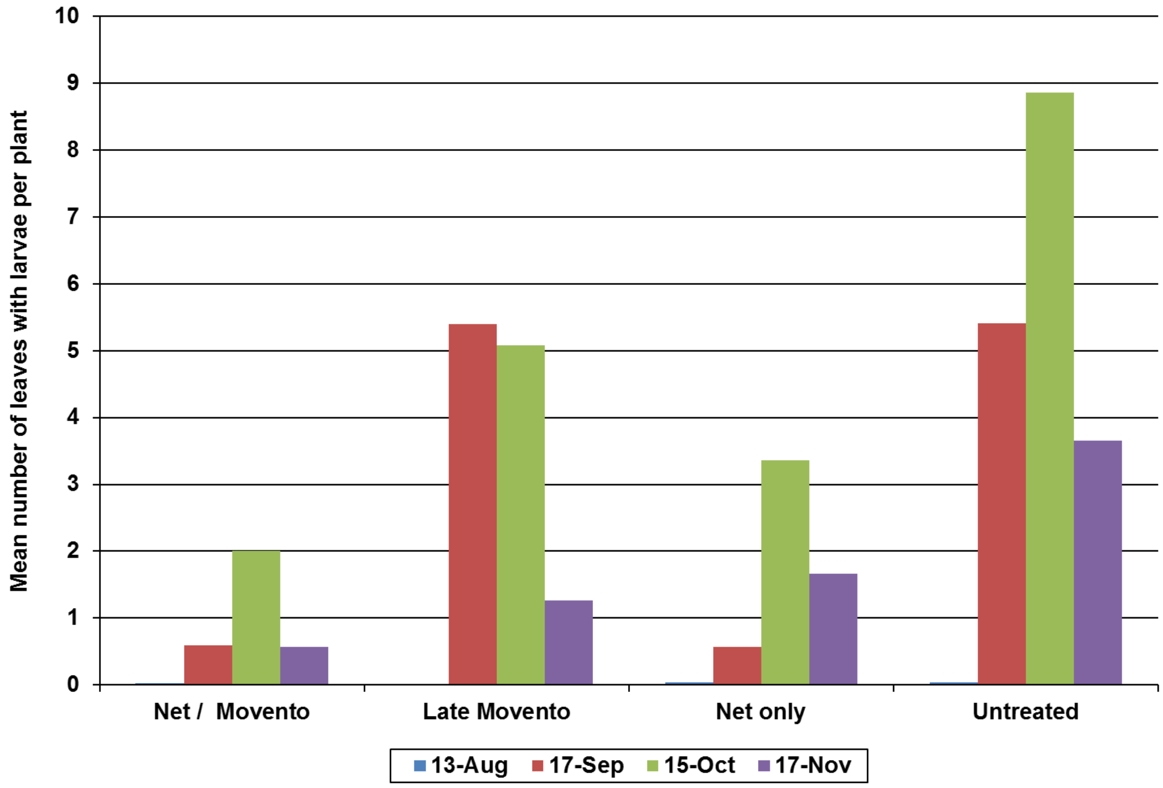

Figure 2.4 Mean number of leaves with larvae per plant (treatments ranked by level of control on 17 November).

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 07 proved ineffective for all metrics throughout the trial.

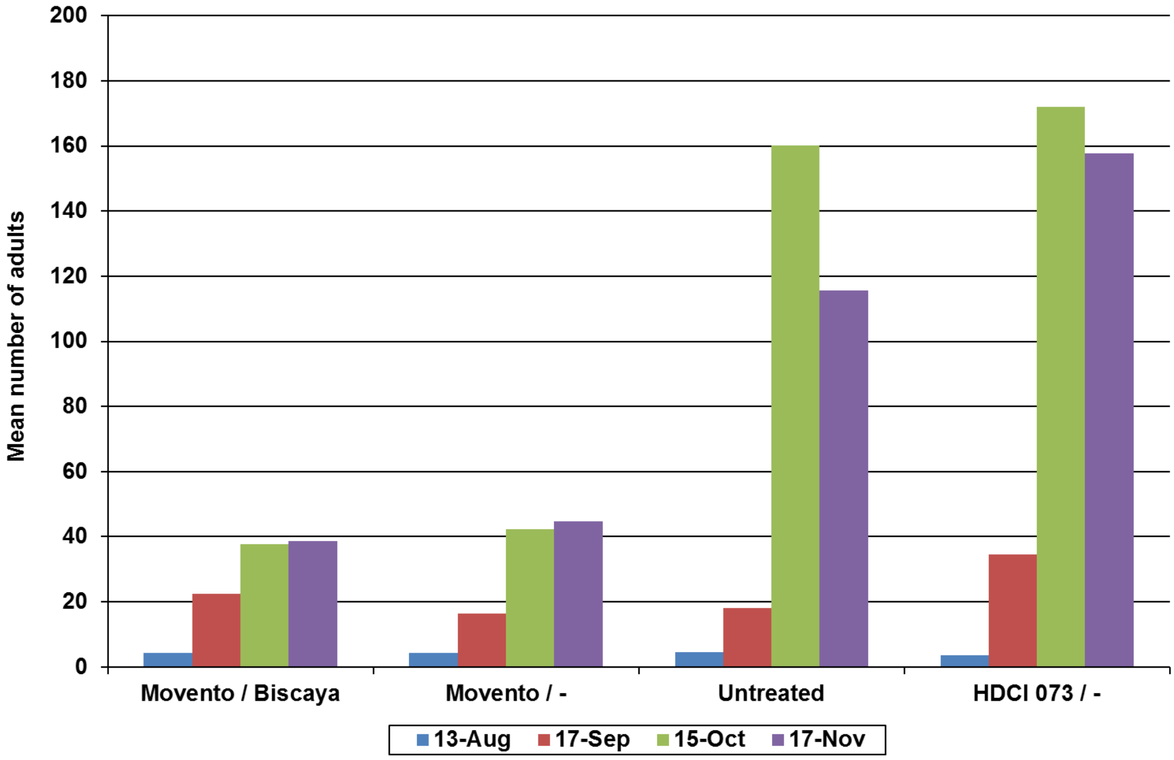

Figure 2.5. Mean number of adult whitefly per plant (treatments ranked by level of control on 17 November).

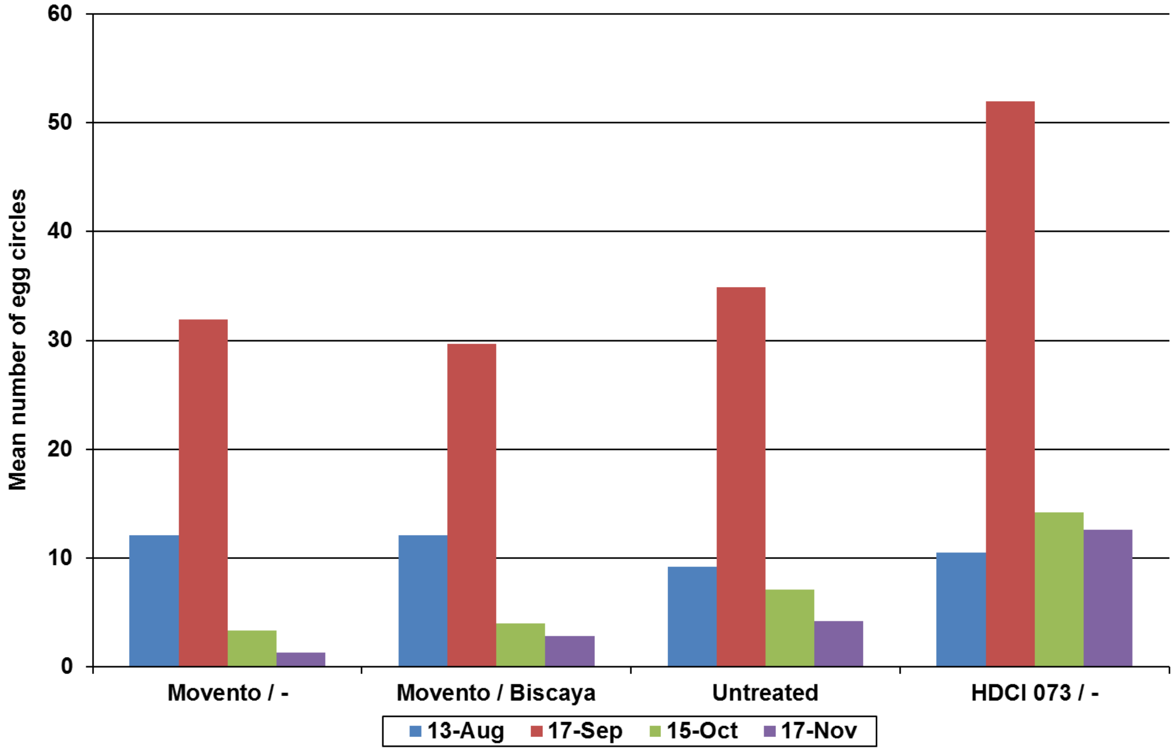

Figure 2.6 Mean number of egg circles per plant (treatments ranked by level of control on 17 November).

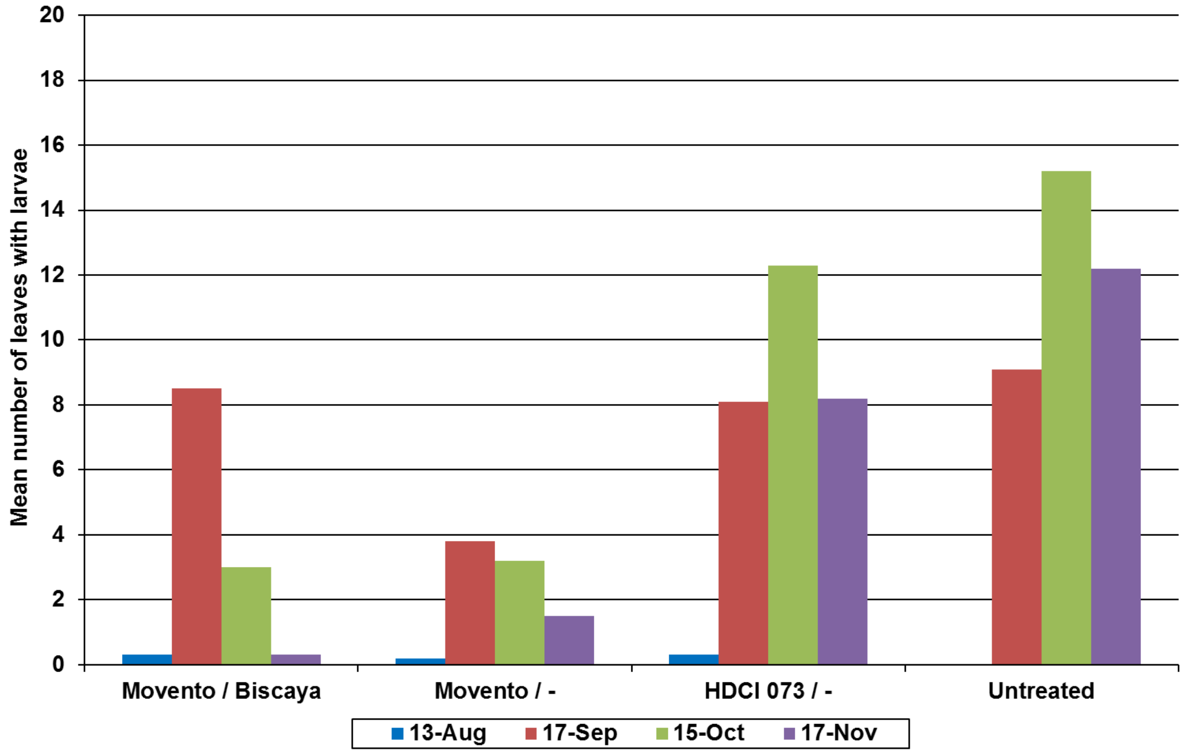

Figure 2.7 Mean number of leaves with larvae per plant (treatments ranked by level of control on 17 November).

Objective 3: Trial 3 - Investigate the most effective overall treatment strategy for whitefly control

Materials and methods

This objective was addressed 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, a single spray of Movento (rate as in Trial 1) was applied soon 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). Figure 3.1 shows the numbers of whitefly on a monitoring plot of kale in 2014. The dates of the emergence of adults of each generation were

First – 29th May
Second – 9th July
Third – 7th August
Fourth – 20th September

The sprays were applied on 9 June, 17 July, 20 August and 12 September.

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.

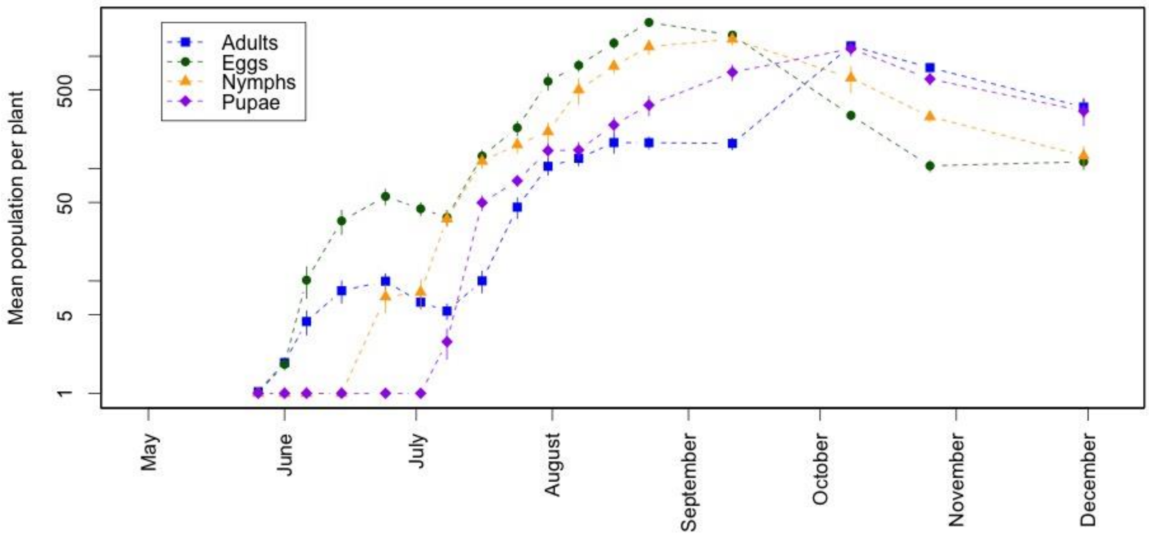

Figure 3.1 Mean numbers of whitefly per plant on kale at Wellesbourne in 2014. Data provided by Spencer Collins.

Results

Table 3.1 and Figures 3.2-3.4 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 3.1 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. Values followed by * are significantly different from the untreated control (p<0.05).

	30-Jul		**05-Sep**		**26-Sep**	
Egg circles	**Per plot sqrt**	**Per plant back-trans**	**Per plot sqrt**	**Per plant back-trans**	**Per plot sqrt**	**Per plant back-trans**
Untreated control	7.2	8.6	38.5	247.5	47.9	381.7
Sprayed 9 June	7.5	9.3	42.6	302.4	49.9	415.7
Sprayed 17 July	1.2*	0.2	14.9*	37.1	20.8*	72.2
Sprayed 20 August	7.7	10.0	18.1	54.7	23.9	95.1
Sprayed 12 September	9.5	15.2	43.0	308.5	43.8	319.2
p	0.028		0.110		0.147	
SED	2.335		12.943		13.841	
LSD (5%) (two-sided)	4.977		27.587		29.501	
LSD (5%) (one-sided)	4.093		22.689		24.263	
Larvae	**Per plot sqrt**	**Per plant back-trans**	**Per plot sqrt**	**Per plant back-trans**	**Per plot sqrt**	**Per plant back-trans**
Untreated control	1.7	0.5	7.3	8.8	9.2	14.2
Sprayed 9 June	1.9	0.6	9.4	14.6	10.4	17.9
Sprayed 17 July	0.0*	0.0	2.8*	1.3	7.4	9.1
Sprayed 20 August	1.1	0.2	6.6	7.2	4.6*	3.5
Sprayed 12 September	1.5	0.4	7.9	10.3	8.8	12.8
p	0.314		0.003		0.002	
SED	0.944		1.385		1.139	
LSD (5%) (two-sided)	2.012		2.951		2.428	
LSD (5%) (one-sided)	1.655		2.427		1.997	
Adults	**Per plot**	**Per plant**	**Per plot**	**Per plant**	**Per plot**	**Per plant**
Untreated control	3.7	0.6	10.5	1.8	19	3.2
Sprayed 9 June	6.8	1.1	11	1.8	19.8	3.3
Sprayed 17 July	3.2	0.5	6	1.0	11.8	2.0
Sprayed 20 August	5.9	1.0	7	1.2	13.5	2.3
Sprayed 12 September	6.5	1.1	10.75	1.8	18	3.0
p	0.656		0.301		0.076	
SED	2.094		2.885		3.101	
LSD (5%) (two-sided)	4.462		6.150		6.610	
LSD (5%) (one-sided)	3.670		5.058		5.436	

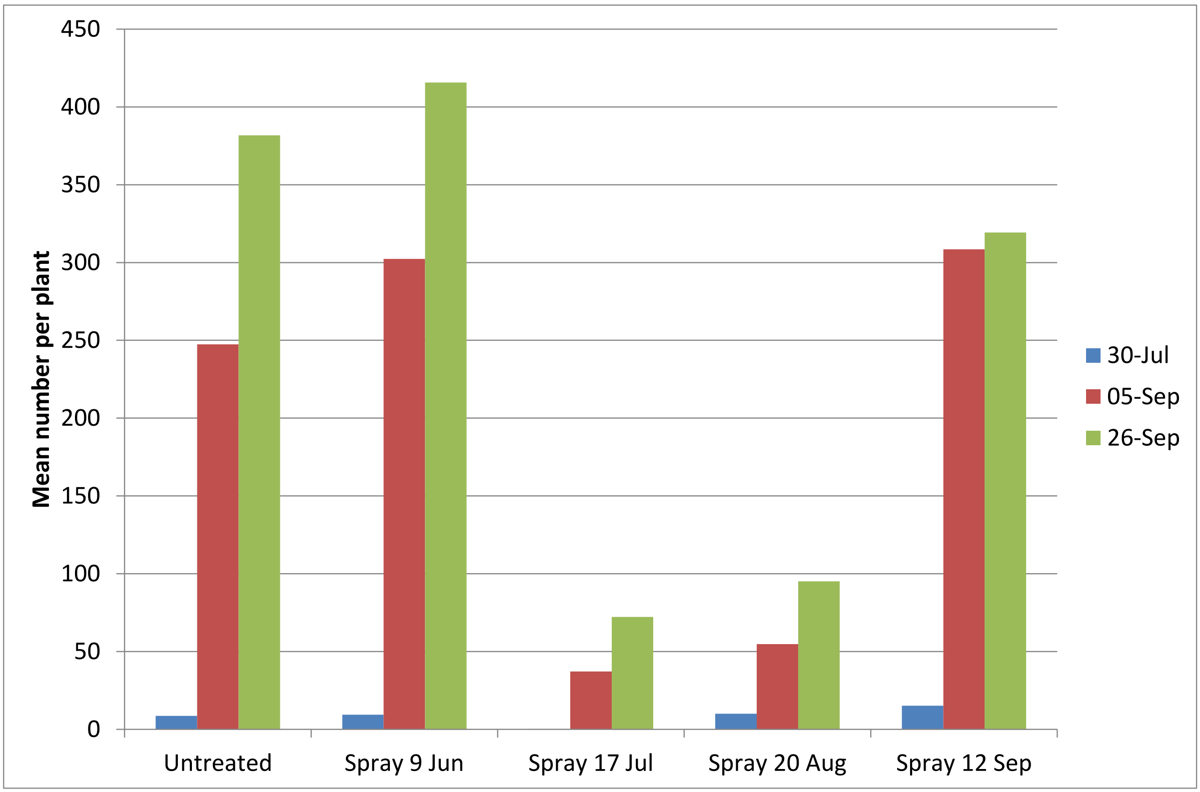

Figure 3.2 Mean number of egg circles per plant on 3 assessment occasions.

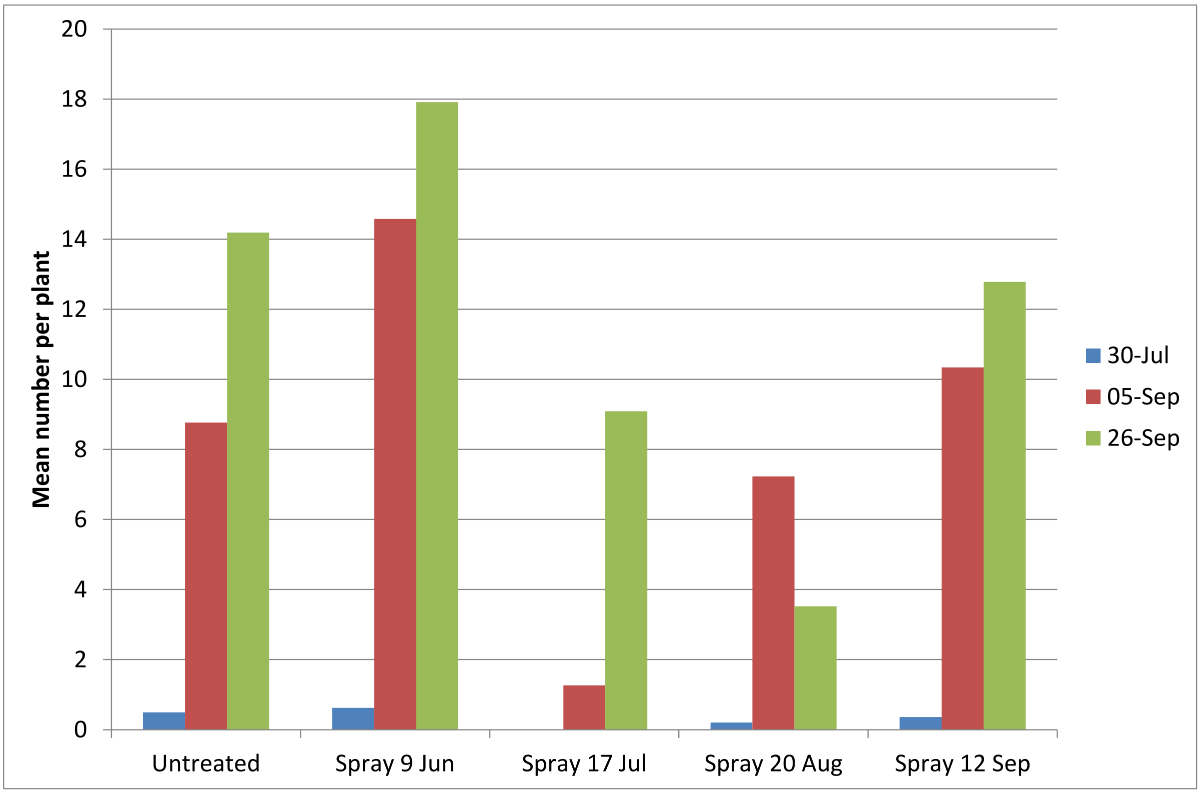

Figure 3.3 Mean number of leaves with larvae per pant on 3 assessment occasions.

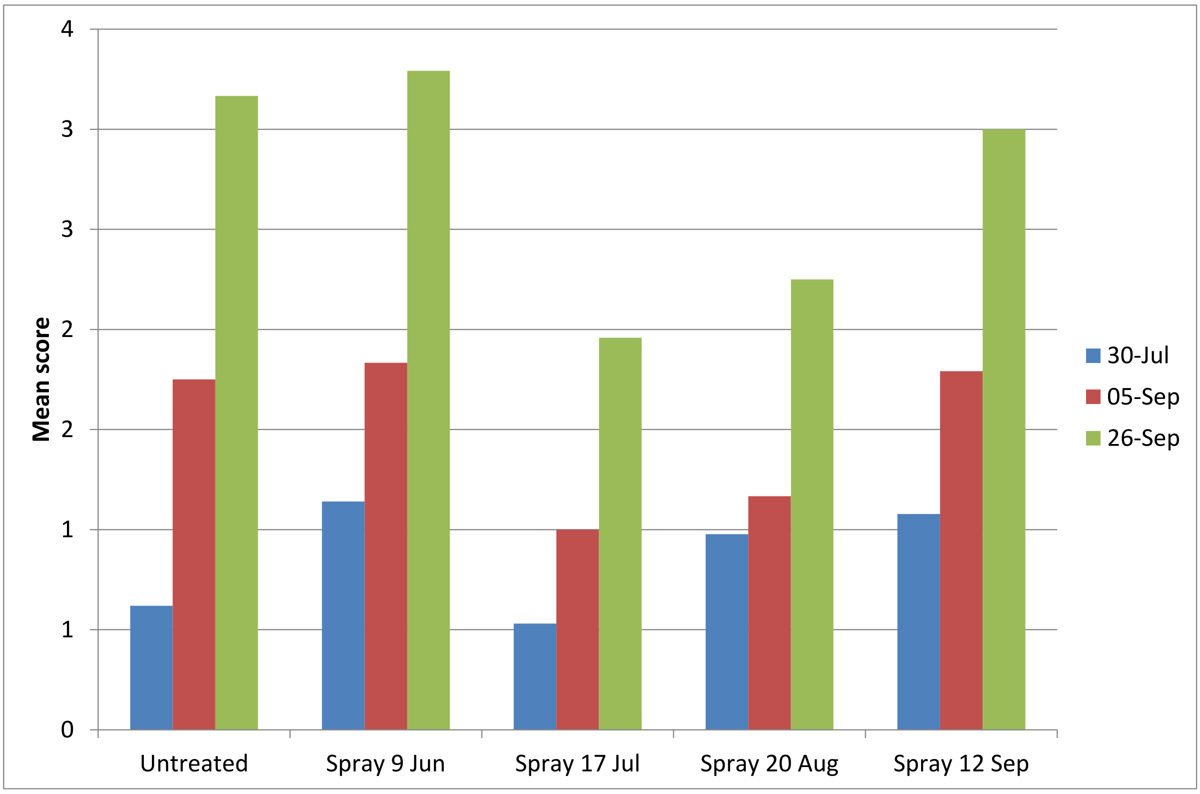

Figure 3.4 Mean adult score per plant on 3 assessment occasions.

Objective 4: Trial 4 - Investigate the most effective way to use Movento and other effective insecticides in terms of the interval between treatments.

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 4.1). The plants were sown on 23 April and transplanted on 21 May and sprayed on 20 August.

Table 4.1. 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 4.1 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 4.1. 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*

Table 4.2 and Figures 4.1-4.3 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 4.2. Mean numbers of egg circles, leaves with larvae and adult score on 17 September and 23 October.

17-Sep	**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	
23-Oct	**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	

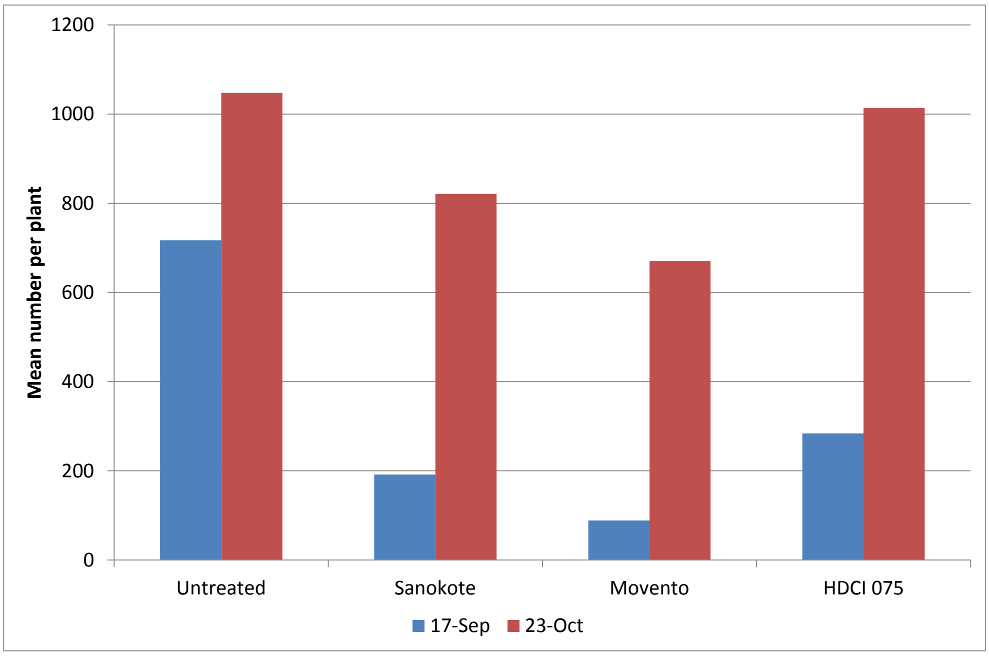

Figure 4.1 Mean numbers of egg circles per plant on 17 September and 23 October.

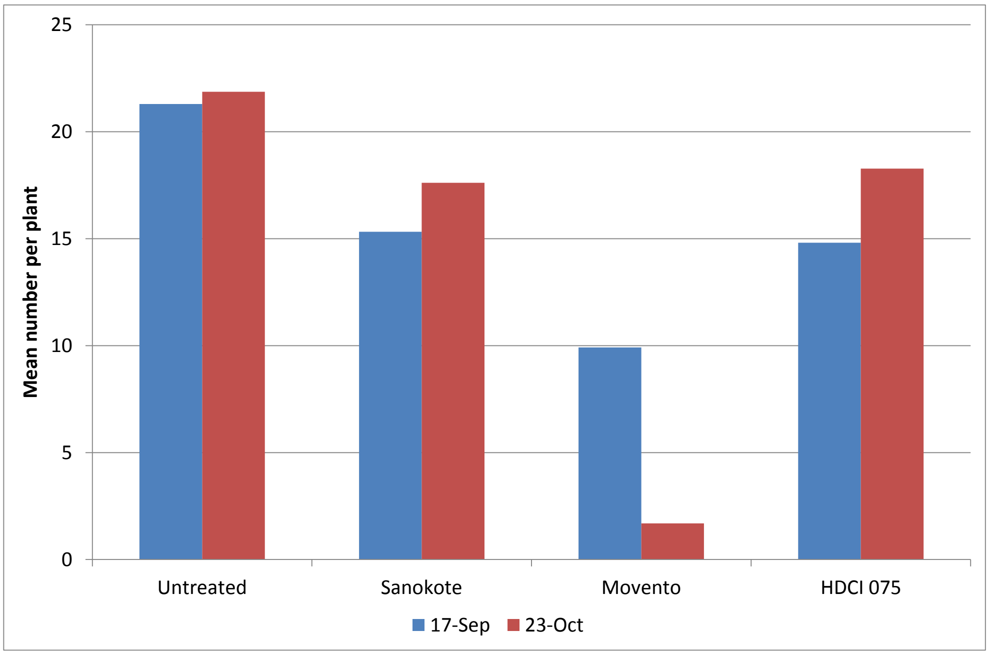

Figure 4.2 Mean numbers of leaves with larvae per plant on 17 September and 23 October.

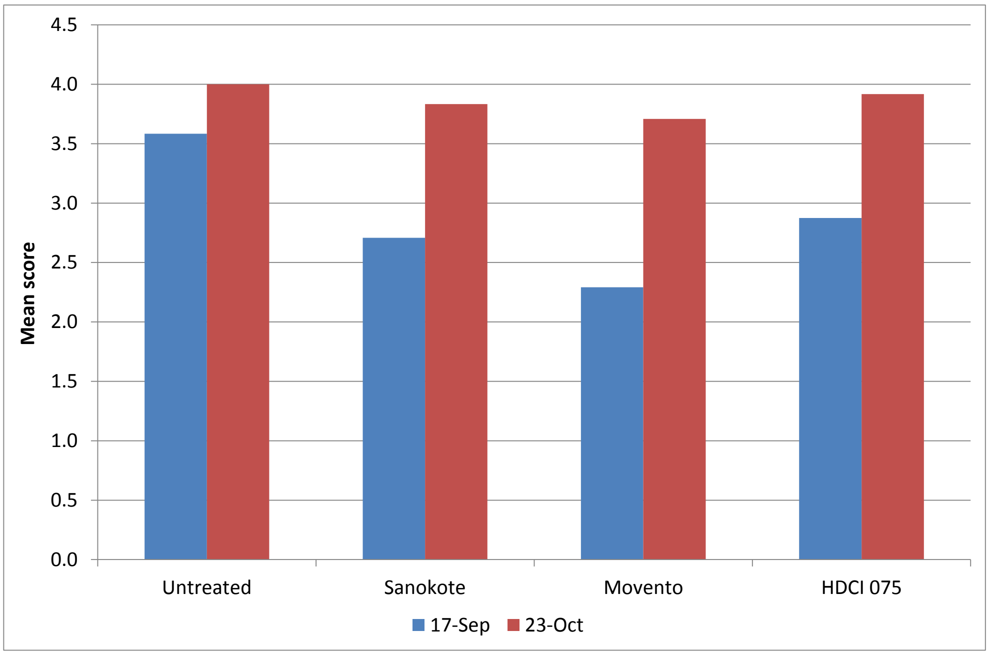

Figure 4.3 Mean adult score per plant on 17 September and 23 October.

Figures 4.4 - 4.6 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 4.1 and 4.2).

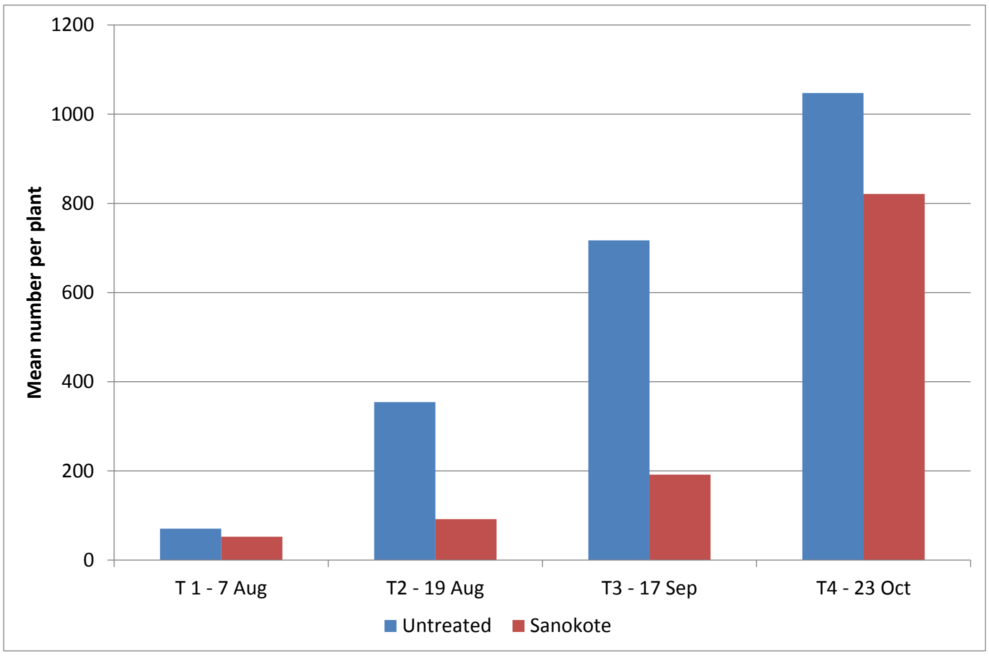

Figure 4.4 Mean numbers of egg circles per plant for all the Sanokote (imidacloprid) treatments.

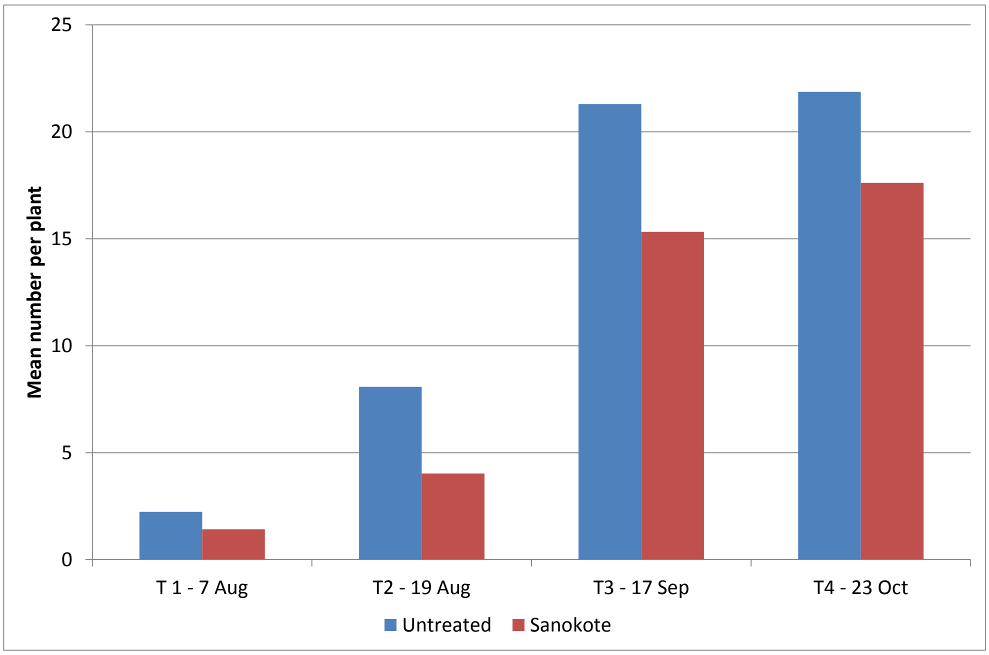

Figure 4.5 Mean numbers of leaves with larvae per plant for all the Sanokote (imidacloprid) treatments.

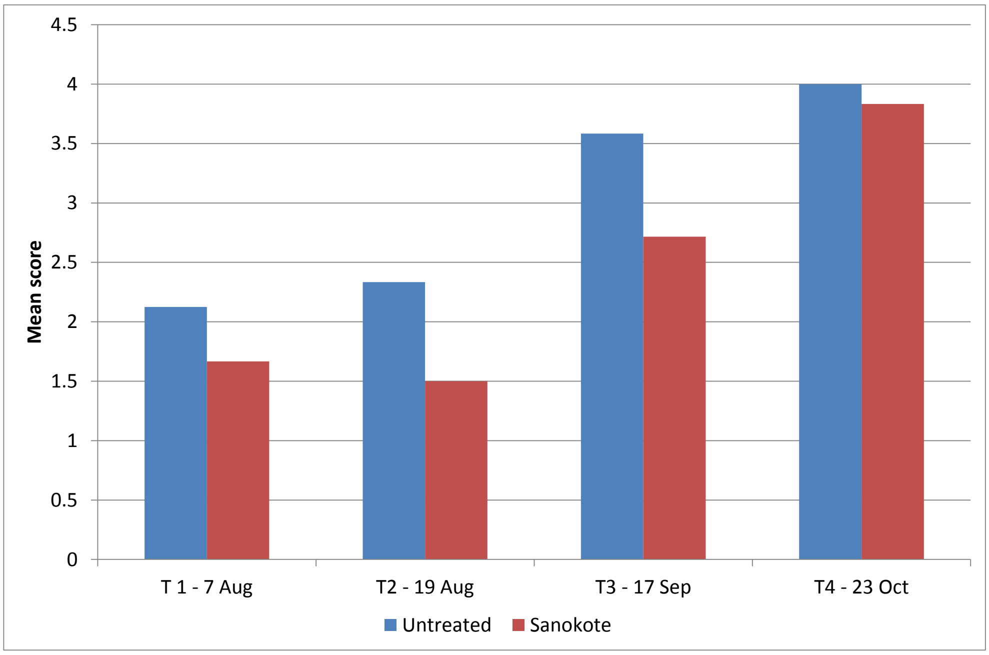

Figure 4.6 Mean adult score per plant for all the Sanokote (imidacloprid) (imidacloprid) treatments.

Discussion

Insecticides and biopesticides

The field trials confirmed the efficacy of Movento (spirotetramat) and HDCI 073 as foliar sprays and indicated that Sanokote seed treatment with imidacloprid (Gaucho) suppressed the development of whitefly infestations, particularly early in the season, compared with the untreated control. HDCI 075 also showed statistically-significant levels of control with a reasonable amount of persistence. Overall, reductions compared with the untreated control in numbers of egg circles and larvae were 'greater' than reductions in adults (Figure 5.1) which probably reflects the mobility of the adults, which may move from plot to plot very readily.

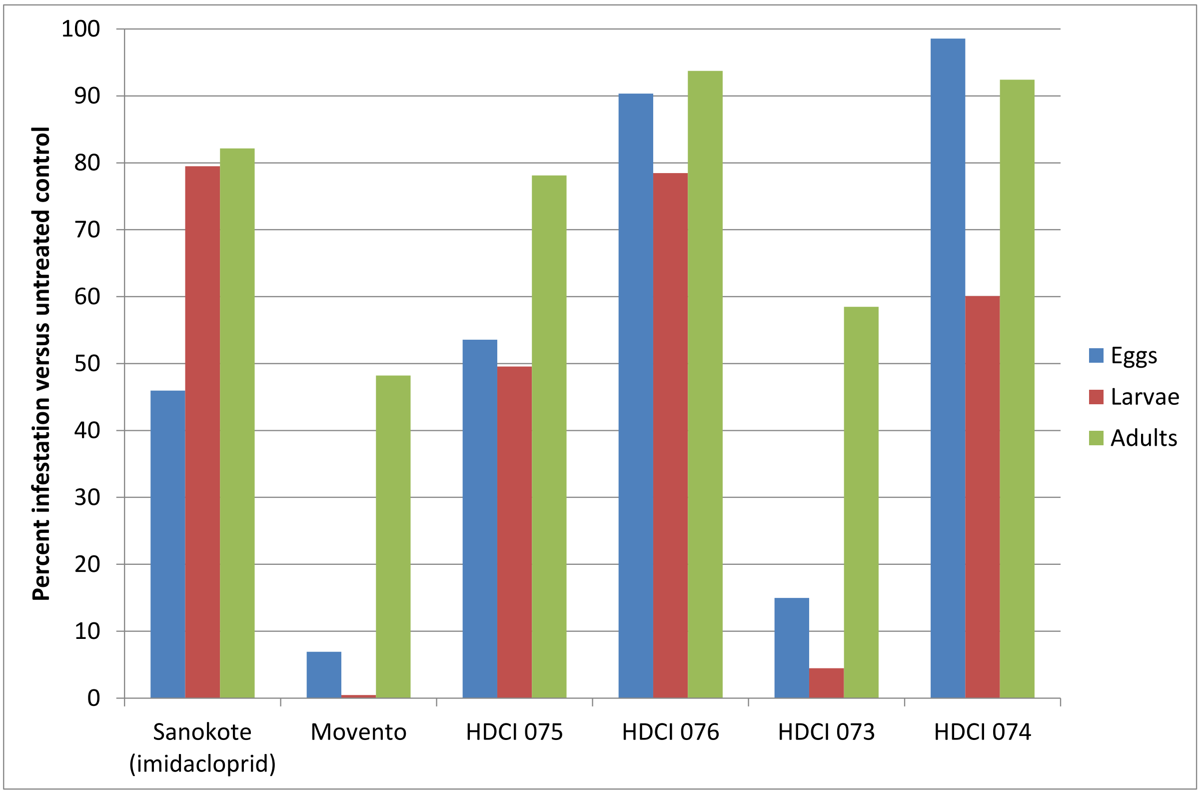

Figure 5.1 Trial 1 – percentage infestation on treated plots versus untreated control. Assessment made on 22 October and the last sprays in the programme were applied on 12 September (38 days after last spray). N.B. 'Eggs' are the number of egg circles and 'larvae' are the number of leaves with larvae.

Biological control

The failure to produce and subsequently test the parasitoids in the field was a substantial disappointment and prevented the primary function of the trial in Objective 2 from being achieved. Despite this, useful data were still extracted from the trial in relation to insecticides and crop covers.

Crop covers

The potential value of short-term netting for exclusion of adult whiteflies was shown, with the effects persisting to the end of the trial. However, a heavier infesting pest pressure would be required to test other eventualities. Also data from studentship CP 091 may indicate whether such short-term covers would be effective in other cases or if whitefly immigration is less predictable.

Treatment timing

Treatment timing was investigated particularly in Trials 2 and 3. The application of crop covers in Trial 2 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 5.2).

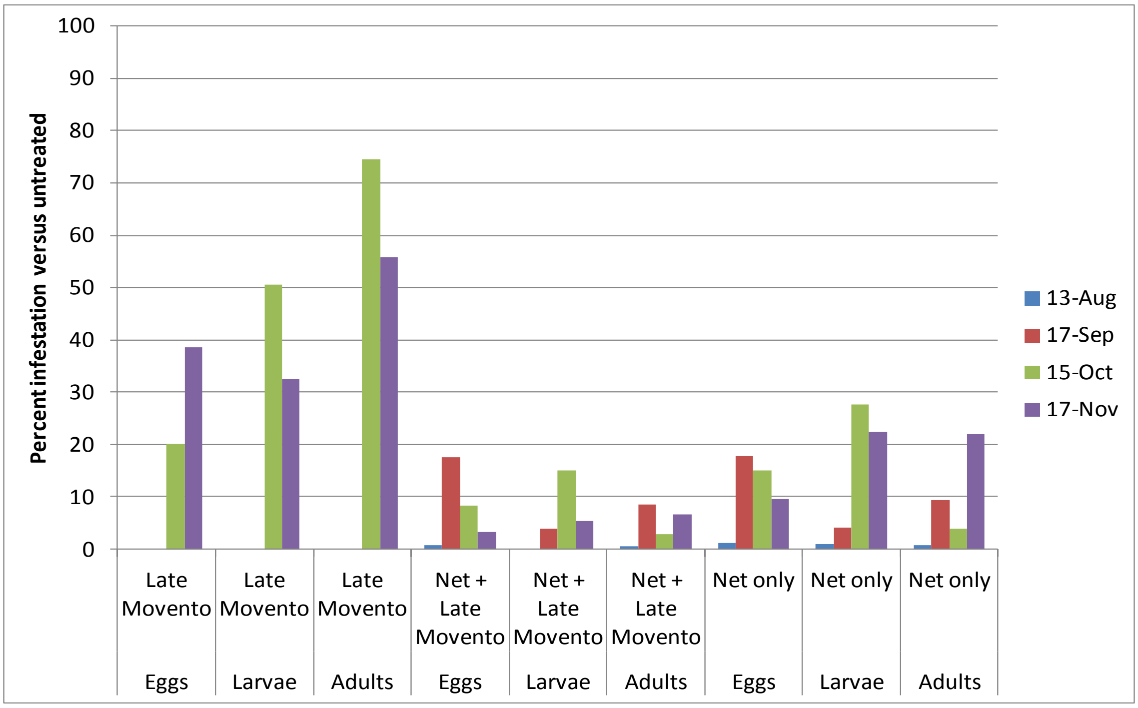

Figure 5.2 Trial 2 – percent infestation versus untreated control. Covers in place 7 July – 6 August and late Movento spray applied on 22 September. N.B. 'Eggs' are the number of egg circles and 'larvae' are the number of leaves with larvae.

Similarly, the applications of Movento on either 17 July or 20 August in Trial 3 were the most effective treatments at the final assessment on 26 September (Figure 5.3), whereas the spray applied very early (9 June) and the late spray (12 September) had no, or much less, impact. Thus there is evidence that the treatment programme should begin 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.

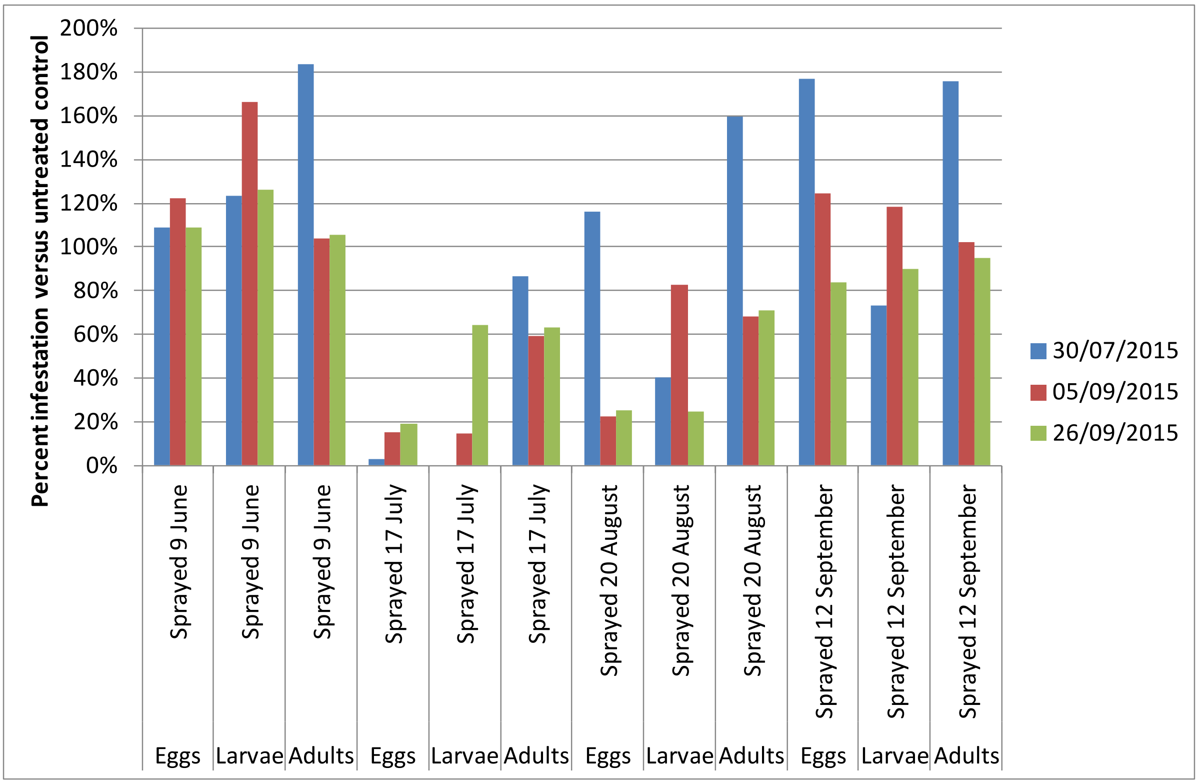

Figure 5.3 Trial 3 – percent infestation versus untreated control. N.B. ‘Eggs’ are the number of egg circles and ‘larvae’ are the number of leaves with larvae.

Different insecticide treatments are likely to have varying direct effects on the different life stages of whitefly. For example, as diapausing female insects were developing at the time of late Movento application in Trial 2, 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 when comparing the netting treatments, despite a significant reduction in the late Movento only treatment compared to the untreated control. In contrast, Movento application was highly effective in reducing leaf contamination by larvae. The positive effects of the late Movento application in both treatments contradict earlier indications from FV 406, where such treatments appeared to provide no additional benefit, though the infestation was much heavier in that previous trial in 2012.

Persistence of treatments

In Trial 4, 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 persisted for 40 days after the last spray was applied (Figure 5.1). 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.

Acknowledgements

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