Project title:	Biological, semiochemical and selective chemical management methods for insecticide resistant western flower thrips on protected strawberry
Project number:	SF 120, HL01107
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GROWER SUMMARY

Headlines

- Significant progress has been made in developing a prediction model for western flower thrips and a practical IPM control programme which growers can follow.

Background and expected deliverables

The development and spread of pesticide resistant strains of WFT, which cannot be controlled with currently approved products, 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 pesticide resistant western flower thrips (WFT) on tunnel-grown strawberry in the UK. The methods include improved monitoring methods 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 project and main conclusions

Progress in year 5 on continuing objectives of the project is summarised below.

Objective 2 (Model)

New information was obtained on overwintering behaviour of WFT adults. Three commercial sites in Kent that had serious thrips damage in 2013 were visited to determine if they were suitable to monitor early season thrips occurrence to determine the temperatures at which thrips adults become active and lay eggs. After initial sampling, only one site was found to be suitable for monitoring. At this site the strawberries had been grubbed in autumn 2013, but the polythene-covered raised beds remained in place and weeds were present in the alleys. The most common weed was groundsel; thrips adults had been recorded in groundsel flowers throughout the winter in Staffordshire in earlier monitoring experiments in this project. Replicate samples of groundsel flower spikes were collected into alcohol on each sampling occasion. These flowers were washed in the laboratory and any arthropods

present were recorded and identified. Samples were taken weekly from the beginning of March. The first thrips larvae were recorded on 28 March. By 10 April, numbers of first and second instar larvae were increasing and adult numbers had decreased. This indicates that females are laying eggs in early March at the latest.

Laboratory experiments were also done to determine both the rate of development of eggs at low temperatures and the effect of low temperatures on oviposition.

The assumptions made for these experiments were:

- Only adult females overwinter;
- Adults do not diapause;
- Adults need pollen before they can oviposit;
- Eggs can survive low temps and develop in stages when the temp increases;
- Females only need a few days acclimation to low temps to exhibit effects.

Two temperature regimes were used for both experiments: constant 10°C and 25°C (as control) all at 8D/16L.

To determine the rate of development of eggs at low temperatures, females were taken from culture plants and added to boxes containing green bean pods plus pollen and left for 24 hours at 20°C to oviposit. The bean pods containing eggs were then transferred into the experimental regimes and the cumulative number of larvae emerging recorded to give an estimate of the effect of temperature on percentage egg hatch.

At 25°C a total of 122 eggs hatched from the bean pods; the first egg hatched after two days but the peak of hatch was on days 5 and 6 when cumulatively 47% and 79% of eggs had hatched. The last egg hatched on day 10.

At 10°C only one egg hatched and this was on day 10. The beans were inspected until day 16 but no further eggs hatched in that time. In earlier experiments, all eggs held at 14/10°C had hatched by day 15 (see annual report for year 4). The bean pods were transferred to 25°C to determine if any eggs had been laid that would develop after a 16 day cold period. Three days after transfer to 25°C, 16 eggs hatched from the bean pods. Since most of the eggs which had been held at 25°C hatched after 5-6 days, and the eggs which had been transferred to 25°C (from the regime of 16 days at 10°C) hatched after three days at the

higher temperature, the results suggest that the eggs were developing, although slowly, at 10°C. Numbers hatching were lower than in the beans held at 25°C so it is possible that at the lower temperatures, fewer eggs develop successfully.

In the experiment to determine the effects of low temperatures on oviposition, females were shown to continue to oviposit during 1-3 days at 10°C. Similarly, eggs were laid in plant material that had been exposed to females after 4-15 days at 10 ºC. A total of 37 eggs hatched when the plant material was transferred to 25°C with most hatching 3-4 days after transfer to the higher temperature. This result suggests that females in cold conditions continue to oviposit at low rates.

The data obtained from the monitoring programme and the experimental studies have been incorporated into the WFT phenological model. Data obtained from the weekly monitoring in the trapping experiment (Objective 5) were used to validate the model. The model prediction on the timing of early activity of adults fits well with the observed behaviour. However, the predicted emergence of the first generation of WFT larvae on strawberry was much later than the observed, about 7-10 days late.

Objective 5 (IPM strategy)

Two experiments were set up by EMR in April 2014 in Kent on commercial sites; one on a first year Jubilee crop and the other on a second year Camarillo crop, using blue sticky roller traps in conjunction with the grower applied biocontrol programme (early sachets of *N. cucumeris* followed by regular introductions with loose product). There were two experimental treatments: 30 cm wide blue sticky roller traps with WFT pheromone lures every 2.2 m along the trap and a control treatment with no roller traps or pheromone. The roller traps were positioned at crop height in each of the leg rows in treated plots. Each plot was 30 m long and three tunnels wide and there were four replicate plots for each treatment. Assessments of thrips in flowers were made each week by collecting flowers and washing thrips and predators off the flowers in the laboratory. In addition, until mid-July, thrips adults in individual flowers were counted directly in the field. A sample of fruit was assessed for thrips damage every two weeks.

In the first year crop, no WFT were identified through the season and an application of Tracer on 28 June reduced the numbers of other thrips present; this application also reduced numbers of *N. cucumeris* to close to zero. There was a significant reduction in adult thrips

numbers in the treated plots in September, but no earlier treatment effects were recorded in this planting. There was very little fruit damage recorded in the Jubilee.

In the second year Camarillo crop there was a mix of thrips species present initially but WFT became dominant after the Tracer application in June; in this planting *N. californicus* and *N. cucumeris* were both present with *N. californicus* becoming dominant after the Tracer application. In the second year crop there was a significant effect of treatment, with a reduction in numbers of thrips adults recorded in flowers compared with the untreated plots in July and in September; numbers of thrips reached a mean of over 30 per flower in July in the untreated plots. Despite the large pest infestation, fruit damage was much lower than that recorded in 2013 and the grower continued to pick marketable fruit throughout September. Less damage was recorded on ripe than on white fruit.

In both plantings low numbers of adult thrips were recorded initially on 10 cm wide portions of the blue sticky trap in the field; numbers increased from July in both plantings. This corresponds with the significant reduction in adult thrips seen in flowers in the treated plots at that time. In the field and laboratory counts of thrips adults, higher numbers were always recorded in the samples washed in the lab. However, there was a linear relationship between the direct counts and the laboratory washed counts.

ADAS set up a third experiment on 2 July on a second year crop of the variety Amesti. The crop had a history of WFT in 2013 and WFT was confirmed in flowers, together with both *Thrips major* and *Thrips tabaci* in June 2014, just before the trial was set up. The grower applied *Neoseiulus cucumeris* every two weeks for thrips control within his IPM programme, starting from 17 April. Release rates were 20 per plant during April and May, 30 per plant during June and 50 per plant from July. Every two weeks until 24 September, assessments were made of numbers and species of thrips adults per flower using by-eye counts in the field, and also using laboratory extraction from flowers sampled into alcohol. Assessments were also made every two weeks on numbers of thrips adults on 10cm lengths of roller trap, numbers and species of predatory mites per green fruit and thrips damage to ripe fruit (number of seeds surrounded by bronzing). Mean numbers of adult thrips per flower assessed by eye in the field peaked at 8.4 (without traps) and 7.1 (with traps) on 30 July. On all other dates, mean numbers were below one per flower. Mean numbers of adult thrips per flower assessed in the laboratory on 30 July were 23 (without traps) and 14.9 (with traps), indicating that by-eye counts in the field under-estimated numbers. Confirmation of thrips species has not yet been completed for all dates, but up to and including 30 July, the majority were *Thrips major*, with very few WFT being recorded.

The grower applied spinosad (Tracer) to the crop on 16 August as he was concerned about the numbers of *T. major* in flowers. However, in-field counts of thrips numbers per flower had already dropped to a mean of 0.7 (without traps) and 0.5 (with traps) by 13 August, so the reduction was not due to using Tracer. Mean numbers of predatory mites per green fruit were 1.7, 1.1 and 0.3 on 2 July, 16 July and 30 July respectively, indicating that the increase in thrips numbers on 30 July may have been associated with a drop in predator numbers. However, predatory mite species identification has only been completed so far for those recorded on 2 and 16 July, when all were confirmed as *N. cucumeris*. Predatory mite numbers increased during August and September, reaching a mean of one per green fruit by 27 August.

The grower's pesticide and fungicide records will be checked to determine whether any may have had an adverse effect on *N. cucumeris* during July. Thrips damage to ripe fruit remained low, with bronzing around five seeds or less throughout the experiment period. Mean numbers of thrips adults on the 10cm-lengths of roller trap remained below one on most dates, with a maximum of 1.3 per trap portion on 30 July and 13 August. It is possible that *T. major* is not as attracted to blue as WFT is, and certainly this species would not be attracted to the specific WFT pheromone lure.

A conspectus of the eleven mass trapping trials conducted under objective 1 from 2012-2013 and under objective 5 from 2013-2014, confirmed the value of mass trapping. In the completed trials in which the thrips density approached or exceeded the damage threshold, despite the grower's usual control measures, six out of seven trials showed a significant reduction in the adult thrips density per flower when mass trapping was used in addition to existing control measures. In the completed trials in which fruit damage approached or exceeded the threshold for downgrading, three out of six trials showed a significant reduction in fruit damage when mass trapping was used in addition to existing control measures.

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

recent years outbreaks have 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 £120,000 per ha. On some farms, WFT damage to everbearer fruit has been so severe following failure to control the pest, that total crop loss occurred for the latter third of the season, i.e. a loss of £40,000 per ha. WFT damage can lead to at least 20% of the fruit being downgraded to class 2 for half of the picking season. Assuming the value of class 2 fruit is around half that of class 1 fruit, WFT can cause minimum estimated financial losses of approximately £6,000 per ha per season. Based on the results obtained in this project, an example control strategy, using two applications of sticky traps + lures per season; application of sachets containing *N. cucumeris* without hooks early in the season at 1/linear metre of bed and regular (10 x) loose *N. cucumeris* applications at 25 mites per plant, costs a total of £6,125/ha. Thus overall, if damage to untreated crop results in more than 5% reduction in farm gate value, then the cost of the combined control strategy outlined is cost effective.

If two applications of blue sticky traps are applied without lures, the cost/ha would be reduced by £3,244. The blue sticky traps significantly reduced WFT and fruit damage without the pheromone lures in experiments in this project, but addition of the lures gave a significantly greater reduction. This would further increase the benefit of using the techniques developed.

Action points for growers

- Plan your IPM programme carefully in early spring, together with a consultant 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 10cm 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 in general increased with increasing numbers of adult thrips per flower. Significant damage that might result in downgrading of fruit occurred when there were about 4 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 4 or 8 adult thrips per flower in controlled experiments .
- In commercial crops where predators had been released, economic damage was observed at or above 5 adult thrips per flower. Economic damage occurred at 5 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.
- *N. cucumeris* should be released early in the season before thrips numbers begin to increase; releases using the sachet formulation were most effective in trials. Loose product should subsequently be released regularly.
- 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.
- Consider using blue sticky traps to reduce adult populations. In 2012 the use of blue roller traps along the tunnel legs (30 cm wide, 100 m long) 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%. In Kent in 2013, using the same experimental set-up, 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 a second ADAS experiment in Cambridgeshire there was no significant effect of the roller trap treatment on thrips numbers in the flowers. In 2014, in two experiments in Kent, the roller trap significantly reduced numbers of thrips adults in flowers in July and September. However, there was no associated effect on fruit damage; damage to fruit was low even though thrips numbers were higher in 2014 than in 2013. In the ADAS experiment in 2014 numbers of thrips were low in the crop throughout; very few WFT were identified. There was no effect of treatment on thrips numbers in flowers, and very little fruit damage. These results over multiple sites and years indicate that the use of sticky traps to reduce thrips numbers may give variable results, and any effect is normally seen towards the end of the season. 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)

Completed in year 4.

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

Information obtained during years 1-4 were used to design IPM programmes that were tested in years 4 and 5 (see below for 2014 results). Further work on mass trapping was continued in objective 5.

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 using 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.

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 are using data collected during this project, where mixed populations of thrips were present in the crop, to validate the model.

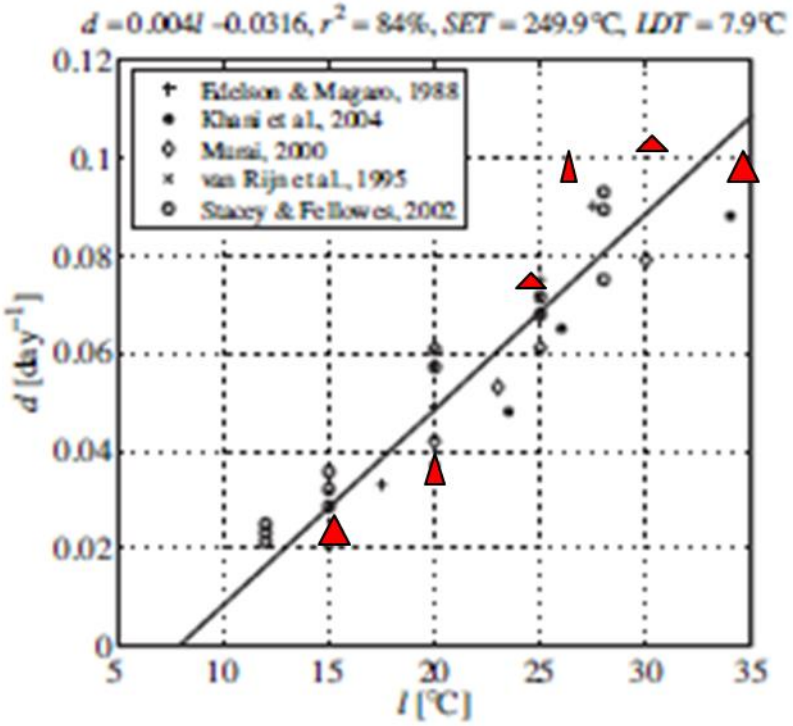

Figure 2.1.1 Relationship between mean developmental rate and temperature for *T. tabaci* based on the data from several published studies, together with the data (red triangle symbols) for WFT

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. Earlier results in this project 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). This is important for developing the model.

Methods

Early season development of populations; field monitoring

In 2013 sticky traps and dataloggers had been sent to seven commercial strawberry growers in late January to enable them to record early movement of thrips adults from plants to traps. The selected farms were in the West Midlands, Lincolnshire, Cambridgeshire, Kent and East Sussex. However, no informative data was obtained from this strategy; few thrips were

recorded on any of the traps in March or April. Because of this a different strategy was adopted in 2014.

Three commercial sites in Kent that had serious thrips damage in 2013 were visited to determine if they were suitable to monitor early season thrips occurrence to determine the temperatures at which thrips adults become active and lay eggs. After initial sampling only one site was found to be suitable for monitoring; one site had been completely grubbed and put to cereals, the second was found to have had other species of thrips in 2013. The strawberries at the third site had been grubbed in autumn 2013. However, the polythene-covered raised beds remained in place and weeds were present in the alleys. The most common weed was groundsel; thrips adults had been recorded in groundsel flowers throughout the winter in Staffordshire in earlier monitoring experiments in this project.

Replicate samples of groundsel flower spikes were collected into alcohol on each sampling occasion. These flowers were washed in the laboratory as described in Objective 5, and any arthropods present were recorded and identified. Samples were taken weekly from the beginning of March until thrips larvae were seen. Two dataloggers were placed in the sampled area to record temperature during the recording period; dataloggers were held inside white delta traps for protection.

Development at low temperatures; laboratory experiments

Assumptions made for these experiments:

- Only adult females overwinter;
- Adults do not diapause;
- Adults need pollen before they can oviposit;
- Eggs can survive low temps and develop in stages when the temp increases;
- Females only need a few days acclimation to low temps to exhibit effects.

Two temperature regimes were used for both experiments: constant 10°C and 25°C (as control) all at 8D/16L.

Determine threshold for WFT egg development

Females were taken from culture plants and added to boxes containing green bean pods plus pollen and left for 24 hours at 20°C to oviposit. The bean pods containing eggs were

then transferred into the experimental regimes and the cumulative number of larvae emerging recorded to give an estimate of the effect of temperature on percentage egg hatch.

Determine temperature required for female WFT to oviposit

Females were taken from culture plants and added to boxes containing green bean pods plus pollen as above. After three days acclimatisation of females at 10°C the bean pods were removed and fresh pods and pollen placed in the boxes. The bean pods that were removed from the females on day 3 of acclimatisation were transferred to 25°C to determine if any eggs had been laid in that period. Females were left at the set temperatures to oviposit on the new bean pods. The bean pods from the cold regimes were then removed and placed at 25°C. Cumulative numbers of larvae emerging from eggs were recorded to give an estimate of numbers of eggs laid at the different temperatures.

Results

Early season development of populations

Thrips numbers recorded from the washed flower spikes are shown in Table 2.2.2. The grower applied a herbicide treatment to the groundsel after the sample was taken on 10 April; by 16 April the plants were mostly dead and no sampling was possible. The first thrips larvae were recorded on 28 March. By 10 April numbers of first and second instar larvae were increasing and adult numbers had decreased.

Table 2.2.2. Numbers of WFT adults and larvae recorded on groundsel flowers in a previously WFT infested commercial strawberry planting in 2014

Date	WFT adults	1st instar larvae	2nd instar larvae	Number of flower spikes
4 March	1	0	0	60
13 March	5	0	0	105
21 March	14	0	0	135
28 March	9	1	1	160
10 April	0	18	17	100

Determine threshold for WFT egg development

Results are presented for constant 10°C and 25°C. It is not possible to determine the number of eggs laid by thrips by inspecting the bean pods; the eggs are small and are inserted into the plant tissue, so it is not possible to gain an accurate record of the percentage of eggs developing at the different temperatures. At 25°C a total of 122 eggs

hatched from the bean pods; the first egg hatched after two days but the peak of hatch was on days 5 and 6 when cumulatively 47 and 79 percent of eggs had hatched. The last egg hatched on day 10. At 10°C only one egg hatched and this was on day 10. The beans were inspected until day 16 but no further eggs hatched in that time. In earlier experiments all eggs held at 14/10°C had hatched by day 15 (see annual report for year 4). The bean pods were transferred to 25°C to determine if any eggs had been laid that would develop after a 16 day cold period. Three days after transfer to 25°C, 16 eggs hatched from the bean pods. Since most of the eggs held at 25°C hatched after 5-6 days but the eggs transferred from 10°C to 25°C after 16 days hatched after three days at the higher temperature the results suggest that the eggs were developing, although slowly, at 10°C. Numbers hatching were lower than in the beans held at 25°C so it is possible that at the lower temperatures fewer eggs develop successfully.

Determine temperature required for female WFT to oviposit

Larvae were recorded in the boxes containing the bean pods that had been transferred after three days of acclimatisation of adults, showing that the females did not stop laying eggs immediately in cold conditions; a total of 37 larvae were recorded 11 days after transfer to 25°C. Similarly, eggs hatched from the bean pods that had been exposed to females between four and 15 days at 10°C after they had been transferred to 25°C. A total of 37 eggs hatched with most hatching 3-4 days after transfer to the higher temperature. This result suggests that females in cold conditions continue to oviposit at low rates.

Task 2.3. Field WFT monitoring (EMR)

Methods

Samples of 20 flowers were taken weekly into alcohol for examination in the laboratory during the IPM experiment detailed in Objective 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. Since none of the thrips identified from the cv. Jubilee planting were WFT the data from cv. Camarillo only has been used for model validation. The data are shown in graphical form in Figures 5.2.2 and 5.2.3 and are not repeated here. Temperature recordings from the planting are shown in Figure 5.2.5.

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

Of these sites monitored thrips in early seasons, there were only two sites with reasonable number of thrips caught. One of the two sites was an open-field site full of weeds where WFT problem was severe on strawberry the previous season; WFT were sampled from groundsel. The other site was a tunnel strawberry crop. Temperature data for both sites were available to predict WFT population dynamics.

Fig. 2.4.1 shows the predicted WFT dynamics against the observed WFT adults and larvae. The model prediction on early active adults fits well with the observed (note, as this is only phenology model, the key is to compare the pattern of the dynamics rather than the relative size of the dynamics). However, the predicted emergence of WFT larvae was much later than the observed, about 7-10 days late (Fig. 2.4.1).

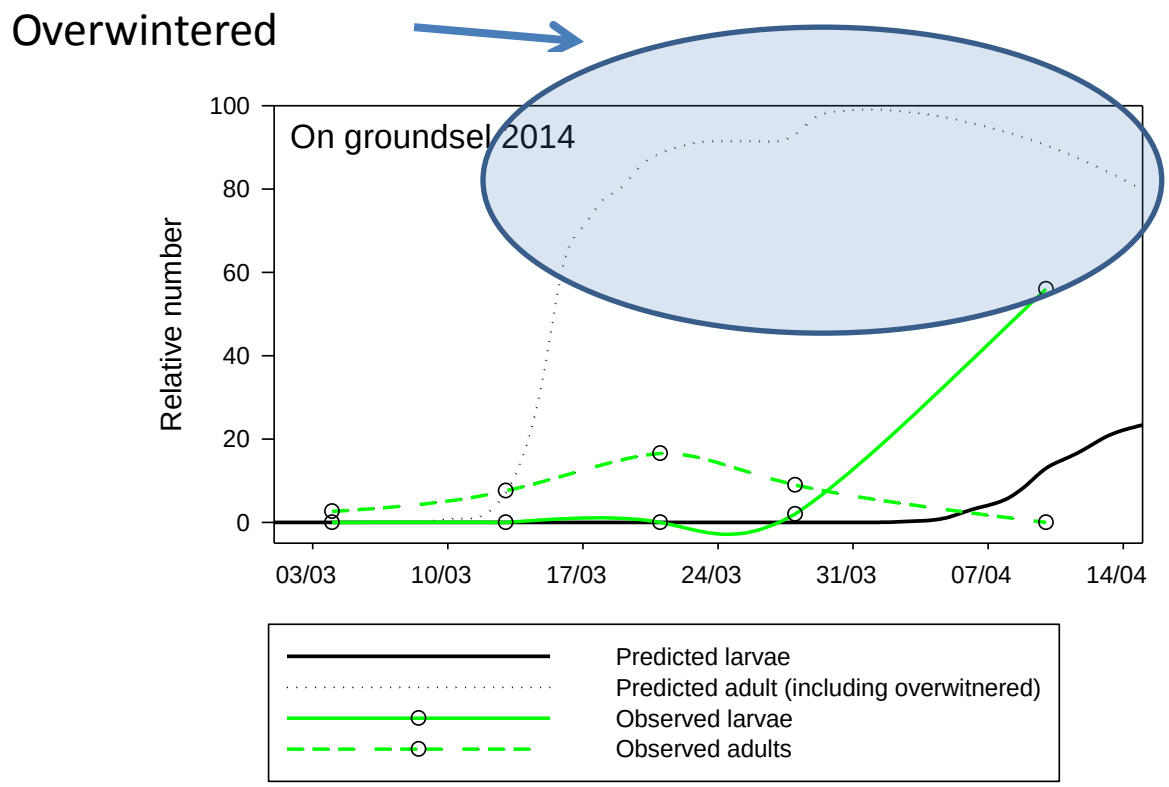

Figure 2.4.1 Predicted and observed dynamics of WFT adults and larvae in the early season 2015 on groundsel in open field at East Malling

For the tunnel strawberry crop, the patterns were rather more difficult to compare. However, if we assume that the larvae caught in the strawberry crop was the second generation (i.e. derived from the eggs [the peak of their larval appearance was predicted to occur around late-April to early May – Fig. 2.4.2] laid by the first generation of adults resulting from the

overwintered adults), then the observed larval peak around late June would be the one predicted by the model to occur in early July (Fig. 2.4.2). Thus, again the model prediction was about 7-14 days late.

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.

Both controlled lab fluctuating experiments and the two field datasets suggested that the model underestimates WFT development in early seasons (i.e. low temperature). The present model was developed from data collected under constant temperatures – from 15°C to 35°C; the developmental rate is zero in the range of 10-13°C depending on the development stages concerned. Thus, it is essential to conduct more studies to obtain WFT developmental rates at low temperatures (8-15°C) to improve the model.

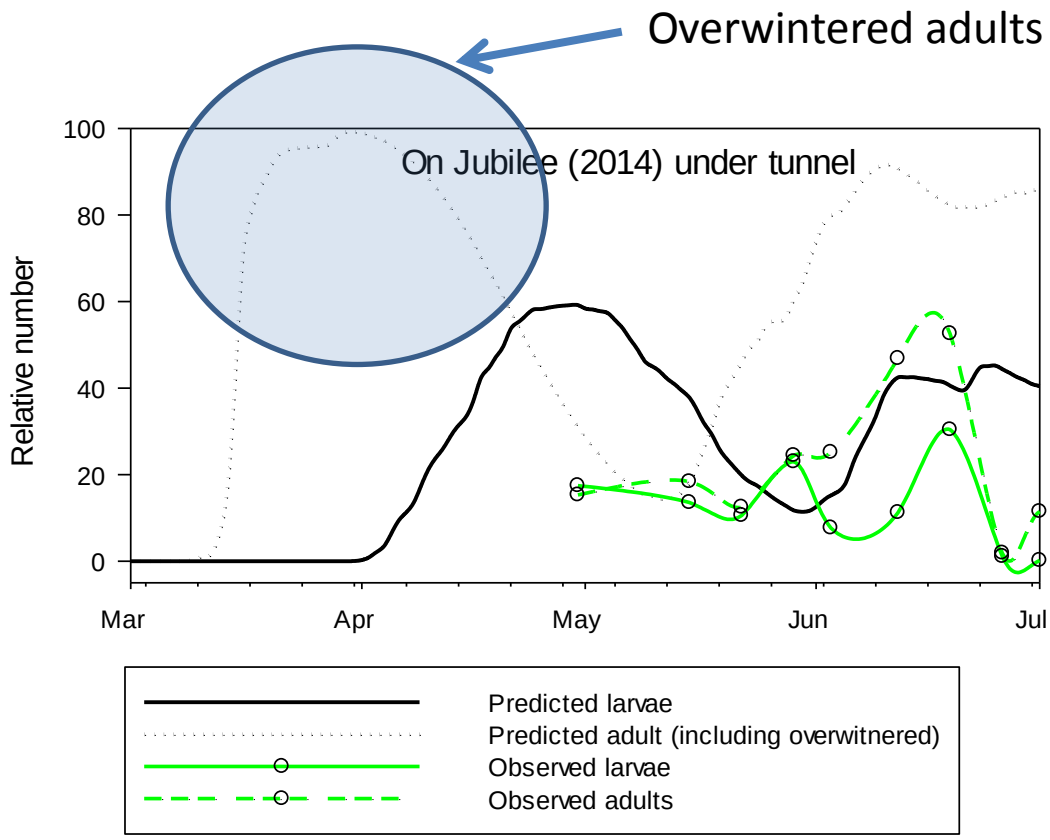

Figure 2.4.2 Predicted and observed dynamics of WFT adults and larvae in the tunnel strawberry cv. Jubilee crop in the early season 2015 near Hadlow, Kent

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 work in this objective was completed in year 4.

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).

Completed in year 3.

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 and again in 2014 in comparison with the standard commercial programme used at the time by the host grower, on three plantings, two in Kent (EMR) and one in Cambridgeshire (ADAS).

Methods - EMR sites

Experimental set-up

Experiments were set up on two plantings by kind permission of Hugh Lowe Farms.

Site 1: Dairy Field; planted with cv. Camarillo in 2013 into blue plastic mulch. Plants covered with polythene 15 April 2014. Experiment set up on 23 April.

Site 2: Paddock Field; planted with potted cv. Jubilee plants in mid-March 2014 under polythene tunnels. Planted into black plastic mulch. Experiment set up on 30 April.

Both plantings had the grower's standard pest and disease control programmes applied over all plots. This included the best predator release strategy determined in years 1-3 of the project (see Table 5.2.1).

Table 5.2.1 Biocontrol applications to Dairy and Paddock fields 2014

Wk No	Product	Rate
14	*Amblyseius* CRSx500	6172/ha
21	*Amblyseius cucumeris* loose	50/m^2
24	*Amblyseius cucumeris* loose	50/m^2
28	*Amblyseius cucumeris* loose	50/m^2
28	*Orius*	3/m^2 (cv. Camarillo only)

Phytoseiulus persimilis were also used for *T. urticae* control

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.

The trapping experiment was set up on each site as a randomised block design with four replicates and with each treatment paired as a block. Each plot consisted of three tunnels 30 m long. Blue roller trap and pheromone lures (Syngenta Bioline) were put out in April. 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). 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. Traps were replaced between 17 and 27 June. Two mini dataloggers were placed in each field to take ½ hourly records of temperature in the crop.

Pest and predator assessments

Assessments were made from first flowering. A major assessment on each planting was done every two weeks; numbers of thrips adults in flowers were recorded in the field prior to counting adults and larvae and predatory mites in the lab. Fruit damage was also assessed. In the weeks between these major assessments numbers of thrips adults and larvae and predatory mites were recorded from flowers assessed in the lab only (see below). Thus for each site, numbers of pests and predators were recorded every week throughout the season until October.

- Major assessment: Every two weeks numbers of adult and larval thrips/flower were recorded in 20 mid-aged flowers (petals open and all present, pollen shed, anthers brown). Flowers were taken from the top (not side) of each bed in each central tunnel. Five flowers were taken from each of four beds in the centre of the plot. Flowers were picked and numbers of adult thrips recorded in the field using a ×10 magnifier. These flowers were then placed in 70% alcohol in sealed containers. Numbers of thrips adults and larvae in the flower samples were counted in the lab by washing them off the picked flowers onto a filter which was then inspected under a stereomicroscope. Numbers of predatory mites were also counted in these samples
- Intermediate assessment: In the weeks between the fortnightly sampling 20 flowers (as described above) were collected from each plot directly into alcohol and numbers of thrips adults, larvae and predators present counted in the lab
- Additionally on each sample date 20 flowers were collected individually into alcohol from each plot to enable the distribution and co-occurrence of thrips and predators within the crop to be determined; these samples were taken from the fifth bed in each plot that was not used for the main assessments
- A subsample of the adult thrips and predatory mites collected from the flower washing were mounted on microscope slides for identification
- Numbers of flowers and fruit of different stages/plant on four plants per plot were

recorded. Only open flowers with at least one petal present were counted (not buds or fully senescent flowers).

Fruit damage assessment

- Numbers of seeds surrounded by bronzing were counted on 20 fully expanded white fruits and 20 fully ripe fruits from the centre of each plot; five plants were assessed in each of the same four beds that the flower samples were taken from.

Sticky trap catches

- Every two weeks, 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.

Analysis

An analysis of numbers of thrips adults, thrips larvae and phytoseiids in flowers was carried out. All analyses were carried out using ANOVA with dates regarded as split-plot treatments within each experimental plot; this is the simplest form of repeated measures analysis.

Results: cv. Camarillo second year crop

Pest and predator assessments

Counts of thrips adults recorded directly in the fields are shown in Figure 5.2.1. Due to the high numbers of thrips in the flowers, which makes accurate counting very difficult, the field assessments were terminated after the 14 July assessment. Counts of thrips adults, larvae and phytoseiid mites from flowers washed in the lab are shown in Figures 5.2.2-5.2.4. In the analysis of the counts there was no evidence of Date $\times$ Treatment interactions for adult, larva or phytoseiid numbers, implying that the ratio of Count (Treated) to Count (Control) did not differ over time. In the analysis of thrips adults (Tables 5.2.2 and 5.2.3), there was evidence of an overall treatment effect ($p=0.015$), so that numbers in the treated plots were on some dates significantly different from those in the control (Table 5.2.2). Numbers also significantly differed over time ($P<0.001$).

There were no significant effects of treatment on thrips larvae (P= 0.118) or phytoseiid numbers (P= 0.725). The Tracer (spinosad) application on 28 June did not reduce thrips numbers (Figures 5.2.2. and 5.2.3) showing that the thrips were resistant to this product. There were no differences in numbers of thrips larvae in the different treatments (Figure 5.2.3). Numbers of thrips declined through August but there were still 5-10 adults per flower in September, highlighting the problem of possible carry-over of thrips from year to year.

A release of Orius had been made at the beginning of July and low numbers of adults and nymphs were recorded in the flower samples so it is possible that this release resulted in the reduction in thrips populations during August. Numbers of phytoseiids appeared to dip after applications of Aphox (pirimicarb) on 24 May and Aphox (pirimicarb) plus Tracer (spinosad) on 28 June (Figure 5.2.4) but were not eliminated. The peaks of phytoseiids in flowers correspond roughly to dates of release of the loose product over the whole planting in the weeks commencing 19 May, 9 June and 7 July.

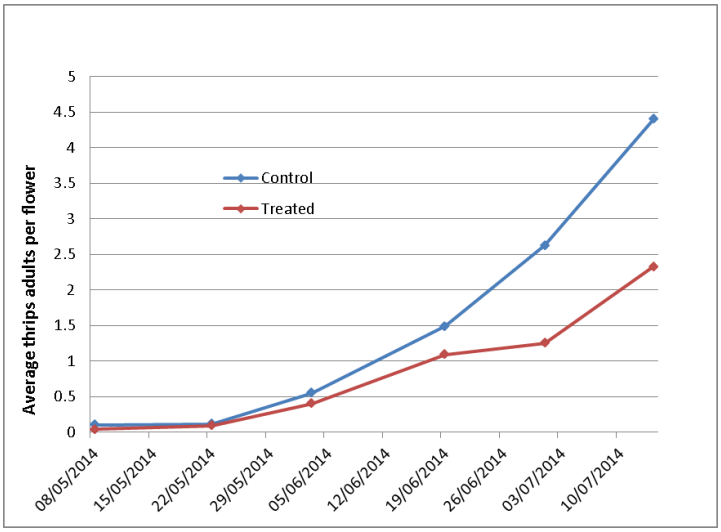

Figure 5.2.1 Mean number of adult thrips per flower in direct field assessments on cv. Camarillo

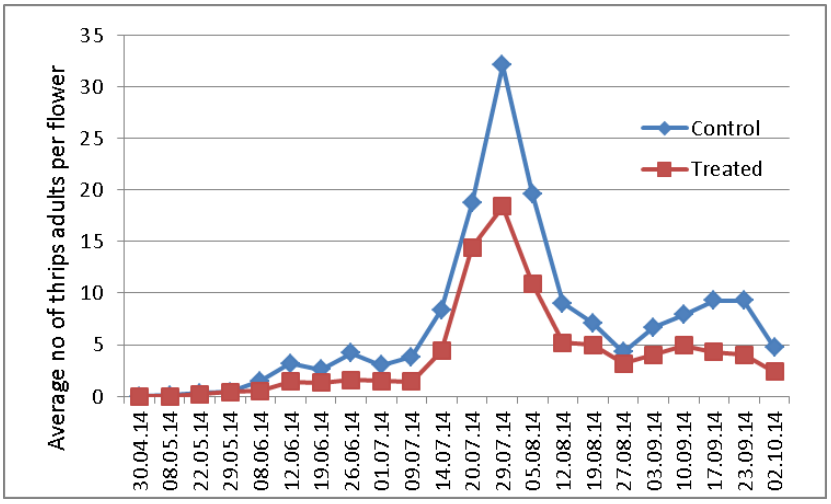

Figure 5.2.2 Mean number of adult thrips per flower from washed flowers of cv. Camarillo

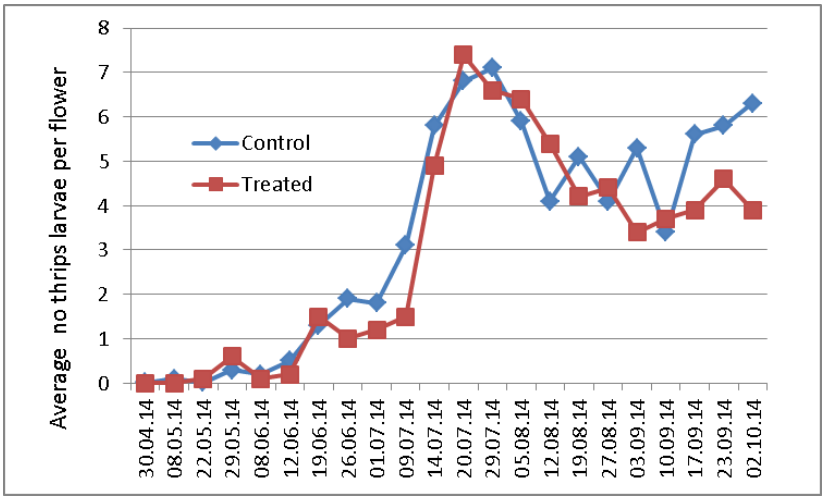

Figure 5.2.3 Mean number of thrips larvae per flower from washed flowers of cv. Camarillo

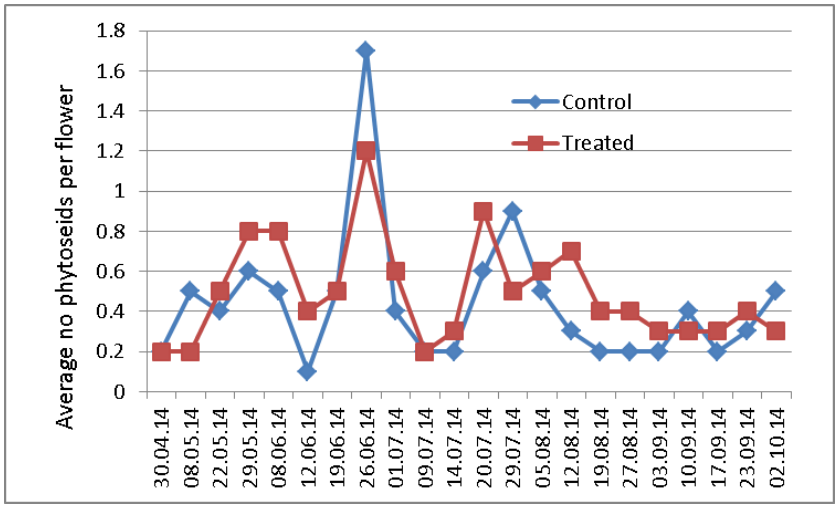

Figure 5.2.4 Mean number of phytoseiid mites per flower from washed flowers of cv. Camarillo

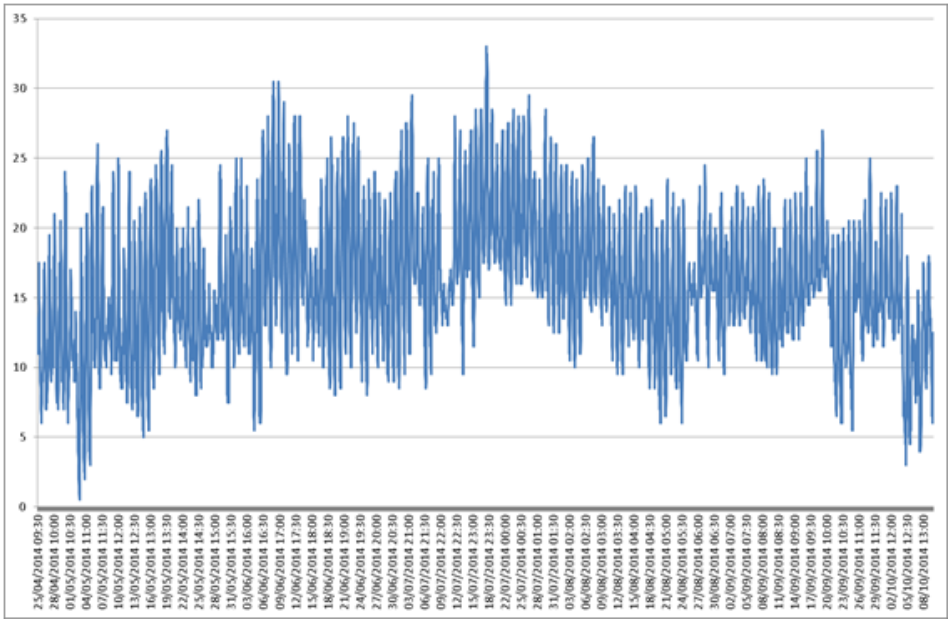

Figure 5.2.5 Temperature data from the cv. Camarillo planting

Table 5.2.2 Square root transformed mean numbers of thrips adults per 20 cv. Camarillo flowers

Date	Control	Treated	Difference (T-C)
30-Apr-14	0.25	0.25	0.00
08-May-14	0.93	0.25	-0.68
22-May-14	2.18	1.72	-0.45
29-May-14	2.73	2.59	-0.14
03-Jun-14	5.39	3.05	-2.34
12-Jun-14	7.87	4.89	-2.98
19-Jun-14	7.09	4.95	-2.14
26-Jun-14	9.01	5.18	-3.83
01-Jul-14	7.67	5.28	-2.39
09-Jul-14	8.69	4.86	-3.83
14-Jul-14	12.82	8.87	-3.95
22-Jul-14	22.46	16.45	-6.00
29-Jul-14	25.16	19.12	-6.04
05-Aug-14	19.57	14.73	-4.84
12-Aug-14	13.26	10.07	-3.19
19-Aug-14	11.41	9.77	-1.64
27-Aug-14	8.95	7.83	-1.12
03-Sep-14	11.47	8.83	-2.63
10-Sep-14	12.42	9.65	-2.76
17-Sep-14	13.52	9.15	-4.37
23-Sep-14	13.61	8.70	-4.91
02-Oct-14	9.63	6.60	-3.03
Treatment Mean	10.28	7.40	

		SED	d.f.
Treatment		0.577	3
Date		0.978	13
Treatment x Date			
	Between Dates	1.469	16
	Between Treatments for a date	1.383	13

Red highlights indicate significant differences between treatments

Table 5.2.3 Backtransformed mean numbers of thrips adults per 20 flowers

Date	Treatment	
	Control	Treated
30-Apr-14	0.06	0.06
08-May-14	0.87	0.06
22-May-14	4.74	2.97
29-May-14	7.44	6.69
03-Jun-14	29.04	9.30
12-Jun-14	**61.97**	**23.96**
19-Jun-14	50.26	24.53
26-Jun-14	81.14	26.82
01-Jul-14	58.81	27.83
09-Jul-14	75.51	23.60
14-Jul-14	164.23	78.61
22-Jul-14	504.25	270.67
29-Jul-14	633.24	365.72
05-Aug-14	382.87	216.86
12-Aug-14	175.73	101.42
19-Aug-14	130.28	95.54
27-Aug-14	80.10	61.33
03-Sep-14	131.51	78.05
10-Sep-14	154.16	93.17
17-Sep-14	182.68	83.69
23-Sep-14	185.17	75.74
02-Oct-14	92.73	43.59
Treatment mean	105.59	54.76

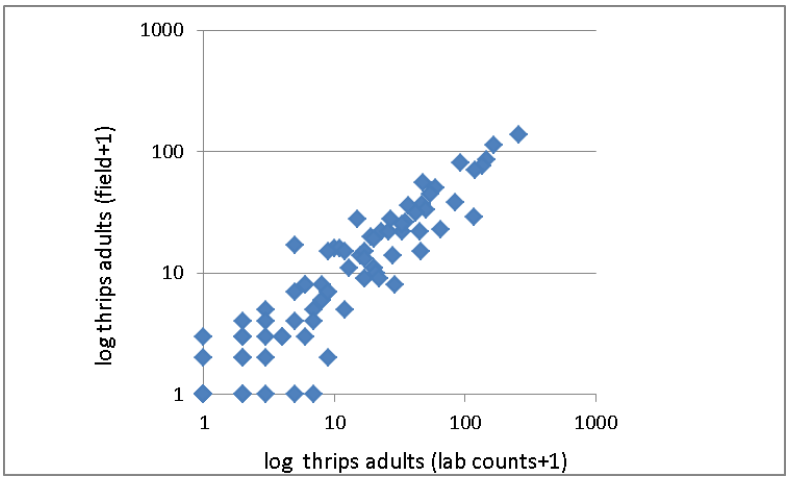

Figure 5.2.6 Relationship between numbers of thrips counted in the field and subsequently washed and recorded in the lab

Numbers of thrips recorded in the lab were always higher than counts from the same flowers assessed directly in the field (Figures 5.2.1 and 5.2.2). However there was a good linear

relationship between numbers recorded in the field and the lab (Figure 5.2.6).

Thrips identification

Several species of thrips are commonly found on strawberry. In earlier EMR experiments the most abundant were WFT, *Thrips major* and *Thrips tabaci*. The species of thrips cannot be identified without clearing individuals and then inspecting them under a high power microscope. There are several distinguishing characteristics that make it relatively easy to identify WFT under the microscope. Since WFT are currently the only species that cannot be controlled with insecticides, for the purposes of managing thrips in these plots it was agreed, in discussion with the trials manager at HLF, that the samples would be sorted into WFT and 'others'. The percentage of WFT in samples from different collection dates (between 24 April and 5 August) totalled for the season in cv. Camarillo is shown in Table 5.2.4. The proportion of WFT in the samples increased over the season as other species were affected by the Tracer (spinosad) application on 28 June. Other species present included *T. major* and *T. tabaci*.

Table 5.2.4. Thrips and phytoseiid species present in flower in the cv. Camarillo planting

	Total thrips assessed	**% WFT**	**% other spp**	**Total phytoseiids identified**	**% *N. cucumeris***	**% *N. californicus***
Camarillo	131 (11)	87	17	50	34	66

The figure in parentheses is number of individual dates used to produce the total assessed

Predator identification

Phytoseiid mites can only be identified to species under a high power microscope. Although only *N. cucumeris* was released in the plantings, *N. californicus* was also found in the flowers in the cv. Camarillo planting (Table 5.2.4) and later in the season very few *N. cucumeris* were present. Predatory mites were also found in a small sample of fruit collected from the cv. Camarillo. Predators were recorded in nine out of 12 small green fruit, six out of 13 white fruit and one out of seven ripe fruit; these mites were not identified to species.

Sticky trap catches

Numbers of thrips caught on the traps was initially very low. By the end of July numbers were increasing (Table 5.2.5). The final count was made on cut sections of the trap in the lab.

Table 5.2.5. Cumulative numbers of adult thrips counted on sixteen 10 x 30 cm portions of sticky trap in the cv. Camarillo planting

Date	Number caught
8 May	0
22 May	0
3 June	9
19 June	26
1 July	40
14 July	41
29 July	448
27 August	582
2 October	4,306

Fruit damage assessment

Damage through the season was much lower than that seen in the experiments in 2013. Damage, both in terms of total fruits with bronzing and the severity of bronzing, peaked on the assessment on 29 July (Table 5.2.6). This corresponded to the peak in thrips adult and larval numbers in the crop (Figures 5.2.2-5.2.4). There was no difference in damage seen in the treated and control plots. Much less damage was seen on ripe fruit than white fruit.

Table 5.2.6. Cv. Camarillo: Total number of fruit showing bronzing out of 80 fruit assessed and numbers of fruit on each date showing 25% or more surface bronzing

	White fruit				Red fruit			
	Treated		Control		Treated		Control	
	total	>25%	total	>25%	total	>25%	total	>25%
22 May	1	0	2	0	0	0	0	0
3 June	4	0	2	0	0	0	0	0
19 June	18	2	30	14	2	0	4	0
1 July	21	11	30	15	4	2	9	3
14 July	21	1	21	13	1	1	1	2
29 July	43	21	49	21	27	11	29	18
12 August	39	19	37	15	3	1	1	0
27 August	35	4	36	7	23	4	17	3

Plant architecture

The mean numbers of open flowers, green, white and ripe fruit are shown in Figure 5.2.7.

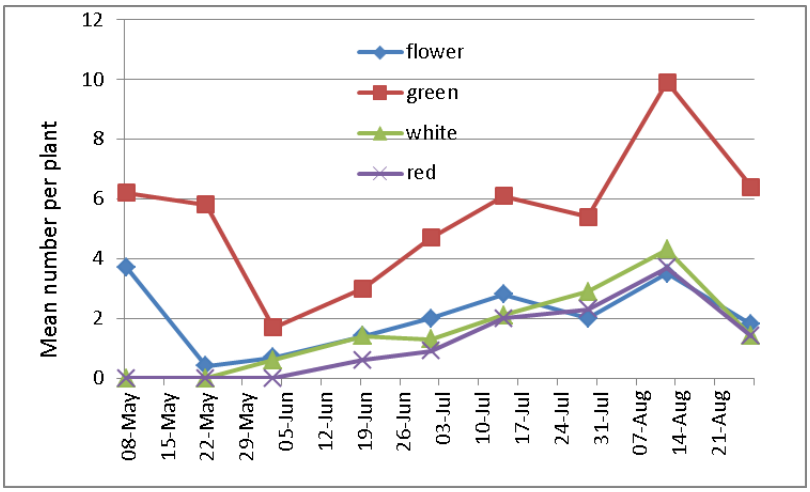

Figure 5.2.7 Mean number of open flowers and fruit stages per plant

Husbandry

Pesticide applications made to the entire experimental area are shown in Table 5.2.7.

Table 5.2.7 Dairy Field - cv. Camarillo pesticide applications 2014

21 March	Fortress
	Rovral
	Thianosan
03 April	Apollo
	Masai
29 April	Signum
06 May	Stroby
	Systhane
13 May	Topaz
20 May	Plenum
	Signum
	Systhane
24 May	Amistar
	Aphox
06 June	Sulphur
18 June	Serenade
28 June	Aphox
	Tracer
	Systhane
08 July	Nimrod
16 July	Sulphur
	Serenade
18 August	Sulphur
	Pot Bicarb
19 August	Sulphur
	Serenade

Conclusions

- Numbers of thrips were high in this second year crop; low numbers of adults and larvae were recorded in the first sample taken on 30 April, and numbers increased to a mean of over 30 adults per flower in the control plots in July. Numbers of thrips larvae also peaked in July with a mean of seven per flower.
- Over the season 87% of adult thrips identified were WFT; the proportion of WFT increased to nearly 100% after the Tracer (spinosad) application.
- A Tracer (spinosad) application in June did not reduce thrips populations indicating that they were resistant to this pesticide.

- Phytoseiid mite numbers were reduced by the Tracer (spinosad) application but not eliminated; over the season 34% of those identified were *N. cucumeris* - the species that had been released. The remaining 66% were *N. californicus*. By the end of the season very few *N. cucumeris* were recorded in the planting.
- Low numbers of thrips adults were recorded on the blue sticky traps in the field until July; there was no effect on numbers of thrips caught close to and far from the pheromone lure. Numbers of adults caught increased in late July and continued to increase until the end of the experiment on 2 October.
- There was a significant effect of treatment on thrips numbers in flowers but this effect was not seen until late June, with the greatest effect recorded in late July. This may relate to the increase in numbers of adults caught on the sticky traps.
- Despite the very high numbers of thrips adults and larvae recorded in the flowers there were low levels of fruit bronzing; highest damage was recorded in late July when thrips numbers were at their peak.

Results: cv. Jubilee first year crop

Pest and predator assessments

Numbers of thrips were much lower in the first year Jubilee planting than in the second year cv. Camarillo. Adult numbers per flower from the direct field counts are shown in Figure 5.2.8 and from washed flowers in Figure 5.2.9. Peak numbers of adults were around one per flower compared with around 30 recorded in the cv. Camarillo washed flowers (Figures 5.2.2 and 5.2.9).

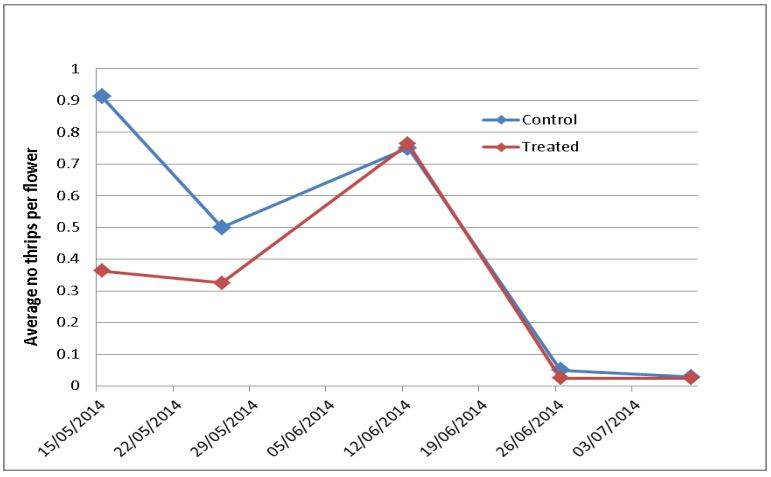

Figure 5.2.8 Numbers of adult thrips recorded directly from cv. Jubilee flowers in the field

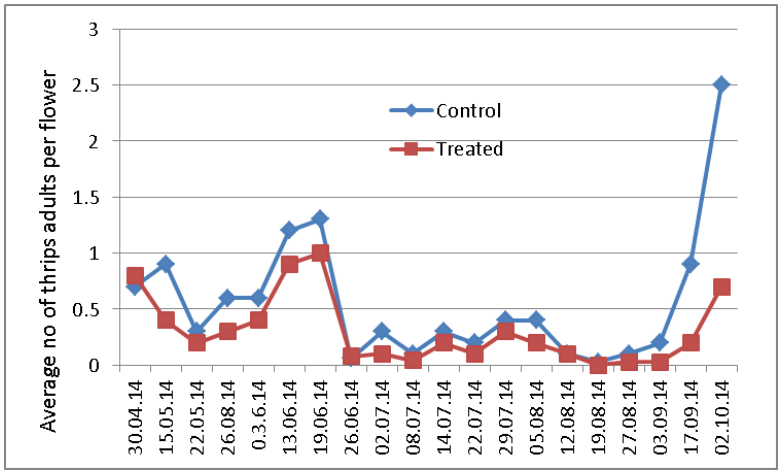

Figure 5.2.9 Mean numbers of adult thrips recorded from washed flowers of cv. Jubilee

Thrips larvae were also lower in the cv. Jubilee with less than one larva per flower throughout the main picking season (Figure 5.2.10). There was an increase of both adults and larvae in the samples taken in September and October. This is likely due to the low numbers of flowers present in the planting at the time.

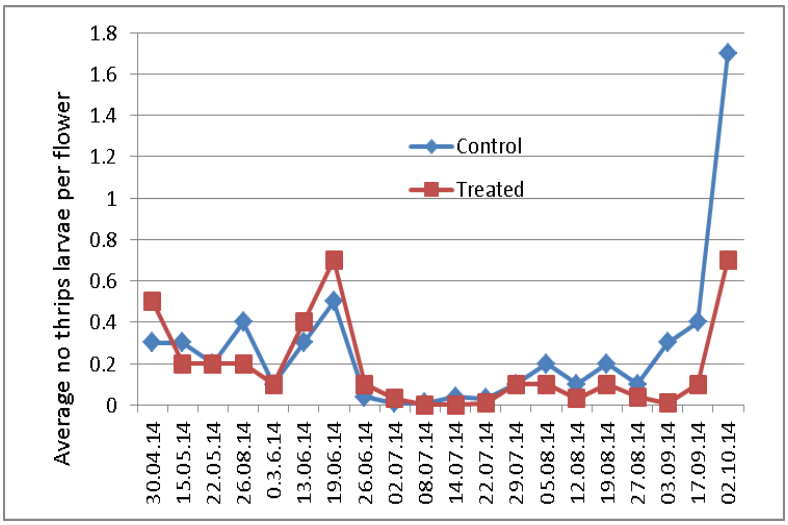

Figure 5.2.10 Mean number of thrips larvae per flower from washed flowers of cv. Jubilee

Phytoseiid numbers were initially high at around one per flower but numbers declined over the season (Figure 5.2.11). The two peaks are likely the result of the loose *N. cucumeris* releases made in weeks commencing 19 May and 7 July. The Tracer (spinosad) application on 28 June reduced numbers to close to zero.

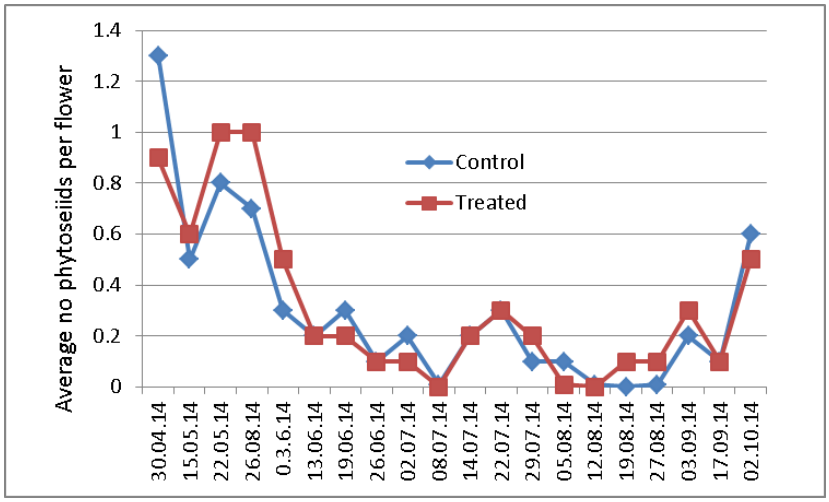

Figure 5.2.11 Mean number of phytoseiid mites per flower from washed flowers of cv. Jubilee

In the analysis of counts from washed flowers, as in the cv. Camarillo, there was no treatment by date interaction. For adult thrips there was a significant effect (P= 0.001) of treatment only in September (Table 5.2.8). Backtransformed numbers of adults are shown in Table 5.2.9.

Table 5.2.8. Square root transformed means of thrips adults in 20 cv. Jubilee flowers

Date	Treatment		Difference
	C	T	(T-C)
30 April	2.72	2.44	-0.28
15 May	2.98	2.24	-0.73
22 May	2.45	1.97	-0.48
29 May	3.43	2.33	-1.09
03 June	3.48	2.79	-0.69
12 June	4.75	4.19	-0.55
19 June	5.03	4.46	-0.57
26 June	0.96	1.00	0.04
01 July	2.35	1.62	-0.73
09 July	0.68	0.60	-0.08
14 July	2.27	2.06	-0.21
22 July	1.42	1.43	0.01
29 July	2.83	2.50	-0.33
05 August	2.86	1.95	-0.91
12 August	1.22	0.85	-0.37
19 August	0.35	0.00	-0.35
27 August	1.14	0.35	-0.79
03 September	2.05	0.50	-1.55
17 September	3.91	1.47	-2.44
02 October	6.93	3.54	-3.39
Treatment Mean	2.69	1.92	

		SED	d.f.
Treatment		0.061	3
Date		0.418	17
Treatment x Date			
	Between dates	0.579	17
	Between treatments for a date	0.691	

Red highlights show significant differences between treatments

Table 5.2.9 Backtransformed mean number of thrips adults per 20 cv. Jubilee flowers

Date	Treatment	
	C	T
30 April	7.38	5.94
15 May	8.86	5.03
22 May	6.00	3.90
29 May	11.76	5.45
03 June	12.09	7.77
12 June	22.53	17.59
19 June	25.28	19.87
26 June	0.92	1.00
01 July	5.54	2.62
09 July	0.47	0.36
14 July	5.14	4.24
22 July	2.02	2.05
29 July	8.02	6.26
05 August	8.20	3.80
12 August	1.49	0.73
19 August	0.13	0.00
27 August	1.30	0.13
03 September	4.18	0.25
17 September	15.29	2.16
02 October	48.07	12.56
Treatment Mean	7.24	3.67

In cv. Jubilee there was also a significant effect (P= 0.019) of treatment on thrips larvae in September (Table 5.2.10). Backtransformed numbers are shown in Table 5.2.11.

Table 5.2.10 Square root transformed mean numbers of thrips larvae per 20 cv. Jubilee flowers

Date	Control	Treated	Difference (T-C)
30 April	2.40	3.09	0.69
15 May	2.12	2.07	-0.04
22 May	1.87	1.82	-0.05
29 May	2.76	1.77	-0.98
03 June	1.60	1.41	-0.18
12 June	1.93	2.56	0.64
19 June	3.17	3.65	0.48
26 June	0.60	0.66	0.06
01 July	0.25	0.35	0.10
09 July	0.25	0.00	-0.25
14 July	0.60	0.00	-0.60
22 July	0.35	0.25	-0.10
29 July	1.25	0.87	-0.38
05 August	1.62	1.21	-0.41
12 August	0.71	0.50	-0.21
19 August	1.22	0.50	-0.72
27 August	1.12	0.43	-0.68
03 September	1.79	0.25	-1.54
17 September	2.75	1.00	-1.75
02 October	5.75	3.36	-2.38
Treatment Mean	1.70	1.29	

		SED	d.f.
Treatment		0.0893	3
Date		0.4684	16
Treatment x Date			
	Between Dates	0.6518	16
	Between Treatments for a date	0.6625	16

Red highlights show significant differences between treatments

Table 5.2.11 Backtransformed mean number of thrips larvae in 20 cv. Jubilee flowers

Date	Control	Treated
30 April	5.77	9.58
15 May	4.48	4.30
22 May	3.49	3.31
29 May	7.60	3.15
03 June	2.55	2.00
12 June	3.72	6.57
19 June	10.04	13.33
26 June	0.36	0.44
01 July	0.06	0.13
09 July	0.06	0.00
14 July	0.36	0.00
22 July	0.13	0.06
29 July	1.56	0.75
05 August	2.61	1.46
12 August	0.50	0.25
19 August	1.50	0.25
27 August	1.25	0.19
03 September	3.19	0.06
17 September	7.56	1.00
02 October	33.02	11.31
Treatment Mean	2.91	1.66

There was no effect of treatment on phytoseiid mite numbers (P= 0.738).

Thrips and phytoseiid identification

Table 5.2.12 shows the phytoseiid species identified in the cv. Jubilee plot. In contrast to the cv. Camarillo planting, no WFT were identified in this planting and only *N. cucumeris* were recorded throughout the season. Species identified in this crop included *T. major* and *T. tabaci*.

Table 5.2.12 Thrips and phytoseiid identification in the cv. Jubilee planting

	Total thrips assessed	% WFT	% other spp.	Total phytoseiids identified	% *N. cucumeris*	% *N. californicus*
Jubilee	121 (9)	0	100	53	100	0

Sticky trap catches

As in the cv. Camarillo only low numbers of thrips adults were recorded on the sticky traps (Table 5.2.13) but with numbers increasing after July. The final count was made in the laboratory on cut sections of trap.

Table 5.2.13. Cumulative numbers of adult thrips counted on sixteen 10x30 cm portions of sticky trap in the cv. Jubilee planting

Date	Number caught
15 May	2
26 May	1
13 June	6
26 June	5
8 July	32
3 September	100
2 October	529

Fruit damage assessment

In the cv. Jubilee planting damage was very slight (Table 5.2.14); the highest number of seeds surrounded by bronzing was 25 on white fruit on 26 May, but in general the damage ranged from 1-10 seeds. In the ripe fruit damage was generally only around 1-5 seeds.

Table 5.2.14. Cv. Jubilee: Number of fruit showing bronzing out of 80 fruit assessed

	White fruit		Red fruit	
	Treated	Control	Treated	Control
15 May	9	7	7	5
26 May	13	9	2	5
12 June	6	7	6	0
26 June	48	30	8	12
8 July	19	19	1	1

After 28 June numbers of thrips in flowers in the Jubilee decreased to less than 0.5 per flower after a Tracer (spinosad) application and identification of samples showed these were not WFT. After discussion at EMR it was decided to terminate the fruit damage assessments on this site after 8 July.

Plant architecture

The mean numbers of open flowers, green, white and ripe fruit are shown in Figure 5.2.12.

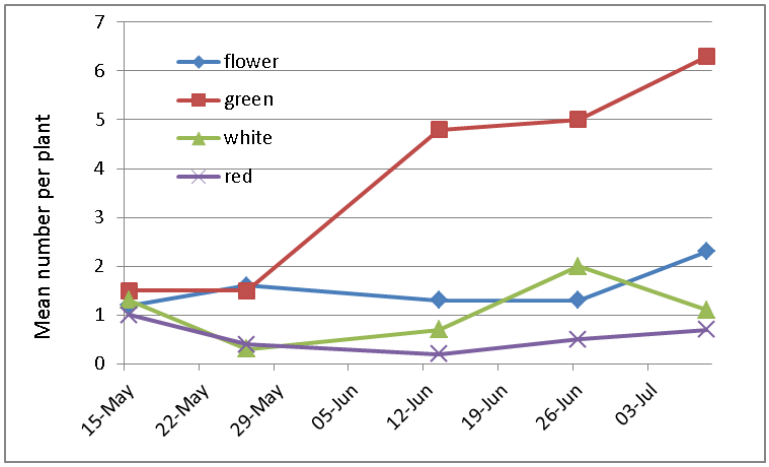

Fig. 5.2.12 Mean number of open flowers and fruit stages per plant

Husbandry

Pesticide applications made to the entire experimental area are shown in Table 5.2.15.

Table 5.2.15 Paddock Field – cv. Jubilee pesticide applications 2014

17 April	Fortress
28 April	Signum
01 May	Systhane
	Stroby
09 May	Amistar
20 May	Topaz
	Teldor
04 June	Nimrod
	Teldor
14 June	Amistar
28 June	Systhane
	Tracer
09 July	Nimrod
16 July	Sulphur
	Serenade
18 August	Sulphur
	Pot Bicarb
19 August	Sulphur
	Serenade

Conclusions

- Numbers of thrips were low in this first year crop; the highest numbers of adults were recorded in June but the peak was around one adult per flower.
- Over the season no WFT were identified from this planting.
- A Tracer (spinosad) application in June reduced thrips populations, indicating that the species present was susceptible to this pesticide.
- Phytoseiid mite numbers were reduced by the Tracer (spinosad) application and were present at very low numbers for the remainder of the season, despite the release in July; over the season all of those identified were *N. cucumeris* - the species that had been released.
- Low numbers of thrips adults were recorded on the blue sticky traps in the field; there was no difference in numbers of thrips caught close to and far from the pheromone lure
- There was a significant effect of treatment on thrips numbers in flowers but this effect was not seen until September.
- There was very little fruit bronzing at this site.

Materials and Methods ADAS experiment 2014

Site

To select a suitable site to set up the trial, two separate sites were monitored for WFT activity. Site 1 was in Nottinghamshire where an everbearer crop had been heavily infested with WFT during the previous season, which resulted in the crop being replaced by a 60 day cv. Sonata crop. In addition to the Sonata crop, table-top crops (cvs. Sweet Eve, Eves Delight and a coded cultivar surrounding this area were monitored for thrips species on four dates during June. Thrips samples were collected and identified.

Table 5.2.16 Thrips species identified at site in Nottinghamshire

Date	cv. Sonata	cv. Sweet Eve 2013	Coded cultivar 2014	cv. Eves Delight, Park
5 June	1 WFT	*Thrips* spp.		
12 June		*T. fuscipennis and T. major*	*Thrips* spp. including *T. major*	
27 June		*Thrips spp.*		
28 June			*Thrips* spp.	*Thrips spp.*

Site 2 was in Staffordshire and had a history of WFT infestations. Two soil-grown crops, cv. Amesti (second year grow bags and plants) and cv. Scarlet (second year grow bags, new plants) were monitored for WFT activity. Thrips samples were collected and identified on three dates in June.

Table 5.2.17 Thrips species identified at site in Staffordshire

Date	cv. Amesti soil crop	cv. Scarlet crop
4 June	1 WFT, *Thrips major and Thrips fuscipennis*	1 WFT
12 June	*Thrips major*	1 WFT and possibly one *Frankliniella intonsa*
26 June	1 WFT, 14 *Thrips* spp	1 WFT / *Frankliniella intonsa* male, 32 *Thrips* spp

Thrips species were more prevalent than WFT on all the crops, despite the history of WFT the previous year. The cv. Amesti crop in Staffordshire had the most WFT activity and this site was selected for the trial.

Host grower: Stephen McGuffie, New Farm Produce, Staffordshire

Everbearer cultivar: Amesti (Had WFT in 2013, 2nd year crop and bags), Field: Baskerville 2.
Growing system: Bags of substrate on raised beds covered with woven ground-cover matting.

Treatments

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 onto the grower's own pest and disease management programme.

Experiment layout

The trial was set up on 2 July 2014. Each plot was three tunnels wide and 30m long. The site used was divided by a road so that four plots were on either side (Figure 5.2.13). The plots were separated widthways by four tunnels and lengthways by 20m (except where the road separated the tunnels). In each plot with roller traps, a 30m length of 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.

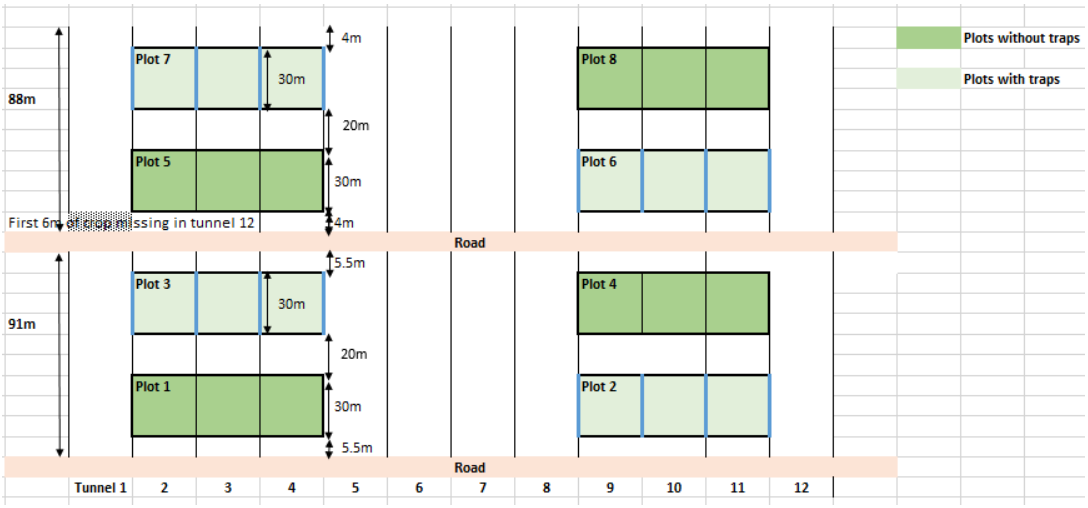

Figure 5.2.13 Trial layout

Figure 5.2.14 Trial just after set-up

Crop canopy temperatures

At each site crop canopy temperatures were recorded every 30 minutes in plots 1 and 8 using USB dataloggers (the logger in plot 8 was later moved to plot 2 by the grower). 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 grower's IPM programme recommended by the grower's consultants.

Assessments

Assessments were carried out on the day of set up and approximately every two weeks thereafter. Assessments took place on 2, 16 and 30 July, 13 and 27 August, 10 and 24 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;
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, green fruit and ripe fruit. Four adjacent /neighbouring plants were then selected for further assessment. Five plants were sampled in each sampling area (20 plants per plot). Samples were made outside of the middle 3m section of each bed if necessary until 20 flowers and green fruit had been assessed.

The following assessments were carried out:

Thrips and predators in flowers

On each of the twenty plants sampled in each sampling area, one medium-aged flower sticking up from the top of the plant was selected. In-field counts of the numbers of thrips adults and predators (*Orius* and anthocorids) were made by carefully pulling down the petals on each side of the flower. Five were assessed in each of the four sampling areas, 20 flowers in total). Six of the 20 flowers sampled were placed individually into 70% alcohol and the remaining 14 flowers were bulked together in 70% alcohol and returned to ADAS Boxworth for species confirmation.

In the laboratory the flowers were washed in alcohol and the numbers of thrips adults and larvae, and the number of predatory mites, *Orius* and Anthocorid adults and nymphs per flower on individual and bulked flowers were recorded.

From the individual flowers sampled into alcohol, a sample of up to 20 thrips adults were mounted onto glass slides in Heinz medium for species identification (thrips from the bulked flowers were used if not enough thrips were available in the individual flowers).

Mites in flowers and green fruit

On each of the 20 sampling plants the number of predatory mites on one green fruit (20 fruit per plot) was recorded. Any fruit assessed in the field and found to have mites on the surface of the fruit or behind the calyx were removed and sealed in a polythene bag containing dry tissue (one bag per plot) in order to take them to the laboratory where they were washed in alcohol and any predatory mites were counted and identified.

From the individual flowers sampled into alcohol, a sample of up to 20 large predatory mites were also mounted onto glass slides in Heinz medium for species identification (mites from the bulked flowers were used if not enough mites were available in the individual flowers).

Fruit damage

On each of the 20 sampling plants in each sampling area, the number of seeds surrounded by bronzing on one fully ripe fruit per plant (depending on availability) was recorded.

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. On waste fruit the presence of any other type of damage which could lead to downgraded fruit was also recorded e.g. capsid/mis-shaping, botrytis, mildew, unsuitable size, over-ripe etc. The number of total seeds on five Class 1 fruits were also recorded to allow percentage fruit damage to be estimated.

Numbers of flowers, white and ripe fruit per plant

In sampling area i) only, the numbers of flowers (open flowers with a least one petal present), green fruit and ripe fruit per plant were recorded on the five plants that were assessed for thrips.

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 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 10 m section of the 30m-long trap were selected on each side (Figure 5.2.15). The numbers of thrips adults, *Orius*, *Anthocoris* spp. adults, predatory thrips adults and aphid parasitoids were recorded on each section. Thrips species were not identified from the traps.

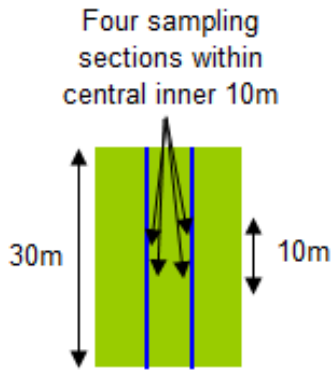

Figure 5.2.15 Two random sections on the inner sides of the traps in the central 10m section of the 30m-long trap were assessed for the numbers of thrips adults

Statistical analysis

An analysis of variance (ANOVA) was carried out on the number of thrips adults, thrips larvae and predatory mites recorded in the field (in-field visual counts) and in the laboratory (based on six flowers per plot) at each sampling date.

Results and Discussion

Mean number of thrips adults per flower

Visual counts of thrips adults in the field peaked on 30 July, with mean numbers of 7.1 and 8.4 per flower in plots with and without roller traps respectively, which were not significantly different, *P*=0.19 (Figure 5.2.16). Mean thrips adult numbers had dropped to below one per flower by the next sampling date on 13 August and on the following assessment dates in plots with and without traps and there were no significant differences between numbers in plots with or without roller traps on any date. The grower applied spinosad (Tracer) for control of thrips on 16 August (Table 5.2.16), after mean numbers of thrips per flower had dropped to below one per flower. Therefore the use of spinosad was not responsible for the drop in thrips numbers before 16 August. Although the grower had experienced WFT resistance to spinosad in previous years, it was applied during this trial as the grower was concerned about the numbers of *Thrips major* and *Thrips fuscipennis* (Table 5.2.18) and their potential for fruit damage.

Higher numbers of thrips were recorded in the laboratory counts made on the six individual flowers per plot collected into alcohol on 30 July than the counts made by eye in the field, with means of 14.9 and 23.1 adults per flower in plots with and without roller traps respectively (Figure 5.2.17). However, these differences between plots with and without traps on 30 July were not significant. As with the visual counts made in the field, mean thrips adult numbers per flower had dropped by 13 August (7.17 without traps, 6.71 with traps, not significantly different) and as on 30 July, laboratory counts were higher than the in-field counts. After 13 August, mean thrips adult counts made in the laboratory were below one per flower in plots both with and without roller traps. A significant difference was recorded in the laboratory counts of thrips adults in flowers collected on 10 September (*P*=0.01), with mean numbers significantly lower in plots with traps (0.04) than in plots without traps (0.38), although the numbers were small.

Mean number of thrips larvae per flower

Counts of thrips larvae in the laboratory (based on the six individual flowers per plot) also peaked on 30 July with mean numbers of 6.7 and 13.4 larvae per flower in plots with and without roller traps respectively (Figure 5.2.18). On this date, numbers of larvae were significantly lower in plots with traps than without (*P*= 0.031). As with numbers of thrips adults, mean numbers of larvae per flower were lower on the next assessment date on 13 August (4.58 without traps and 2.75 with traps, not significantly different) and then dropped to below one per flower on the remaining assessment dates. After 30 July there were no significant differences between numbers of larvae per flower in plots with or without traps.

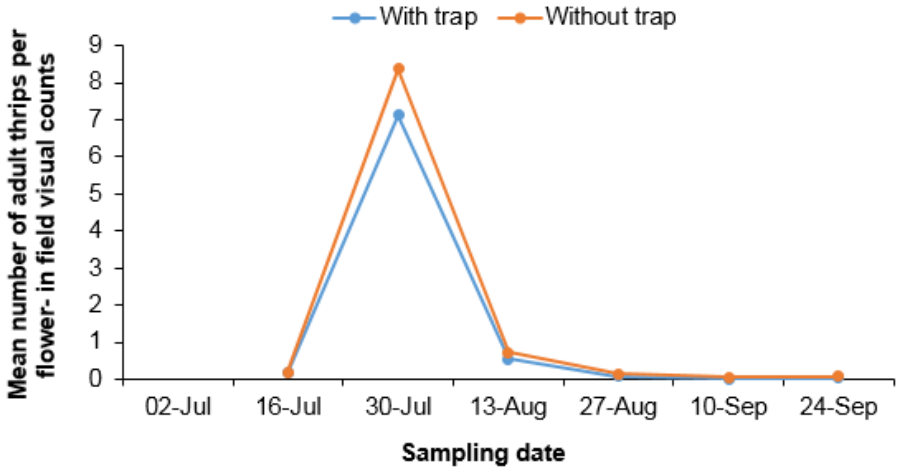

Figure 5.2.16 Mean number of adult thrips per flower recorded with in-field visual counts

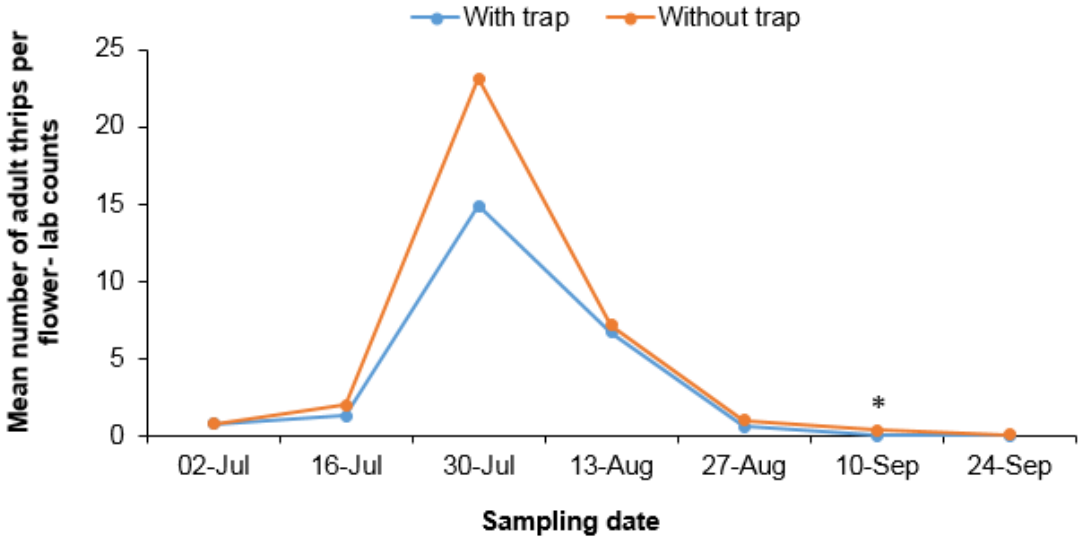

Figure 5.2.17 Mean number of adult thrips per flower recorded using counts in the laboratory. * indicates a significant difference between numbers in plots with or without roller traps (*P*<0.05).

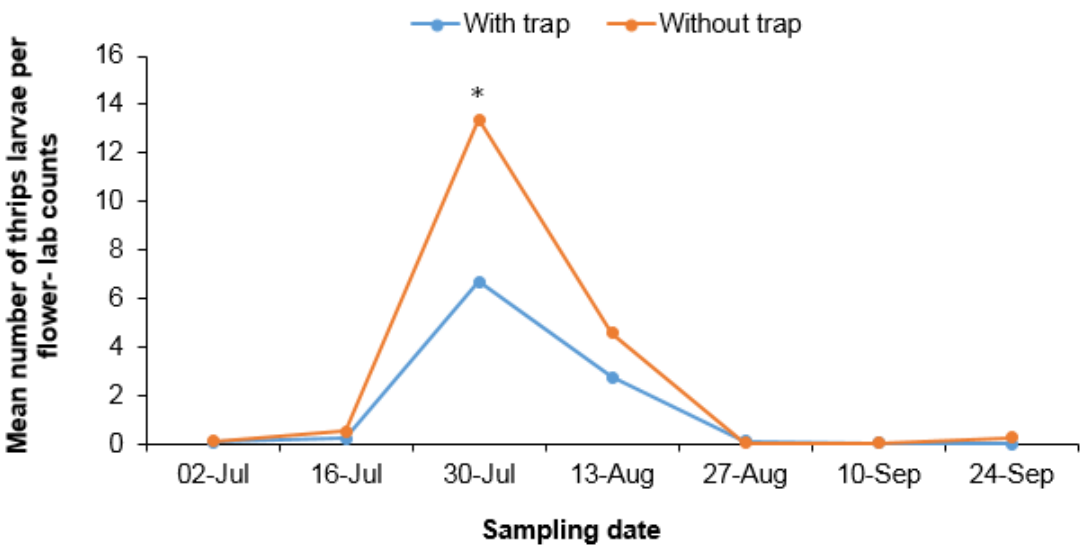

Figure 5.2.18 Mean number of thrips larvae per flower recorded using counts in the laboratory. * indicates a significant difference on that sampling date between numbers in plots with or without roller traps (P<0.05)

Thrips species

WFT was present on the date the trial was set up on 2 July but *Thrips major* was the most prevalent species during most of the trial period (Table 5.2.18) and was the only species recorded on 30 July when peak numbers of thrips adults and larvae per flower were recorded. Other thrips species recorded were *Thrips fuscipennis*, *Thrips tabaci*, WFT and *Frankliniella* sp. (not possible to distinguish between *F. occidentalis* (WFT) or *F. intonsa* on these particular specimens). WFT was not recorded on 30 July and 13 August but was recorded on 10 September (7.1%) and on the last assessment date on 24 September, when it was the predominant species (57%). The increase in the proportion of WFT on and after 27 August is likely to be due to the use of spinosad (Tracer) on 16 August which will have reduced numbers of other species in the thrips population but allowed WFT to survive due to spinosad resistance.

Table 5.2.18 Thrips species confirmed

Date	Percentage *WFT*	Percentage *T. major*	Percentage *T. fuscipennis*	Percentage *T. tabaci*	Percentage *Frankliniella spp*
2 July	11	53	31	5	0
16 July	7	73	20	0	0
30 July	0	100	0	0	0
13 August	0	96	4	0	0
27 August	11	56	22	0	11
10 September	7.1	57.1	14.3	21.4	0
24 September	57	14	0	29	0

Mean number of flowers, ripe fruit and green fruit per plant

At the start of the trial on 2 July, mean numbers of flowers per plant were 3.7 and 4.9 respectively in plots with and without traps (Figure 5.2.19). On 30 July, mean numbers of flowers per plant had dropped to 2.4 and 1.25 per plant in plots with and without traps respectively. The drop in flower numbers on 30 July is likely to have contributed to the peak numbers of thrips per flower on that date, as the thrips adults will have become concentrated in the few remaining flowers. Similarly, mean numbers of ripe fruit per plant peaked on 30 July, with 1.9 per plant in plots both with and without traps (Figure 5.2.21). Numbers of flowers per plant tend to decrease when numbers of ripe fruit per plant increase.

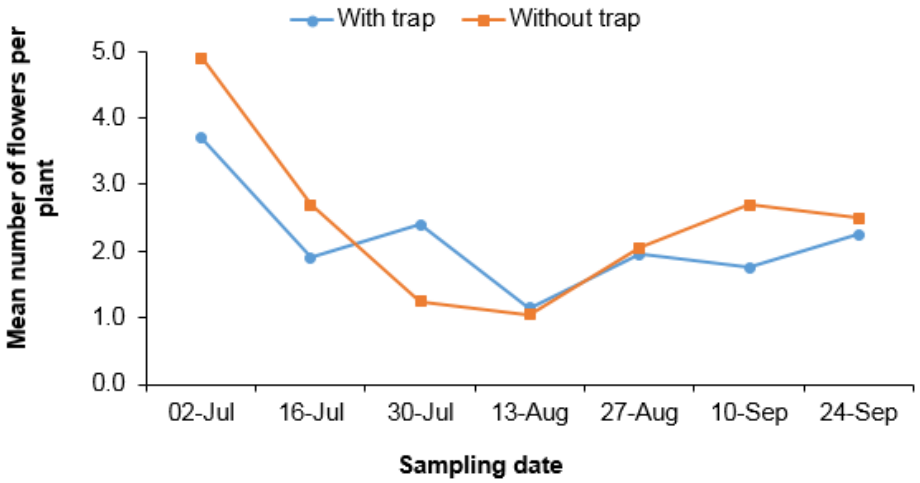

Figure 5.2.19 Mean number of flowers per plant

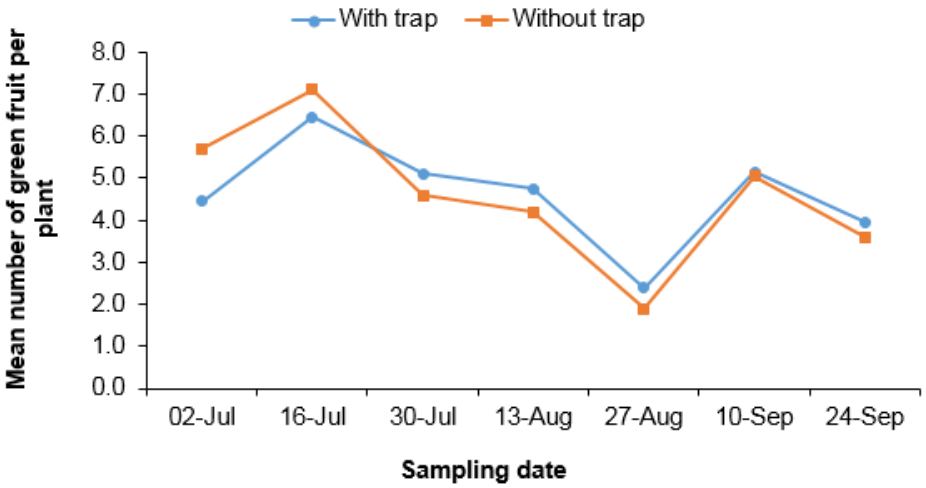

Figure 5.2.20 Mean number of green fruit per plant

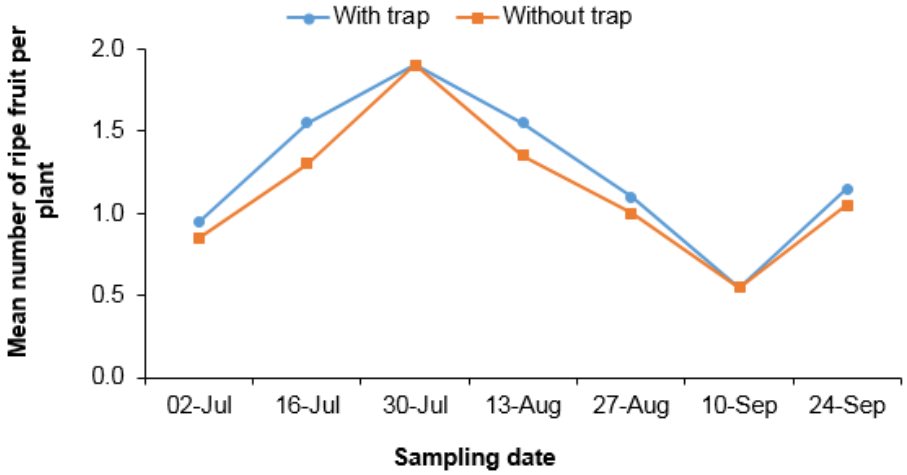

Figure 5.2.21 Mean number of ripe fruit per plant

Mean number of predators per flower and per fruit

No *Orius* spp or other anthocorids were observed in the flowers in the field when making visual counts.

Predatory mites were recorded in laboratory assessments of flowers and green fruit on all assessment dates (Figures 9 and 10). The peak number of predatory mites per flower (based on the six individual flowers per plot) coincided with the peak number of thrips numbers per flower on 30 July, with the predatory mites reaching means of 2.5 and 1.5 per flower in plots with and without roller traps respectively (Figure 5.2.22).

The grower had made fortnightly releases of *N. cucumeris* between 17 April and 29 May, increasing these to weekly releases between 9 June and 23 June before returning to fortnightly releases which continued until 21 August (Table 3). The most prevalent predatory mite species confirmed throughout the trial period was *N. cucumeris,* although naturally-occurring *N. californicus* and *Amblyseius andersoni* also occurred in late August and September (Table 5.2.19).

The only significant difference recorded in mean numbers of predatory mites in plots with and without roller traps was on 10 September, when plots with traps had significantly fewer mites per flower (0.04) than plots without traps (0.29), *P*=0.045), Figure 5.2.22.

Table 5.2.19 Predatory mite species confirmed during the trial

Date	Percentage of *Neoseiulus cucumeris*	Percentage of *Neoseiulus californicus*	Percentage of *Amblyseius andersoni*
2 July	100	0	0
16 July	100	0	0
30 July	100	0	0
13 August	20	0	80
27 August	50	17	33
10 September	100	0	0
24 September	50	12.5	37.5

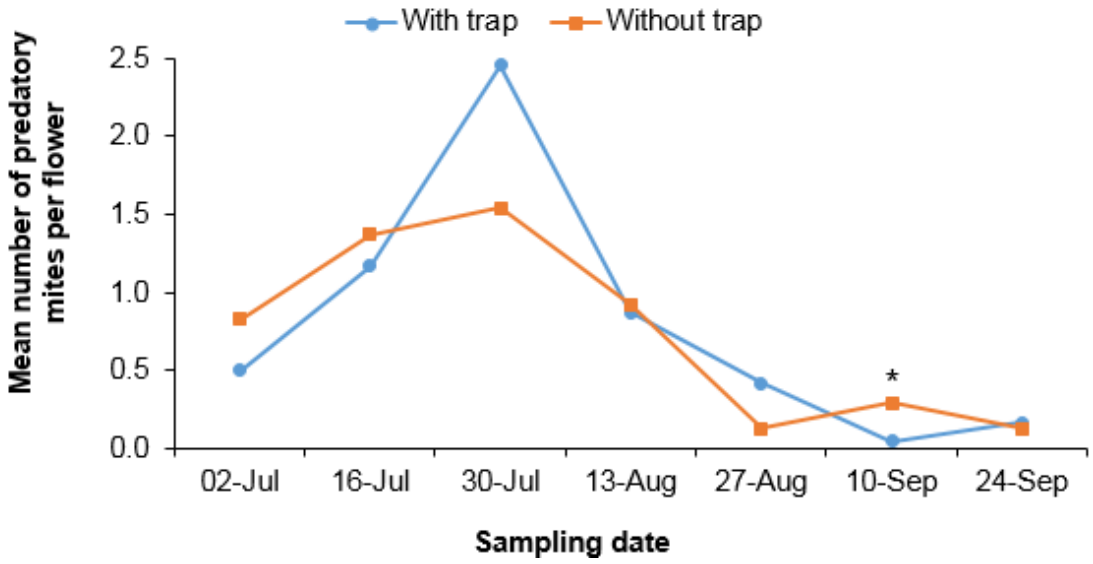

Figure 5.2.22 Mean number of predatory mites per flower (based on six flowers per plot/ 24 flowers per treatment). * indicates a significant difference on that sampling date, *P*<0.05

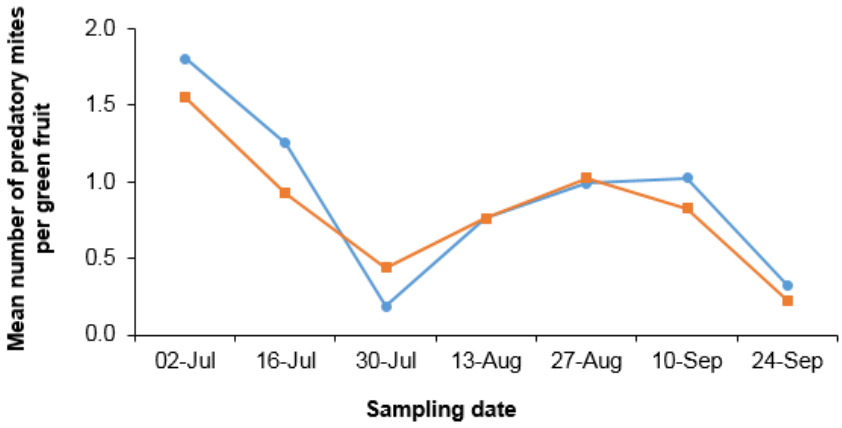

Figure 5.2.23 Mean number of predatory mites per green fruit

Table 5.2.20 Biological control agents released by the grower during the trial period

Date	Beneficial	Numbers per plant
17 April	*N. cucumeris*	20/ plant
1 May	*N. cucumeris*	20/ plant
15 May	*N. cucumeris*	20/ plant
29 May	*N. cucumeris*	20/ plant
9 June	*N. cucumeris*	10/ plant
16 June	*N. cucumeris*	25/ plant
23 June	*N. cucumeris* *P .persimilis*	20/ plant 10/m
7 July	*N. cucumeris*	20/ plant
9 July	*P .persimilis*	5 / m
21 July	*N. cucumeris*	20/ plant
7 August	*N. cucumeris*	20/ plant
21 August	*N. cucumeris*	20/ plant

Mean percentage of flowers with both thrips and predatory mites

On 2 and 16 July, the percentage of flowers with thrips was similar to the percentage with predatory mites in both plots with and without roller traps (Figures 5.2.24 and 5.2.25). On 30 July, when mean numbers of thrips per flower peaked, the percentage of flowers with thrips was 92% and 100% in plots with and without traps respectively, but the percentage of flowers with predatory mites was lower (67% and 54% in plots with and without traps respectively. This result is likely to have contributed to the numbers of thrips per flower peaking on 30 July, as not all flowers with thrips also had predatory mites. On 27 August, after the grower had applied spinosad (Tracer) on 16 August, the percentage of flowers with thrips had dropped to 42% and 46% respectively in plots with and without roller traps. Similarly, the percentage of flowers with predatory mites had dropped to 25% and 8% respectively in plots with and without roller traps. Tracer (spinosad), sprayed onto all trial plots on 16 August, is 'harmful' to *N. cucumeris* for 1-2 weeks after application (kills over

75%) and this is likely to have contributed to the lower proportions of flowers with thrips and predatory mites on 27 August. On 13 and 27 August, the thrips species were predominantly *Thrips major* and *T. fuscipennis,* which are susceptible to spinosad (Tracer) at present.

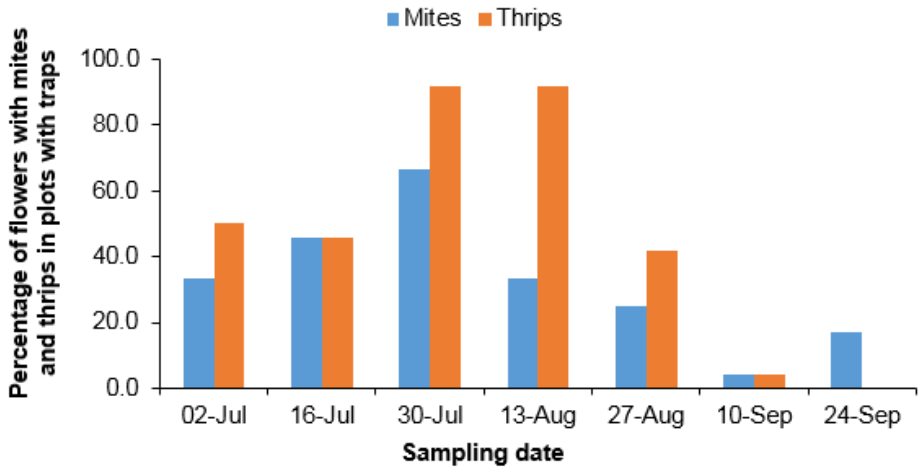

Figure 5.2.24 Percentage of flowers with mites and thrips in plots with traps (based on six flowers per plot, 24 flowers per treatment)

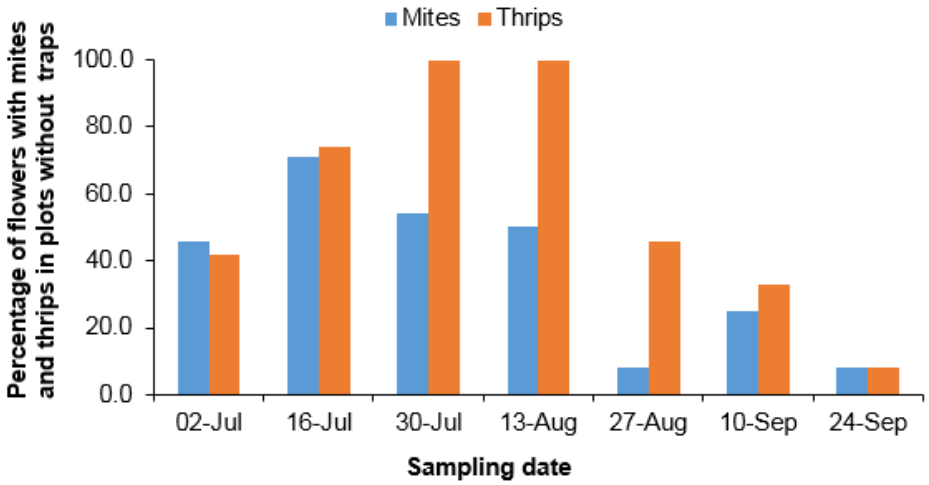

Figure 5.2.25 Percentage of flowers with mites and thrips in plots without traps (based on six flowers per plot, 24 flowers per treatment)

Ripe fruit damage

Following the high numbers of thrips per flower observed on 30 July there was an increase in the mean number of seeds which were surrounded by bronzing on ripe fruit on the two subsequent sampling dates. On 30 July, the mean numbers of seeds with bronzing was significantly higher in plots with roller traps (3.03) than without traps (1.03), *P*=0.012 (Figure 5.2.26). On 13 and 27 August, the mean numbers of seeds surrounded by bronzing increased to 3.95 and 4.07 respectively in plots with roller traps and 4.42 and 4.70

respectively in plots without roller traps. There were no significant differences on any sampling date after 30 July.

The seeds on 25 ripe fruit were counted to give a mean of 263.4 seeds per fruit. As the mean number of seeds surrounded by bronzing per fruit only reached a maximum of 4.7 in this trial, damaged fruit had only approximately 1.8% of seeds surrounded by bronzing which is well below the 10% threshold where downgrading occurs.

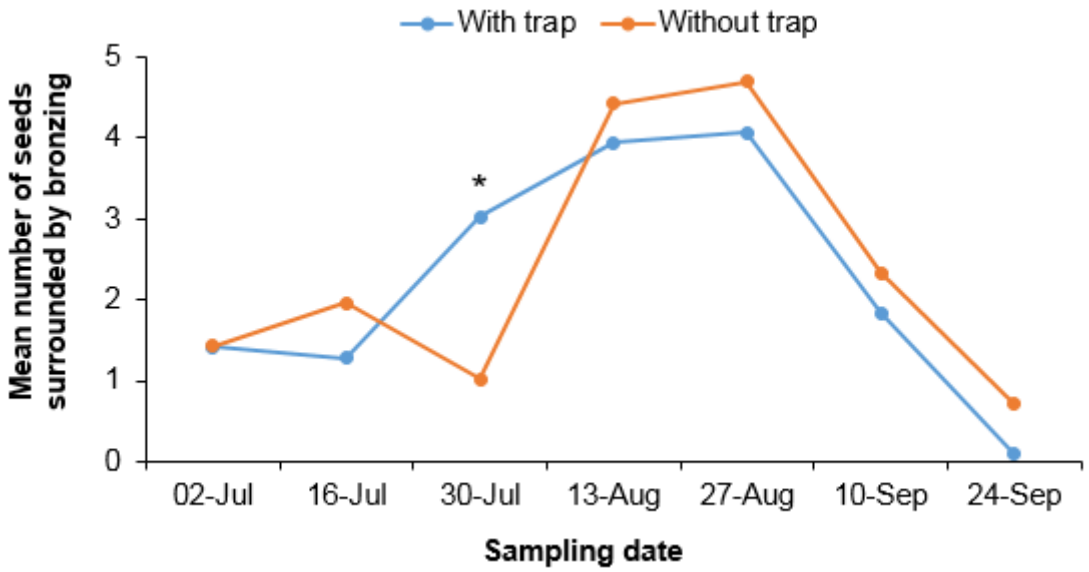

Figure 5.2.26 Mean number of seeds surrounded by bronzing on ripe fruit

Thrips on roller traps

The numbers of thrips counted on the blue roller traps remained low throughout the trial period, peaking at 1.31 thrips per 10cm section of roller trap on 30 July (when mean numbers of thrips per flower also peaked) and on 13 August (Figure 5.2.27). The lures were replaced on 30 July and 27 August and the traps were replaced on 27 August. As all the thrips in flowers on 30 July were confirmed to be *T. major* and most of them were *T. major* on 27 August, with some *T. fuscipennis*, these results suggest that these species are not attracted to blue traps. Furthermore, the lure is not attractive to *Thrips* species as it is specific for WFT.

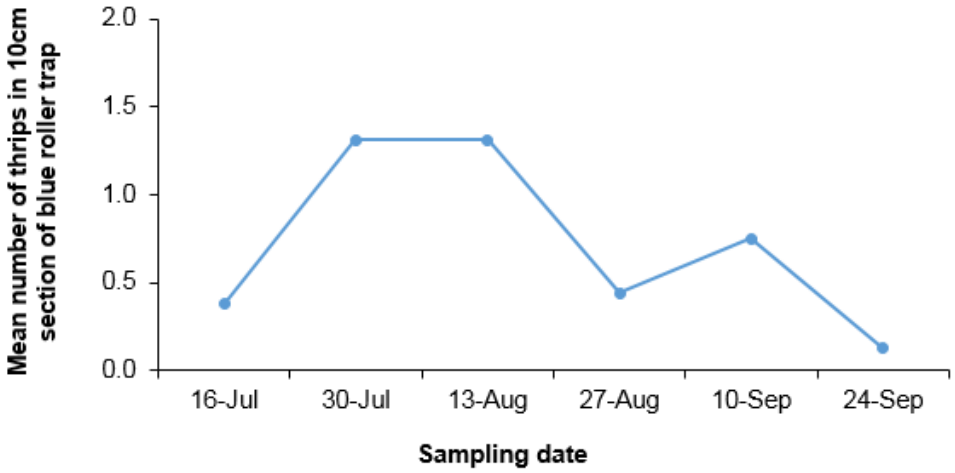

Figure 5.2.27 Mean number of thrips in a 10 cm section of the blue roller traps.

Crop canopy temperatures

Mean minimum, maximum and mean crop canopy temperatures in the tunnels during the experiment are shown in Figure 5.2.28.

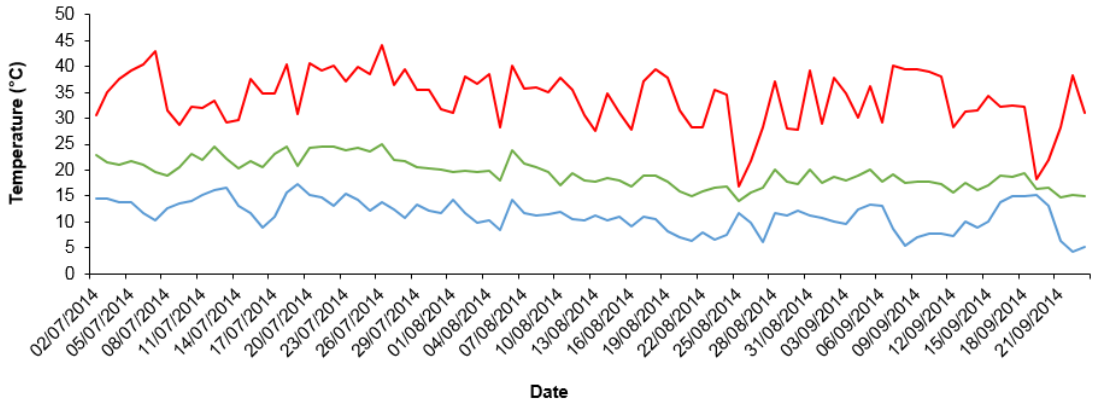

Figure 5.2.28 Mean, minimum and max temperature recorded in the crop canopy during the trial

Pesticide and fungicide applications

Pesticides and fungicides applied by the grower during the trial period are listed in Table 5.2.21.

Table 5.2.21 Pesticides and fungicides applied to experimental plots during experimental period

Date	Product	Active ingredient	Product use	Reason
10 July	Pot Bicarb	potassium bicarbonate	nutrient	mildew
10 July	Codacide Oil	95% emulisified vegetable oil	adjuvant	adjuvant
22 July	Pot Bicarb	potassium bicarbonate	nutrient	mildew
22 July	Nimrod	bupirimate	fungicide	mildew
22 July	Slither		wetter	adjuvant
25 July	Rovral WG	75% w/w iprodione	fungicide	botrytis
25 July	Amistar	250 g/l azoxystrabin	fungicide	mildew
29 July	Pot Bicarb	potassium bicarbonate	nutrient	mildew
29 July	Slither		wetter	adjuvant
29 July	Nimrod	bupirimate	fungicide	mildew
05 August	Signum	boscalid and pyraclostrobin	fungicide	mildew, botrytis
05 August	Systhane	myclobutanil	fungicide	mildew
09 August	Signum	boscalid and pyraclostrobin	fungicide	mildew, botrytis
09 August	Systhane	myclobutanil	fungicide	mildew
16 August	Rovral WG	75% w/w iprodione	fungicide	botrytis
16 August	Amistar	250 g/l azoxystrabin	fungicide	mildew
16 August	Tracer	spinosad	insecticide	thrips
16 August	Attrackter	sugar	adjuvant	
22 August	Frupica	mepanipyrim	fungicide	mildew, botrytis
22 August	Systhane	myclobutanil	fungicide	mildew
28 August	Teldor	fenhexamid 50	fungicide	botrytis
28 August	Nimrod	bupirimate	fungicide	mildew

Conclusions

- WFT was present at the start and towards the end of the trial but *Thrips major* was the most prevalent thrips species, with *T. fuscipennis* and *T. tabaci* also occurring.
- The use of spinosad (Tracer) by the grower on 16 August led to the proportion of WFT increasing on subsequent dates due to its resistance to this insecticide.
- A large difference was observed between visual counts of thrips adults in flowers made in the field compared to counts made in the laboratory from flowers sampled into alcohol. This indicates that counting adults in the field can underestimate numbers, particularly when adult numbers are high.
- Mean numbers of thrips adults, larvae and predatory mites (mainly *N. cucumeris*) peaked in flowers on 30 July.
- The drop in thrips numbers recorded on 13 August was not related to the use of Tracer (spinosad) applied on 16 August.

- The only significant reductions in thrips numbers given by the roller traps was in numbers of adults per flower on 10 September and in numbers of larvae per flower on 30 July when counts were made in the laboratory.
- Thrips damage to ripe fruit was low and below the downgrading threshold.
- Very few thrips were found on the blue roller traps, suggesting that *T. major* and *T. fuscipennis* are not attracted to blue traps. Furthermore, the lure is not attractive to *Thrips* species as it is specific to WFT.

Summary of results for mass trapping experiments

A total of 11 mass trapping trials were carried out by Keele University, ADAS and EMR at sites in Cambridgeshire, Essex, Kent and Staffordshire from 2012 to 2014. These are summarised graphically in Figure 5.2.29. The use of mass trapping with blue sticky roller traps and pheromone lures in addition to each grower's usual control measures gave a significant reduction in the adult thrips density per flower, at the peak thrips density, in six out of 11 trials.

However, in some of these trials, the thrips density was very low (<2 adults per flower) and it was not realistic to show a further reduction from mass trapping. Two trials were terminated early. If these trials are excluded, six out of seven trials showed a significant reduction in the adult thrips density per flower.

In Figure 5.2.29, each trial is represented by a red triangle (the peak density **without** mass trapping) and a corresponding blue circle (the density **with** mass trapping). The distance that the blue circle is **below** the red triangle indicates the extent of any reduction in thrips density. The blue line shows where the blue circles (representing the thrips density with mass trapping) would lie on the graph if mass trapping gave a 50% reduction in thrips density per flower.

Mass trapping in addition to each grower's usual control measures gave a significant reduction in fruit damage (bronzing), when damage was at its peak, in three out of 11 of the trials. However, in some of these trials there was very little fruit damage (<5 seeds with bronzing) with the grower's usual control measures (without mass trapping) and it was not realistic to show a further reduction from mass trapping. Two trials were terminated early. If these trials are excluded, three out of six trials showed a significant reduction in fruit damage.

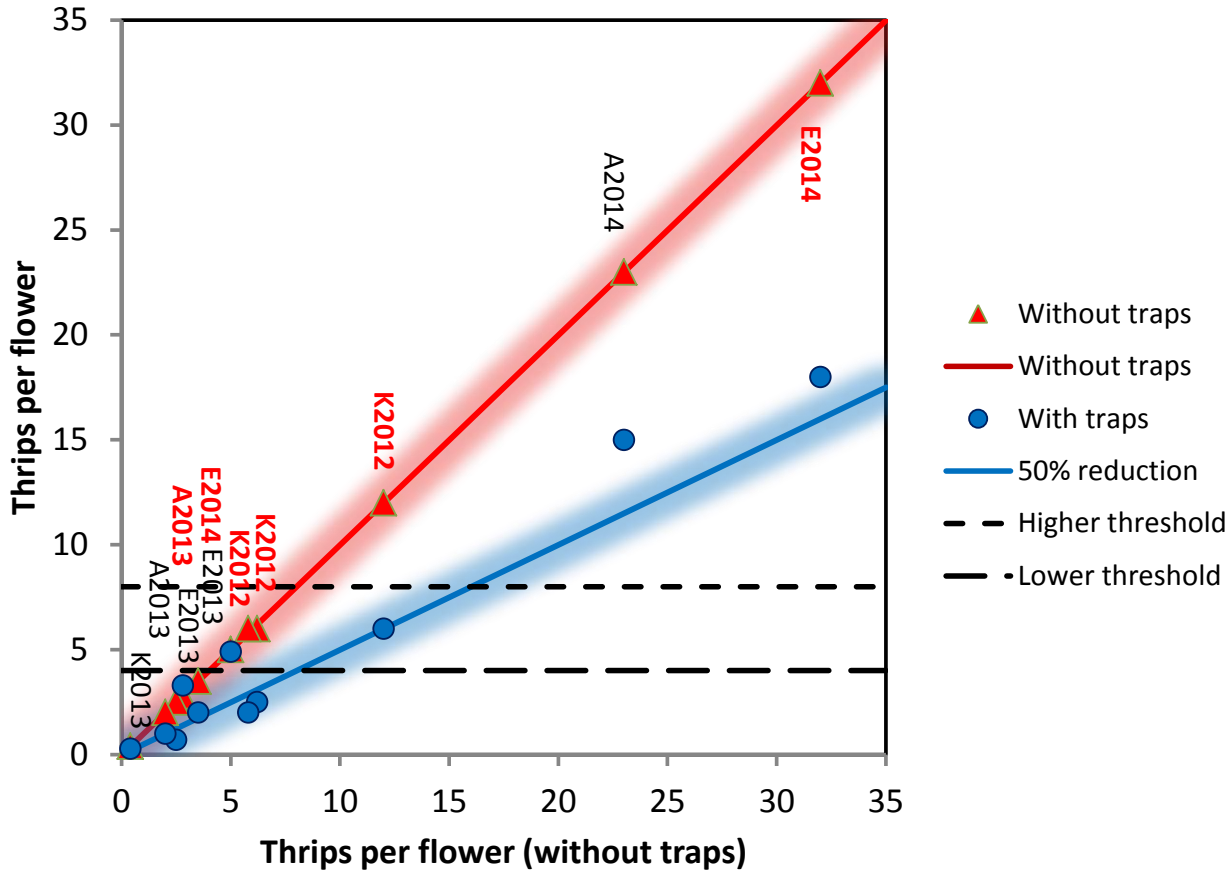

Figure 5.2.29 A graphical summary of all the mass trapping trials arranged in order of increasing density of adult thrips per flower (without mass trapping) from left to right. The red triangles on the red line show the adult thrips density with the grower's usual control measures (without mass trapping). The blue circle on or vertically below each red triangle shows the adult thrips density when traps were used in addition to the grower's usual control measures. Thrips densities are either counts by eye or, when available, counts from samples in alcohol. The dashed horizontal lines show the damage thresholds established previously for cv. Camarillo. Trials in which the traps significantly reduced the adult thrips density at the peak density are labelled in red. Key: A=ADAS trial; E=EMR trial; K=Keele trial (e.g. K2012 = a trial carried out by Keele in 2012)

Task 5.3. Prepare best practice guidelines (all partners)

It has been agreed that the current AHDB Horticulture Factsheet on Thips in strawberry will be updated to include the information obtained in this project. This will be co-ordinated by Scott Raffle of AHDB Horticulture and relevant science team members will input into it.

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

Background

On some farms WFT damage to everbearer fruit has been so severe that total crop loss occurred for the latter third of the season. Even on farms where some control of the pest is maintained, WFT damage can lead to at least 20% of the fruit being downgraded to Class 2 for half of the picking season. Since resistance to available pesticides is now widespread, biocontrol and physical control strategies have the best potential for reducing populations of the pest. Within this project we have demonstrated the potential of releases of *N. cucumeris,* together with the use of blue sticky traps with and without pheromone, to reduce both WFT numbers and fruit damage. Here we outline the cost benefit of using these techniques. Costs mentioned below are derived from commercial costs of the biocontrol agents, pheromone and the sticky roller trap quoted by Syngenta Bioline and Russell IPM in March 2015. Labour costs and farm gate prices for everbearer strawberries were provided by Richard Harnden of Berry Gardens Growers. The example control strategy is based on the results from the current project and possible grower practise regarding *N. cucumeris* releases.

Assumptions

- Strawberry tunnels are 8m wide; thus assume 12 tunnels 100m long /ha.
- There are five strawberry beds/tunnel; thus 6,000m of bed/ha.
- Strawberry beds are 0.9m wide.
- There are three rows of plants/bed; thus 18,000m of row/ha.
- Strawberries are planted 0.5m apart in rows; thus 36,000 plants/ha.
- The average everbearer crop yields 20,000 kg of class one fruit/ha.
- Farm gate value of everbearer crop is £120,000/ha.
- Labour costs are £8.40/h (minimum wage plus employers' contributions).

Control measure costs

- Sticky trap strips 30 cm wide cost £25/100m strip; 13 strips are needed per ha, so cost is £325. Labour to apply strips estimated at 36h/ha, so cost is £302. Thus total cost for applying blue sticky roller trap is £627/ha. In practise two applications are likely to be necessary due to loss of stickiness of the traps over time.

- WFT aggregation pheromone lures cost £2.75 each; if placed 2.2m apart , fixed to sticky trap strips, then 590 are required per ha, so cost is £1,622. We assume labour costs for application of lures is included within the 36h sticky trap application labour cost. Two applications are likely to be necessary.
- Mite sachets without hooks cost £41.72 for 500; at one sachet/2m of bed as used in this project, then 3,000 are required per ha, so cost is £250.32/ha. Labour to apply the sachets - if we assume the worker walks at 3km/h, takes 2h, so the labour cost is £16.80. Therefore total cost of application is £267.12/ha.
- Mite sachets with hooks cost £21.42 for 200; as above 3,000 are required so cost is £321.30 plus £16.80 labour costs. Therefore the total cost of application is £338.10/ha.
- Loose mites cost £33.15/250,000. At release rates of 25 mites/plant, 900,000 mites are required per ha, so cost is £119.34/ha. Labour to apply loose product assumed to be 2h/ha (as for sachets), so cost is £16.80. Therefore total cost is £136.14/ha. Up to 10 releases may be needed.

Example control strategy

2 × applications of sticky traps + lures/ha	£4,498
Application of sachets without hooks early in the season/ha	£267
Regular (10 x) loose mite applications/ha	£1,360
Total/ha	**£6,125**

If sachets with hooks are used the cost/ha would be increased by £71.

If two applications of blue sticky traps are applied without lures the cost/ha would be reduced by £3,244 (the blue sticky traps significantly reduced WFT and fruit damage without the pheromone lures in experiments in this project but addition of the lures gave a significantly greater reduction).

Cost/benefit in various damage scenarios using the assumptions, costs and example control strategy shown above

- If there was total crop loss in untreated crops the loss would be £120,000/ha. The cost/benefit ratio using the costs of the example control strategy would be 6,000/120,000, i.e. 1/20.

- If there was total crop loss for the final third of the cropping season the loss would be £40,000/ha and the cost/benefit ratio would be 6,000/40,000, i.e. 1/7.
- If damage in untreated crops was as little as downgrading 20% of fruit to Class 2 due to WFT damage for half the season (and assuming that Class 2 fruit is worth half that of Class 1 fruit), the loss would be £6,000/ha, and equal to the cost of treatment, i.e. the break-even point.

Thus overall, if damage to an untreated crop results in more than 5% reduction in farm gate value, then the combined control strategy outlined above is cost effective.

SIX MONTHLY REPORT TO HORTICULTURE LINK PROGRAMME MANAGEMENT COMMITTEE
(Due 31 March 2015)

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; BerryGardens 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-M Xu
Project Start/Completion Dates:	1 April 2010 to 31 March 2015
Reporting Period:	30 September 2014 to 31 March 2015
Number of Months Since Commencement:	60
Date of Last Management Meetings:	
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	Y
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. *No effective approved pesticides or EPFs were identified in field bioassays.*	N
P5.1	31 Mar 2013	IPM programme for thrips for evaluation in years 4 and 5 devised	Y
P5.2	31 Mar 2015	Thrips IPM programme evaluated in commercial crops for 2 seasons	Y
P5.3	31 Mar 2015	Best practice guidelines for thrips IPM prepared	Y
P5.4	31 Mar 2015	Economic and environmental impact analysis of thrips IPM completed	Y
S1.1	31 Mar 2011	Data on release rates of pheromone components by WFT obtained	Y
S1.2	31 Mar 2012	Initial designs to exclude other insects tested	Y
S1.3	31 Mar 2013	Optimum flower sampling methods determined	Y
S1.4	31 Mar 2014	Optimum trap density and spacing determined	Y
S1.5	31 Mar 2015	Feasibility of using traps to control WFT determined	Y
S2.1	31 Mar 2011	Experimental protocols for lab experiments established	Y
S2.2	31 Mar 2014	Sufficient amount of field data on WFT obtained	Y
S2.3	31 Mar 2015	A model for a specific BCA incorporated with the WFT model. *Entomopathogens were not effective against the pest in field expts so were not included in the model.*	N
S3.1	30 Sep 2010	Emergence of *N. cucumeris* from sachets quantified	Y
S3.2	31 July 2010	Pilot experiment with *O. laevigatus* establishment completed	Y
S3.3	31 mar 2011	Protocol for trial with release rates of both predators agreed	Y
S3.4	31 Mar 2013	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 Jan 2012	Protocol for collection of natural predators agreed	Y
S4.1	31 Mar 2011	First field trial evaluating pesticides and EPF sprays completed	Y
S4.2	31 Mar 2012	2nd field trial evaluating pesticides and EPF soil treatments completed	Y
S4.3	31 Mar 2013	Confirmatory field trial testing most effective pesticide and EPF treatments completed. *Effective treatments were not identified in small plot experiments so field trials were not appropriate at this stage*	N

3.	**Milestones for the six month period:** (from project proposal, or other more recently approved planning document)		
P1.5	31 Mar 2015	Damage thresholds established for thrips flower counts	Y
P2.4	31 Mar 2015	A final model for WFT on strawberry completed	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
P5.2	31 Mar 2015	Thrips IPM programme evaluated in commercial crops for 2 seasons	Y
P5.3	31 Mar 2015	Best practice guidelines for thrips IPM prepared	Y
P5.4	31 Mar 2015	Economic and environmental impact analysis of thrips IPM completed	Y
S1.5	31 Mar 2015	Feasibility of using traps to control WFT determined	Y
S2.3	31 Mar 2015	A model for a specific BCA incorporated with the WFT model. *Entomopathogens were not effective against the pest in field expts so were not included in the model.*	N
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

No work was planned for this objective in 2014

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 obtained from laboratory controlled studies and from field sampling were incorporated into the WFT phenological model. Running the revised model showed that it predicted the first generation of larvae in the crop about 7-14 days late. This result, together with our low temperature lab studies, indicates that eggs and larvae are developing slowly at low temperatures early in the season. This highlights the importance of releasing biocontrol agents before adults are seen in the crop for maximum efficacy.

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 2014

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

No work was planned for this objective in 2014

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

Two experiments were set up by EMR in April in Kent on a commercial site, one on a first year Jubilee crop and the other on a second year Camarillo crop using blue sticky roller traps in conjunction with the grower applied biocontrol programme (early sachets of *N. cucumeris* followed by regular introductions with loose product). There were two experimental treatments: 30 cm wide blue sticky roller traps with WFT pheromone lures every 2.2m along the trap and a control treatment with no roller traps or pheromone. The roller traps were positioned at crop height in each of the leg rows in treated plots. Each plot was 30m long and three tunnels wide and there were four replicate plots for each treatment. Assessments of thrips in flowers were done each week and a sample of fruit was assessed for thrips damage every two weeks. In the first year crop no WFT were identified through the season and an application of Tracer reduced the numbers of other thrips present; this application also reduced numbers of *N. cucumeris* to close to zero. There was very little fruit damage in this planting. In the second year crop there was a mix of thrips species present initially but WFT became dominant after the Tracer application; in this planting *N. californicus* and *N. cucumeris* were both present with *N. californicus* becoming dominant after the Tracer application. In the second year crop there was a significant effect of treatment on numbers of thrips adults recorded in flowers compared with the untreated plots; numbers of thrips reached a mean of over 30 per flower in July in the untreated plots. Despite the large pest infestation fruit damage was much lower than that recorded in 2013 and the grower continued to pick marketable fruit throughout September.

ADAS set up a third experiment on 2 July on a second year crop, cv. Amesti. The crop had a history of WFT in 2013 and WFT was confirmed in flowers, together with both *Thrips major* and *Thrips tabaci* in June 2014 just before the trial was set up. The grower applied *Neoseiulus cucumeris* every two weeks for thrips control within his IPM programme, starting from 17 April. Release rates were 20 per plant during April and May, 30 per plant during June and 50 per plant from July. Assessments were done every two weeks until 24 September, on numbers and species of thrips adults per flower using by-eye counts in the field, and also using laboratory extraction from flowers sampled into alcohol. Assessments were also done every two weeks on numbers of thrips adults on 10cm lengths of roller trap, numbers and species of predatory mites per green fruit and thrips damage to ripe fruit (number of seeds surrounded by bronzing).

Mean numbers of adult thrips per flower assessed by eye in the field peaked at 8.4 (without traps) and 7.1 (with traps) on 30 July. On all other dates, mean numbers were below one per flower. Mean numbers of adult thrips per flower assessed in the laboratory on 30 July were 23 (without traps) and 14.9 (with traps), indicating that by-eye counts in the field under-estimated numbers. Confirmation of thrips species has not yet been completed for all dates, but up to and including 30 July, the majority were Thrips major, with very few WFT being recorded. The grower applied spinosad (Tracer) to the crop on 16 August as he was concerned about the numbers of T. major in flowers. However, in-field counts of thrips numbers per flower had already dropped to a mean of 0.7 (without traps) and 0.5 (with traps) by 13 August, so the reduction was not due to using Tracer. Mean numbers of predatory mites per green fruit were 1.7, 1.1 and 0.3 on 2 July, 16 July and 30 July respectively, indicating that the increase in thrips numbers on 30 July may have been associated with a drop in predator numbers. However, predatory mite species identification has only been completed so far for those recorded on 2 and 16 July, when all were confirmed as *N. cucumeris*. Predatory mite numbers increased during August and September, reaching a mean of one per green fruit by 27 August. The grower's pesticide and fungicide records will be checked to determine whether any may have had an adverse effect on *N. cucumeris* during July. Thrips damage to ripe fruit remained low, with bronzing around five seeds or less throughout the experiment period. Mean numbers of thrips adults on the 10cm-lengths of roller trap remained below one on most dates, with a maximum of 1.3 per trap portion on 30 July and 13 August. It is possible that T. major is not as attracted to blue as WFT is, and certainly this species would not be attracted to the specific WFT pheromone lure.

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 management. Annual conference of the Entomological Society of America. Austin, Texas, USA, 10-13 November 2013

Sampson, C. Biological, semiochemical and selective chemical management methods for insecticide resistant western flower thrips on protected strawberry (project update). EMR/AHDB Horticulture soft fruit meeting, 21 November 2013

Jean Fitzgerald included a summary of this project in a presentation on the use of phytoseiid mites in fruit growing at a Royal Entomological Society meeting at EMR in November 2013

Jude Bennison gave an update on the ADAS trapping work to ADAS fruit consultants on 5 Feb 2014

Jude Bennison presented the results of the ADAS experiment to date to the project consortium at the field site meeting at Hugh Lowe Farms on 5 September 2014

Jude Bennison discussed the results during the experiment with the host grower and ADAS fruit consultants

Jean Fitzgerald presented the results of the EMR experiments to date to the project consortium at the field site meeting at Hugh Lowe Farms on 5 September 2104

Jean Fitzgerald discussed the results during the experiment with the host grower

Clare Sampson attended the meeting of the IOBC Working Group "Integrated Control in Protected Crops, Temperate Climate" in Ghent (Belgium), 14–18 September 2014 and discussed her research with other attendees

William Kirk attended the 4th Symposium on Palaearctic Thysanoptera in Vienna, 8-11 September 2014 and presented research results

William Kirk attended the 10th European Congress of Entomology in York,

3-8 August 2014 and presented research results

Jean Fitzgerald gave a presentation on the results of the 2014 field experiments to Waitrose agronomists at EMR on 24 October

Jean Fitzgerald and Jude Bennison gave an overview of the project at the AHDB Horticulture/EMRA day at EMR on 26 November 2014

Clare Sampson attended the AAB Conference on "Advances in IPM" in Marsden, UK, 19-20 November 2014 and gave a talk on the management of the western flower thrips in strawberry

Clare Sampson attended the EMRA/AHDB Horticulture soft fruit day at EMR on 26 November 2014 and gave a talk on the reasons for success and failure of western flower thrips control

Jean Fitzgerald and Jude Bennison gave a practical demonstration of thrips identification at the AHDB Horticulture Agronomists day at EMR on 12 February 2015

Jean Fitzgerald gave an overview of the project at the Berry Gardens grower day at EMR on 10 March 2015

Chantelle Jay gave an overview of the project to the Leafy Salads Group at EMR on 19 March 2015

7.	**Exploitation plans:**	(give an update on perceived exploitation opportunities and future plans.)
Much of the research undertaken in this project on release of predators, in particular the use of the predatory mite *Neoseiulus cucumeris*, to reduce thrips populations have been widely taken up by the industry. It is now part of the management strategy of many growers who have had problems with WFT and is recommended by most advisors and grower groups to their growers. The use of trapping is also being used by some growers. Further development of the trapping system is now under way in a separate project.		