Project title:	Biological, semiochemical and selective chemical management methods for insecticide resistant western flower thrips on protected strawberry
Project number:	SF120, HL01107
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[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

GROWER SUMMARY

Headline

- The use of blue sticky roller traps along the tunnel legs (30 cm wide, 100 m long, Optiroll, Russell IPM) can significantly reduce thrips numbers and fruit damage.

Background and expected deliverables

The development and spread of pesticide resistant strains of WFT, which cannot be controlled with pesticides, seriously threatens the viability of the UK strawberry industry. In 2009 serious outbreaks occurred in several high value crops in southern and central England causing serious losses. The aim of this project is to develop a comprehensive range of new effective methods for managing insecticide resistant western flower thrips (WFT) in tunnel-grown strawberry in the UK. The methods include improved monitoring with attendant damage thresholds, a computer-based population and risk forecasting model, new selective pesticide treatments, new biopesticides, mass trapping and novel, more cost-effective strategies for using existing predators. These components will be integrated into a comprehensive management strategy for the pest which will be tested on a commercial scale in the later stages of the project.

Summary of the project and main conclusions

Progress on each objective of the project is summarised below:

Objective 1 (Monitoring, trapping and damage thresholds)

In controlled experiments, four or eight adult thrips per flower and their subsequent larvae resulted in bronzing that exceeded the economic injury level of 10% of the fruit surface bronzed, in the absence of predators. The addition of the predatory mite *Neoseiulus cucumeris* to flowers reduced fruit bronzing below the economic injury level when there were four or eight adult thrips per flower. The results confirm that it is the larval stages of the western flower thrips that cause most of the fruit bronzing, as *N. cucumeris* do not feed on adults. The presence/absence of *N. cucumeris* must be taken into account when developing action thresholds for growers.

Economic fruit damage (sufficient to downgrade fruit to Class 2) occurred in commercial crops when there were between five and 11 adult thrips per flower (mean of seven adult thrips per flower in six crops monitored). Damage occurred at five adult thrips per flower in a field with poor establishment of predatory mites (4% of fruits with predatory mites). Damage occurred at 11 adult thrips per flower in a field with good establishment of predatory mites (72% of fruits with predators), although there was a lot of variability. There was no economic crop loss due to thrips bronzing in six crops where thrips density remained below five adult thrips per flower throughout the season, in the presence of predatory mites. Further data is required to determine the numbers or percentage incidence of predators required to reduce fruit damage in the field, although 100% incidence is ideal. There were insufficient data to draw conclusions on the relative susceptibility of different cultivars to thrips damage, but the limited data available showed similar susceptibility to damage between the cultivars tested. Weekly monitoring is required to predict damage as thrips numbers can change rapidly.

Objective 2 (Model)

New data have been obtained on the rates of development of WFT on strawberry at fluctuating temperatures in the laboratory confirming that WFT developmental rate at 10°C is not zero as assumed by all previous studies (minimum temperature for development was said to be around 10°C). Most eggs hatched after 8-10 days under the constant temperature of 16°C, close to the 8-9 days predicted by the model. However under the 16/10°C, most eggs hatched between 9-11 days which is shorter than the predicted 14-15 days (assuming the developmental rate is zero at 10°C). Similarly for the 14/10°C regime, the predicted length is around 18 days, compared to the observed 11-13 days. These data are being used to validate the model developed in Years 1 and 2.

Objective 3 (Predators)

No work on this objective was planned for 2013.

Objective 4 (Pesticides and biopesticides)

The fungal biopesticides used in the first years of the project are known to be pathogenic to WFT (i.e. they kill WFT in laboratory experiments). However, in our experiments there was a lack of control in cage and polytunnel experiments. To try to understand the reasons for this

an experiment was done to quantify the deposition of a commercial biopesticide spray within a strawberry crop, to enable us to understand whether biopesticides are being deposited in places where thrips are located, and to give information on the number of spores that are acquired by thrips. All parts of the strawberry plant sampled received a number of viable spores. All of the thrips found were located in the flowers but they varied in number of spores that they received. This suggests that secondary pick up of viable spores is an important means of inoculation for WFT biocontrol with entomopathogens. Further work is required to evaluate the persistence of the fungal spores on the strawberry crop and to determine the number of spores per thrips required to cause death.

Objective 5 (IPM strategy)

In two EMR experiments on a commercial site in Kent we were unable to provide confirmation of the effectiveness of roller traps to reduce crop damage caused by WFT feeding. Very low numbers of thrips were attracted to the blue roller traps in the early assessments, even though there were thrips present in the flowers. It is likely that the flowers present in the planting were more attractive to WFT early in the season. In the last assessments, when numbers of flowers were decreasing and numbers of thrips per flower were increasing, numbers of thrips caught on the traps increased. Damage to fruit was high in both plantings and the crop became unmarketable. Because the experiment was terminated by the grower we were not able to determine if the traps reduced populations on the plants from July onwards; in 2012 the roller traps caught higher numbers of thrips from July (see 2012 Annual Report) and thrips populations and fruit damage decreased significantly at this time.

In the ADAS experiment in Cambridgeshire, there was no effect of the roller trap treatment on reducing thrips numbers. Percentage of fruit damaged by thrips was low, however, there was a trend that ripe and white fruit damage was always higher in the control treatment. Significantly less ripe fruit with five or more seeds surrounded by bronzing were found in plots with roller traps compared to the control. Mean numbers of WFT remained below two adults per flower in plots with or without roller traps throughout the experiment, probably as a result of the biological control programme used by the grower. At the ADAS Essex site, the roller trap treatment significantly reduced the number of thrips per flower on 25 July, 9 and 22 August. Percentage of fruit damaged by thrips was low and there was no difference in fruit damage between the two treatments. Mean numbers of thrips remained below four per flower in plots with or without roller traps. More predators, particularly *Orius* sp. were found at the Cambridgeshire site where they used a biological control programme compared to the

Essex farm where they used pesticides. No predatory bugs were recorded on the roller traps on any assessment date at either site. This suggests that using roller traps does not trap flying anthocorid adults. At both sites there was no difference between the numbers of thrips found on the roller traps close to and far from the pheromone lure, indicating that a 2.2m distance between lures was effective in making the roller trap evenly attractive to WFT across the entire 30m.

Financial benefits

Strawberry production in the UK is intensive and the crop is of high value, the UK industry being amongst the most effective in Europe. In 2007, 50,739 tonnes of strawberries, worth approximately £212 million were produced from approximately 2,922 ha grown in Britain. A further estimated 41,126 tonnes, worth approximately £174 million, were imported.

The development and spread of pesticide resistant strains of WFT which cannot be controlled with pesticides seriously threatens the viability of the UK strawberry industry. In 2009 serious outbreaks occurred in several high value crops in southern and central England causing serious loss. The average everbearer crop yields 20,000 kg of Class 1 fruit over one season with a current value of £2.70 per kg (£54,000 per ha). On some farms in 2009, WFT damage to everbearer fruit was so severe following failure of spinosad to control the pest that total crop loss occurred for the latter third of the season, i.e. a loss of £18,000 per ha. Even on farms where spinosad is still effective, WFT damage can lead to at least 20% of the fruit being downgraded to Class 2 for half of the picking season. The value of Class 2 fruit is less than £1.50 per kg. Thus, WFT currently causes minimum estimated financial losses of approximately £3,000 per ha per season. There is great concern that UK everbearer crop losses will escalate with the further spread of spinosad-resistant strains of WFT. Furthermore, WFT is favoured by hot summer weather conditions. If the 2009 summer weather had been hot it is possible that losses would have been much more extensive.

This project will deliver a new sustainable cost-effective IPM strategy for management of WFT on tunnel-grown everbearer crops which is vital to the survival of the UK strawberry industry. The development of a reliable IPM strategy for successful control of WFT would benefit growers by preventing crop losses and fruit downgrading due to WFT damage. In this project we aim to develop a range of complementary methods for managing WFT. For instance, using WFT predators which may include two releases of *Amblyseius cucumeris* in sachets (costing up to £325 per ha) and two releases of *Orius laevigatus (*costing up to £600 per ha). If this strategy prevented fruit downgrading due to WFT damage for the whole

everbearer season, use of the two predators could give a minimum potential 324% return on investment. On farms with spinosad resistance the benefit of investing in a reliable IPM strategy would be much greater as it could prevent entire crop losses.

Action points for growers

- Plan your IPM programme carefully in early spring, together with a consultant who is experienced and up to date in thrips management strategies on everbearers.

- Western flower thrips were shown to overwinter in senescent/dead strawberry flowers and weeds, such as chickweed, groundsel and dandelion. Overwintering in crops resulted in significantly more thrips in second year crops than in first year crops at the beginning of the season. Growing one year crops, avoiding planting new crops in used grow-bags or reducing the overwintering thrips population would reduce thrips risk.

- In first year crops, the first thrips were observed around the outside of the crop, particularly near weedy field margins, demonstrating the need for good weed control to reduce thrips risk.

- Once thrips had established they were found throughout crops, but numbers were greatest in the mid to top areas of sloping fields (excluding the tunnel ends and sides) where temperatures are higher. This is the area of greatest risk of fruit damage.

- Before the crop is flowering, WFT can be most effectively monitored using blue sticky traps with a pheromone lure. In strawberry the best position for traps is to mount them onto a post (a cheap bamboo cane is sufficient) held in place with a rubber band, with the bottom of the trap (landscape orientation) about 10 cm above the top of the crop (one hand width). If any flowering weeds e.g. dandelion or groundsel are present, thrips can be monitored by tapping the flowers over a white card.

- From crop flowering, the number of adult thrips per flower is the best estimate of thrips numbers. When monitoring for thrips the selection of flower age and position affects population estimates. Select flowers of medium age (all petals present, anthers brown, pollen shed) from the top of the plant for monitoring thrips adults, as

young (petals fresh, anthers yellow, pollen not shed) or senescent (petals dropping) flowers will result in an underestimation.

- Bronzing damage to strawberry fruit increased with increasing numbers of adult thrips per flower. Significant damage that might result in downgrading of fruit occurred when there were about four adult thrips per flower in the absence of predatory mites.

- The addition of the predatory mite *Neoseiulus cucumeris* to flowers maintained fruit bronzing below the economic damage threshold when there were four or eight adult thrips per flower in controlled experiments.

- In commercial crops where predators had been released, economic damage was observed at or above five adult thrips per flower. Economic damage occurred at five adult thrips per flower when there was poor predator establishment (4% of fruits with predators) and as high as 11 adult thrips per flower where there was good predator establishment (74% of fruits with predators), therefore good predator establishment is an important component of IPM programmes.

- Growers should monitor *N. cucumeris* establishment (they are most easily seen under the calyx on fruit). Use compatible spray treatments and continue to release predators until they can be found on most fruits.

- Damage thresholds can only be a guideline as there is much variability. Damage can be caused or exacerbated by spraying, sun scorch and other factors.

- In 2012 the use of blue roller traps along the tunnel legs (30 cm wide, 100 m long, Optiroll, Russell IPM) reduced thrips numbers by 61% and fruit damage by 55%. The use of blue roller traps with additional WFT aggregation pheromone reduced thrips numbers by 73% and fruit damage by 68%. However, in experiments in Kent in 2013 there was no evidence to suggest that the blue traps with pheromone lures had any effect on thrips numbers or fruit damage from May to July; the experiments were terminated by the host grower at the beginning of August due to crop damage. At the ADAS Essex site the roller trap treatment significantly reduced the number of thrips per flower in July and August. However, there was no difference in fruit damage between the two treatments. In an experiment in Cambridgeshire there was no

significant effect of the roller trap treatment on thrips numbers in the flowers; at this site thrips were well-controlled by the growers's biological control programme. Note that the aggregation pheromone is a precision monitoring tool and there is no approval for its use as a control agent in commercial crops at this time.

- Monitor thrips numbers in flowers and fruit damage **weekly** throughout the season. Confirmation of thrips species by an entomologist experienced in thrips identification will provide useful information should it be necessary to consider insecticide treatment.

SCIENCE SECTION

Objective 1. To develop an easy to use, pest-specific semiochemical monitoring method and attendant damage thresholds for WFT in strawberry crops in Spanish tunnels.

Task 1.1 Optimise the blend of the pheromone components (KU, NRI; Years 1-2)

Completed in Year 2.

Task 1.2 Investigate whether pheromone can be synergised with plant volatiles (KU, NRI; Years 1-2)

Completed in Year 2.

Task 1.3 Optimise trap design for mass trapping (KU, NRI; Years 1-3)

Completed in Year 3.

Task 1.4 Determine flower count damage thresholds (KU, NRI, EMR, ADAS; Years 3-5)

1.4.1 Flower monitoring

In 2011-12 we concluded that counting adult thrips per flower gave a better correlation with fruit damage than trap counts and that 10-20 medium aged flowers (avoiding newly opened and senescent flowers) should be sampled from an area to give a reasonable estimate of a population. Although thrips larvae were shown to cause proportionally more damage than adults to strawberry fruit, larvae cannot be monitored reliably by eye so adult counts are used.

1.4.2 The relationship between flower counts and damage

In the following section, an economic damage threshold is used of 10% of the fruit surface area. This is the amount of damage on the surface of the fruit that downgrades the fruit from Class 1 to Class 2 fruit. It was derived from assessment of bronzing on first and second-class fruit in a commercial pack-house (mean of three occasions) (see 2013 annual report). The assessment of damage on the pack-house fruit was on red fruit, but was done in the laboratory with x10 magnification and a bright light, so that bronzing could be seen. Fruit assessments in the following experiments and in the field sampling were done on white fruit

where bronzing shows up more easily. The assessments on red and white fruit were therefore considered broadly comparable in this case and the 10% fruit surface was used to define thresholds for both red and white fruit.

1.4. (2a) What is the effect of N. cucumeris on F. occidentalis fruit damage? (KU)

Introduction

Earlier experiments showed that fruit damage increases with increasing numbers of adult thrips per flower, but it is the larvae (produced by those adults) that cause most of the damage. The greatest amount of damage to fruit usually occurs at the end of flowering when the flowers are senescent and larval numbers are at their highest, although further damage occurs throughout fruiting and damage occurs later if there is a late influx of adults. Economic damage occurred when fruit damage covered 10% of the fruit surface (in a commercial pack-house), so the aim of these experiments was to test whether *N. cucumeris* (which feeds on thrips larvae) reduced fruit damage caused by thrips.

In order to test the effect of *N. cucumeris* on fruit bronzing caused by thrips, adult thrips were caged on individual flowers at a single density, with or without the predator *N. cucumeris*, and the amount of bronzing was recorded subsequently on the fruits that developed from those flowers. If reduction in damage exceeded 50%, this would also provide supporting evidence that larvae are responsible for most of the damage to strawberry. *Neoseiulus cucumeris* feed mostly on first instar thrips larvae because they are less able to catch larger prey (Bakker & Sabelis, 1989). The experiment was carried out at thrips densities of four and eight per flower, as these were around the lower and upper damage thresholds observed in the field (see Year 2 report).

Methods

Two experiments were carried out in an open-sided polytunnel (2 m × 5 m), at Keele University (N 53° 00.37' W 2° 27.71'), in June and July 2013. Strawberry (*Fragaria* × *ananassa*, cv. Camarillo) was grown in coir growbags (10 cm wide × 100 cm long, BVBSublime, Maasland, NL), each containing ten flowering and fruiting plants. Spontaneous outbreaks of aphids and spider mites were controlled with specific parasitoids and predators, *Aphidius* spp. (Hymenoptera: Aphidiidae) and *Phytoseiulus persimilis* (Acarina: Phytoseiidae) (Aphidsure and Phytosure respectively, BCP Certis, Ashford, Kent). Powdery mildew was controlled by potassium bicarbonate sprays (1 g per 100 ml water).

At four thrips per flower

The two treatments were with and without *N. cucumeris*. The experiment was laid out in a randomised block design, with four blocks, on 11 June 2013. Each block consisted of two separate growbags and two replicates per treatment (two flowers with predators in one growbag and two flowers without predators in a second growbag). The treatments were in separate growbags and each growbag was surrounded by blue sticky traps placed on the ground in order to reduce the spread of predatory mites from treated to untreated growbags (Figure 1.4 A).

Newly-opened flowers of a similar size were selected, then each was infested with four adult female *F. occidentalis*, and enclosed in a nylon pyramid teabag cage (75 mm long × 33 mm wide at the top, Tea Forte, St Albans, UK, Figure 1.4 B) that was sealed with clear adhesive tape. Treated flowers were infested with five active *N. cucumeris* (Ambsure (c), BCP Certis, Ashford, Kent), which would be equivalent to a good establishment of the predators in the field. Mixed-aged and mixed-sex *N. cucumeris* were used to match releases made by growers. The predatory mites were collected directly from the commercial product (Ambsure (c)) using a damp paint brush, and transferred into Eppendorf tubes (12 mm × 37 mm). Tubes containing the predators, or an empty tube for the control, were placed into the flower cages, opened, and left in situ to allow the mites to escape.

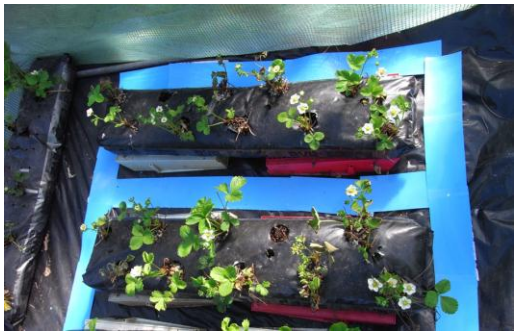
After one week the cages were removed to allow the fruits to develop normally. All fruits were harvested at the fully swollen white fruit stage (growth stage 85 (Meier *et al.*, 1994)), 27 days after they were infested, just as they were starting to turn pink. The fruits were harvested at this stage because some fruits were ripening faster than others, so harvesting early allowed direct comparison of all fruit at the same colour stage on the same date. Also, a toad and a blackbird were feeding on fruit as they ripened, so the fruit were harvested in case they got eaten! Each fruit was assessed for damage by counting the numbers of seeds surrounded by bronzing. The fruits were weighed and the total numbers of seeds per fruit counted.

At eight thrips per flower

The experiment was carried out as above, except with eight adult female *F. occidentalis* per flower instead of four. The experiment was set up on 4 June 2013 and harvested at the white fruit stage, which was after 30 days.

Tables and figures show untransformed data. Log_{10} (n+1) transformation was used for analyses to normalise the variance. Data were analysed using analysis of variance and residuals checked for normality. Statistical analysis was carried out with Minitab 16.

A



B

Figure 1.4.1. Photographs showing experimental methods for the fruit damage experiments: (A) the lay-out of a single plot with and without predatory mites (B) caged flowers.

Results

At four thrips per flower

The addition of *N. cucumeris* (five per flower) to flowers containing four adult female *F. occidentalis* reduced fruit bronzing from about 26% to <1% of the fruit surface (one-factor ANOVA with blocks, $F_{(1, 3)} = 11.6$, $P = 0.042$, Figure 1.4.2. B), bringing bronzing below the damage threshold. There was no difference observed between treatments in fruit weight (one-factor ANOVA with blocks, $F_{(1, 3)} = 0.02$, $P = 0.90$, Figure 1.4.2. D), or number of seeds per fruit (one-factor ANOVA with blocks, $F_{(1, 3)} = 7.46$, $P = 0.07$), which averaged (± SEM) 314.1 ± 17.4 and 351.3 ± 21.9 with and without *N. cucumeris* respectively. At the end of the experiment there were 3.8 ± 1.0 predators per fruit in treated plots and 1.0 ± 0.5 predators per fruit in untreated plots (one-factor ANOVA with blocks, $F_{(1, 3)} = 11.0$, $P = 0.045$), indicating that there had been some movement of predators between the plots over six weeks. Minimum and maximum temperature and humidity were 4.5°C, 30°C and 48%, 95.5% RH respectively.

At eight thrips per flower

The addition of *N. cucumeris* (five per flower) to flowers containing eight adult female *F. occidentalis* reduced fruit bronzing from about 51% to about 4% of the fruit surface (one-factor ANOVA with blocks, $F_{(1, 3)} = 75.5$, $P = 0.003$, Figure 1.4.2 A), bringing bronzing below the damage threshold. There was no difference observed between treatments in fruit weight (one-factor ANOVA with blocks, $F_{(1, 3)} = 0.05$, $P = 0.84$, Figure 1.4.2 C), or number of seeds per fruit (one-factor ANOVA with blocks, $F_{(1, 3)} = 0.6$, $P = 0.49$), which averaged (± SEM) 352.75 ± 9.2 and 360.5 ± 6.9 with and without *N. cucumeris* respectively. At the end of the experiment there were 3.5 ± 0.2 predators per fruit in treated plots and 0.5 ± 0.2 predators per fruit in untreated plots (one-factor ANOVA with blocks, $F_{(1, 3)} = 87.4$, $P = 0.003$), indicating that there had been some movement of predators between the plots over the six weeks. Minimum and maximum temperature and humidity were 4.5°C, 30°C and 48%, 95.5% RH respectively.

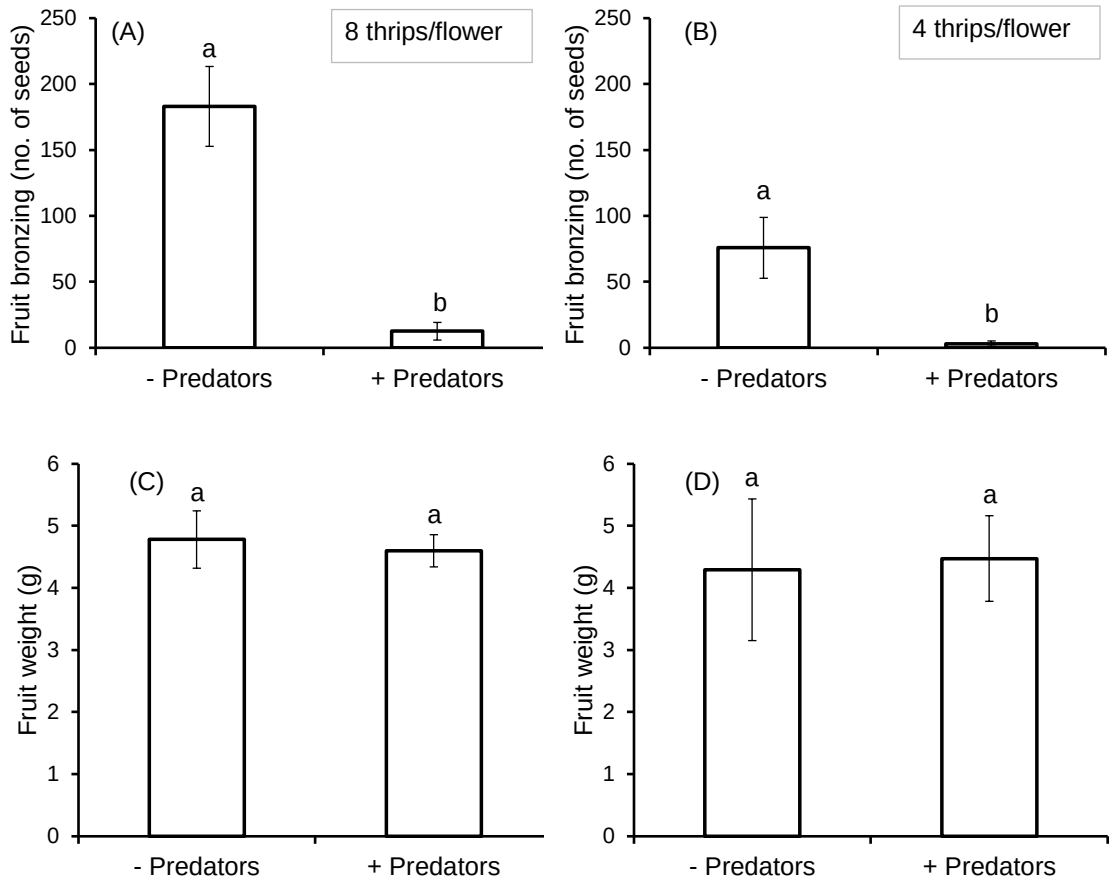


Figure 1.4.2. The mean numbers ± SEM of seeds surrounded by bronzing per fruit following infestation with (A) eight adult female thrips per flower and (B) four adult female thrips per flower and the mean fruit weight ± SEM following infestation with (C) eight thrips per flower

and (D) four thrips per flower, all with or without the predator *N. cucumeris* in a strawberry crop (n = 4 blocks). Means with the same letter are not significantly different ($P > 0.05$).

Conclusions

- In the absence of predators, four and eight adult thrips per flower resulted in bronzing over 21% and 51% of the fruit surface respectively, which is above the economic injury level of 10% (around 36 seeds in this case) observed in commercial crops, but fruit weight was not affected.
- The addition of the predator *N. cucumeris* reduced fruit bronzing below the economic injury level when there were four or eight adult thrips per flower.
- The results confirm that it is the larval stages of the western flower thrips that cause most of the fruit bronzing, as *N. cucumeris* do not feed on adults.
- The presence/absence of *N. cucumeris* must be taken into account when developing action thresholds for growers.

1.4. (2b) *Damage thresholds observed in commercial crops* (KU)

Introduction

Controlled damage experiments showed that four or more adult thrips per flower resulted in fruit bronzing that would result in downgrading in a commercial pack-house (10% of the fruit surface bronzed) but that eight adult thrips per flower could be tolerated when there was good establishment of *N. cucumeris*. The aim of this study was to test the relationship between thrips populations and fruit damage in commercial crops, including crops from different cultivars and regions (EMR/ADAS sites). Unfortunately the EMR data could not be used because of discrepancies in the sampling methods. Note that a single cultivar (cv. Camarillo) was used for most experiments to allow for comparison between experiments.

Methods

Regression analysis was carried out between mean numbers of adult thrips per flower and mean fruit damage (recorded as the numbers of seeds surrounded by bronzing on white fruit) in different fields, cultivars and years. The data were taken from different experiments carried out throughout the project and the methods for collecting the data will not be repeated here (see Year 3 report). Analysis was carried out on data collected weekly through the growing season from two crops in 2011, but on single dates (at a time when thrips damage became apparent) in the other crops. Thrips density was compared to fruit bronzing on the same date.

Whilst damage on white fruit will have resulted from thrips present over the previous three weeks, thrips numbers at the time of damage are a good indicator of damage because thrips numbers can change rapidly between weeks and damage can occur right up to harvest. White fruit were used to assess bronzing, where damage shows up more clearly than on red fruit. The thresholds are therefore considered to be conservative. The thresholds were calculated as the numbers of thrips per flower that corresponded with bronzing on fruit around 30 seeds, which corresponded to about 10% of the fruit surface bronzed based on the mean number of seeds per fruit counted on pack-house fruit. Lower damage thresholds might apply when there is a glut of high quality fruit.

Results

Damage thresholds between five and 11 adult thrips per flower were identified in commercial crops, which supported the thresholds identified in controlled experiments (Table 1.4.1). Thrips numbers remained below five adults per flower throughout the season without economic crop damage (in the presence of *Neoseiulus* spp.) in six crops (Table 1.4.1).

There was a strong correlation between numbers of thrips per flower and fruit damage (which will have occurred over the previous three weeks) on the same date. This could be because the thrips numbers at the time reflect those of three weeks ago, or because numbers of thrips per flower reflects recent damage (e.g. in the previous 10 days). This might occur when thrips populations are increasing when you get relatively more damage later in fruit development.

Neoseiulus spp. establishment varied between sites and sample dates (not shown), but the lowest threshold (economic damage at five adult thrips per flower) was observed in the field with the lowest cover of predatory mites and the highest threshold (economic damage at 11 adult thrips per flower) in the field with the highest cover of predatory mites (Table 1.4.1).

In most crops, damage occurred from late July through August, but damage was also observed in May on fruit from autumn-initiated flowers in a second-year crop (cv. Finesse) that had a large overwintering thrips population and >30 flowers per plant in the first flower flush. Increased damage occurred at the end of flower flushes, when thrips concentrate into fewer flowers, resulting in increased numbers of thrips per flower.

Table 1.4.1. Damage thresholds (DT) observed in commercial semi-protected strawberry crops, derived from regression analysis between numbers of adult thrips per flower and fruit bronzing around 10% of fruit surface. The mean numbers of adult thrips per flower when the thrips populations were at their peak and the percentage of fruit supporting predatory mites (*Neoseiulus* spp.) are shown, where the data were available. N/A = Not available, MF = Manor Farm monitoring, *peak sampling density is taken from the whole season.

Location (year)	Cultivar	Peak sampling density (adults per flower)*	% fruit with predators	r^2	*P*	DT	Data source
Stafford (2011)	Camarillo	12.9	4%	91%	<0.001	5.0	KU
Tamworth (2011)	Camarillo	10.3	42%	85%	<0.001	5.0	KU
Stafford (Sept 2012)	Camarillo	6.0	5%	88%	<0.001	6.3	KU
Tamworth (May 2012)	Finesse	12.5	62%	65%	0.009	8.7	KU
Tamworth (Aug 2012)	Camarillo	18.5	60%	63%	<0.001	8.8	KU
Tamworth (Aug 2012)	Camarillo	17.1	72%	62%	<0.001	10.6	KU
The following crops did have sufficient thrips to cause fruit downgrading:							
Stafford (2012)	Camarillo	1.0	72%	-	-	N/A	KU
Tamworth (2012)	Finesse	3.1	N/A	-	-	N/A	MF
Tamworth (2012)	BG EME	4.9	N/A	-	-	N/A	MF
Tamworth (2013)	Finesse	1.0	N/A	-	-	N/A	KU
Colchester (2013)	Finesse	3.7	N/A	-	-	N/A	ADAS
Cambridge (2013)	Jubilee	2.0	N/A	-	-	N/A	ADAS

Conclusions

- Bronzing covering about 10% of the fruit surface occurred when mean thrips per flower reached five or more adult thrips per flower.
- No economic fruit damage was observed in crops where the numbers of adult thrips per flower remained below five (through the season), in crops where predatory mites were present.
- Further data is required to determine the numbers or percentage cover of predators required to reduce fruit damage in the field, although growers should aim for 100% cover.
- There is increased risk of fruit damage at the end of a flower flush, when thrips concentrate into fewer flowers.
- There are insufficient data to draw conclusions on the relative susceptibility of different cultivars to thrips damage, but the limited data available showed similar susceptibility to damage between the cultivars tested.

1.4. (2c) *Can thrips density in flowers be used to predict future damage?* (KU)

Introduction

Whilst it is useful to know whether thrips populations are approaching damaging levels (e.g. five adult thrips per flower), we also need to know whether the assessment of thrips density in flowers is a good predictor of fruit bronzing in the future, which would allow time for growers to make interventions in order to prevent damage. This was tested in two crops (to reflect different field situations), one with a stable thrips population and one where the thrips population was increasing rapidly. Where thrips numbers are stable the thrips density in flowers should be a good predictor of damage as most of the damage is likely to occur in the late flowering, early green-fruit stages (see 2013 report), soon after those flowers had been assessed. When thrips numbers are increasing, further damage would occur in the later stages of fruit development, which could outweigh damage done at an earlier stage, so a poor correlation might be expected (as the damage would reflect the higher thrips numbers that occurred later in the fruit development).

Methods

When thrips numbers are stable

To test whether thrips density in flowers is a good predictor of damage on fruit that develop from those flowers in a crop with a stable thrips population, thrips density was assessed in 22 plots of 0.5 m^2 in a second-year crop (Manor Farm, Tamworth, cv. Camarillo) on 13 August 2012, then on white fruit 23 days later in the same plots (on 5 September), when the flowers from 13 August had formed white fruit. Thrips density and fruit bronzing were compared on the same date (5 September) as a comparison, using the same methods. White fruit was assessed so that damage could be compared to the controlled damage experiments, which were assessed at the same stage. The numbers of adult thrips per flower and the numbers of seeds surrounded by bronzing per fruit were counted by eye, using a ×7 head lens (optiVISOR), on five flowers and five white fruit and per plot.

When thrips numbers are changing (by variable amounts)

To test whether thrips density in flowers is a good predictor of damage on fruit that develop from those flowers in a crop with a changing thrips population, thrips density was assessed in nine plots of 150 m^2 in a second-year crop (Littywood Farm, Stafford, cv. Camarillo) on 8 August, then on red fruit in the same plots 33 days later (on 10 September), when the flowers from 8 August had formed red fruit. Thrips density and fruit bronzing was compared on the same date (10 September) as a comparison, using the same methods. Flower count data were used from a mass trapping experiment (in the same plots) for which the methods are detailed in the 2013 annual report (section 1.5.2), so will not be repeated here.

Assessments from August and September were used, when thrips numbers remained stable in treated plots but increased rapidly in control plots. On 8 August 2012, 40 medium-aged flowers were sampled regularly across nine plots and this was repeated on 10 September. In addition, 20 red fruit were sampled regularly across each plot on 10 September (when the flowers from 8 August had formed red fruit). The numbers of adult thrips per flower and the numbers of seeds surrounded by bronzing per fruit were counted by eye using a ×7 head lens (optiVISOR), as above.

Regression analysis was used to test the relationship between fruit bronzing and thrips density in the different fields, using mean thrips per flower and mean bronzing on fruit (white or red) that developed from those flowers and on flowers and fruit comparing thrips density and fruit damage on the same date.

Results

When thrips numbers were stable

When thrips numbers were relatively stable (mean numbers of thrips per flower = 4.5 and 3.4 on 13 August and 5 September respectively), the numbers of adult thrips per flower were better predictors of damage on the fruit that developed from those flowers (Figure 1.4.2 A): Regression analysis, log (bronzing +1) (no. of seeds) on September fruit = 0.73 + 0.69 log (adult thrips per flower +1) in August, $r^2_{(1,20)}$ = 62%, *P* <0.001, than when thrips density and fruit damage were compared at the same time (Figure 1.4.2 B): log (bronzing +1) (no. of seeds) = 0.79 + 0.66 log (adult thrips per flower + 1); $r^2_{(1,20)}$ = 41%, *P* = 0.001.

When thrips numbers are changing (by variable amounts)

When thrips numbers were increasing rapidly (mean numbers of adult thrips per flower increased from <1 to >6 over a five-week period in control plots), there was poor correlation between numbers of adult thrips per flower and damage on the fruit that developed from those flowers five weeks later (Figure 1.4.2 C): Regression analysis, log (bronzing +1) (no. of seeds) = 1.42 – 1.9 log (adult thrips per flower +1); $r^2_{(1,7)}$ = 18%, *P* = 0.14, showing that they could not be used to predict future damage. However, there was excellent correlation between thrips density and fruit damage when they were assessed at the same time (Figure 1.4.2 D): Regression analysis, log (bronzing +1) (no. of seeds) = 0.27 + 1.31 log (adult thrips +1) per flower; $r^2_{(1,7)}$ = 88%, *P* <0.001.

Conclusions

- Numbers of adults per flower is a good indicator of fruit damage at the time or soon after (e.g. up to two weeks after flowering).
- The numbers of adult thrips per flower alone cannot be used to predict damage on the fruit that develop from those flowers (five weeks later) because thrips numbers often increases rapidly in between, causing more damage on the later stages of fruit development that would not be predicted if thrips numbers had stayed the same. Appropriate action can also prevent damage from occurring on developing fruit.
- Growers need to monitor weekly in order to assess risk of damage.

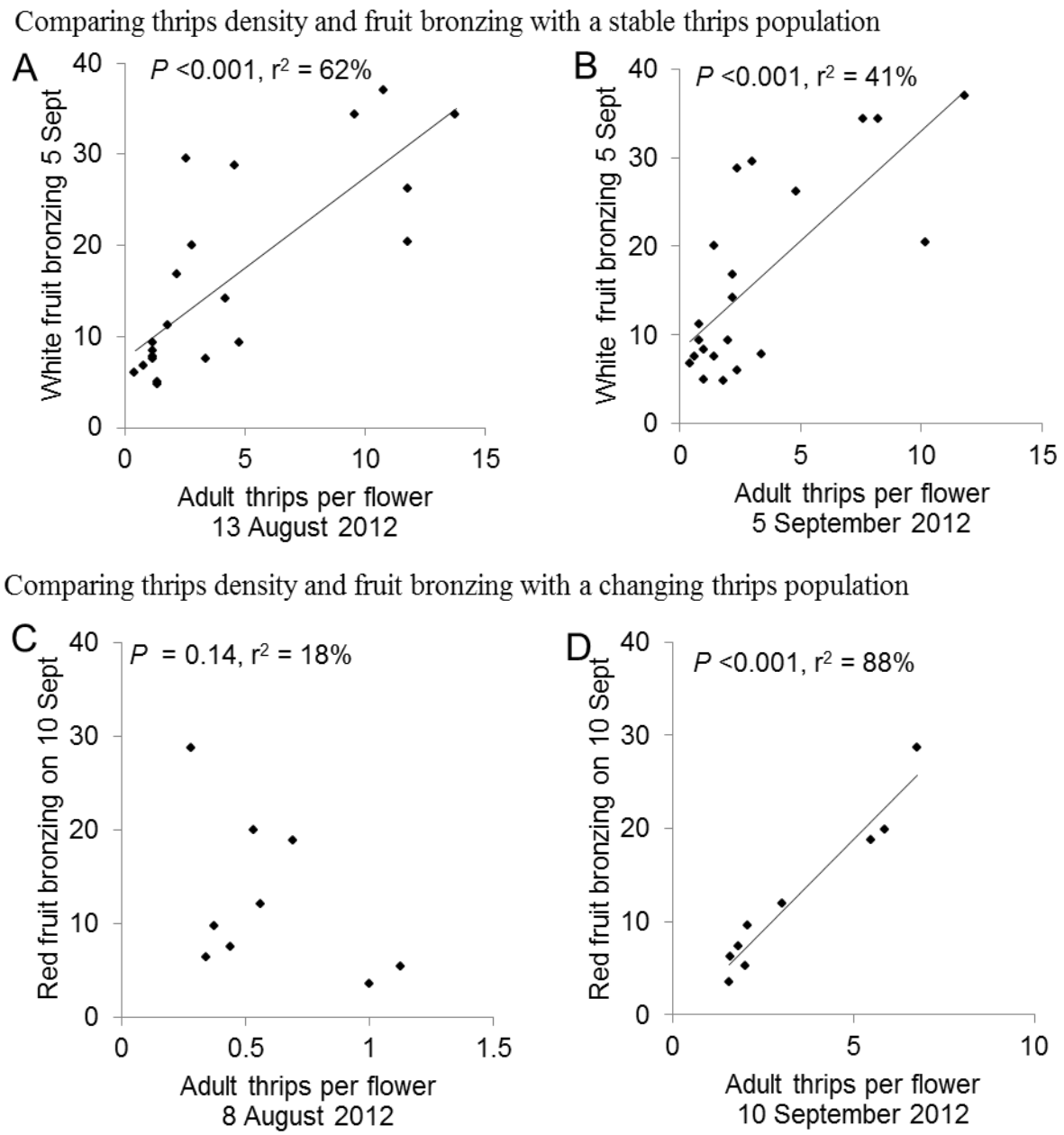


Figure 1.4.2. Correlation between numbers of adult thrips per flower and fruit bronzing in semi-protected strawberry fields with a stable or rapidly changing thrips population, comparing: (A) thrips density with bronzing on fruit that develop from those flowers and (B) thrips density and fruit damage at the same time, in a field with a stable thrips population and (C) thrips density with bronzing on fruit that develop from those flowers and (D) thrips density and fruit damage at the same time, in a field with a changing thrips population. Analysis was on log-transformed data whilst the charts show untransformed data.

Task 1.5. Investigate the possibilities of using traps for control of WFT (KU, NRI, EMR, ADAS; Years 3-5)

1.5.1. Does the density of pheromone lures affect trapping efficacy? (KU)

Introduction

In mass trapping experiments during 2012, a high density of pheromone lures was used (every 2.2 m) in pheromone treated plots. This established that the addition of pheromone increased trap catch. The aim of this experiment was to determine whether a lower density of lures would be more cost-effective.

Methods

Site details: A first-year semi-protected strawberry crop (cv. Finesse), at Manor Farm (Tamworth). The whole crop was treated with blue sticky roller traps in April, which were replaced on 23 July 2013 (Figure 5.1.1). The traps were clipped onto the legs of the polytunnels using polytunnel securing clips (20 mm wide, 30 mm diameter) protected by a polythene strip (approx. 30 mm x 80 mm) with the base of the trap level with the crop canopy (30 cm) and two clips per leg. The predatory mite *N. cucumeris* was released approximately fortnightly throughout the cropping period.

Figure 1.5.1. Photograph of the trial field in September 2013 (at the end of the trial).

Plot details: Each plot was 22 m long and 13 m (two tunnels) wide, with 11 m between plots. All plots were located at least 40 m in from the end of the polytunnel.

Treatments

There were three treatments, each with seven replicates arranged in a randomised block design:

1. Traps only (control) – Blue sticky roller traps (Optiroll, 100m x 30 cm, Russell IPM).
2. Traps with pheromone lures every 2.2 m – Roller traps (Optiroll), with additional pheromone lures at 2.2 m intervals, each containing 30 µg neryl (*S*)-2-methylbutanoate (source Thripline ams, Syngenta Bioline). Each lure was pushed into a hole made in the roller trap with a hole punch.
3. Traps with pheromone lures every 6.6 m – Roller traps (Optiroll), with additional pheromone lures at 6.6 m intervals (as above).

Set up and assessment dates:

Pre-trial assessment:	16 July 2013
Traps and lures put up:	23 July 2013
Assessments:	5 September 2013.

Assessments: On each assessment date and in each plot, 40 mid-aged open flowers and 20 swollen white fruit were sampled evenly over each plot (n=40 flowers, n=20 fruit). The numbers of adult thrips per flower were counted by eye using a x7 head lens. The numbers of seeds surrounded by bronzing were counted per fruit.

Results

Thrips numbers remained low for the whole season and averaged around 0.1 adult thrips per flower in all plots on 16 July. By September, there was a trend towards lower thrips numbers with increasing density of pheromone lures (Figure 1.5.2) but the differences were not significantly different because thrips numbers were so low ($F_{(2, 12)}$ = 0.58, P = 0.57). Fruit bronzing remained well below the damage threshold throughout the season (100% Class 1 fruit), with bronzing observed around 7 ± 1 seeds per fruit on 9 September in all plots ($F_{(2, 12)}$ = 0.16, P = 0.85).

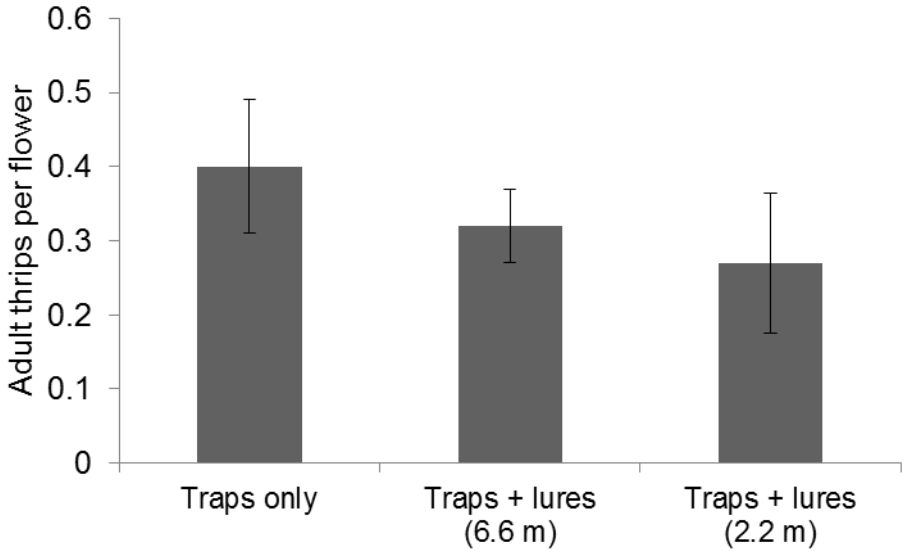


Figure 1.5.2. Mean numbers of adult thrips per flower ± SEM in plots with different pheromone lure densities, on 5 September 2013.

Conclusions

- There were insufficient thrips to draw conclusions on the optimum lure density for mass trapping, although there was a trend towards fewer thrips with increased density of pheromone lures.
- The IPM programme used, combining the use of predatory mites with mass trapping, resulted in season long control of thrips in this first year crop (in a field that had economic crop loss from thrips damage in the previous three seasons).

References

Bakker, F.M. & Sabelis, M.W. (1989) How larvae of *Thrips tabaci* reduce the attack success of phytoseiid predators. Entomologia Experimentalis et Applicata *50, 47-52.*

Meier, U., Graf, H., Hess, M., Kennel, W., Klose, R., Mappes, D., Seipp, D., Stauss, R., Streif, J. & van den Boom, T. (1994) Phänologische Entwick lungsstadien des Kernobstes (*Malus domestica* Borkh. und *Pyrus communis* L.), des Steinobstes (*Prunus*-Arten), der Johannisbeere (*Ribes*-Arten) und der Erdbeere (*Fragaria* x *ananassa* Duch.). *Nachrichtenbl. Deut . Pflanzenschutzd.* 46, 141-153.

Objective 2. To develop a computer based model of thrips population development for predicting risk of WFT infestation and rapidity of population increase

Background

The population growth of WFT depends mainly on temperature and host plant. Depending on temperatures, many generations of WFT can develop within a season on ever-bearer strawberry. Predicting WFT population development may assist growers in controlling WFT by allowing accurate timing of biological control agents/pesticides for maximum control, and assisting in interpreting trap catches.

Task 2.1. Developing models (EMR)

A prototype model was developed (see year 2 report) and modified by combining additional data on WFT development on cucumber leaves (see year 3 report). Weather data from EMR was used to run the model. This showed that distinguishing different generations may be difficult because of overlapping generations (short generation time). Another problem in validating and using the model is that several species of thrips may be present in strawberry crops (WFT, *Thrips major* and *T. tabaci* have been the most common in sampling undertaken in this project in several commercial crops). Thus to get a clear idea of WFT population development within this mix it would be necessary to identify large numbers of thrips from samples taken at each assessment; this would need to be done by scientists or advisors under a microscope. Thrips larvae are difficult to identify to species so it might be necessary to estimate the numbers of each larval species present, based on the proportion of adults of each species present in the planting.

It is not clear if the other thrips species cause the same fruit damage as WFT. If they do, and if all the thrips species have similar development rates, it might be possible to use the mixed data in the model to get an overall picture of 'thrips' development within the crop. To this end a literature search was undertaken to determine if developmental data had been published for *T. tabaci* and *T. major*. From the limited published data available, although there is considerable variability in the developmental rate between different thrips species, there is also similar variability in the developmental rate of the same thrips species on different hosts. Furthermore, when combining all the published data on *T. tabaci* in comparison to available data on WFT, it is reasonable to assume that the relationship of the developmental rate with temperature is similar between the two thrips species (Figure 2.1.1). In another study, the developmental rates were similar for WFT, *T. tabaci* and *T. major* at the same site.

Thus we aim to use data collected during this project where mixed populations of thrips were present in the crop to validate the model.

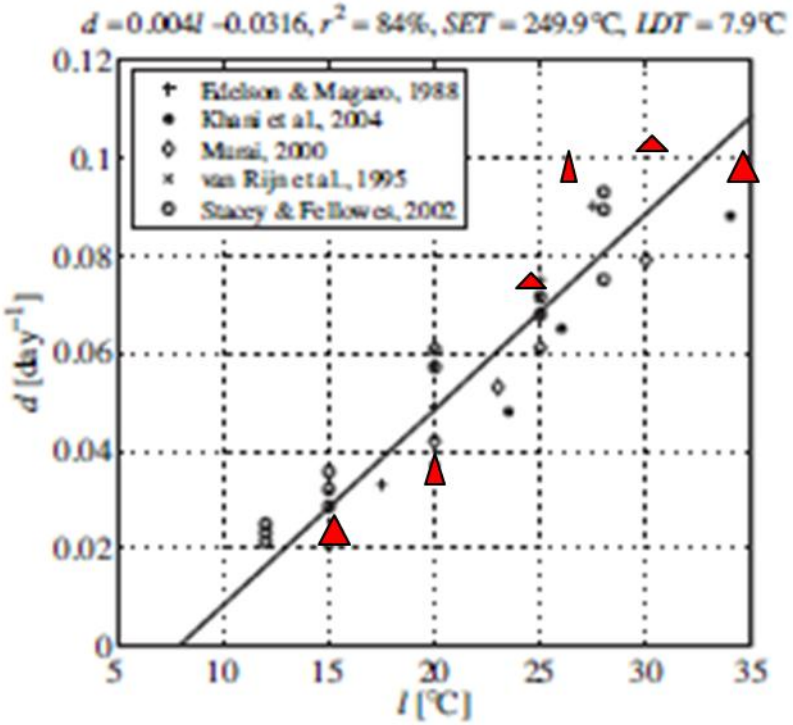


Figure 2.1.1 Relationship between mean developmental rate and temperature for *T. tabaci* based on the data from several published studies, together with the data (red triangle symbols) for WFT.

Task 2.2. Obtaining new data for model validation (EMR)

We are particularly interested in how WFT development is affected by the low temperatures experienced in the spring because previous research on WFT was primarily done on glasshouse crops with temperatures > 15°C. Experiments were done in cages exposed to the external environment to assess the timing of emergence from overwintering sites, and at controlled fluctuating temperatures in the lab, to identify the extent of non-linear relationships at low temperatures. Non-linearity of response may cause considerable prediction errors around these temperature ranges.

Methods

Early season development of populations: Cages containing potted strawberry and groundsel plants were set up at EMR on gravel beds. The cages were embedded into the gravel to reduce insect escape. Temperature loggers were placed in each cage. The cages were left until early March and the plants tapped to determine if WFT adults were present.

In 2014 more sampling will be done in early spring in commercial plantings to determine when WFT become active and begin to lay eggs. In addition laboratory studies will be done to determine the threshold temperatures for oviposition by adult WFT and for egg development

Development at low temperatures: Experiments investigated the effects of fluctuating temperatures on WFT development on weaned strawberry plants derived from micropropagated plants. This experimental design was chosen after several other designs with leaf disc material had failed to enable us to obtain reliable data on thrips development from egg to adult over the extended period required at low temperatures. The plants were weaned in vermiculite at 22°C until well rooted. They were then transplanted into pots consisting of rigid plastic tubing with the bottoms covered in fine mesh. The mesh enabled the plants to be watered by capillary action. The pot was sealed by placing another similar tube, also with a mesh bottom, on top of it and sealing the two tubes together with parafilm. The gauze top then allowed ventilation to the plants and prevented loss of any thrips on the plants. The set-up is shown in Figure 2.2.1.

The experiment was set up in controlled environment cabinets at fluctuating (16/10°C and 14/10°C) and constant temperatures (20°C, 16°C and 14°C) with a 14/10 L/D period. Adult females were introduced to strawberry leaf discs held above a water reservoir on filter paper in small plastic pots and left to lay eggs. The adults were removed after 24 hours. The leaf discs were inspected every day until larval emergence and the time for egg development recorded. Recently emerged larvae were then transferred to the strawberry plants described above. Strawberry pollen was added as a food source. The plants were inspected each day and the stage of thrips development recorded.

Figure 2.2.1. Micro-propagated strawberry plants are weaned and then used in experiments to assess development times of WFT larvae

Results

Early season development of populations: In the external cage experiments no thrips were found on the plants when they were sampled in March. This indicates that numbers overwintering successfully in this situation were low. This is in line with results obtained in an earlier HDC funded project SF 80 where plants were infested with large numbers of thrips in September but very low numbers were found in the following March. In these earlier experiments the first adult WFT were recorded in the second week of March in Herefordshire and Kent (Bennison & Fitzgerald 2009).

Development at low temperatures: Additional data on egg hatch time at the different temperatures were obtained in 2013. These results were combined with those obtained in 2012 and are shown in Table 2.2.1 and Figure 2.2.2. The results clearly showed that WFT developmental rate at 10°C is not zero as assumed by all previous studies (minimum temperature for development was said to be around 10°C). For instance, most eggs hatched after 8-10 days under the constant temperature of 16°C, close to the 8-9 days predicted by the model, (the range was 8-13 days). However under the 16/10°C, most eggs hatched between 9-11 days (range 8-13 days), which is shorter than the predicted 14-15 days (assuming the developmental rate is zero at 10°C). Similarly for the 14/10°C regime, the predicted length is around 18 days, compared to the observed 11-13 days (range 9-15).

Table 2.2.1. Development time for WFT eggs at different temperatures and 14/10 L/D. Number of eggs hatched on each day after oviposition are given

Treatment	Days after oviposition													Total
	4	5	6	7	8	9	10	11	12	13	14	15	16	hatched
20º/20 ºC	71	175	13	8										267
16º/10ºC					1	41	64	17	6	7				136
16º/16ºC				1	12	26	15	8	8	2	1			73
14º/10ºC						1	2	13	9	15	3	9		52
14º/14ºC					9	13	22	28	8					80

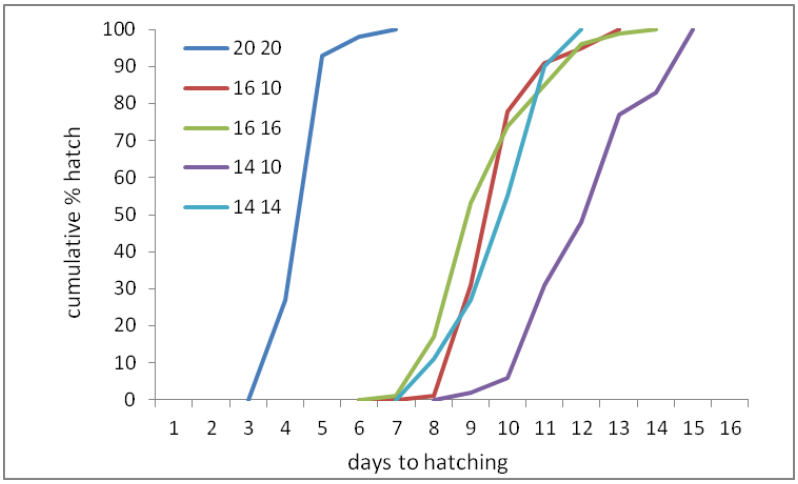


Figure 2.2.2. Cumulative WFT egg hatch at different temperatures

A total of fifty individuals were set up in each temperature regime in several experiments using the small weaned strawberry plants, but only small numbers of individuals survived from egg hatch to the adult stage (Tables 2.2.2 and 2.2.3); survival at 20 ºC was greater than at any of the lower temperatures. Work is in progress to assess thrips development rates at the other end of the fluctuating spectrum around 35-38°C.

Table 2.2.2. Mean duration of WFT developmental stages in different temperature regimes

Temperature	Mean duration of stage (days)		
	instars 1 + 2	pre pupa	pupa
20º/20 ºC	11 (11)	2.2 (5)	3 (5)
16º/10ºC	19.5 (6)	2.5 (6)	7 (4)
16º/16ºC	20 (2)	3 (1)	9 (1)
14º/10ºC	28 (2)	4.5 (2)	8 (1)
14º/14ºC	22.5 (2)	3 (2)	8 (1)

Table 2.2.3. Mean duration from egg hatch to adult WFT in different temperature regimes

Temperature	Mean duration egg hatch to adult stage (days)	
	males	females
20º/20 ºC	15 (10)	14.6 (17)
16º/10ºC	30 (3)	25 (2)
16º/16ºC	28 (1)	-
14º/10ºC	-	39 (1)
14º/14ºC	26 (1)	-

Task 2.3. Field WFT monitoring (EMR)

Methods

Samples of 10 flowers were taken regularly into alcohol for examination in the laboratory during the IPM experiment detailed in Object 5. The samples were washed and thrips larvae and adults counted under a microscope; this technique is the same as that used in earlier experiments (see previous Annual Reports) to enable comparisons to be made across years and sites. A sample of the thrips adults were mounted on microscope slides and identified to species; all those identified from this site in 2013 were WFT.

Results

The results from 2013 sampling are shown in Table 2.2.4. These data, together with data obtained during the IPM trials in Years 1-3, will be used to validate the model.

Table 2.2.4. Numbers of WFT washed from samples of 10 flowers in 2013

	Numbers per 10 flowers	
Jubilee	**Thrips larvae**	**Thrips adults**
23 May	0	0
8 July	10	29
24 July	139	56
1 August	17	71

Camarillo		
9 May	7.5	0
22 May	1	1
7 June	3.5	75
8 July	10	162
15 July	51	149
24 July	136	177
1 August	56	129

Discussion

As growers are moving more towards using biocontrol strategies for thrips in strawberries and reducing pesticide use several species of thrips (in particular *Thrips major* and *T. tabaci*) are now commonly found in commercial plantings together with WFT. This makes it difficult to undertake a sampling programme for WFT to validate the model as the other species are also present and it is very time consuming to separate WFT from the other species. Species of thrips adults can only reliably be identified after making a slide of the individual, clearing the specimen and inspecting it under a compound microscope. For the large populations of thrips seen in some plantations it is not practical to do this for all individuals and subsampling is necessary. Identifying larval thrips is more difficult. Thus it would not be possible to obtain information on the development stages of WFT alone in a planting given the time available for this part of the project. There is much information about the thrips (all species) present in different fields in results of Objectives 1 and 4 of this project. A literature search was made to access developmental data for the three thrips species commonly found in strawberry. Development rates were found to be similar so the data reported in Objectives 1 and 4 will be used to validate a general thrips development model.

Task 2.4. Adapting, validating and modifying the model (EMR)

This work is ongoing.

Objective 3. To determine reliable and cost-effective methods of using predators for biological control of WFT

Task 3.1 Optimise A. cucumeris release strategies (BCP, EMR, Year 1)

Task 3.2 Optimise O. laevigatus release strategies (ADAS, Years 1-2)

Task 3.3 Combine A. cucumeris and O. laevigatus release strategies for improved WFT control (ADAS, EMR, Years 2-3)

Tasks 3.1, 3.2 and 3.3 were completed in Years 1, 2 and 3

Task 3.4 Use of thrips attractant with banker plants (ADAS, EMR, KU, Years 4-5)

After discussion of results of 2012 it was decided not to progress this aspect of the project.

Task 3.5 Assessment of potential naturally occurring predators (ADAS, EMR, Years 3-5)

In the samples of plants taken in Years 1-4 by EMR, very low numbers of predatory arthropods were recovered. For example in 2012 in 375 plants sampled over three sample dates only 26 spiders were recorded; no other predators were seen. Thus it seems unlikely that there will be high numbers of naturally occurring predators in commercial crops.

Objective 4. To evaluate pesticide products, adjuvants and entomopathogenic fungi for control of WFT in strawberry, the latter in flowers versus in the soil

The aim of this project Objective is to evaluate novel insecticide treatments and proprietary fungal biopesticides on a commercial crop. A number of experiments have been done previously in the project to evaluate the efficacy of fungal biopesticides against WFT populations. These were done in a polytunnel and also using WFT populations maintained on strawberry plants in small cages outside. These experiments did not result in significant

levels of pest control. The fungal biopesticides used in these experiments are pathogenic to WFT (i.e. they kill WFT in laboratory experiments) and it is not known why there was a lack of control in the cage and polytunnel experiments. To start to address this, an experiment was done to quantify the deposition of a commercial biopesticide spray within a strawberry crop. This would help us understand whether biopesticides are being deposited in places where thrips are located, and to give information of the number of spores that are acquired by thrips.

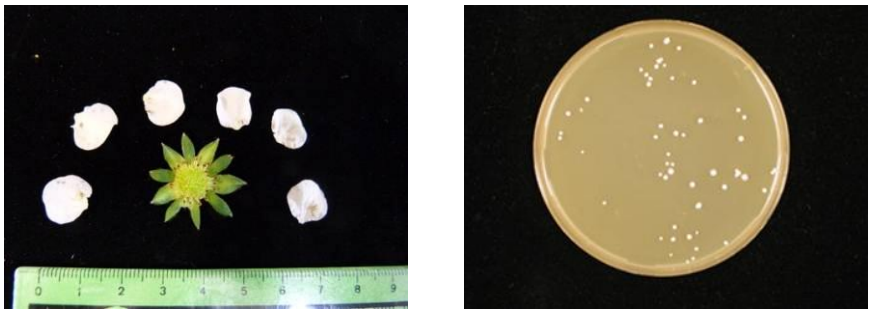
Methods

In 2013, Naturalis (*Beauveria bassiana*) was applied, at a volume rate of 500 l/ha with a CP 20 pump knapsack sprayer according to the manufacturers' recommendation, to twenty strawberry plants (cv. Finesse) in 1L pots which were infested or non-infested with WFT (Figure 4.1).

Figure 4.1: Experimental plants

One hour after spray application, flower and leaf samples were removed from the plants. The flowers were dissected into two parts (petals and calyx), photographed and all samples (petals, calyx and leaves) washed in 0.05% Triton X-100. Aliquots were plated onto selective medium, incubated, in the dark, at 20°C (± 2°C) and the number of colonies grown on the plate counted after five days (Figure 4.2).

Figure 4.2: Dissected flower samples and inoculated selective medium



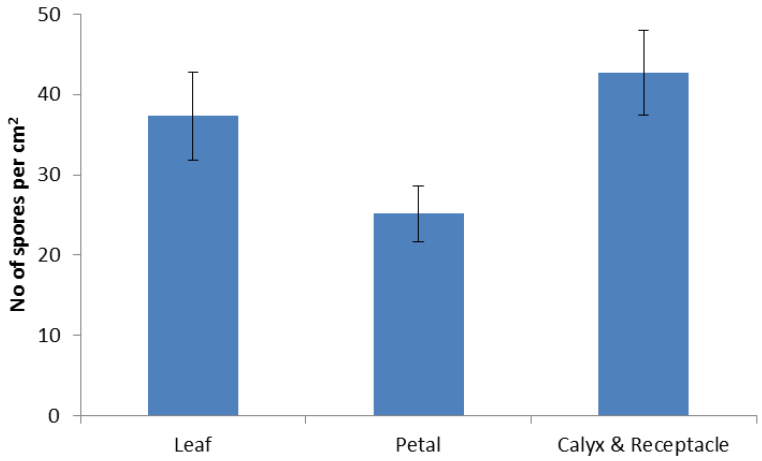
WFT were removed from infested plants (SOP: 780 Sampling and assessing thrips numbers in flowers. (C Jay, EMR, June 2010)). Numbers of thrips were counted under a binocular microscope at low magnification and washed in 200 µl of 0.05% Triton X-100. Aliquots were plated onto selective medium, incubated, in the dark, at 20°C (± 2°C) and the number of colonies grown on the plate counted after five days.

Analysis and Results

The area of the leaves, petals and the calyx/receptacle were measured using image processing software (Image J) and the number of colonies per plate adjusted to determine the number of viable spores sprayed per unit area before analysis of variance (Genstat, 2007).

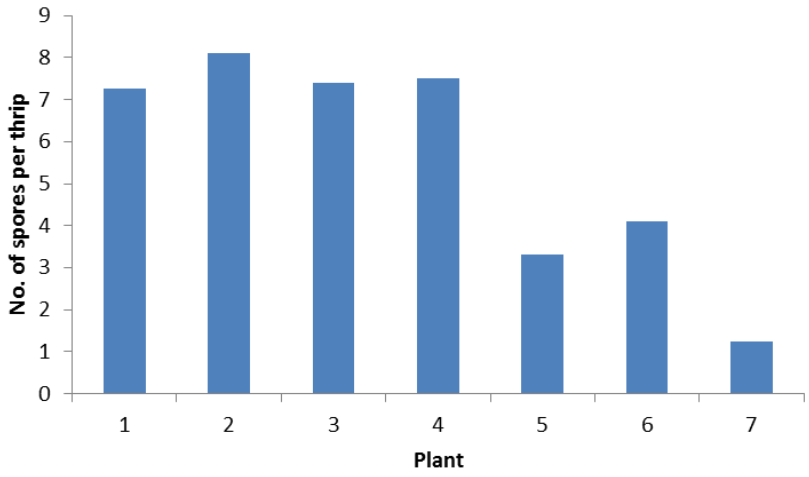
All parts of the strawberry plant sampled had viable fungal spores (Figure 4.3). The number of viable spores found on the petals was 25 per cm^2; leaves = 37 per cm^2 and calyx/receptacle were 43 per cm^2. The number of viable spores per cm^2 varied between plants and plants parts with the number of viable spores found on petals ranging from 0 to 46 spores per cm^2; leaves ranging from 7 to 86 spores per cm^2 and the calyx/receptacle ranging from 11 to 93 spores per cm^2. There was a significant (lsd = 13.62, df=57, P≤ 0.05) number of viable spores counted on the calyx/receptacle compared with on the petals but no significant differences between the other flower parts. However caution should be used when interpreting these results due to the possible underestimation of the area of the calyx and receptacle.

Figure 4.3: The mean number of spores per cm^2 after treatment with *Beauveria bassiana*. Error bars represent the standard error of the mean.



Fifty seven percent of the thrips added to the strawberry plants were recovered. The thrips that were recovered were all found in the flowers of the treated plants. All of the thrips recovered from the treated plants had viable fungal spores (Figure 4.4). The mean number of viable spores per thrips was 6 spores (S.E= 1.003). The number of spores per thrips varied significantly (t=2.447, P≤ 0.05) between plants and ranged from one viable spore per thrips to seven spores per thrips.

Figure 4.4: The number of spores per thrips after treatment with *Beauveria bassiana.*



Conclusions

All parts of the strawberry plant sampled received a number of viable spores. All of the thrips found were located in the flowers but they varied in number of spores that they received. This suggests that secondary pick up of viable spores is an important means of inoculation for WFT biocontrol with entomopathogens. Further work is required to evaluate the persistence of the fungal spores on the strawberry crop and to determine the number of spores per thrips required to cause death.

Objective 5. To optimise the use of the above components in a joined up IPM programme for WFT control on strawberry and to evaluate and refine it on a commercial scale

Task 5.1 - Devise IPM programme for thrips (end year 3, all partners).

A draft IPM programme was produced in discussion with the consortium members. Because of the impressive results in 2012 where thrips numbers and damage to fruit were significantly reduced by using sticky blue roller traps it was decided that the work in 2013 should concentrate on developing this technique alongside other biocontrol strategies developed in Years 1-3 (releases of the predatory mite *Neoseiulus cucumeris*).

Task 5.2. - Test IPM strategy in commercial crops (EMR, ADAS and grower partners)

The IPM strategy devised in 5.1 and agreed by the consortium was tested in 2013 in comparison with the standard commercial programme used at the time by the host grower, on four plantings, two in Kent (EMR), one in Herefordshire (ADAS) and a fourth in East Anglia (ADAS).

Methods EMR sites

The EMR experiments were set up on a commercial site in Kent. One experiment was on a second year Camarillo planting and the second on a first year planting of Jubilee. The two plantings were adjacent to each other in the same field. The Camarillo were planted on 18 March 2012, in 2013 there were two rows of plants per bed and five beds per tunnel; in 2013 the tunnels were covered on 3 May. The Jubilee were planted on 12 March 2013 under fleece with three rows of plants per bed and five beds per tunnel. The fleece was removed

on 2 May and the tunnels covered on 3 May. Both plantings were in soil on raised beds covered with blue polythene mulch.

Duration of experiment

The experiment in the Camarillo started on 18 April and in the Jubilee on 1 May. Initially the plan had been to continue the experiment until at least the end of August but the grower decided to take down the tunnels and cover the plants on 13 August in an effort to prevent WFT movement onto other plantings, so the experiment was terminated then.

Treatments

There were two treatments:

- 30 cm wide blue roller trap with WFT pheromone lures inserted every 2.2 m along the trap.
- Control treatment with no sticky roller or pheromone

Experimental design

Each experiment was set as a randomised block design with four replicates and with each treatment paired as a block. Each plot consisted of three tunnels circa 30 m long. Treated tunnels and control tunnels were at least two tunnels apart.

Treatment application

Blue roller trap (Russell IPM) and pheromone lures (Syngenta Bioline) were set up on 18 and 19 April in the Camarillo and on 1 and 9 May in the Jubilee, as soon as the fleece was removed (Figure 5.2.1). Traps were placed in each leg row of the treated tunnels, so four traps per treated plot, cut to plot length. The traps were clipped to the tunnel legs using polytunnel securing clips (20 mm wide, 30 mm diameter), protected by a polythene strip (approx. 30 mm x 80 mm), as described in the 2012 Annual Report for the project in Task 1.5 (Figure 5.2.2). The base of the trap was set to be level with the crop canopy. Pheromone lures were attached to the trap 2.2 m apart by inserting the rubber septa impregnated with the pheromone into holes punched into the plastic trap material (Figure 5.2.2). The grower strawed the plantings, which resulted in the traps becoming non-sticky, so the traps were replaced on 4 and 10 June. Pheromone lures were replaced every four weeks. Traps had to be re-attached to tunnel legs several times due to weather damage (Figure 5.2.3).

Figure 5.2.1. Blue roller trap with pheromone lure in planting of Jubilee

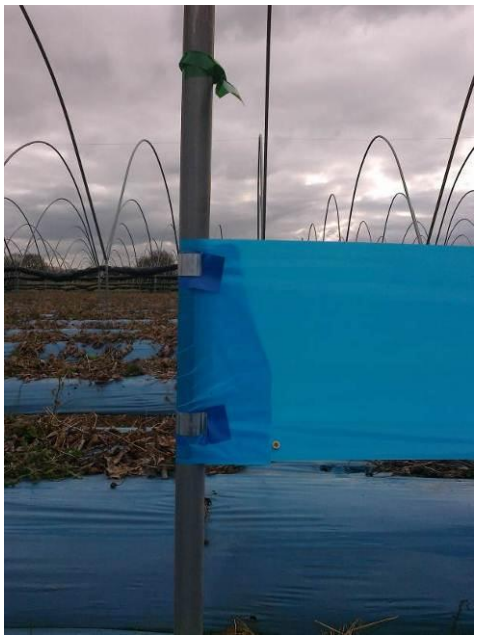


Figure 5.2.2. Attachment of roller trap to tunnel legs with clips, and positioning of pheromone lure

Figure 5.2.3. Re-attaching roller trap after weather damage

Husbandry

The trap treatment was used in addition to the grower's routine pest and disease management programmes. The same P & D treatments were applied to both the experimental and control plots by the host grower. Treatments applied against arthropod pests are shown in Table 5.2.1; the predators were released specifically for thrips control. During July regular picking of the fruit was stopped due to fruit damage making the fruit unmarketable. This affected the numbers of new flowers and fruit produced.

Table 5.2.1. Treatments applied against arthropod pests in both Kent plantings

Date	**Product**	**Predator release rate**
11 April	*Neoseiulus cucumeris*	1 sachet per 2.5 m
7 May	*Neoseiulus cucumeris*	50 per plant
9 May	*Hypoaspis miles*	200 m^2
17 May	*Neoseiulus cucumeris*	50 per plant
23 May	Apollo/Floramite	
6 June	Naturalis	
12 June	*Neoseiulus cucumeris*	50 per plant
19 June	Calypso	
27 June	Majestic-Attracker-Tracer	
4 July	Naturalis	
10 July	Majestic-Attracker-Tracer	

Crop canopy temperature recording

Two mini loggers were placed in each planting to take half-hourly records of temperature in the crop. These were downloaded every six weeks.

Assessments

Field assessments-Flowers and fruits: Assessments were made fortnightly from first flowering to the end of July. Separate samples were assessed from the middle bed and from the edge bed in the centre tunnel of the experimental plots; the middle bed samples were also used to develop damage thresholds for the pest (Objective 1; Task 1.4). The same sampling strategy was used for both middle and edge samples.

On each sample date the following were assessed in each sample area:

- Numbers of adult thrips/flower in 10 or 20 mid-aged flowers (petals open and all present, pollen shed, anthers brown). Flowers were taken from the top (not side) of each plant. Thrips were counted in the field using x10 head-mounted lens. Each flower was assessed separately. The flower was picked from the plant for assessment.
- Numbers of flowers/plant on 10 plants. Only open flowers with at least one petal present were counted (not buds or fully senescent flowers).
- Numbers of green, white and fully ripe fruit.
- Numbers of seeds surrounded by bronzing on 10 fully swollen white fruits.
- Numbers of seeds surrounded by bronzing on 10 fully ripe fruits.

The aim was to sample one flower, one white and one red fruit and count the flowers/plant on the same plant and repeat this for 10 adjacent different plants. At the start of the season it was possible to take samples separately from beds 1, 3, 4 and 5 in the central tunnel. As the season progressed it was not possible to find adjacent plants with the correct stages present for assessment so the later samples were from beds 1 and 3 only but 20 plants were assessed from each bed. If there were no fruit or flowers of the right stage available on the same plant, samples were taken from the nearest neighbouring plant. The same area (approx. 3m section of bed) was sampled on each occasion as far as possible so that thrips numbers per flower could be related to fruit damage four weeks later. However, on some assessment dates it was not possible to assess 20 flowers and 20 white and ripe fruit from the designated central area of the beds.

In addition to the samples agreed in the joint EMR and ADAS protocol, additional samples of flowers from each plot were collected into alcohol and returned to the lab. These were washed (as described in the previous annual reports) and numbers of thrips adults and larvae and predatory mites present counted. A sub sample of adult thrips and mites were mounted on microscope slides and identified to species.

Full plant assessments were made on 9 and 22 May, 7 and 17 June, 3 and 15 July in the Camarillo and on 23 May, 10 and 26 June, 8 and 24 July in the Jubilee. Samples of flowers were taken in alcohol on 9 and 22 May, 7 June, 8, 15 and 24 July and 1 August in the Camarillo and on 23 May, 8 and 24 July and 1 August in the Jubilee. The grower took down the tunnels and covered the plants on 13 August and the experiment had to be terminated (Figure 5.2.4).

Figure 5.2.4. Experimental site on 13 August; covers from the tunnels were removed and used to contain thrips on plants

Sticky traps: On each sample date in each treatment plot, four 10 cm long pieces of roller trap (30 cm wide) were inspected using a lens and numbers of thrips present counted. The inspected portion of the trap was from the inner sides of the trap in the centre tunnel. Two records were taken from each side of the tunnel. Different sections of trap were counted on each visit. Samples of trap from each central tunnel were also collected when the traps were taken down (either for replacement or at the end of the experiment) and numbers of thrips counted in the laboratory.

Assessment of commercially harvested and graded fruit: Picked and graded fruit were assessed for damage to get data to add to the threshold development work to determine what level of damage was deemed to be acceptable to the industry. Results from these assessments are given in Objective 1. Assessments were:

- Numbers of seeds surrounded by bronzing per fruit obtained from the packhouse; 25 Class 1 fruit and 25 Class 2 fruit were assessed in the laboratory.
- Presence/absence of other reasons for downgrading (e.g. capsid/misshaping, botrytis, mildew, size, overripe etc.) in the packhouse fruit.
- Total numbers of seeds per fruit in five mature Class 1 fruits from the packhouse sample.

Results

Jubilee: In the first assessment on 23 May only eight adult thrips were recorded in 160 flowers. Numbers rose steadily to a peak of 2.8-3.3 per flower by late-July. Over the course of the experiment (until terminated by the grower) there were no differences in numbers of thrips adult recorded in flowers in the field (Figure 5.2.5).

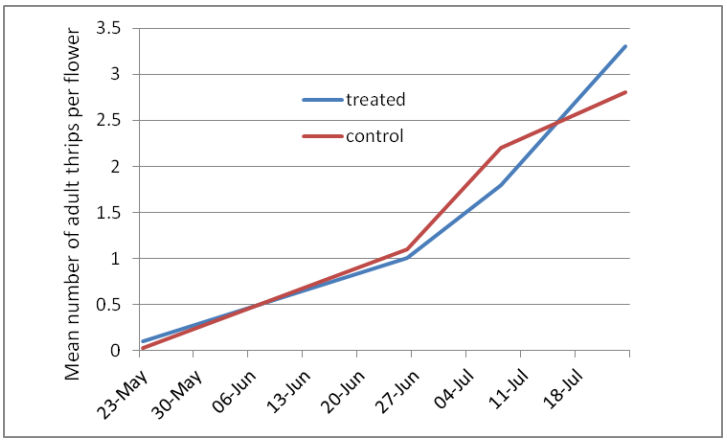


Figure 5.2.5. Mean numbers of thrips adults per flower in Jubilee crop

Numbers of flowers (Figure 5.2.6), green, white and ripe fruit (Figure 5.2.7) were also similar in both treatments. Figures 5.2.5-5.2.7 show the means from all beds sampled on a particular date.

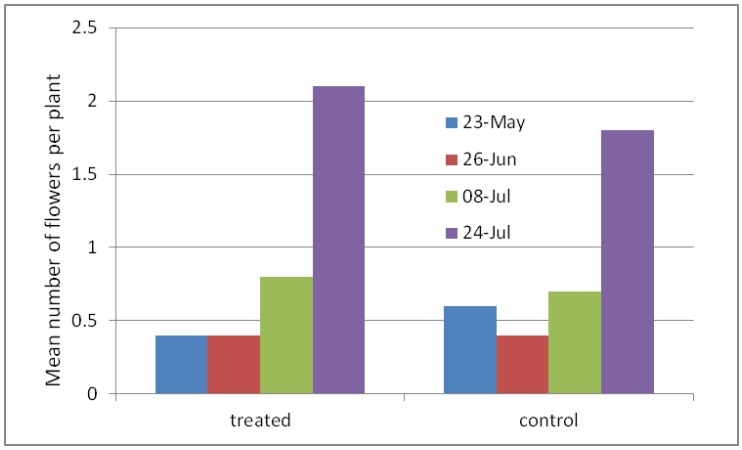


Figure 5.2.6. Mean number of flowers per plant in Jubilee planting

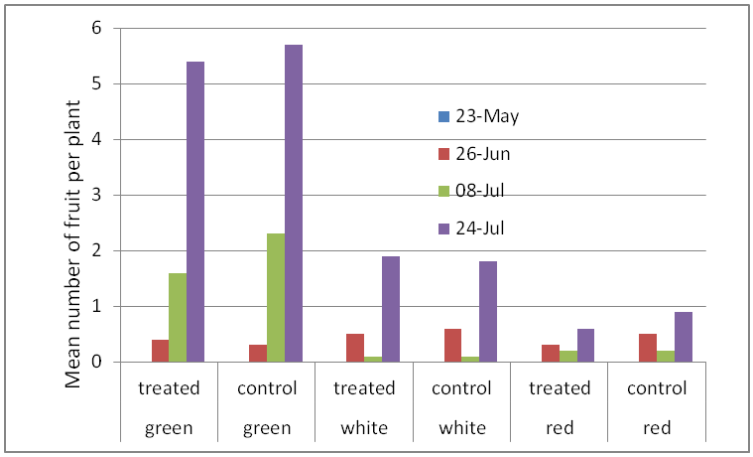


Figure 5.2.7. Mean number of green, white and red fruit per plant in Jubilee planting

There was little fruit damage in the first three assessments but damage increased significantly in the assessment on 24 July (Figure 5.2.8); at this time two or more adult thrips were recorded per flower. Fruit damage was very variable in both treatments, with some fruit completely bronzed while a neighbouring fruit had no visible damage. Mean number of seeds surrounded by bronzing in white and ripe fruit in both treatments in the Jubilee crop is shown in Figure 5.2.8. After counting the number of seeds in white and ripe fruit in the laboratory, 100% bronzing of fruit was estimated as 250 seeds surrounded with damage in the field assessments. There was no effect of treatment on fruit damage assessed in the field. Damaged fruits are shown in Figure 5.2.9.

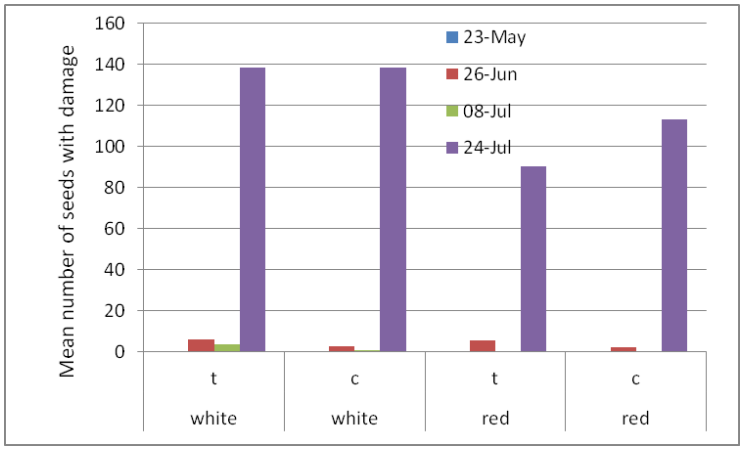


Figure 5.2.8. Mean number of seeds surrounded by bronzing assessed in the field

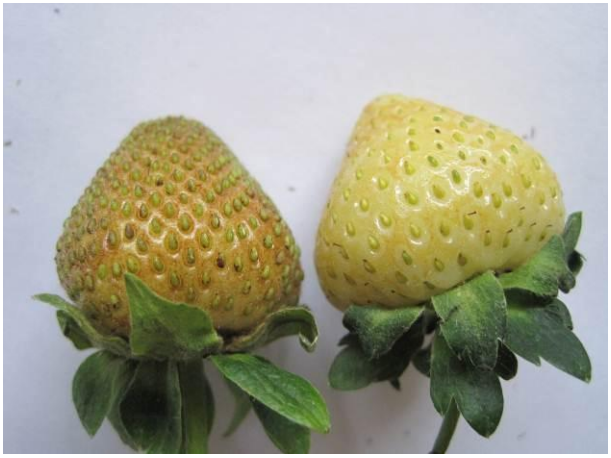


Figure 5.2.9. Damage on white and ripening fruit

There was no effect of plant position within the tunnel on thrips adults per flower or flowers per plant; numbers were similar in the plants in the central and edge beds (Figures 5.2.10 and 5.2.11).

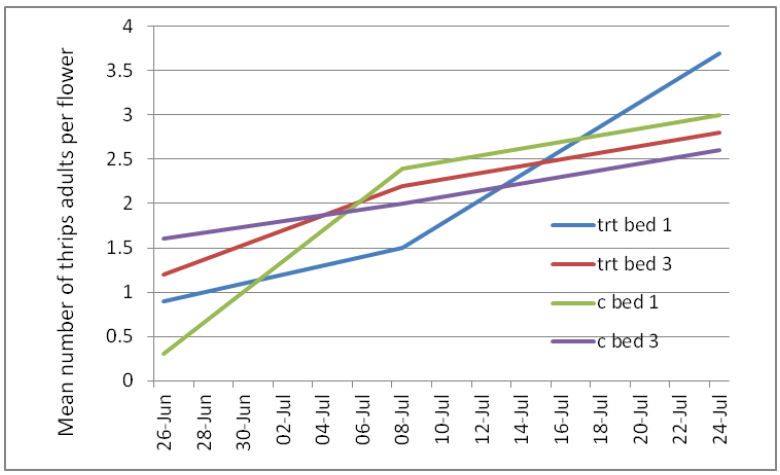


Figure 5.2.10. Comparison of numbers of adult thrips in edge (bed 1) and centre (bed 3) beds in both treated and control plots in the Jubilee planting

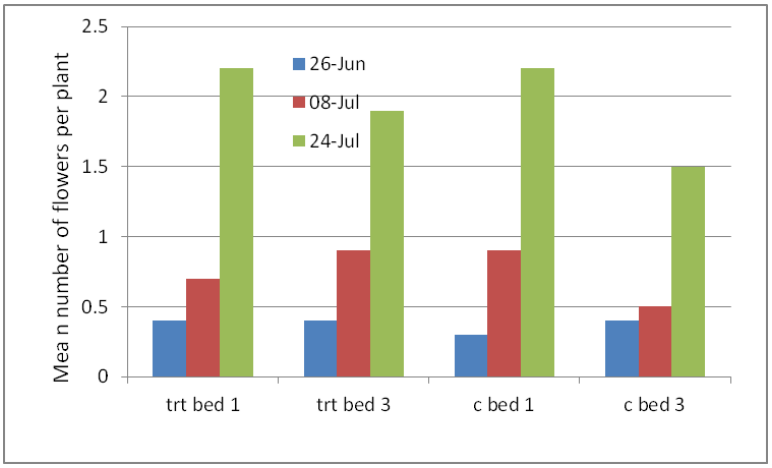


Figure 5.2.11. Comparison of number of flowers per plant in edge (bed 1) and centre (bed 3) beds in both treated and control plots in the Jubilee planting

Numbers of adult thrips counted from washed flowers in the lab were considerably higher than those counted in the field (Figures 5.2.12); in the field thrips larvae were not recorded. This suggests that recording thrips numbers in flowers removed from plants in the field is likely to give an underestimate of numbers present per flower. There was no effect of treatment on numbers of thrips adults or larvae recorded in the washed samples. Very few predatory mites were recorded in these washed flower samples despite the numbers released by the grower (150 per plant in three loose releases plus an early sachet release). This may be in part due to the application of Floramite and Apollo made on 23 May (Table 5.2.1). There is conflicting evidence of the effect of bifenazate (the active ingredient of Floramite) on predatory mites, while clofentezine (the active ingredient of Apollo) is safe. Only one release of *N. cucumeris* was made after these pesticides were applied. Spinosad applications in June and July are also likely to have reduced predator numbers and had no effect on the thrips population present, indicating the presence of a resistant WFT population.

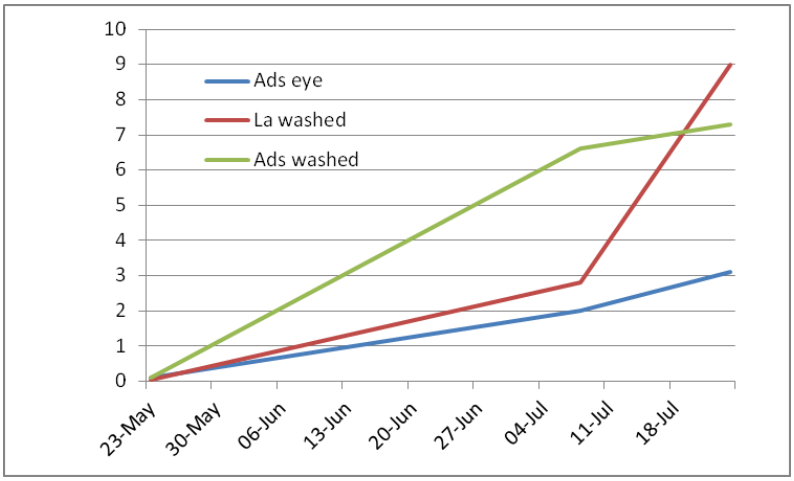


Figure 5.2.12. Mean number of thrips per flower in the Jubilee plots counted in the field (eye) and laboratory (washed); the same flowers were not assessed in the field and lab.

A total of 80 thrips adults were mounted on slides from both plantings and identified under the microscope (10 on each sample occasion). All thrips identified were WFT.

Mean numbers of adult thrips recorded on sticky traps close to and between pheromone lures is shown in Table 5.2.2. There were no catches in May and very low catches of thrips in the assessments made between June and the end of July, even though flower assessments showed there was a mean of three adults per flower in mid-July (Figure 5.2.5). Numbers were higher in the last assessment, which was made in the laboratory after termination of the experiment. There was no effect of distance from the pheromone lure on thrips catches on the sticky trap.

Table 5.2.2. Mean number of adult thrips recorded on sections of sticky trap in the Jubilee planting close to or between pheromone lures

	Close to lure	**Between lures**
23-May	0	0
26-Jun	0.5	0.9
08-Jul	1.9	1.6
24-Jul	5.5	6.5
20-Aug	38.9	45

Camarillo: As in the Jubilee planting there were no overall differences in numbers of thrips adults per flower in the two treatments (Figure 5.2.13). However, numbers of adults were higher in this second year planting than in the first year Jubilee crop; numbers reached a mean of four per flower in early June, whereas in the Jubilee numbers only reached three per flower in mid-July. This demonstrates the overwintering success of WFT in the second year planting and the potential for overwintered crops to act as a source of infestation to new plantings. Numbers in the washed flower samples again were higher than those counted in the field as was seen in the Jubilee results. The results from the two plantings highlight the difficulty of counting thrips in the field when populations are very high. Numbers of predatory mites were higher in the Camarillo than the Jubilee flowers (highest number per 10 flowers was three in the Jubilee flowers and 50 in the Camarillo) but were still very low considering the number released. A subsample of adults was identified; all were identified as *Neoseiulus californicus*.

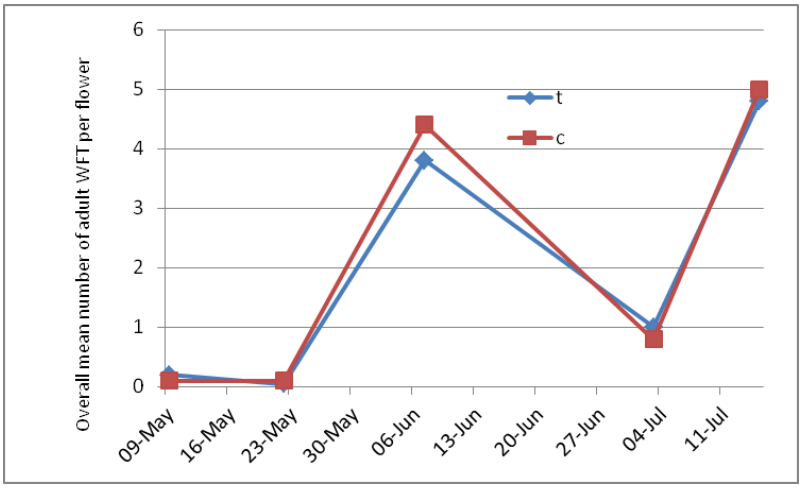


Figure 5.2.13. Overall mean number of thrips adults per flower in a second year crop of Camarillo

There were similar numbers of flowers per plant in both treatments (Figure 5.2.14)

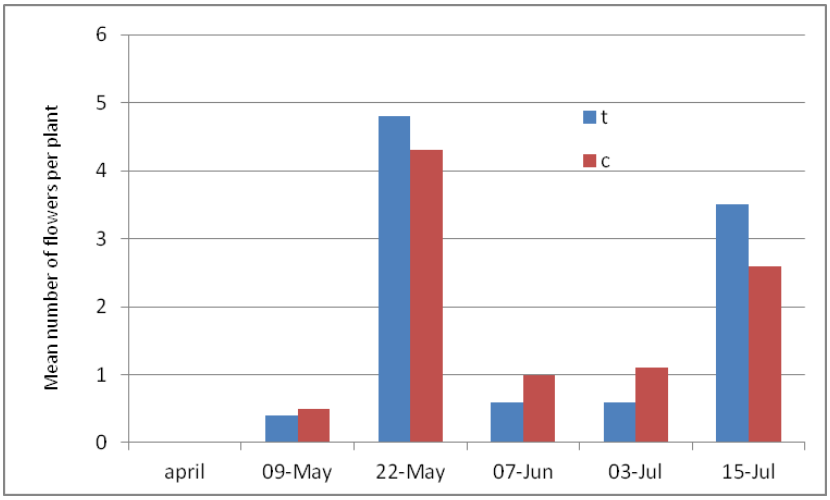


Figure 5.2.14. Mean number of flowers per plant in the two treatments in the Camarillo planting

There were similar numbers of white fruit in the two treatments (Figure 5.2.15). On 17 June there were lower numbers of red fruit on the control plot; this is likely to be due to the picking schedule on the farm.

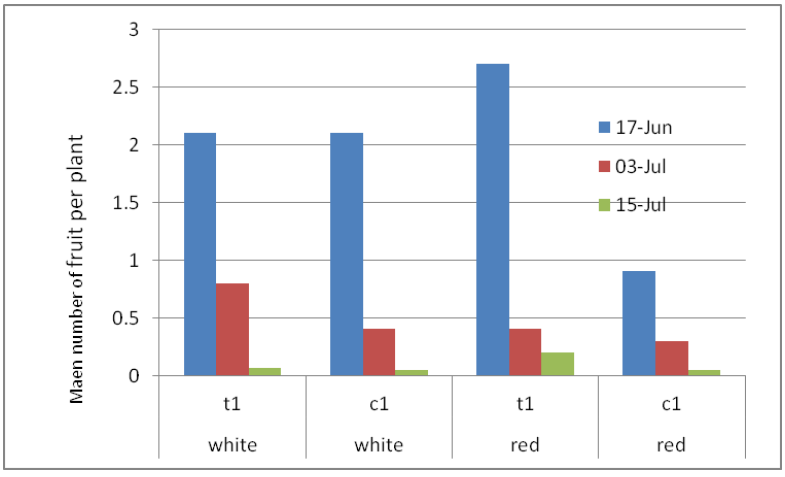


Figure 5.2.15. Mean number of white and red fruit per plant in the two treatments in the Camarillo planting

There was no effect of treatment on damage observed on either white or red Camarillo fruit (Figure 5.2.16)

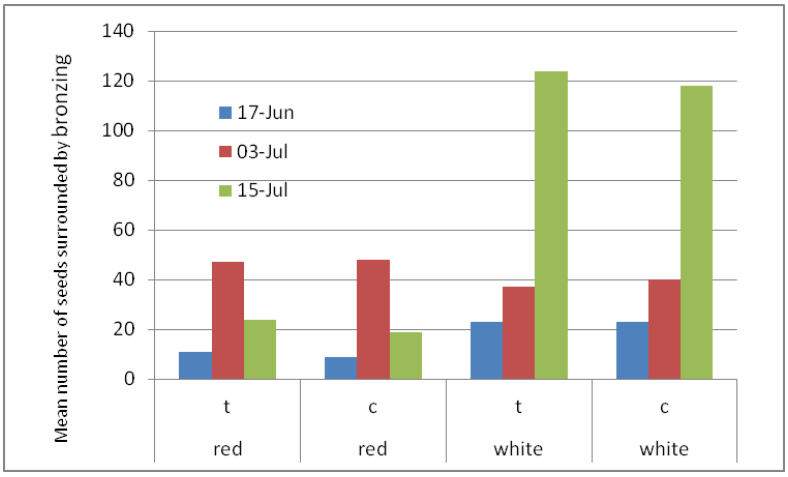


Figure 5.2.16. Damage as measured by mean number of seeds surrounded by bronzing on white and red Camarillo fruit assessed in the field

Mean numbers of adult thrips recorded on sticky traps close to and between pheromone lures is shown in Table 5.2.3. None were recorded in June, and numbers were low in July, even though numbers of thrips reached around five per flower when recorded in the field on two sampling occasions (in mid-June and mid-July) (Figure 5.2.13) and were recorded as 15 per flower in the washed flower samples in July (Figure 5.2.14). There was a large increase in numbers caught at the last assessment, which was made in the laboratory after termination of the experiment. There was no effect of distance from the pheromone lure on thrips catches on the sticky trap.

Temperature data for the tunnelled crop is shown in Figures 5.2.17 (average daily temperature) and 5.2.18 (maximum daily temperature).

Table 5.2.3. Mean number of adult thrips recorded on sections of sticky trap in the Camarillo planting close to or between pheromone lures

	Close to lure	**Between lures**
09-May	0	0
22-May	0	0
04-Jun	0	0
03-Jul	9.4	12.4
15-Jul	10	9.8
20-Aug	253	299

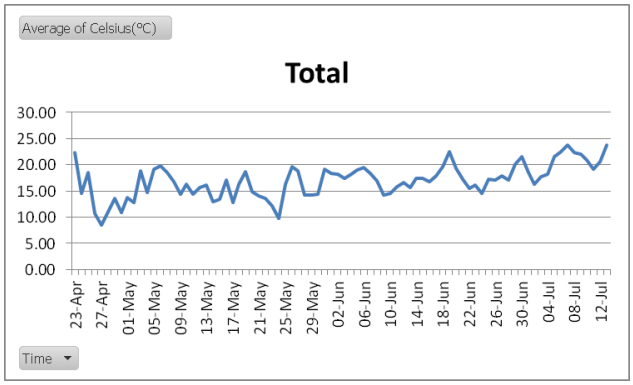


Figure 5.2.17. Mean daily temperature in the tunnels used in the experiments in Kent

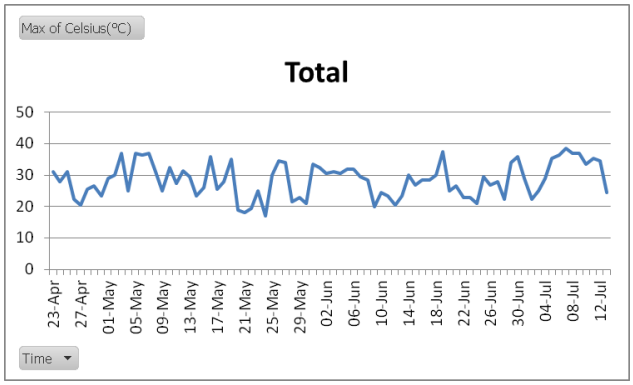


Figure 5.2.18. Maximum daily temperature in the tunnels used in the experiment in Kent

Conclusions

- This experiment was unable to provide confirmation of the effectiveness of roller traps to reduce crop damage caused by thrips feeding. Very low numbers of thrips were attracted and stuck to the blue roller traps in the early assessments. Although thrips are attracted to blue traps it is likely that the flowers present in the planting were more attractive early in the season. In the last assessments, when numbers of flowers were decreasing, numbers of thrips caught on the traps increased.
- Damage to fruit was high in both plantings and the crop became unmarketable.
- As the experiment was terminated by the grower we were not able to determine if the traps reduced populations of thrips on the plants from July onwards; in 2012 the roller traps caught higher numbers of thrips from July (see 2012 Annual Report) and thrips populations and fruit damage decreased significantly at this time.
- The experiment indicated the underestimation of adult thrips numbers in flower assessments done in the field when populations are very high, with up to three times greater numbers recorded from washed flowers in the laboratory. The washing technique also enables numbers of thrips larvae to be assessed.

- Numbers of thrips were higher in the second year Camarillo; this planting is likely to have been the source of thrips infestation in the newly planted Jubilee
- All the thrips identified from this experiment were WFT. The grower applied Spinosad twice but this had no effect on thrips populations, confirming their resistance to this compound at that site.
- Very low numbers of predatory mites were recorded in the experiment despite the numbers released; this may be due to pesticide applications. Those identified were *N. californicus;* numbers were higher in the second year Camarillo planting.

Materials and methods at ADAS sites

Site 1

Host grower and site 1: Stephen Long. Lutton Farm, Peterborough, Cambs.
Everbearer variety: Driscoll Jubilee
Growing system: Bags of substrate on raised beds covered with woven ground-cover matting.
Risk of WFT: This was a first year crop planted into three year old grow-bags during March 2013. The field (Tansor 10) had a history of WFT damage every year prior to the trial. Prior to the trial set up on 19 March four thrips were collected from groundsel and were identified as WFT. A further six thrips were collected from groundsel and identified as WFT on 19 April when the trial was set up (strawberries were pre-flowering).

Site 2

Host grower and site 2: Peter Kemp, Boxford farms, Colchester, Essex.
Everbearer variety: Finesse
Growing system: Bags of substrate on raised beds covered with woven ground-cover matting.
Risk of WFT: This was a second year crop planted in three year old bags. During 2012 thrips and damage had been observed but thrips species had not been confirmed. On 23 April (prior to the trial set up), four thrips were collected from nettle, groundsel and strawberry plants and identified as WFT.

Treatments:

At both sites there were two treatments:

1. Control (no roller traps or lures)
2. Roller traps plus WFT sex pheromone lures, spaced 2.2m apart.

At each site there were four replicate plots of each treatment (eight plots in total) which were superimposed on to the grower's own pest and disease management strategy.

Experiment layout

Lutton Farm (Site1)

On 19 April, the first trial was set up at Lutton Farm (site 1). Each plot was three tunnels wide and 30m long. Plots were separated widthways by three tunnels and lengthways by 20m (Figure 5.2.19). In each plot with roller traps, a 30m length of roller trap was secured to the tunnel legs in the leg rows of each tunnel using poly tunnel clips (two clips per leg). Heavy -gauge polythene strips (approx 3 cm x 8 cm) were placed underneath each clip to protect the trap from ripping. WFT sex pheromone lures were attached (2.2m apart) to the base of the trap by making a hole with a hole punch and pushing the lure through. Figure 5.2.20 shows the trial following set up at Lutton Farm.

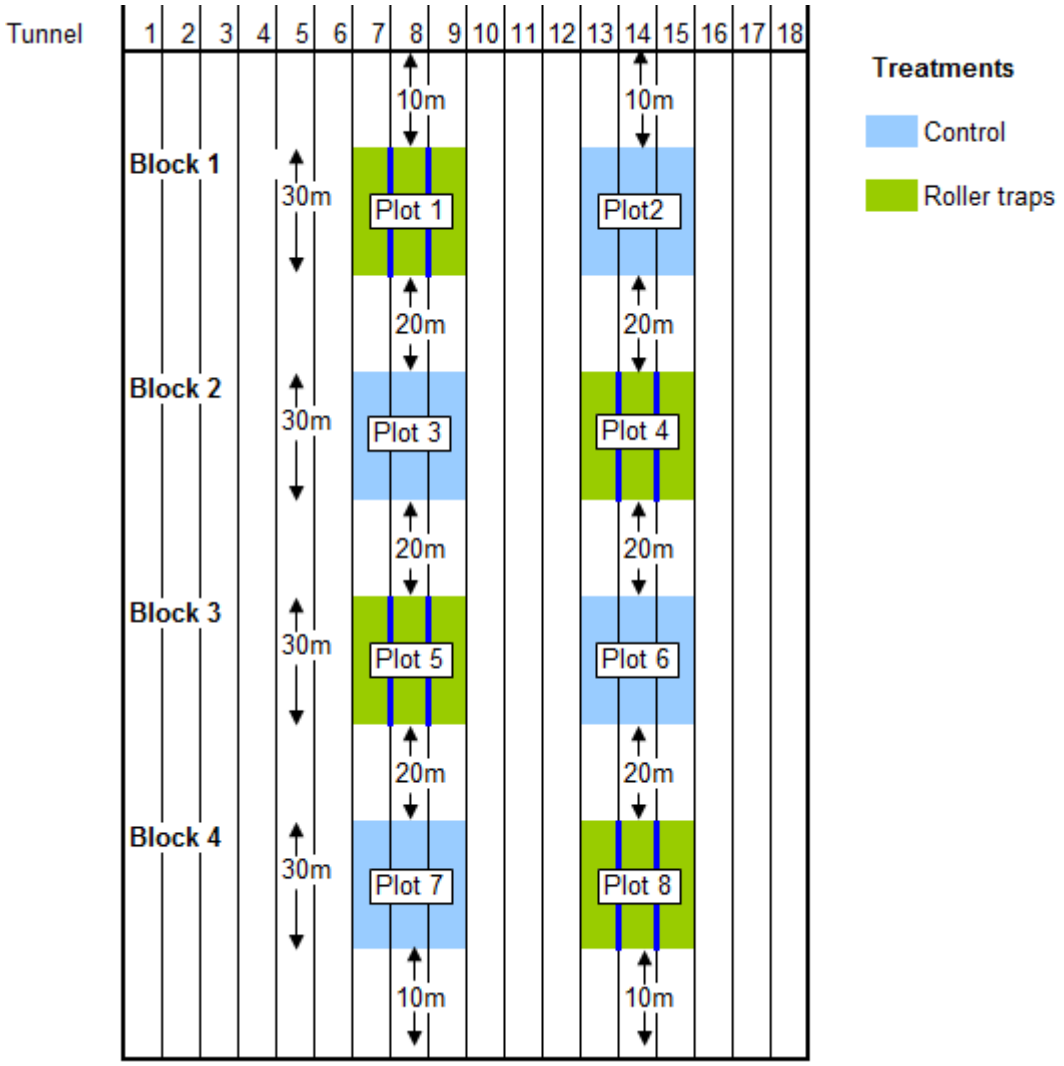


Figure 5.2.19 Trial layout at Lutton Farm (Site 1)

Figure 5.2.20 Roller traps (30m) in the leg rows at Lutton Farm (Site 1)

Boxford Farms (Site 2)

On 16 May, the second trial site was set up at Boxford Farms (Site 2). Due to the presence of side walls in the tunnel the experiment layout had to be amended compared to Site 1. Like Site 1 each plot was three tunnels wide and 30m long. However, the first four tunnels were separated from the remaining three by a tunnel side wall. The lengths of the tunnels were also separated by walkways resulting in three sections measuring 67m, 81m and 88m. Plots were arranged as per Figure 5.2.21. Figure 5.2.22 shows the trial following set up at Boxford Farm.

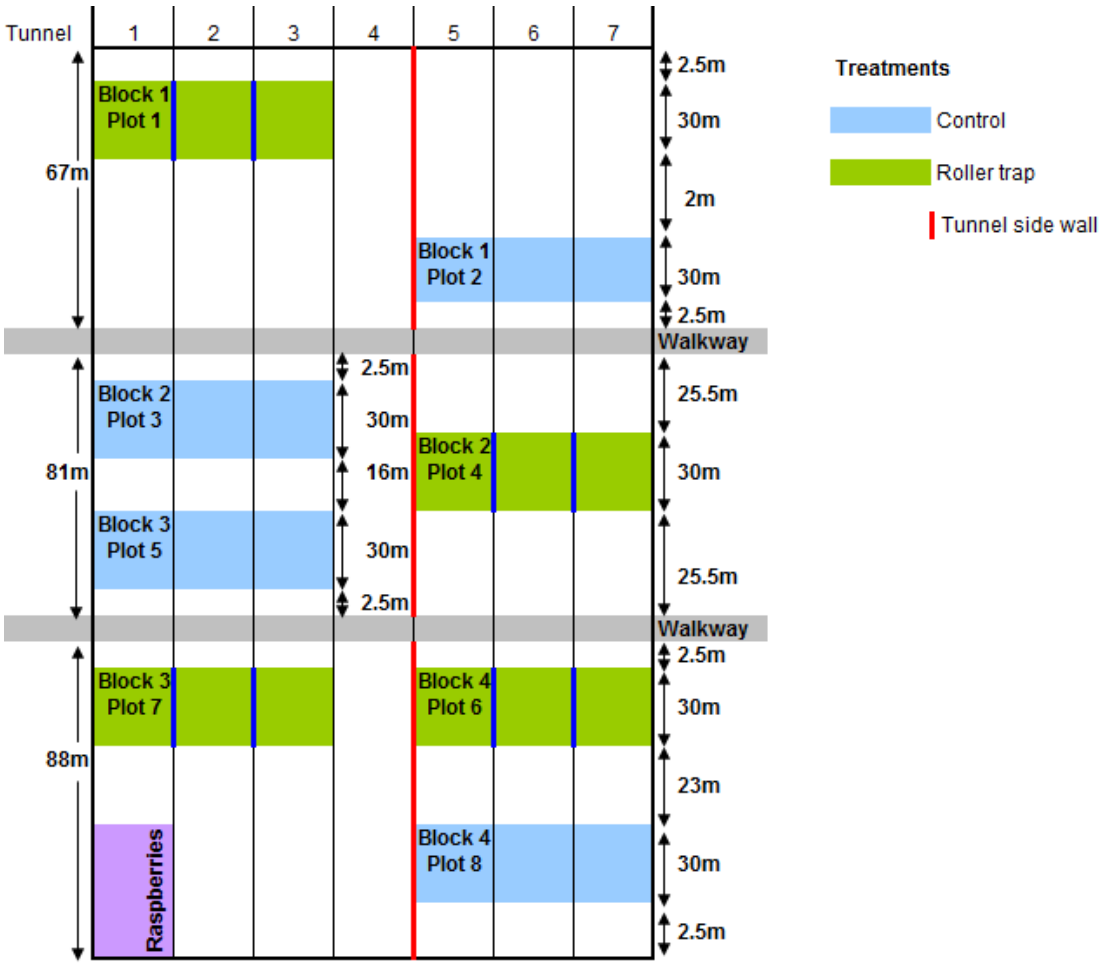


Figure 5.2.21 Trial layout at Boxford Farm (Site 2)

Figure 5.2.22 Roller traps (30m) in the leg rows at Boxford Farms (Site 2)

Crop canopy temperatures:

At each site crop canopy temperatures were recorded every 30 minutes in two plots with USB dataloggers. The dataloggers were shaded with ventilated white shades to reflect any direct sunlight.

Integration of pesticides:

Any pesticides used and their application dates were recorded. The roller traps were superimposed over the growers integrated pest management programme recommended by the growers' consultants.

Assessments:

Assessments were carried out on the day of set up and approximately every two weeks thereafter. Assessments at Site 1 (Lutton Farm) took place on 19 April, 3 May, 17 May, 7 June, 20 June, 4 July, 18 July and 30 July, 15 August and 29 August. Assessments at Site 2 (Boxford Farms) took place on 16 May, 31 May, 13 June, 27 June, 11 July, 25 July, 9 August, 22 August and 5 September.

Assessments were only made in the middle tunnel of each plot in four sampling areas:

i) The middle 3m section of the central bed (this area was used to correlate numbers of thrips adults to subsequent fruit damage by Clare Sampson at Keele University)
ii) The middle 3m section in the bed to the right of the central bed
iii) The middle 3m section of the left hand outer bed
iv) The middle 3m section of the right hand outer bed

In each of these sampling areas, a plant was selected at random with flowers, white fruit (fully expanded, turning pink at base) and ripe fruit. Adjacent /neighbouring plants were then selected for further assessment. Ten plants were sampled in each sampling area (40 plants per plot).

The following assessments were carried out:

- *Thrips in flowers*

On each of the ten plants sampled in each sampling area, one medium-aged flower sticking up from the top of the plant was selected. By eye counts of the number of thrips adults were made by carefully pulling down the petals on each side of the flower (10 flowers were assessed in each sampling area i.e. 40 per plot). Thrips from the trial area (approximately six adult thrips per plot) were also collected into a tube of 70% alcohol and returned to Boxworth for species confirmation.

- *Fruit damage*

On each of the ten plants sampled in each sampling area, the number of seeds surrounded by bronzing was recorded on white and red fruit (ten red and ten white fruit sampled in each sampling area i.e. 40 per plot). Sometimes less than ten white or ripe fruit were assessed depending on availability. The grower also provided punnets (containing 25 fruit) from the packhouse representing Class 1, Class 2 and waste fruit. The number of seeds surrounded by bronzing on the 25 fruit in each punnet was recorded so that percentage damaged fruit in the crop could be estimated. On waste fruit the presence of any other type of damage which could lead to downgraded fruit was also recorded e.g. capsid/misshaping, botrytis, mildew, wrong size, over-ripe etc. The number of total seeds on five Class 1 fruits was also recorded.

- *Thrips predators in flowers*

The numbers of thrips predators in the flowers were also recorded in each sampling area i.e. *Orius* adults and nymphs, *Anthocoris* spp. adults and nymphs, predatory thrips (predatory mites were not recorded as in-situ counts are unreliable and species confirmation is not possible on-site).

- *Numbers of flowers, white and ripe fruit per plant*

In sampling area i) only the numbers of flowers, fully expanded white fruit and ripe fruit per plant were recorded on the same ten plants that thrips numbers were assessed.

- *Thrips on roller traps*

Starting on the second assessment date (two weeks after set-up), four 10cm-long sections of the roller trap were inspected using a head lens magnifier. In the central tunnel of each plot containing a roller trap, two random assessment sections on the inner sides of the traps in the central 10m section of the 30m-long trap were selected on each side (Figure 5.2.23a). On each side, one section was <0.6m from a lure and one section was >0.6m from a lure (Figure 5.2.23b). The numbers of thrips adults were recorded on each section. Species were not identified from the traps.

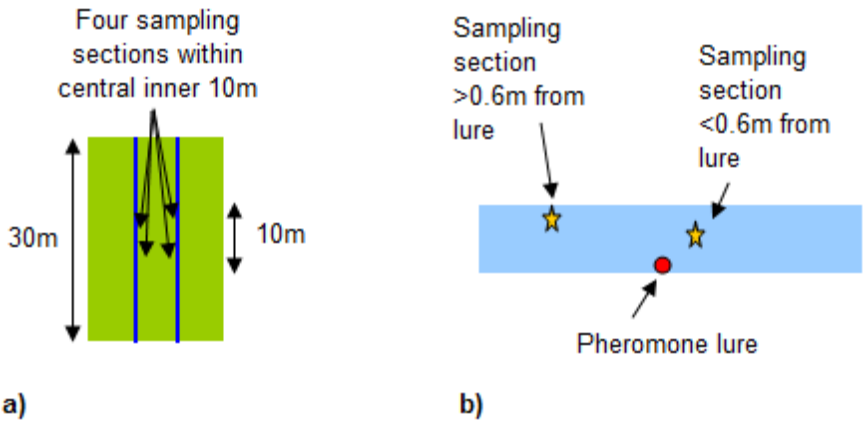


Figure 5.2.23 a) Two random sections on the inner sides of the traps in the central 10m section of the 30m-long trap were assessed for the numbers of thrips adults b) On each trap, one of the assessment sections was <0.6m from a lure and one section was >0.6m from a lure.

- *Assessment of commercially harvested and graded fruit*:

Picked and graded fruit were assessed for damage to obtain data to add to the threshold development work to determine what level of damage was deemed to be acceptable to the industry. Results from these assessments are given in Objective 1. Assessments were:

i) Numbers of seeds surrounded by bronzing per fruit obtained from the packhouse; 25 Class 1 fruit and 25 Class 2 fruit were assessed in the laboratory.

i) Presence/absence of other reasons for downgrading (e.g. capsid/misshapen, botrytis, mildew, size, overripe etc.) in the packhouse fruit.

ii) Total numbers of seeds per fruit in five mature Class 1 fruits from the packhouse sample.

Results and Discussion

Lutton Farm (Site 1)

Mean numbers of thrips adults per flower:

Assessment of the number of thrips per flower began on 3 May. The mean numbers of thrips adults per plant in each treatment on each assessment date at Lutton Farm (Site 1) are shown in Figure 5.2.24. While there was a consistent trend that more thrips adults were found in plots without roller traps compared to those with traps, there was no statistically significant difference.

Thrips numbers were low throughout the trial. They peaked on 16 July with a mean of 1.92 adult thrips per flower in the control plots and 0.84 in plots with roller traps (Figure 5.2.25). The mean number of flowers per plant (based on 40 plants per treatment) was high prior to the beginning of the trial but once thrips assessments began on 3 May the mean number of flowers per plant did not exceed three.

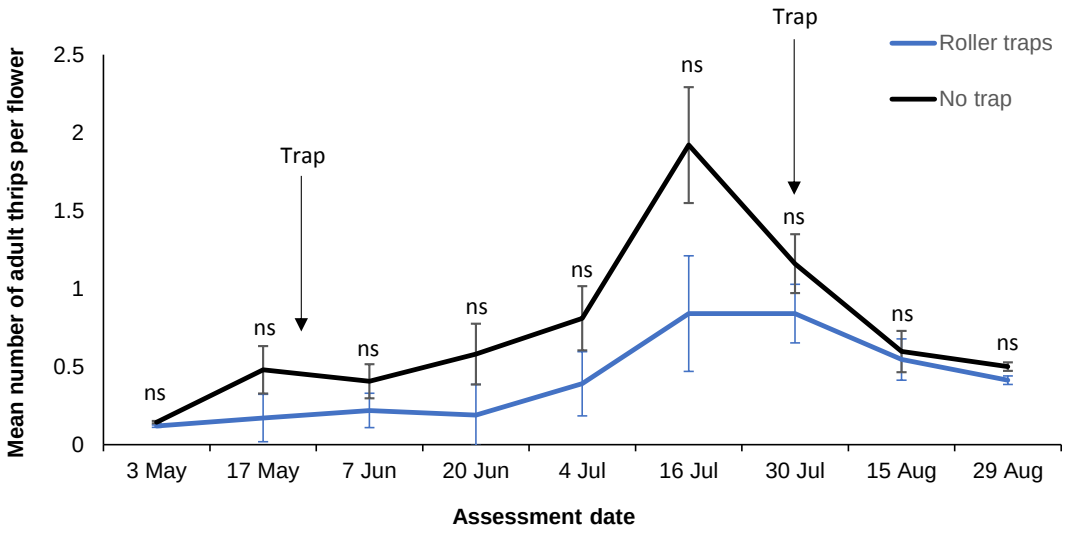


Figure 5.2.24 Mean number of adult thrips per flower at each assessment date at Lutton Farm (Site 1). ns= not significant. Traps were replaced on 23 May and 30 July.

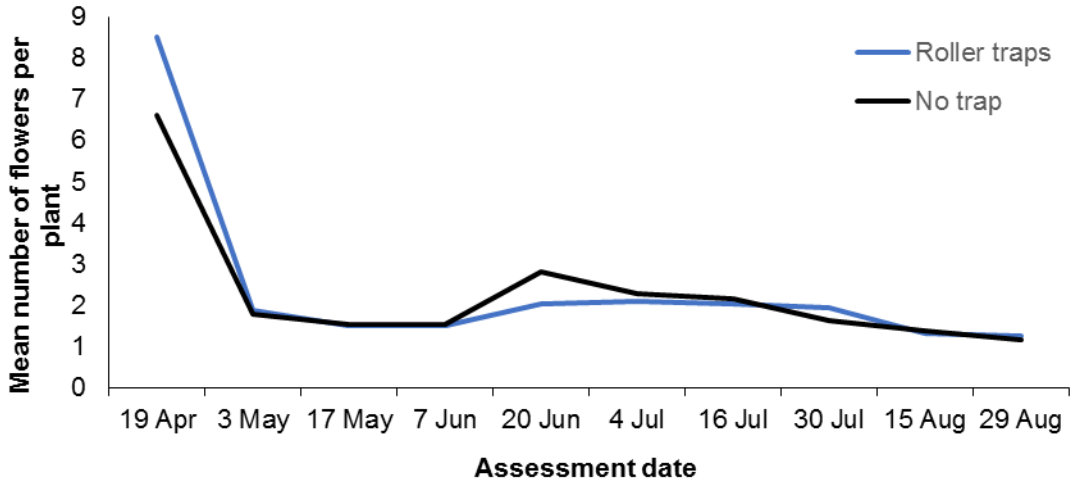


Figure 5.2.25 Mean number of flowers per plant at each sampling date at Lutton Farm (Site 1)

Thrips species collected from flowers:

At least ten of the thrips which were collected from the flowers at each sampling date were mounted and identified. On all of the sampling dates 100% of the thrips were western flower thrips, *Frankliniella occidentalis.*

Mean number of predators per flower:

Figure 5.2.26 shows the mean number of *Anthocoris* sp. and *Orius* sp. per flower in plots with and without traps. *Orius* sp. were first observed in the crop on 7 June which coincides with the first release of *Orius laevigatus* by the grower (Table 5.2.4). The grower reported good establishment of *O. laevigatus* and attributed the low thrips numbers and damage at the site to the biological control programme. *Orius* sp. was the most common predator. Naturally-occurring *Anthocoris sp.* were also recorded.

Predator numbers peaked on 29 August in control plots with a mean of 0.06 *Orius* sp. per flower. There was a trend for the number of predators to be higher in control treatment than the roller trap treatment, however no predatory bugs were recorded in the roller trap assessments. The data has not been statistically analysed as the dataset contains too many zero values. The percentage of flowers with either *Anthocoris* sp. or *Orius* sp. remained low (Figure 5.2.27). The highest incidence of *Anthocoris* sp. was on 4 July when they were present in 1.9% of the flowers assessed. The highest incidence of *Orius* sp. was on 29 August, in 5.8% of the flowers assessed.

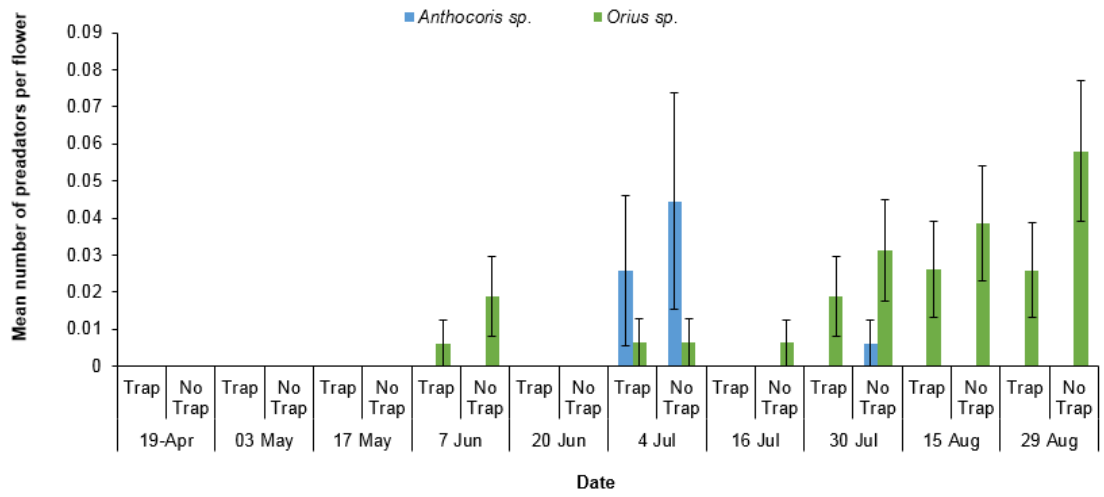


Figure 5.2.26 Mean number of *Anthocoris* sp. and *Orius* sp. per flower at Lutton Farm in plots with traps and plots without traps (Site 1)

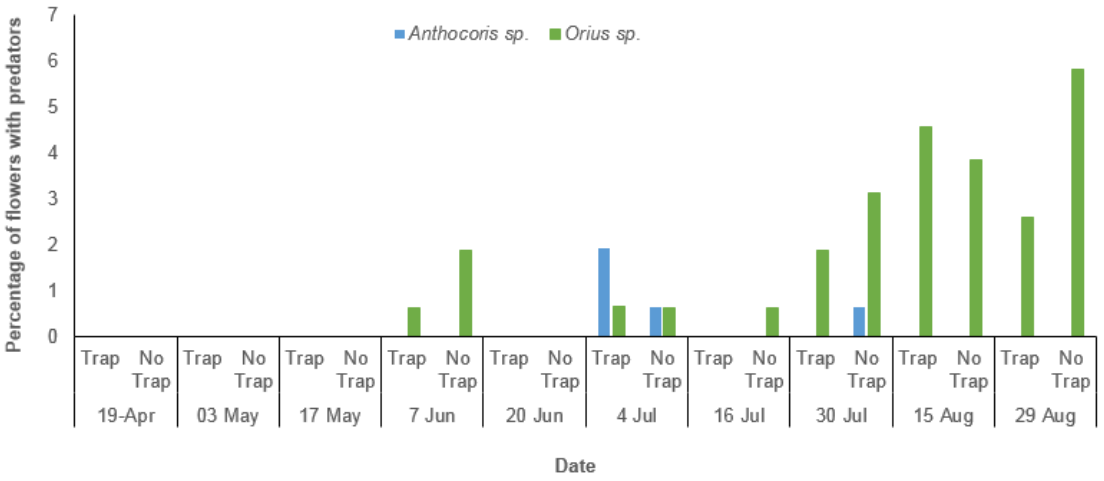


Figure 5.2.27 Percentage flowers with *Anthocoris* sp. and *Orius* sp. at Lutton Farm in plots with traps and plots without traps (Site 1)

Table 5.2.4 Biologicals released by the grower during the trial at Lutton Farm (Site 1)

Date	Beneficial	Numbers released per m2	Numbers per plant
11 April	*Amblyseius cucumeris*	31.25	25
27 April	*Hypoaspis miles*	7.81	6.25
6 June	*Amblyseius cucumeris* *Orius laevigatus*	171.88 0.18	137.5 0.14
16 August	*Amblyseius cucumeris* *Orius laevigatus*	343.75 0.80	275 0.64

White fruit damage:

Damage was assessed from 17 May by counting the number of seeds surrounded by bronzing. Throughout the trial the damage observed on white fruit was low. A peak was observed on 16 July with a mean of 3.7 and 2.4 seeds surrounded by bronzing per white fruit for the control and roller trap treatments respectively (a maximum of 160 fruit per treatment was assessed) (Figure 5.2.28). This peak in fruit damage coincided with the peak in mean adult thrips numbers per flower. On 16 July, only 13.6% and 6.6% of the fruit assessed on this date had five or more seeds surrounded by bronzing (Figure 5.2.29). There was a trend that fruit damage was lower in plots with roller traps compared to the control, however performing an ANOVA on the mean number of fruit per plot with five or more seeds surrounded by bronzing showed that there was no significant difference between the two treatments ($F=3.29$, $p=0.08$).

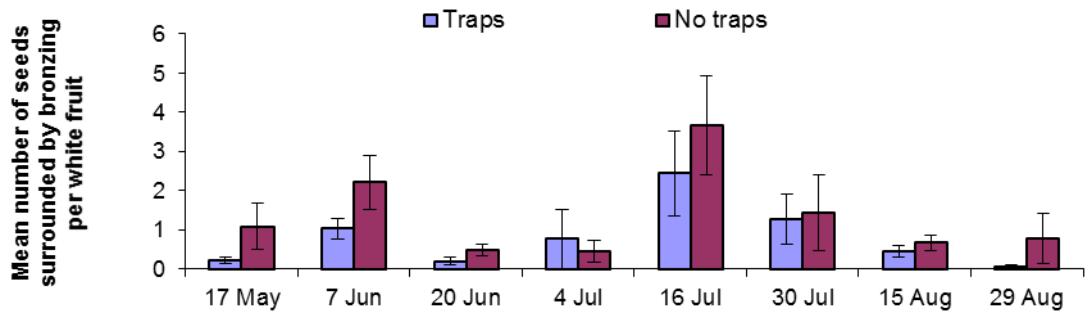


Figure 5.2.28 Mean number of seeds surrounded by bronzing per white fruit at Lutton Farm (Site 1)

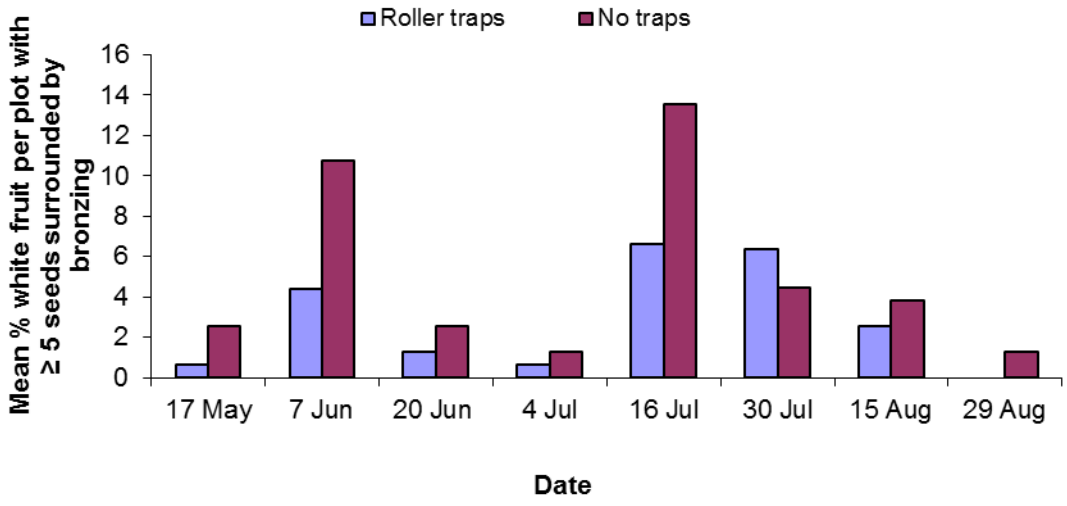


Figure 5.2.29 Mean percentage of white fruit per plot with five or more seeds surrounded by bronzing at Lutton Farm (Site 1)

Ripe fruit damage:

The amount of damage observed on ripe fruit during the trial was lower than observed on white fruit. A peak in fruit damage occurred on 16 July with a mean of 2.1 and 0.8 seeds surrounded by bronzing per ripe fruit for the control and roller trap treatments respectively (a maximum of 160 fruit per treatment was assessed) (Figure 5.2.30). Again this peak in fruit damage coincided with the peak in mean adult thrips numbers per flower.

On 15 August, the percentage of assessed fruit with five or more seeds damaged was 8.3% and 2.6% in plots without roller traps and with traps respectively (Figure 5.2.31).

There was a consistent trend that there was more damaged fruit in control plots compared to those with roller traps (Figure 5.2.31). Performing an ANOVA on the mean number of ripe fruit per plot with five or more seeds surrounded by bronzing showed that overall, plots with roller traps had significantly less damaged fruit than in the control plots (F=6.27, *p*=0.02) (Figure 5.2.32), but the effect of traps was not significant on individual assessment dates (Figure 5.2.30).

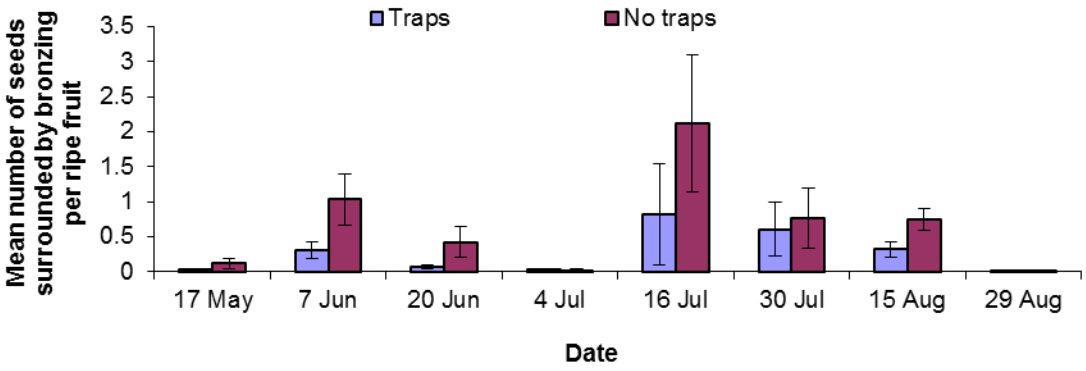


Figure 5.2.30 Mean number of seeds surrounded by bronzing per ripe fruit at Lutton Farm (Site 1)

Figure 5.2.31 Mean percentage of ripe fruit with five or more seeds surrounded by bronzing at Lutton Farm (Site 1)

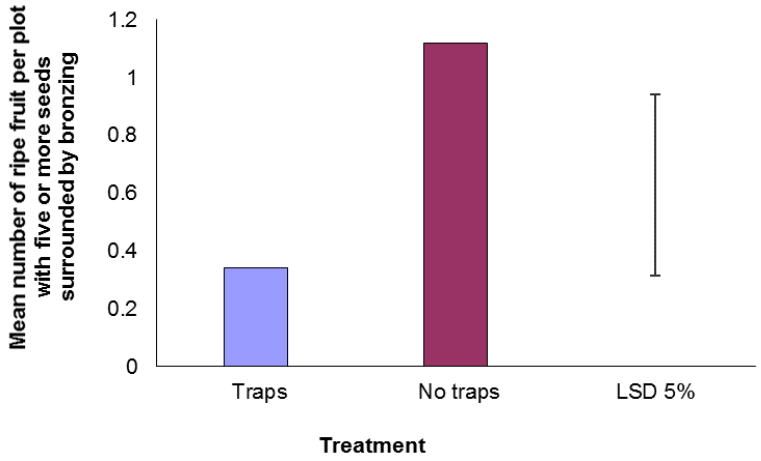


Figure 5.2.32 Mean number of ripe fruit per plot with five or more seeds surrounded by bronzing across all assessment dates at Lutton Farm (Site 1).

Reasons for fruit downgrading to waste fruit in the packhouse:

Twenty-five waste fruit were collected from the packhouse on 17 May, 7 June and 17 June and the reason for their downgrading was recorded (e.g. capsid/misshaping, botrytis, mildew, size, overripe etc.). Only 1% of fruit was downgraded to waste fruit due to thrips damage on 17 June.

On 17 May, 56% of the fruit was overripe, 20% was misshapen, 20% was eaten by birds and 4% had physical damage.

On 7 June, 44% of the fruit was overripe, 20% had capsid damage, 20% was too small, 12% was misshapen and 4% was eaten by birds.

On 17 June, 32% of the fruit had physical damage, 32% was overripe, 4% was misshapen, 8% was not yet ripe, 4% was eaten by birds, 16% had capsid damage and 4% had bronzing damage by thrips.

Thrips on roller traps:

An analysis of variance on the log+1 of the data showed that there was no significant difference between the number of thrips on the roller traps close to (<0.6m) and further from (>0.6m) the lure at each sampling date (F= 0.23, *p*=0.63) (Figure 5.2.33) This suggests that spacing the pheromone lure 2.2m apart makes the roller trap evenly attractive to WFT across the entire 30m.

No assessments of the traps were made on 17 June as the traps slid down the leg rows to the ground due to the rain (Figure 5.2.34). Traps were replaced on 23 May and 30 July.

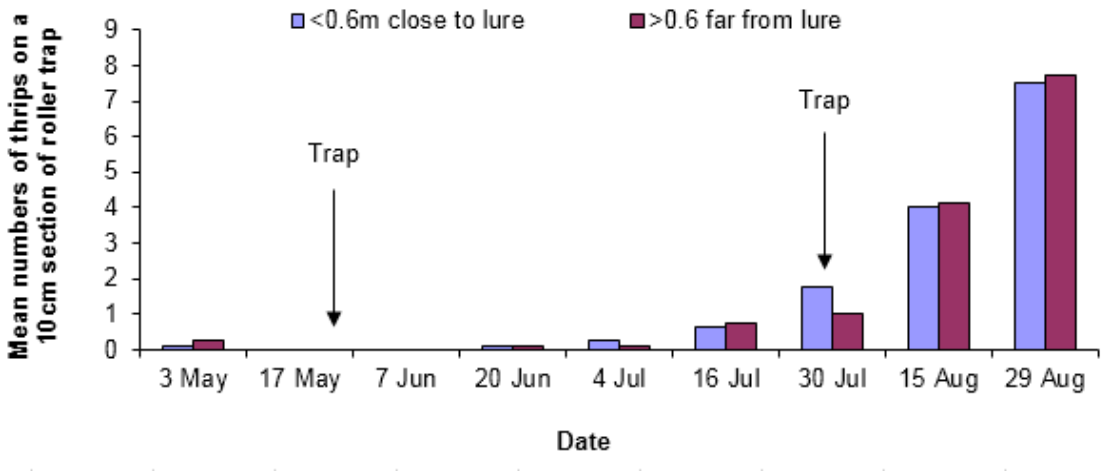


Figure 5.2.33 Mean number of thrips on a 10cm section of roller trap close to (<0.6m) and far from the pheromone lure (>0.6m) at Lutton Farm (Site 1). Traps were replaced on 23 May and 30 July. No assessments were made on 17 May.

Crop canopy temperatures:

Mean minimum, maximum and mean crop canopy temperatures in the tunnels during the experiment at Lutton Farm are shown in Figure 5.2.34.

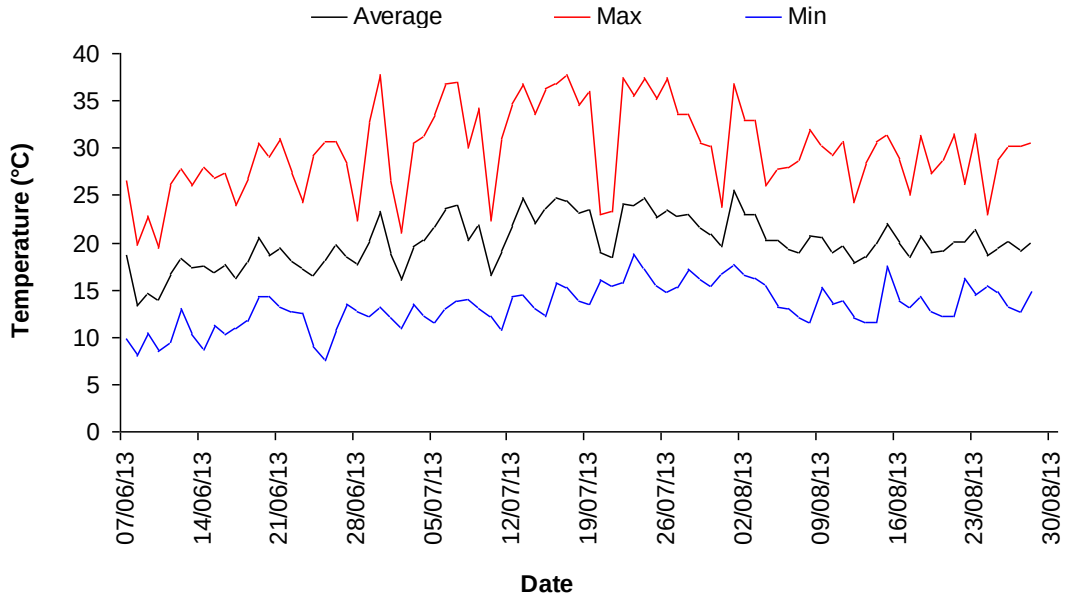


Figure 5.2.34 Mean minimum, maximum and mean temperatures recorded in the tunnels during the experiment at Lutton Farm (Site 1).

Pesticide and fungicide applications:

Pesticides and fungicides applied to Lutton Farm are listed in Table 5.2.5.

Table 5.2.5 Pesticides and fungicides applied to experimental plots at Lutton Farm (Site 1) during experimental period.

Date	Pesticide active ingredient (product name)	Fungicide active ingredient (product name)
19 April	pirimicarb (Aphox) pymetrozine (Chess WG)	quinoxyfen (Fortress) fenhexamid (Teldor)
26 April	pirimicarb (Aphox)	quinoxyfen (Fortress) iprodione (Rovral WG)
12 May		azoxystrobin (Amistar) boscalid and pyraclostrobin (Signum) myclobutanil (Systhane 20EW)
23 May		fenhexamid (Teldor)
4 June		(Bacillus subtilis QST713 (Serenade) *Ampelomyces quisqualis* strain M-10 (AQ 10 WG)
7 June	pymetrozine (Chess WG)	*Ampelomyces quisqualis* strain M-10 (AQ 10 WG)
13 June		myclobutanil (Systhane 20EW) Azoxystrobin (Amistar)
18 June		*Ampelomyces quisqualis* strain M-10 (AQ 10 WG)
23 June	*Beauveria bassiana* (Naturalis)	
26 June		azoxystrobin (Amistar) penconazole (Topas)
29 July		penconazole (Topas) mepanipyrim (Frupica SC) azoxystrobin (Amistar)
9 August		penconazole (Topas) fenhexamid (Teldor)
18 August		myclobutanil (Systhane 20EW) sulphur (Sulphur Flowable)
28 August	thiacloprid (Calypso)	myclobutanil (Systhane 20EW) bupirimate (Nimrod) fenhexamid (Teldor) sulphur (Sulphur Flowable)

Boxford Farm (Site 2)

Mean numbers of thrips adults per flower:

At Boxford Farms (Site 2) the mean numbers of thrips adults per flower were significantly lower for the roller trap treatment than the control treatment on 25 July (F= 14.94, *p*=0.03), 9 August (F= 18.71, *p*=0.02) and 22 August (F=17.67 *p*= 0.03) traps (Figure 5.2.35). Mean numbers of thrips adults per flower peaked on 9 August with a mean of 3.7 per flower in control plots and 2.2 per flower in plots with roller traps (Figure 5.2.35).

At the beginning of the trial there was a mean of 12 and 9.2 flowers per plant in plots with the roller trap treatment and control treatment respectively (Figure 5.2.37). The numbers of flowers decreased to 0 by 11 July and then increased again to 4.15 (roller trap treatment) and 3.35 (control treatment) flowers per plant on 9 August. The increase in flowers on 9 August also coincided with an increase in the number of thrips adults per flower.

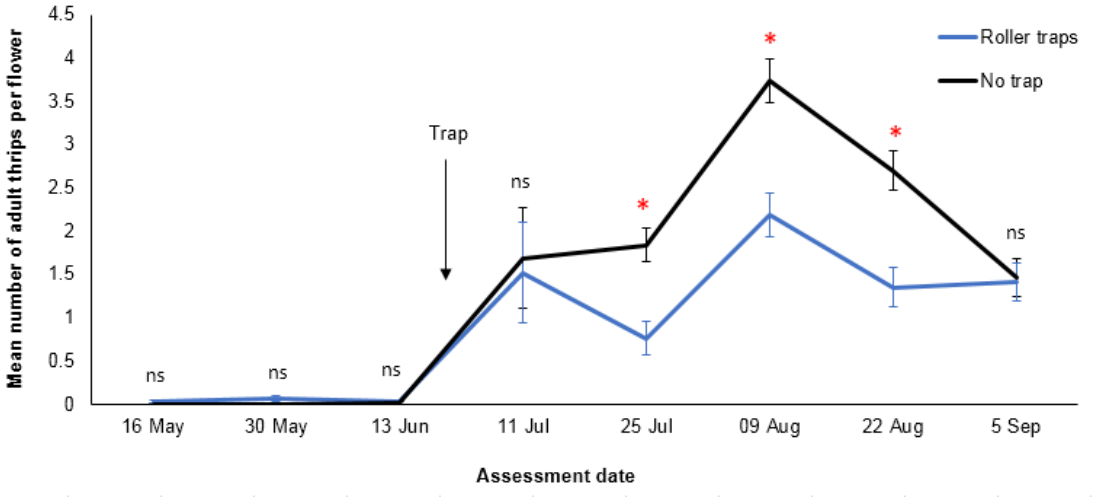


Figure 5.2.35 Mean thrips adults per flower at each assessment date at Boxford Farms (Site 2). * indicates where there is a significant difference between treatments. ns = not significant. Traps were replaced on 27 June.

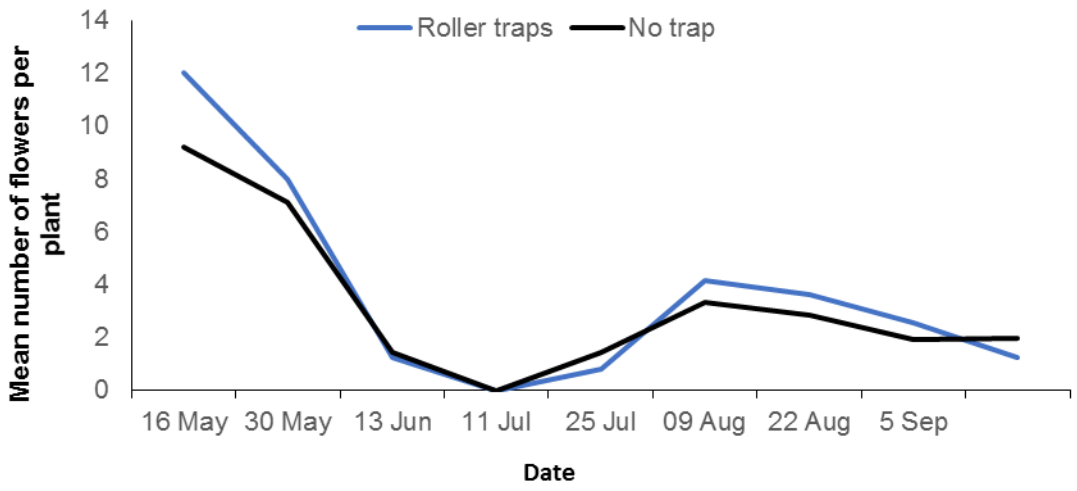


Figure 5.2.36 Mean number of flowers per plant present at each sampling date at Boxford Farms (Site 2).

Thrips species collected from flowers:

At least ten of the thrips which were collected from the flowers on each sampling date were mounted and identified. On 16 May, 31 May, 12 June, 15 July and 9 August all the thrips were identified as western flower thrips, *F. occidentalis.*

On 25 July 75% were *F. occidentalis,* 12.5% were *Frankliniella intonsa* and 12.5% were *Thrips tabaci.*

On 22 August, 8% were *F. intonsa* and 92% were *F. occidentalis.*

On 5 September, 25% were *F. intonsa* and 75% were *F. occidentalis.*

Mean number of predators per flower:

Fewer predators (both *Orius* sp. and *Anthocoris* sp.) were observed at Boxford Farms compared to Lutton Farm as the grower did not have a biological control programme in place. The predators observed were therefore all naturally occurring. Predators were only observed on 9 August and 5 September and did not exceed 0.03 predators per flower (Figure 5.2.37). *Orius* sp. was the most common predator, while *Anthocoris* sp. was only recorded on 9 August in plots with traps.

The percentage of flowers with predators was low throughout the trial (Figure 5.2.38). *Orius* sp. was found on 3.4% of flowers assessed on 5 September in plots without traps and 0.7% of flowers on plots with traps. *Anthocoris* sp. was only found on 9 August on 0.63% of the flowers in plots with traps. As at Site 1, no anthocorid bugs were recorded in the roller trap assessments.

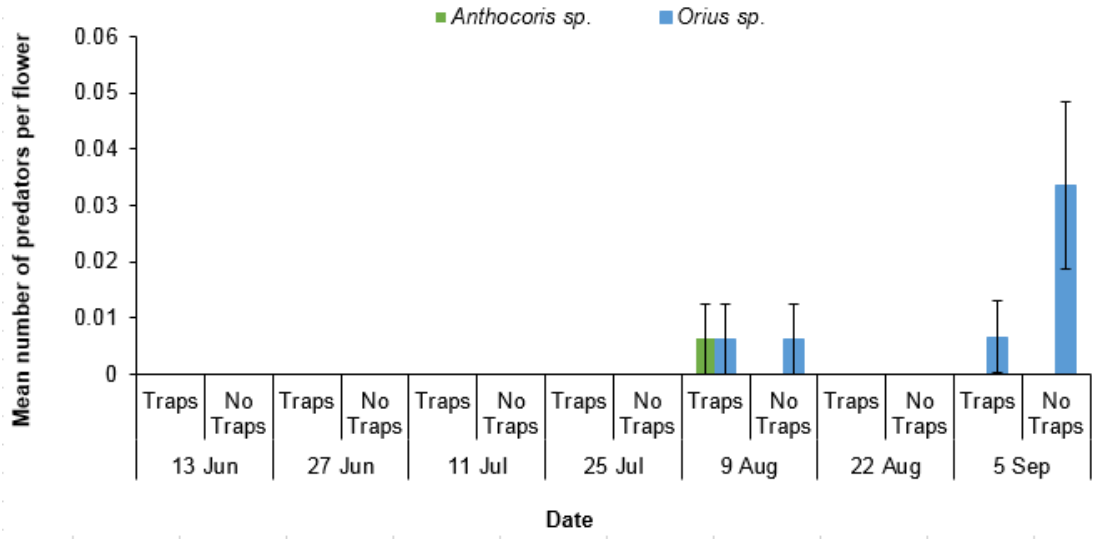


Figure 5.2.37 Mean number of *Anthocoris* sp. and *Orius* sp. per flower at Boxford Farms in plots with traps and plots without (Site 2).

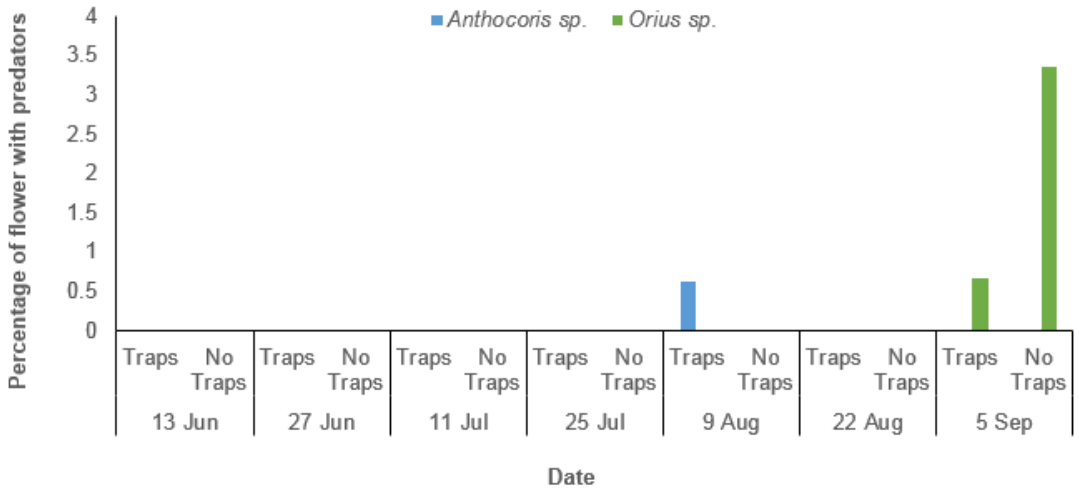


Figure 5.2.38 Percentage flowers with *Anthocoris* sp. and *Orius* sp. at Boxford Farms in plots with traps and plots without traps (Site 2)

White fruit damage:

At Boxford farms the mean number of seeds surrounded by bronzing on the white fruit assessed did not exceed 0.6 for the control treatment and 0.24 for the roller trap treatment (a maximum of 160 fruit per treatment was assessed) (Figure 5.2.39). When the damage on white fruit peaked on 5 September only 3.3% of the fruit assessed had five or more seeds

surrounded by bronzing in control plots and 1.9% in plots with roller traps (Figure 5.2.40). Damage was very low throughout the trial.

Performing an ANOVA on the mean number of fruit per plot with five or more seeds surrounded by bronzing (log +1) showed that there was no difference in damage on white fruit between treatments (F=0.02, *p*=0.885).

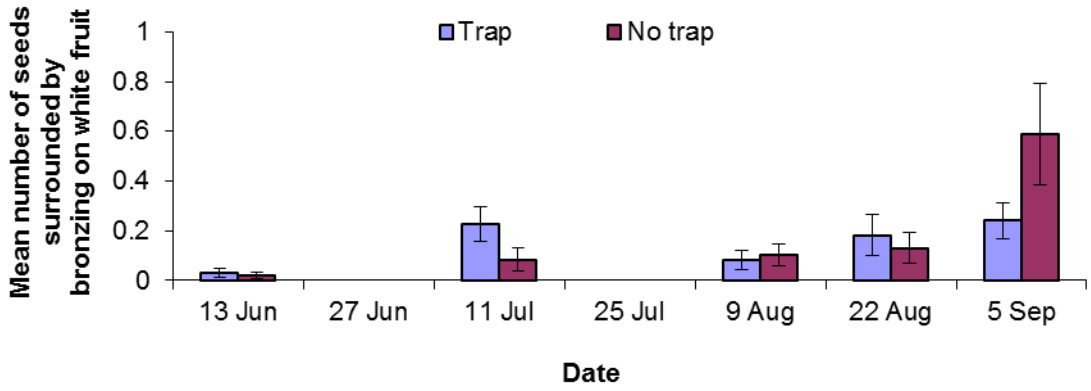


Figure 5.2.39 Mean number of seeds surrounded by bronzing per white fruit at Boxford Farms (Site 2).

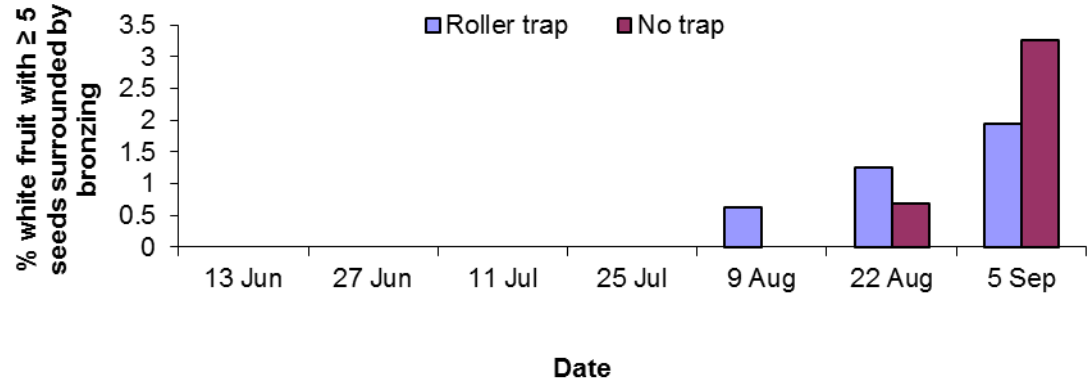


Figure 5.2.40 Percentage of white fruit with five or more seeds surrounded by bronzing at Boxford Farms (Site 2).

Ripe fruit damage:

At Boxford farms no ripe fruit damage was observed between 16 May and 25 July (Figure 5.2.41). Damage was very low throughout the trial. On 5 September damage peaked and the mean number of seeds surrounded by bronzing was recorded at 1.7 seeds for the control treatment and 0.7 for the roller trap treatment (a maximum of 160 fruit per treatment was

assessed) (Figure 5.2.41). At this time only 8.7% of the fruit assessed in control plots had five or more seeds surrounded by bronzing compared to 6.6% in plots with traps (Figure 5.2.42).

Performing an ANOVA on the mean number of fruit per plot with five or more seeds surrounded by bronzing (log+1) showed that there was no difference in damage on ripe fruit between treatments (F=0.36, *p*=0.55).

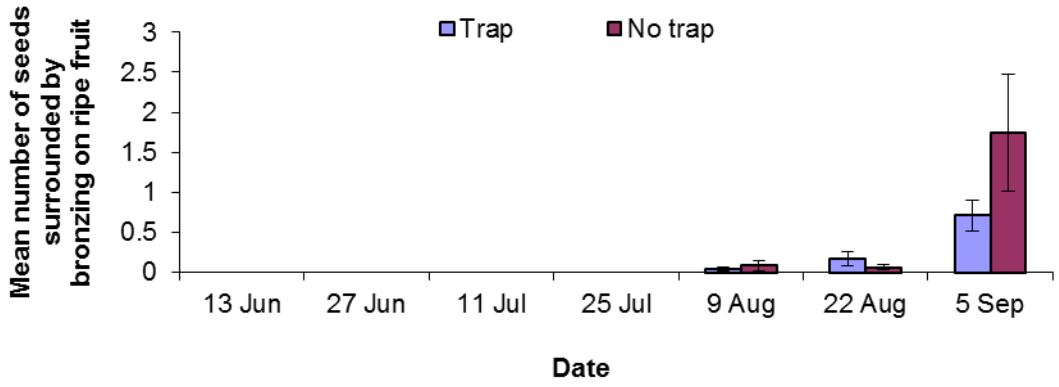


Figure 5.2.41 Mean number of seeds surrounded by bronzing per ripe fruit at Boxford Farms (Site 2).

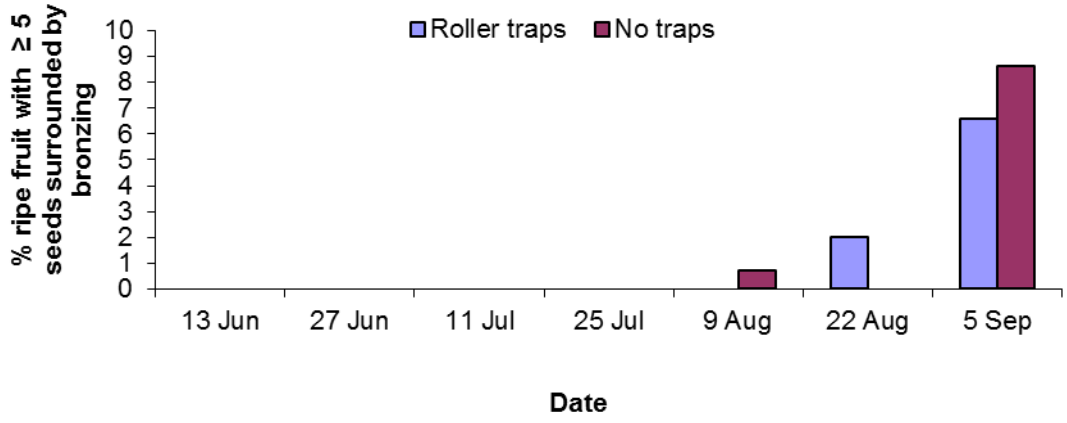


Figure 5.2.42 Percentage of ripe fruit with five or more seeds surrounded by bronzing at Boxford Farms (Site 2).

Reasons for fruit downgrading to waste fruit in the packhouse:

Twenty-five waste fruit were collected from the packhouse on 27 June, 9 August and 22 August and the reason for their downgrading was recorded (e.g. capsid/misshaping, botrytis, mildew, size, overripe etc). No fruit was downgraded due to thrips damage.

On 27 June, 48% of the fruit was overripe, 4% had botrytis, 32% had capsid damage, 8% was misshapen and 8% was damaged.

On 9 August, 28% of the fruit had physical damage, 52% was overripe and 20% had been eaten (e.g. birds).

On 22 August, 28% of the fruit had physical damage, 56% was overripe, 12% had been eaten and 4% had botrytis.

Thrips on roller traps:

An analysis of variance on the log+1 of the data showed that there was no significant difference between the number of thrips on roller traps close to (<0.6m) and far from (.0.6m) the lure at each sampling date (F= 0.04, *p*=0.85) (Figure 5.2.43). This suggests that spacing the pheromone lure 2.2m apart makes the roller trap evenly attractive to WFT across the entire 30m.

No assessments of the traps were made on 13 June as the traps slid down the leg rows to the ground due to the rain. Traps were replaced on 27 June.

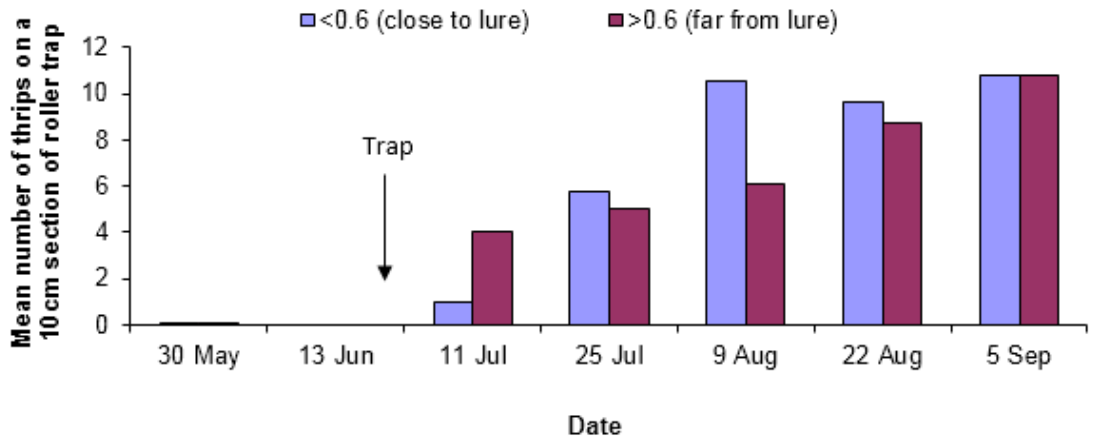


Figure 5.2.43 Mean number of thrips on a 10cm section of roller trap close to (<0.6m) and far from the pheromone lure (>0.6m) at Boxford Farms (Site 2). Traps were replaced on 27 June. No assessments were made on 13 June.

Crop canopy temperatures:

Mean minimum, maximum and mean crop canopy temperatures in the tunnels during the experiment at Boxford Farms are shown in Figure 5.2.44.

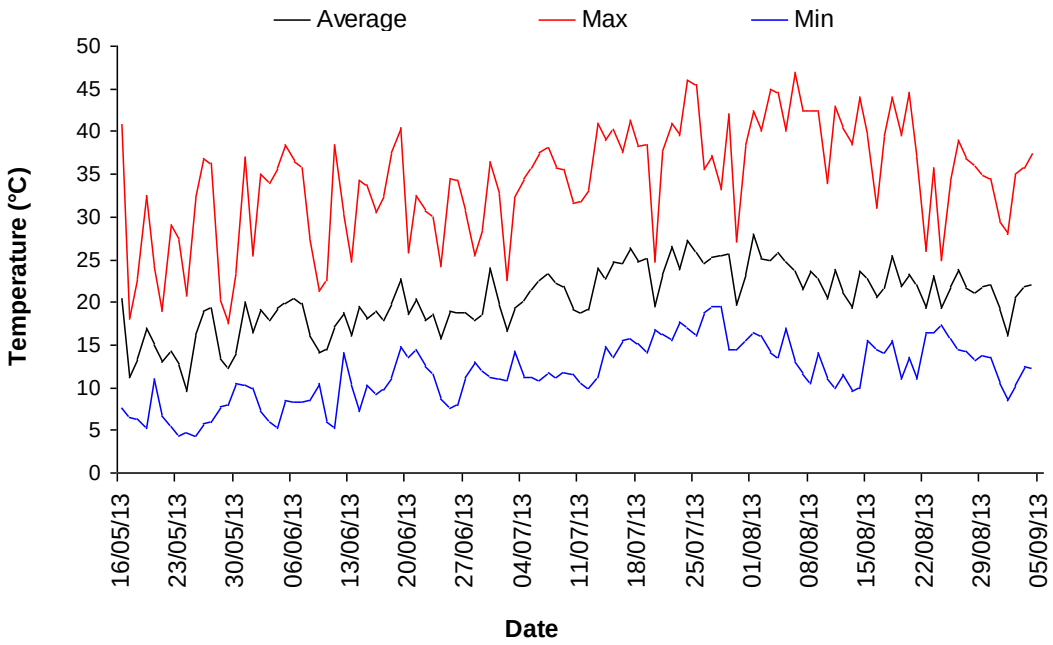


Figure 5.2.44 Mean minimum, maximum and mean temperatures recorded in the tunnels during the experiment at Boxford Farm (Site 2).

Pesticide and fungicide applications:

Pesticides and fungicides applied to experimental plots at Boxford Farms (Site 2) during the experiment period are shown in Figure 5.2.45. This site did not have a biological control programme in place and relied on pesticides for control of both thrips and aphids. As most of the thrips identified were WFT, it is unlikely that some of the pesticides applied were effective, but as there were no plots untreated with pesticides, this is not possible to confirm.

Table 5.2.45 Pesticides and fungicides applied to experimental plots at Boxford Farms (Site 2) during experiment period.

Date	Pesticide active ingredient (product name)	Fungicide active ingredient (product name)
27 April	chlorpyrifos (Equity)	thiram (Thianosan DG) iprodione (Rovral WG)
11 May	thiacloprid (Calypso) pymetrozine (Plenum WG)	Quinoxyfen (Fortress)
3 June	pirimicarb (Aphox)	cyprodinil + fludioxonil (Switch) myclobutanil (Systhane 20EW)
2 July 16 July	abamectin (Dynamec)	boscalid and pyraclostrobin (Signum)
16 August	abamectin (Dynamec) spinosad (Tracer)	
19 August	lambda-cyhalothrin (Hallmark)	fenhexamid (Teldor)

Conclusions

- WFT was the only thrips species confirmed at Site 1 and was the main species confirmed at Site 2, where low numbers of *Frankliniella intonsa* and *Thrips tabaci* were also confirmed in strawberry flowers.
- At Lutton Farm (Site1) there was no effect of the roller trap treatment on reducing thrips numbers. There was a trend that ripe and white fruit damage was always higher in the control treatment. Significantly less ripe fruit with five or more seeds surrounded by bronzing were found in plots with roller traps compared to the control.
- At Site 1, mean numbers of WFT remained below two adults per flower in plots with or without roller traps throughout the experiment and this is thought to be due to the biological control programme used by the grower.
- At Boxford Farms (Site2) the roller trap treatment significantly reduced the number of thrips per flower on 25 July, 9 and 22 August. However, there was no difference in fruit damage between the two treatments.
- At Site 2, mean numbers of thrips remained below four per flower in plots with or without roller traps.
- Fruit damage was low at both sites. The mean numbers of thrips per flower at both sites was not enough to cause economic damage to fruit on cv. Jubilee (Site 1) or cv. Finesse (Site 2).

- More predators, particularly *Orius* sp. were found at Lutton Farm where they had a biological control programme compared to Boxford Farms where they used pesticides.
- No predatory bugs were recorded on the roller traps on any assessment date at either site. This suggests that using roller traps does not trap flying anthocorid adults.
- At both sites there was no difference between the number of thrips found on the roller traps close to and far from the pheromone lure, indicating that a 2.2m distance between lures was effective in making the roller trap evenly attractive to WFT across the entire 30m

Task 5.3. - Prepare best practice guidelines (all partners)

This will be done in year 5

Task 5.4. Economic and environmental impact analysis (EMR, PO and grower consortium members)

This will be done in year 5.

SIX MONTHLY REPORT TO HORTICULTURE LINK PROGRAMME MANAGEMENT COMMITTEE
(Due 31 March 2014)

Project Number:	HL01107
Project Title:	Biological, semiochemical and selective chemical management methods for insecticide resistant western flower thrips on protected strawberry
Project Partners:	East Malling Research, ADAS Boxworth, Warwick HRI, University of Keele, Natural Resources Institute, Agriculture & Horticulture Development Board; Tesco Stores Ltd; K G Growers Ltd; Berry World Ltd; CPM Retail Ltd; Syngenta Bioline Ltd, Certis UK; Russell IPM Ltd; Belchim Crop Protection Ltd; Bayer Crop Science Ltd; East Malling Ltd
Report Written by:	J Bennison, J V Cross, J Fitzgerald, W Kirk, C Sampson, X Xu
Project Start/Completion Dates:	1 April 2010 – 31 March 2015
Reporting Period:	30 September 2013-31 March 2014
Number of Months Since Commencement:	48
Date of Last Management Meetings:	To be confirmed
Dates of Next Management Meetings	

1.	**Project objectives:**	(from project proposal, or other more recently approved planning document)

Objective 1. To develop an easy to use, pest-specific monitoring method and attendant damage thresholds for WFT in strawberry crops in Spanish tunnels

Objective 2. To develop a computer based model of thrips population development for predicting risk of WFT infestation and rapidity of population increase.

Objective 3. To determine reliable and cost-effective methods of using predators for biological control of WFT.

Objective 4. To evaluate pesticide products, adjuvants and entomopathogenic fungi for control of WFT in strawberry, the latter in flowers versus in the soil

Objective 5. To optimise the use of the above components in an integrated pest management programme for WFT control on strawberry and to evaluate and refine it on a commercial scale

2. Table showing overview of progress against milestones for project as a whole (from project proposal, or other more recently approved planning document)

Milestone	Target month	Title	
P1.1	31 Mar 2011	Synthetic pheromone components and dispensers available for field trials	Y
P1.2	31 Mar 2012	Pheromone blend optimised and effect of plant volatiles determined	Y
P1.3	31 Mar 2013	Trap design and positioning optimised	Y
P1.4	31 Mar 2014	Relationships between thrips on crop and damage established	Y
P1.5	31 Mar 2015	Damage thresholds established for thrips flower counts	Y
P2.1	31 Mar 2011	A prototype generic model for WFT developed	Y
P2.2	31 Mar 2013	The first version of WFT model on strawberry developed	Y
P2.3	31 Mar 2014	New biological data for WFT on strawberry collated	Y
P2.4	31 Mar 2015	A final model for WFT on strawberry completed	
P3.1	31 Mar 2011	First trial on release strategy for *N. cucumeris* completed	Y
P3.2	31 Mar 2011	Banker plant for *O. laevigatus* selected	Y
P3.3	31 Mar 2013	Efficacy of combined releases of *N. cucumeris* and *O. laevigatus* determined	Y
P3.4	31 Mar 2015	Role of WFT attractant with banker plants determined *After success with sticky trapping in 2012 it was decided to continue with this rather than assess banker plants*	N

P3.5	31 Mar 2015	Analysis of gut content of naturally occurring predators completed. *Very low numbers of predators were found in the commercial plantings so it was decided to focus on the mass trapping experiments*	N
P4.1	31 Mar 2013	Effective pesticides and EPFs identified	
P5.1	31 Mar 2013	IPM programme for thrips for evaluation in yrs 4 and 5 devised	Y
P5.2	31 Mar 2015	Thrips IPM programme evaluated in commercial crops for 2 seasons	
P5.3	31 Mar 2015	Best practice guidelines for thrips IPM prepared	
P5.4	31 Mar 2015	Economic and environmental impact analysis of thrips IPM completed	
S1.1	31/03/11	Data on release rates of pheromone components by WFT obtained	Y
S1.2	31/03/12	Initial designs to exclude other insects tested	Y
S1.3	31/03/13	Optimum flower sampling methods determined	Y
S1.4	31/03/14	Optimum trap density and spacing determined	Y
S1.5	31/03/15	Feasibility of using traps to control WFT determined	Y
S2.1	31/03/11	Experimental protocols for lab experiments established	Y
S2.2	31/03/14	Sufficient amount of field data on WFT obtained	Y
S2.3	31/03/15	A model for a specific BCA incorporated with the WFT model	
S3.1	30/09/10	Emergence of *N. cucumeris* from sachets quantified	Y
S3.2	31/07/10	Pilot experiment with *O. laevigatus* establishment completed	Y
S3.3	31/03/11	Protocol for trial with release rates of both predators agreed	Y
S3.4	31/03/13	Protocol for using thrips attractant with banker plants agreed *After success with sticky trapping in 2012 it was decided to continue with this rather than assess banker plants*	N
S3.5	31/01/12	Protocol for collection of natural predators agreed	Y
S4.1	31/03/11	First field trial evaluating pesticides and EPF sprays completed	Y
S4.2	31/03/12	2nd field trial evaluating pesticides and EPF soil treatments completed	Y

S4.3	31/03/13	Confirmatory field trial testing most effective pesticide and EPF treatments completed	
3.	**Milestones for the six month period:** (from project proposal, or other more recently approved planning document)		
P2.3	31 Mar 2014	New biological data for WFT on strawberry collated	Y
P1.4	31 Mar 2014	Relationships between thrips on crop and damage established	Y
S1.4	31/03/14	Optimum trap density and spacing determined	Y
S2.2	31/03/14	Sufficient amount of field data on WFT obtained	Y
4.	**Research report:** (concise account including comments on whether targets are being met)		

Objective 1. To develop an easy to use, pest-specific monitoring method and attendant damage thresholds for WFT in strawberry crops in Spanish

Bronzing damage to strawberry fruit increased with increasing numbers of adult thrips per flower, yet the amount of bronzing was very variable. The presence of the predatory mite *Neoseiulus cucumeris*, which feeds on thrips larvae, significantly reduced fruit damage. The influence of flower flushes was identified as a key factor in the timing of damage. To help determine the relationship and timing between thrips per flower and fruit damage, the distribution of thrips on strawberry plants and timing of fruit damage was examined. The greatest amount of damage to fruit occurred at the end of flowering when the flowers are senescent and larval numbers are at their highest, although further damage occurs throughout fruiting.

Comparison of thrips density and fruit damage on different farms and seasons suggested a threshold of 5 adult thrips per flower as the thrips density corresponding with fruit bronzing over 10% of the fruit surface. Bronzing over 10% of the fruit surface resulted in downgrading of fruit to a lower price in a commercial pack-house. No economic fruit bronzing was observed in six crops where thrips numbers remained below 5 adult thrips per flower, in the presence of predatory mites. Economic crop loss was observed in six crops where thrips numbers exceeded 5 adult thrips per flower. Higher thrips numbers could be tolerated without crop loss in some crops where there was good predator establishment, but further work is required to quantify this. Other factors, such as sun scorch and pesticide sprays, also caused or exacerbated fruit bronzing, so thresholds should be viewed with some caution.

Three large-scale, replicated field trials demonstrated that placement of blue roller traps along the legs between tunnels reduced thrips numbers and fruit damage. The use of traps alone (30 cm wide, 100 m long, Optiroll, Russell IPM) reduced thrips numbers by 61% and fruit damage by 55%. The use of roller traps with WFT aggregation pheromone, reduced thrips numbers by 73% and fruit damage by 68%.

Objective 2. To develop a computer based model of thrips population development for predicting risk of WFT infestation and rapidity of population increase

New data have been obtained on the rates of development of WFT on strawberry at fluctuating temperatures in the laboratory that WFT confirming that WFT developmental rate at 10°C is not zero as assumed by all previous studies (minimum temperature for development was said to be around 10°C). These data are being used to validate the model developed in years 1 and 2.

Objective 3. To determine reliable and cost-effective methods of using predators for biological control of WFT

No work was planned for this objective in 2013

Objective 4. To evaluate pesticide products, adjuvants and entomopathogenic fungi for control of WFT in strawberry, the latter in flowers versus in the soil

The fungal biopesticides used in the first years of the project are known to be pathogenic to WFT (i.e. they kill WFT in laboratory experiments). However, in our experiments there was a lack of control in cage and polytunnel experiments. To try to understand the reasons for this an experiment was done to quantify the deposition of a commercial biopesticide spray within a strawberry crop, to enable us to understand whether biopesticides are being deposited in places where thrips are located, and to give information of the number of spores that are acquired by thrips. All parts of the strawberry plant sampled received a number of viable spores. All of the thrips found were located in the flowers but they varied in number of spores that they received. This suggests that secondary pick up of viable spores is an important means of inoculation for WFT biocontrol with entomopathogens. Further work is required to evaluate the persistence of the fungal spores on the strawberry crop and to determine the number of spores per thrip required to cause death.

Objective 5. To optimise the use of the above components in an integrated pest management programme for WFT control on strawberry and to evaluate and refine it on a commercial scale

In experiments on a commercial site in Kent we were unable to provide confirmation of the effectiveness of roller traps to reduce crop damage caused by thrips feeding. Very low numbers of thrips were attracted and stuck to the blue roller traps in the early assessments, even though there were thrips present in the flowers. Although thrips are attracted to blue traps it is likely that the flowers present in the planting were more attractive early in the season. In the last assessments, when numbers of flowers were decreasing, numbers of thrips caught on the traps increased. Damage to fruit was high in both plantings and the crop became unmarketable. Because the experiment was terminated by the grower we were not able to determine if the traps reduced populations on the plants from July onwards; in 2012 the roller traps caught higher numbers of thrips from July (see 2012 Annual Report) and thrips populations and fruit damage decreased significantly at this time.

In an experiment in Cambridgeshire there was no effect of the roller trap treatment on reducing thrips numbers. Percentage of fruit damaged by thrips was low, however, there was a trend that ripe and white fruit damage was always higher in the control treatment. Significantly less ripe fruit with five or more seeds surrounded by bronzing were found in plots with roller traps compared to the control. Mean numbers of WFT remained below two adults per flower in plots with or without roller traps throughout the experiment, probably as a result of the biological control programme used by the grower. At a site in Essex the roller trap treatment significantly reduced the number of thrips per flower on 25 July, 9 and 22 August. Percentage of fruit damaged by thrips was low and there was no difference in fruit damage between the two treatments. Mean numbers of thrips remained below four per flower in plots with or without roller traps. No predatory bugs were recorded on the roller

5.	**Project changes:**	Despite much work in 2011 it did not prove possible to produce a more attractive lure so it was decided to concentrate on developing a more effective trap and on monitoring strategies in 2012. After success with sticky trapping in 2012 it was decided to continue with this in conjunction with releases of biocontrol agents in 2013 rather than assess the efficacy of banker plants.
6.	**Publications and technology transfer outputs:** (including public presentations/talks given. Indicate additions since last report by use of bold type)	

Jude Bennison presented the year 1 results at the AAB conference ' Advances in Biological Control' at the Olde Barn Hotel, Marston, Lincs on 17 November 2010 and at the IOBC/wprs Working Group meeting 'Integrated Control in Protected Crops, Temperate Climate, Norton Park Hotel, Sutton Scotney, 18-22 September 2011.

Bennison, Jude; Pope, Tom & Maulden, Kerry (2011). The potential use of flowering alyssum as a 'banker' plant to support the establishment of Orius laevigatus in everbearer strawberry for improved control of western flower thrips. IOBC/wprs Bulletin 68, 15-18.

Fitzgerald, J. & Jay, C. (2011). Strategies for release of Neoseiulus (Amblyseius) cucumeris to control western flower thrips, Frankliniella occidentalis, in tunnel grown everbearer strawberries. IOBC/WPRS Bulletin 70, 97-100

Jean Fitzgerald presented a summary of the results to date on the use of A. cucumeris to control thrips at the AAB conference ' Advances in Biological Control' at the Olde Barn Hotel, Marston, Lincs on 17 October 2012

Jean Fitzgerald prepared a poster entitled 'Using N. cucumeris to control thrips on strawberry' for the Berry Gardens Growers Ltd Technical Conference on 15 November 2012

Sampson, C. & Kirk, W.D.J. presented 'Flower Stage and Position Affect Population Estimates of the Western Flower Thrips, Frankliniella occidentalis (Pergande), in Strawberry' at 3rd symposium on Palaearctic Thysanoptera, Smolenice, Slovakia. Also in Abstracts, Edited by: P. Fedor, M. Doricová & R. Masarovic. Unpublished. pp 33

Sampson, C. & Kirk, W.D.J. (2012) Flower Stage and Position Affect Population Estimates of the Western Flower Thrips, *Frankliniella occidentalis* (Pergande), in Strawberry. *Acta Phytopathologica et Entomologica Hungarica* 47 (1), 133-139.

Sampson, C., Hamilton, J. G. C., & Kirk, W. D. J. (2012). The effect of trap colour and aggregation pheromone on trap catch of *Frankliniella occidentalis* and associated predators in protected pepper in Spain. IOBC/WPRS Bulletin 80, 313-318.

Sampson, C., Kirk, W.D.J. (2013). Can mass trapping reduce thrips damage and is it economically viable? Management of the western flower thrips in strawberry. PLoS ONE 8(11): e80787. doi:10.1371/journal.pone.0080787

Sampson, C. Use of the *Frankliniella occidentalis* aggregation pheromone for monitoring and mass trapping. *III international conference on pheromones, lure, traps and biological control: tools for integrated protection*. Cartagena (Murcia-Spain), 19-20th November, 2013

Kirk, W.D.J. (2013). Aggregation pheromones of thrips and their use in pest

7.	**Exploitation plans:**	(give an update on perceived exploitation opportunities and future plans.)
None at this stage of the project		