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

Headlines

- Adult female western flower thrips overwinter in senescent/dead strawberry flowers and weeds, such as chickweed, groundsel and dandelion.
- Before flowering, WFT can be most effectively monitored using blue sticky traps with a pheromone lure with the bottom of the trap (landscape orientation) about 10cm above the top of the crop (one hand width).
- From flowering, the number of adult thrips per medium age flower (all petals present, anthers brown, pollen shed) from the top of the plant is the best estimate of thrips populations.
- The use of blue sticky roller traps along the tunnel legs (30 cm wide, 100 m long, Optiroll, Russell IPM) can significantly reduce thrips numbers and fruit damage.

Background and expected deliverables

The development and spread of pesticide resistant strains of WFT which cannot be controlled with pesticides seriously threatens the viability of the UK strawberry industry. In 2009 serious outbreaks occurred in several high value crops in southern and central England causing serious loss.

The aim of this project is to develop a comprehensive range of new effective methods for managing insecticide 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 on each objective of the project is summarised below:

Objective 1 (Monitoring, trapping and damage thresholds)

Information on the distribution of thrips within and between fields was collected to help

advise growers on areas of greatest thrips risk. WFT was shown to overwinter as adult females in senescent/dead strawberry flowers and weeds (such as chickweed, groundsel and dandelion) within fields and in field margins. Overwintering in crops resulted in significantly more WFT in second year crops than in first year crops at the beginning of the season. Growing one-year crops or reducing the overwintering thrips population would reduce thrips risk.

Adult thrips moved into strawberry flowers and started to lay eggs at first flower. In first-year crops, the first thrips were observed around the outside of crops, particularly near weedy field margins, demonstrating the need for good weed control to reduce thrips risk. Once thrips populations had established in fields, they were found throughout the crops monitored, but the number of thrips was greater in the warmer, mid to top areas of sloping fields (excluding the exposed tunnel ends and sides). In general there was a mix of species early in the season (mainly WFT*, Thrips major* and *Thrips tabaci*) with increasing proportion of WFT (>90%) from July, especially after insecticide treatments.

Before flowering, the use of blue sticky traps with a pheromone lure, placed on canes (vertical orientation) 10 cm above the crop bed, was the most effective monitoring method. The addition of the pheromone increased trap catches by three fold. From first flowering, a count of adult thrips in medium-aged open flowers was a more accurate monitoring method than using trap counts. Comparison of population estimates by four people demonstrated that farm staff counted adult thrips in flowers accurately following a short training session (5 minutes) on identification from a hand-out. Analysis of the spatial variation in flower counts and thrips density within commercial crops was used to estimate the numbers of flower samples necessary to estimate thrips numbers at levels around a damage threshold of 4 to 8 adult thrips/flower. Counts of thrips in between 10 and 20 flowers may be sufficient to estimate a population in a particular area, but further analysis is needed to recommend a sampling programme. The possibility of reducing sampling time by using binomial (presence/absence) sampling was tested. Thrips occupied all flowers when the mean thrips/flower was approximately 4 thrips/flower in the variety Camarillo, which may be a useful indicator of damage in high risk situations (e.g. in second year crops without predators, in hot/dry conditions). However this method would not be sensitive enough at higher thresholds. Further development of threshold scoring will be done in 2013.

Bronzing damage to strawberry fruit increased with increasing numbers of adult thrips per flower. Significant damage that might result in downgrading of fruit corresponded to an average of about 4 to 8 adult thrips per flower. In 2012, when humidity was exceptionally

high and in crops where predators were present, there were occasions where adult thrips numbers exceeded 8/flower yet damage was slight and further work will be done in 2013 to examine damage thresholds further.

The influence of flower flushes was identified as a key factor in the timing of damage. Damage often occurred soon after the end of flower flushes when thrips were concentrated into fewer flowers, so future damage cannot be predicted from thrips per flower alone but has to take account of changes in flower density. To help determine the relationship and timing between thrips per flower and fruit damage, the distribution of thrips on strawberry plants and timing of fruit damage was examined. On flowering and fruiting strawberry plants, 74% of adult thrips were found in the flowers, with the rest spread between fruit of different stages of ripeness. Larvae were mostly on flowers (40%) and young fruit (38%) with the rest on mature fruit. Very few thrips were present on leaves. All stages of flowers and fruit were damaged by both adult and larval WFT, with larvae doing about twice as much damage as adults, possibly because they do more feeding than adults. The greatest amount of damage to fruit occurred at the end of flowering when the flowers were senescent and larval numbers were at their highest, although further damage occurred throughout fruiting.

A number of trap designs were examined in order to identify the most effective trap, including the addition of semiochemicals to increase trap catch. The pheromone neryl (*S*)-2-methylbutanoate and the plant volatile methyl isonicotinate increased trap catches by small amounts (between x1.2 and x1.6) in UK strawberry crops during June and August, but there was no synergistic response. This was consistent with 2011 results. Neither scent increased trap catch in early May, during the first full flower flush, when temperatures were below 20°C, thrips numbers were low (<1 thrips/flower) and flower numbers were high (>16 flowers/plant). There was a similar response to pheromone whether using water or sticky traps.

Trap thickness and cylinder-shaped traps did not affect trap catch. Relatively few thrips were caught in yellow funnel traps, with or without scents. Comparison between white and blue sticky traps was made in protected and outdoor strawberry and bright white traps caught x2 and x1.5 more thrips than blue sticky traps, yet blue water traps caught x10 more thrips than transluscent white water traps. It was concluded that both colour and brightness of the traps is important. The use of LED (Light emitting diode) lights during the night increased trap catch (x1.2). Comparison between different trap types demonstrated that the trap colour is the most important component of the traps, the numbers of thrips caught relating to the area of colour/trap, rather than trap type (water or sticky). Placement of sticky traps about 10 cm

above the crop, resulted in the highest trap catch. The cardinal orientation (north/south or east/west) did not affect sticky trap catch but vertical traps caught more than horizontal traps (x2). Traps placed in strawberry beds were vulnerable to damage from tractors. Traps placed in the leg area between tunnels caught fewer thrips in total (x0.9), yet significantly more female thrips (x1.2) than traps in beds. Traps between tunnels were therefore more practical and effective for mass trapping.

Three large-scale, replicated field trials demonstrated that placement of blue roller traps along the legs between tunnels reduced thrips numbers and fruit damage. The use of traps alone (30 cm wide, 100 m long, Optiroll, Russell IPM) reduced thrips numbers by 61% and fruit damage by 55%. The use of roller traps with WFT aggregation pheromone (used for precision monitoring), reduced thrips numbers by 73% and fruit damage by 68%. The addition of roller traps to an IPM programme maintained thrips numbers below economic damage thresholds. The traps remained sticky for at least 2 months but there was a lag between placement and control, so it is recommended that the traps should be in place about 3-4 weeks before damage is expected (e.g. in AprilMay for early flowering second year crops, or early July for everbearers where there is less pest pressure).

Objective 2 (Model)

WFT were reared at a range of constant and fluctuating temperatures to obtain developmental data to incorporate into the model developed in the early years of the project. Time for egg development ranged from 5 days at a constant 20°C to 13 days at a fluctuating 14/10°C. Experiments to determine rates of development for larvae are ongoing.

Objective 3 (Predators)

Experiments were carried out by EMR and ADAS in an attempt to identify the most effective strategy for release of predatory mites in combination with releases of *Orius laevigatus*. In the EMR experiment, on a first year crop, there were 8 treatments replicated 4 times. *O. laevigatus* releases were made to one entire tunnel in an attempt to reduce the potential effects of dispersal of this predator into the no-release *Orius* plots. The treatments were: (1) *N. cucumeris* at one sachet per 2-metre length of row, before flowering in early April and repeated after 6 weeks; (2) as 1 and repeated every 6 weeks; (3) *N. cucumeris* sachets in early April, followed by loose product at 25 per plant every three weeks, starting 6 weeks after the first release of sachets; (4) untreated control; (5) as treatment 1, plus *O. laevigatus* as in 8; (6) as treatment 2, plus *O. laevigatus* as in 8; (7) as treatment 3, plus *O. laevigatus* as in 8; (8) no *A. cucumeris* (as in treatment 4), but treated with four releases of *Orius laevigatus* at 1 per m^2 6 weeks after the first release of *N. cucumeris*.

Thrips larvae and adults were present in similar numbers in all treatments throughout the season, including the no predator release control. Several species were present with 38% of those identified being WFT. No *O. laevigatus* were found in samples taken in the release tunnel. Highest numbers of *N. cucumeris* were found in the plots where sachets had been released every 6 weeks; the peak in predator numbers was also later in this treatment (end of July rather than end of June). However this appears to have had no effect on thrips numbers in the flowers. There was no thrips feeding damage seen in samples taken by EMR at harvest and the grower did not downgrade any of this crop from the experimental tunnel.
In the ADAS experiment the treatments were: (1) Untreated control. (2) *N. cucumeris* at one sachet per 2-metre length of row before flowering on 4 April, repeated at 6-week intervals (on 16 May and 26 June), (3) *N. cucumeris* at one sachet per 2-metre length of row before flowering on 4 April, followed by loose product at 25 per plant after 6 weeks (on 16 May) and thereafter every two weeks (on 31 May, 15 June, 28 June, 12 July and 26 July), (4) untreated with *N. cucumeris* with releases of *Orius laevigatus* adults at 0.5 per m^2 at first flower flush on 10 and 17 May, and again at second flower flush on 26 July, together with nymphs at 3 per m^2 , (5) *N. cucumeris* as in treatment 2, plus *O. laevigatus* as in treatment 4, (6) *N. cucumeris* as in treatment 3, plus *O. laevigatus* as in treatment 4.

Numbers of thrips (all WFT) increased during the experiment in all plots and *O. laevigatus* did not establish well. Very little fruit was downgraded due to thrips damage, but the host grower decided to apply spinosad (Tracer) on 10 August as mean numbers of WFT had reached very high numbers (up to 20 adults per flower on 28 June). Spinosad resistance has not yet developed on this farm.

Objective 4 (Pesticides and biopesticides)

Although there were no significant reductions in WFT populations following treatments with the selected BCAs there were indications of a trend of declining WFT populations over time for the biopesticide Naturalis and the botanical Neem applied as a drench. This method of application is worth investigating further as it could suggest that WFT do not receive a sufficient dose on the crop for lethal fungal infection with foliar applications. Another explanation could be connected with environmental conditions. Entomopathogenic fungi require high humidities and moderate temperatures for activity (the optimum temperature for fungal infection is c. 23°C). In the tunnels the minimum temperatures ranged from 4.5 to 17°C and the maximum temperatures ranged from 23 to 42.5°C. The high temperatures within the tunnels may be detrimental to foliar sprays of fungal biopestcides.

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 conventional crop protection 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 loss. The average everbearer crop yields 20,000 kg of class 1 fruit over one season with a current value of £2.70 per kg (£54,000 per ha). On some farms in 2009, WFT damage to everbearer fruit was so severe following failure of spinosad to control the pest, that total crop loss occurred for the latter third of the season (i.e. a loss of £18,000 per ha). Even on farms where spinosad is still effective, WFT damage can lead to at least 20% of the fruit being downgraded to class 2 for half of the picking season. The value of class 2 fruit is less than £1.50 per kg. Thus, WFT currently causes minimum estimated financial losses of approximately £3,000 per ha per season. There is great concern that UK everbearer crop losses will escalate with the further spread of spinosad-resistant strains of WFT. Furthermore, WFT is favoured by hot summer weather conditions. If the 2009 summer weather had been hot it is possible that losses would have been much more extensive.

This project will deliver a new sustainable cost-effective IPM strategy for management of WFT on tunnel-grown everbearer crops which is vital to the survival of the UK strawberry industry. The development of a reliable IPM strategy for successful control of WFT would benefit growers by preventing crop losses and fruit downgrading due to WFT damage. In this project we aim to develop a range of complementary methods for managing WFT. For instance, using WFT predators which may include two releases of *Neoseilus cucumeris* in sachets (costing up to £325 per ha) and two releases of *Orius laevigatus (*costing up to £600 per ha). If this strategy prevented fruit downgrading due to WFT damage for the whole everbearer season, use of the two predators could give a minimum potential 324% return on investment. On farms with spinosad resistance the benefit of investing in a reliable IPM strategy would be much greater as it could prevent entire crop losses.

Action points for growers

- Plan your IPM programme carefully in early spring, in conjunction with an experienced consultant who us 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, presence of thrips can be monitored by tapping the flowers over a white card.

- From crop flowering, the number of adult thrips per flower is the best estimate of thrips numbers. When monitoring for thrips the selection of flower age and position affects population estimates. Select flowers of medium age (all petals present, anthers brown, pollen shed) from the top of the plant for monitoring thrips adults, as young (petals fresh, anthers yellow, pollen not shed) or senescent (petals dropping) flowers will result in an underestimation.

- Bronzing damage to strawberry fruit increased with increasing numbers of adult thrips per flower. Significant damage that might result in downgrading of fruit corresponded to an average of about 4 to 8 adult thrips per flower.

- Damage thresholds can only be a guideline as there is much variability. The lower damage threshold may apply in hot/dry conditions in fields without predators. Higher damage thresholds may apply in humid conditions and in fields where predators have established.

- The damage threshold can also vary between everbearer varieties. Further work in the project will aim to gain more information on the relationship between numbers of thrips adults per flower and fruit damage.

- The use of blue roller traps along the tunnel legs (30 cm wide, 100 m long, Optiroll, Russell IPM) reduced thrips numbers by 61% and fruit damage by 55%. The use of blue roller traps with additional WFT aggregation pheromone reduced thrips numbers by 73% and fruit damage by 68%. Roller traps may be a useful addition to an IPM programme, and can maintain thrips damage below economic injury levels (i.e. prevent downgrading of fruit). 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.

- Roller traps should be put out about 3-4 weeks before damage is predicted (e.g. in April for early flowering second year crops or early July in crops with less pest pressure. They remain sticky for at least 2 months, although sections of glue are washed off in places.

- Monitor thrips numbers in flowers and fruit damage 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.

General methods for sticky trap experiments in semi-protected everbearer strawberry crops in 2012

Fifteen experiments were conducted in commercial semi-protected strawberry crops, selected mainly for their infestation level and accessibility. The methods below were common to all the sticky trap pheromone and plant volatile experiments done in the U.K. and will not be repeated in each section.

Site details

Table 1 shows fields used in trapping and monitoring experiments. All fields were in the W. Midlands, UK and contained first, second or third year everbearer strawberry crops. Crops were grown in raised beds covered in black plastic mulch and irrigated by T-tape, or in coir growbags on a Mypex mulch, irrigated by drip irrigation. Planting density was 9.5 to 10 plants per m^2.

Table 1. Fields used for trapping and monitoring experiments in UK strawberry.

Field No.	Location (field name)	Area (ha)	No. of tunnels	Growing System	Variety	Crop year
1	Tamworth (Block 4)	2.0	22	Beds	Albion	3
2	Tamworth (12 acre)	1.0	8	Beds	Finesse	2
3	Tamworth (PYO)	0.5	Outdoor	Beds	Camarillo	1
4	Tamworth (Taylor's)	2.1	14	Growbags	Camarillo	1
5	Tamworth (Road)	2.4	22	Beds	Camarillo	2
6	Tamworth (Block 5)	2.0	22	Beds	Finesse	1
7	Tamworth (Meadow)	1.0	8	Growbags	EME676	1
8	Stafford (a)	21.4	40	Beds	Camarillo	1
9	Tamworth (Quarry)	2.4	17	Beds	Finesse	2
10	Stafford (b)	21.4	40	Beds	Camarillo	2

Plant monitoring

At the start of each trapping experiment, the number of adult and larval thrips per flower and the number of flowers per plant (n=10) was counted.

Blue sticky traps (25 cm x 10 cm, Russell IPM) were stuck vertically (landscape orientation) onto bamboo canes (60 cm) with the bottom edge of the traps about 10 cm above the crop (one hand width). The canes were stuck into the ground so that the tops of the canes were

just above the top of the traps and would fit under a tractor (Figure 1). In some experiments the sticky traps were placed in the 'legs' between the strawberry tunnels. Experiments were laid out with randomised complete blocks designs and appropriate controls. In the majority of experiments, pheromone septa (Thripline ams, Syngenta Bioline) or plant volatile sachets were stuck onto the traps centrally. The controls used a blank natural rubber septum identical to that used for the pheromone (6.3 mm diam × 10.8 mm long; International Pheromone Systems Ltd.). The blank septa were solvent cleaned and dried in an oven at 50°C before use. The plant volatile controls were empty sachets. All traps were oriented so that the septum/vial/sachet side faced north to avoid direct sunlight on the release device. Maximum and minimum air temperatures were recorded during each experiment. Traps were placed at least 20 m from the ends of the tunnels to reduce sunlight and edge effects. At the end of the experiment, traps were placed in a polythene wrapper and stored in a freezer. The numbers of thripids were counted under a binocular microscope in the Keele laboratory. Males and females were counted separately but only adult numbers are shown in experiments were the sexes respond in a similar manner. Aeolothripid (with broad wings) and phlaeothripid thrips (with a tube at the end of the abdomen) were excluded from the counts. Thirty flowers were collected from the trial area at the start of each experiment and placed in alcohol. Thrips were extracted and mounted on slides in order to identify the species and calculate the percentage of *F. occidentalis* (n=25 to>200/sample).

(a) (b)

Figure 1. Back (N facing) of the traps a) without lures b) with lures, used for trapping experiments.

Statistical analysis

Tables and figures show untransformed data. Log_{10} (n+1) transformed data were used for the statistical analyses to normalise the variance. Data were analysed using analysis of variance and residuals checked for normality. Multiple comparisons used Tukey's test. Comparisons with the control used Dunnett's test. Where data were not normally distributed Kruskal-Wallis or Mann-Whitney tests were used. Statistical analysis was carried out with Minitab 16. The treatment/control ratio in trap catch between each treatment and the control was calculated by comparing the total catch on the two trap types for untransformed data.

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

Task 1.1 (1) Synthesis of chiral forms of the male produced compounds (NRI).
Completed in Year 1.

Task 1.1 (2) Measurement of the natural release rates of the pheromones (KU).
Completed in Year 1.

Task 1.1 (3) Measurement of release rates of the pheromone components from different dispensers at different temperatures (NRI).
Completed in Year 1.

Task 1.1 (4) Field trials to investigate the effects of the pheromones, their release rates and their enantiomeric composition on attractiveness to WFT (KU).
Completed in Year 2.

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

Summary

The pheromone neryl (S)-2-methylbutanoate alone increased trap catches in UK strawberry crops by small amounts (x1.2, x1.4). The plant volatile methyl isonicotinate (an analogue of a flower odour) resulted in similar small increases (x1.4, x1.6). The increase in total thripids per trap was slightly greater with plant volatiles than with the pheromone at the start of the season, when the thrips population was of mixed species (*Thrips major, T. tabaci* and *F. occidentalis*). The plant volatile increased trap catch of other species of thrips as well as *F. occidentalis* whereas the pheromone only increased the trap catch of *F. occidentalis*, which is the most damaging thrips species in summer. The plant volatile anisaldehyde alone did not increase trap catches. The combined use of pheromone and plant volatiles did not increase trap catch above that of the best scent, in contrast to 2011 results where they were consistently higher. None of the scents increased trap catch in experiments carried out when the crops were in full flower early in the season, when thrips numbers were <1/flower (less flight because there was no competition for food), temperatures were largely below 20°C (less flight in cooler temperatures) and there were >16 flowers per plant (competition between flower scents may reduce the attraction of the lures). No synergism between the *F. occidentalis* aggregation pheromone and plant volatiles was observed.

1.2 (a) Do methyl isonicotinate or anisaldehyde increase trap catch? (KU)

Introduction

Experiments carried out in Spanish pepper crops in 2011 showed small increases in trap catch using plant volatiles which were not statistically significant. Comparison of control

means between experiments showed that the plant volatiles, which were released in very high doses, may have reached the control traps and increased their catch. Also, the scents had not been tested in UK strawberry under Spanish tunnels which are more open than the pepper tunnels used in Spain. The aim of experiment 1.2 (a) was to compare the synthetic pheromone neryl (*S*)-2-methylbutanoate at a standard dose with two other compounds that have been found to increase trap catches in greenhouses, in UK strawberry and at wider trap spacing than was used in the pepper crops, so that any carry over to the controls was reduced.

Methods – For full methods see Objective 1, General Methods.

Treatments

Control = blank septum (30 µl hexane) and blank sachet.
NSMB = 30 µg neryl (*S*)-2-methylbutanoate (in 30 µl hexane) in septum and blank sachet.
MIN = 250 µl neat methyl isonicotinate in sachet and blank septum.
AN = 250 µl neat anisaldehyde in sachet and blank septum.

Blue Takitrap (Syngenta Bioline) with one septum on the top front left and one sachet on the top front right, one cm above the top of the glue, shaded from the sun. Source of scents: NRI

Site details

Site: Field 1 (3rd year Albion, Table 1).
Date: 30 Aug 2011 (9.30 am to 19.00 pm).
Traps per treatment: 20
Trap spacing within rows: 11 m along a tunnel.
Trap spacing between rows: 13 m (every second tunnel).
Thrips occupancy of flowers: 100%.
Thrips species: >90% WFT.

Results and conclusions

The maximum and minimum temperatures and humidities during experiment 1.2 (a) are shown in table 1.2.1 and the mean trap catch with pheromone, methyl isonicotinate and anisaldehyde is shown in figure 1.2.1.

Table 1.2.1 Environmental conditions within the plastic house during experiment 1.2 (a).

	Minimum	Maximum
Temperature (°C)	12	19
Relative humidity (%)	72	88

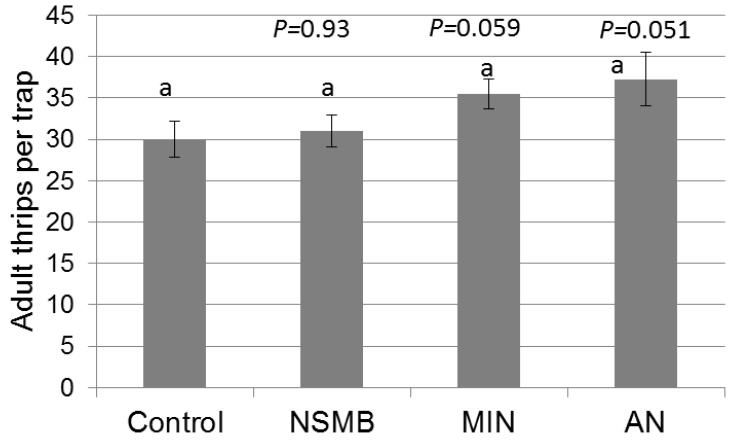

Figure 1.2.1. Mean trap catch ± S.E. of thripids with different scents. Bars with the same letter are not significantly different. *P* value shows comparison with control using Dunnett test. NSMB= Neryl (*S*)-2-methylbutanoate, MIN=methyl isonicotinate, AN=anisaldehyde.

The plant volatile scents resulted in a similar, but small (x1.2) increase in trap catch with a significant effect of treatment overall ($F_{(3,57)}$ =3.11, *P*= 0.034). However no individual comparison was significant using Dunnetts' test (Figure 1.2.1), partly because the scents produced a similar, small increase and partly because at the wider spacing of 11 m, the thrips numbers were very variable between traps, reducing the power of the analysis. Response to scents may have been reduced because it was a cool, cloudy day with temperatures below 19°C.

1.2 (b) Does methyl isonicotinate increase trap catch during first flower flush? (KU)

Introduction

The aim of the experiment was to test whether the presence of plant volatiles increases trap catch early in the season (May) at first flower flush and to identify the best trap spacing (near, medium or far).

Methods – For full methods see Objective 1, General Methods.

Treatments

Near control = blank sachet at 1.1 m spacing from methyl isonicotinate.

Near MIN = 250 µg methyl isonicotinate in a sachet at 1.1 m spacing from control.

Medium control = blank sachet at 4.4 m spacing from methyl isonicotinate.

Medium MIN = 250 µg methyl isonicotinate in a sachet at 4.4 m spacing from control.

Far control = blank sachet at 8.8 m spacing from methyl isonicotinate.

Far MIN = 250 µg methyl isonicotinate in a sachet at 8.8 m spacing from control.

Site details

Blue sticky trap (25cm x 10cm Russell IPM) with sachet placed on the north of the trap, centrally, 1 cm from the top of the trap.

Source of methyl isonicotinate: NRI.

Site: Field 2 (second year Finesse, Table 1).

Date: 16-23 May 2012.

Traps per treatment: 15.

Trap spacing within rows: 1.1 m, 4.4 m or 8.8 m along a tunnel.

Trap spacing between rows: 15 m (every 2.5 tunnels).

Thrips occupancy: 50%, 0.63 adult thrips /flower, 17.2 flowers /plant.

Thrips species: 70% WFT.

Results and conclusions

The maximum and minimum temperature and humidity during experiment 1.2 (b) are shown in Table 1.2.2 and the mean trap catch with and without pheromone at three distances apart is shown in Figure 1.2.2.

Table 1.2.2. Environmental conditions within the plastic house during experiment 1.2 (b).

	Minimum	Maximum
Temperature (°C)	7	25.5
Relative humidity (%)	40	84

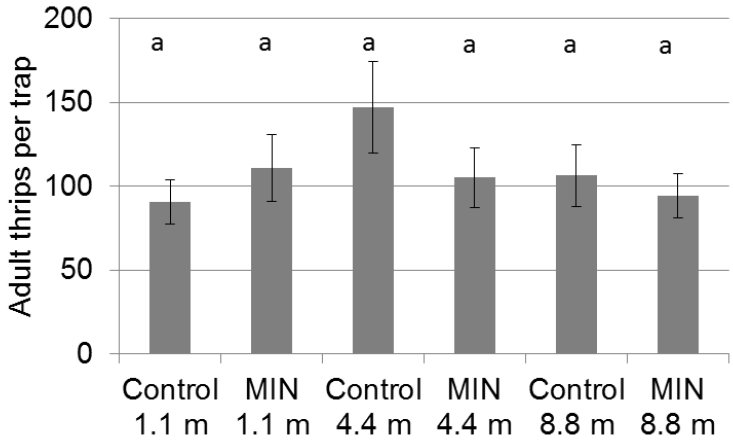

Figure 1.2.2. Mean trap catch ± S.E. of thripids with and without methyl isonicotinate at different trap spacings. Bars with the same letter are not significantly different. MIN=methyl isonicotinate

Methyl isonicotinate did not increase trap catch at any of the trap spacings in late May ($F_{(1.60)}$=0.39, P=0.53). The distance between traps did not affect treatment effect (MIN x spacing interaction, $F_{(2.60)}$=0.03, P=0.97). A number of factors may have contributed to this

result. The experiment was done when thrips numbers were low (0.63 thrips adults/flower) and the crop was in full flower (17 flowers/plant), so there was little competition for resources. The plant volatile lures were competing with a large amount of naturally produced plant volatiles in the strawberry flowers, which would reduce the attraction of the lure. Temperatures only exceeded 20°C (an approximate temperature threshold above which thrips flight increases) for an average of three hours/day during the experiment. The low temperatures may have reduced the spread of the lure scent from the trap area. Early season distribution of thrips within the field was patchy and high spatial variance dwarfed treatment variance when traps were 8.8 m apart.

1.2.(c) Does the pheromone increase trap catch during the first flower flush? (KU)

Introduction

The aim of the experiment was to test whether the pheromone increased trap catch early in the season (May) during the first flower flush and to identify the best trap and pheromone spacing.

Methods – For full methods see Objective 1, General Methods.

Treatments

Near control = blank septum (30 µl hexane) at 1.1 m spacing from neryl (*S*)-2-methylbutanoate.
Near NSMB = 30 µg neryl (*S*)-2-methylbutanoate (in 30 µl hexane) in septum at 1.1 m spacing from control.
Medium control = blank septum (30 µl hexane) at 4.4 m spacing from neryl (*S*)-2-methylbutanoate.
Medium NSMB = 30 µg neryl (*S*)-2-methylbutanoate (in 30 µl hexane) in septum at 4.4 m spacing from control.
Far control = blank septum (30 µl hexane) at 8.8 m spacing from neryl (*S*)-2-methylbutanoate.
Far NSMB = 30 µg neryl (*S*)-2-methylbutanoate (in 30 µl hexane) in septum at 8.8 m spacing from control.

Site details

Blue sticky trap (25cm x 10cm Russell IPM) with one septum placed through the string hole.
Source of neryl (S)-2-methylbutanoate: Thripline ams (Syngenta Bioline).
Site: Field 2 (second year Finesse, Table 1).

Date: 2-9 May 2012.

Traps per treatment: 15.

Trap spacing within rows: 1.1 m, 4.4 m or 8.8 m along the tunnels.

Trap spacing between rows: 15 m (every 2.5 tunnels).

Thrips occupancy: 33%, 0.1 adult thrips /flower, 30.6 flowers /plant.

Thrips species: 70% WFT.

Results and conclusions

The maximum and minimum temperatures and humidities during experiment 1.2 (c) are shown in Table 1.2.3 and the mean trap catch with and without pheromone at three distances apart is shown in Figure 1.2.3.

Table 1.2.3. Environmental conditions within the plastic house during experiment 1.2 (c).

	Minimum	Maximum
Temperature (°C)	3.3	23.5
Relative humidity (%)	41	91.5

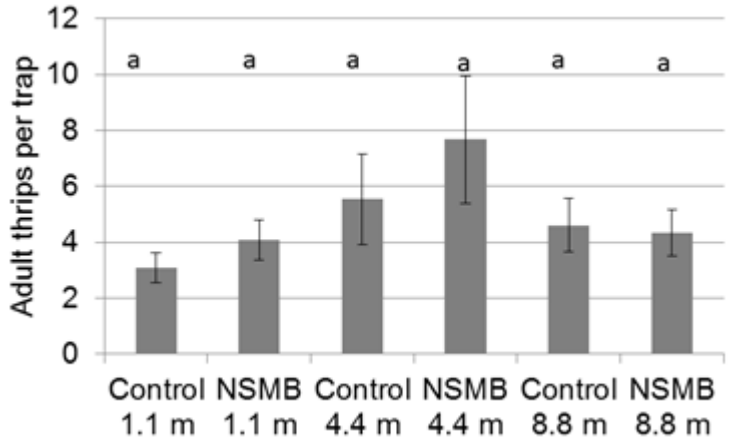

Figure 1.2.3. Mean trap catch ± S.E. of thripids at different trap spacing. Bars with the same letter are not significantly different. NSMB= neryl (*S*)-2-methylbutanoate

There was no effect of pheromone on trap catch at any of the trap spacing tested ($F_{(1,70)}$=2.19, P=0.14). The distance between traps did not affect treatment effect (interaction between pheromone x spacing, $F_{(2.70)}$=1.58, P=0.213). It is likely that the low response to pheromone was partly because there was a mix of thrips species at the start of the season, so fewer were responding to the aggregation pheromone, which is specific to *F. occidentalis*. In addition, the pheromone was in competition with strawberry flower plant volatiles as the crop was in full flower (30 flowers/plant).

1.2 (d) Is there a synergistic response between the aggregation pheromone and plant volatile? (KU)

Introduction

The aim of the experiment was to compare the synthetic pheromone neryl (*S*)-2-methylbutanoate at a standard dose with the plant volatile methyl isonicotinate and to test whether the presence of plant volatiles synergises the effect of the pheromone in UK strawberry. Experiments in Spanish pepper crops in 2011 showed no synergistic response. The experiment was done in June then repeated in September in differing environmental conditions and thrips populations.

Methods – For full methods see Objective 1, General Methods.

Treatments

Control = blank septum (30 µl hexane) and blank sachet.

NSMB = 30 µg neryl (S)-2-methylbutanoate (in 30 µl hexane) in septum and blank sachet.

MIN = 250 µl neat methyl isonicotinate in sachet and blank septum (30 µl hexane).

NSMB +MIN = 30 µg neryl (S)-2-methylbutanoate (in 30 µl hexane) and 250 µl neat methyl isonicotinate.

Blue sticky traps (Russell IPM) with 1 septum on the top front left and one sachet on the top front right, one cm above the top of the glue, shaded from the sun.

Source of scents: NRI (MIN), Syngenta Bioline (NSMB).

Site details

Blue sticky trap (25cm x 10cm Russell IPM).
Source of neryl (S)-2-methylbutanoate: Thripline ams (Syngenta Bioline).
Site: Field 2 (second year Finesse, table 1).

Dates:	a) 6-12 June 2012.	b) 10 August 2012: 10.30 to 18.30.
Traps per treatment:	a) 18	b) 18.
Trap spacing within rows:	a) 6.6 m	b) 6.6 m.
Trap spacing between rows:	a) 8.8 m	b) 8.8 m.
Thrips occupancy:	a) 100%, 9.7 adult thrips /flower, 3.4 flowers /plant.	
	b) 100%, 16.4 adult thrips /flower, 1.0 flowers /plant.	

Thrips species: 88% WFT in June, 97% WFT in August.

Results and conclusions

The maximum and minimum temperature and humidity during experiment 1.2 (d) are shown in Table 1.2.4 and the mean trap catch with pheromone, methyl isonicotinate and the mix of both is shown in Figure 1.2.4. Table 1.2.5 summarises the analysis and interactions between the treatments.

Table 1.2.4. Environmental conditions within the plastic house during experiment 1.2 (d).

	(a) 6-12 June		(b) 10 August	
	Minimum	Maximum	Minimum	Maximum
Temperature (°C)	12.5	28	21	27
Relative humidity (%)	51	89	54	69

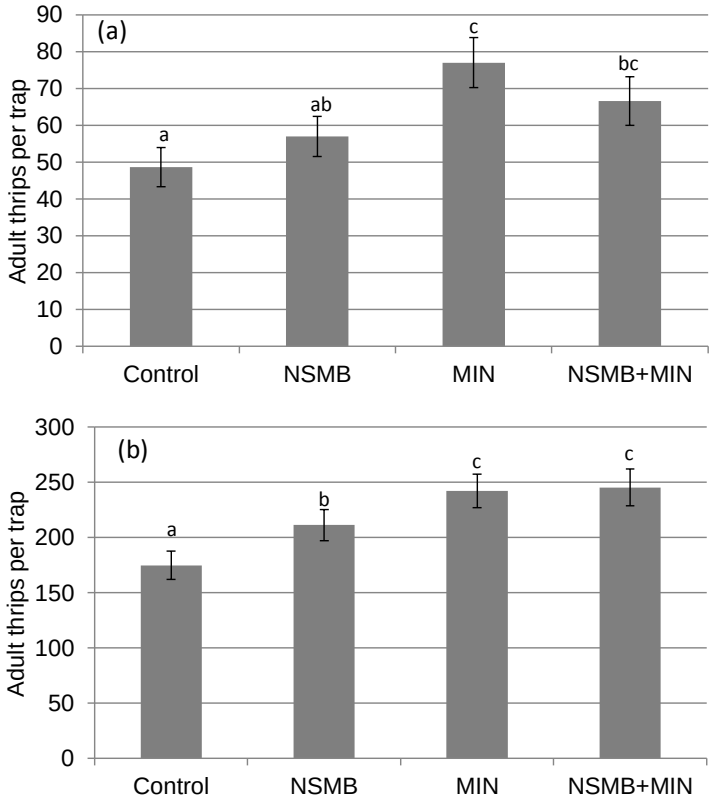

Figure 1.2.4. Mean trap catch ± S.E. of thripids with pheromone and methyl isonicotinate in (a) June and (b) August 2012. Bars with the same letter are not significantly different. NSMB=neryl (*S*)-2-methylbutanoate, MIN=methyl isonicotinate.

Table 1.2.5 Summary of the analysis of effects and interactions between pheromone, methyl isonicotinate and the interaction between the two on trap catches of *F. occidentalis.*

Treatment	(a) 6-12 June		(b) 10 August	
	$F_{(1, 48)}$	P	$F_{(1, 51)}$	P
Neryl (*S*)-2-methylbutanoate	0.15	0.69 ns	7.26	0.01**
Methyl isonicotinate	29.68	<0.001***	47.62	<0.001***
Interaction	7.97	0.007**	5.15	0.027*

The pheromone increased trap catch by x1.2 in June and August. Methyl isonicotinate increased trap catch by x1.6 in June and x1.4 in August. The combined effect of pheromone and methyl isonicotinate was no worse than the best trap catch but there was no gain and no synergistic response was observed. In 2011 experiments in pepper crops, where approx. 98% of the thrips were *F. occidentalis,* the increase in trap catch was similar with pheromone and methyl isonicotinate. The better response to methyl isonicotinate in June may be because there was a lower proportion of *F. occidentalis.* The methyl isonicotinate is increasing the trap catch of all species of thrips whereas the pheromone only increases the trap catch of *F. occidentalis.*

Task 1.3 Optimise trap design and positioning (KU, NRI; Years 1-3)

Summary

Comparison between different trap types confirmed that trap colour and brightness is the most important component of the traps. Bright white traps caught more thrips than standard blue traps in protected and outdoor crops (x2, x1.5) yet blue water traps caught x10 more thrips than dull white water traps. The cardinal orientation (north/south or east/west) did not affect sticky trap catch but vertical traps caught more than horizontal traps (x2). The use of LED lights during the night increased trap catch (x1.2). Trap thickness and cylinder-shaped traps did not affect trap catch. Trap height had a significant effect on trap catch that is consistent with results found by other research workers and in 2011 results. Traps placed in strawberry beds were vulnerable to damage from tractors. Traps placed in the leg area between tunnels caught fewer thrips in total (x0.87), yet significantly more female thrips (x1.3) than traps in beds and were therefore more practical and effective for mass trapping.

The most effective trap will depend on cost and practicality as well as total trap catch. Considering these aspects, blue sticky roller traps (to maximise the area of blue) with additional scent lures (*F. occidentalis* aggregation pheromone and plant volatile methyl isonicotinate, currently used for precision monitoring) attached to the legs between tunnels (practical and effective) would maximise trap catch.

Task 1.3 (1) Identify the best height and position of traps for WFT in strawberry (KU).

1.3.(1a) Does trap orientation affect trap catch of F. occidentalis? (KU)

Introduction

To use traps for decision making or maximum trap catch growers need to know how best to position the traps. The aim of this experiment was to determine which trap orientation

results in the most trap catch in UK strawberry.

Methods – For full methods see Objective 1, General Methods.

The traps were suspended above the crop by sticking them onto bamboo garden canes that had been pushed into the ground and were secured with clothes pegs. The horizontal trap was supported on bent wire curled around the bamboo cane. The different trap orientations are shown in Figure 1.3.1.

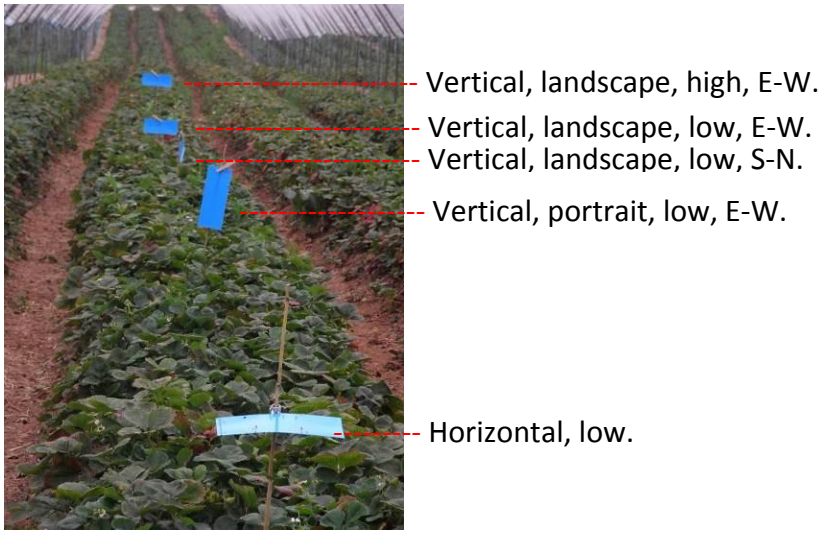

Figure 1.3.1 Trap orientation experiment 1.3. (1a).

Treatments

VLLS = Vertical trap with Landscape orientation, Low (base 10 cm above the crop), South facing.

VLLE = Vertical trap with Landscape orientation, Low (base 10 cm above the crop), East facing.

VPLE= Vertical trap Portrait orientation, Low (base 10 cm above the crop), East facing.

VLHE = Vertical trap Landscape orientation, High (base 30 cm above the crop), East facing.

Horiz. = Horizontal trap, 10 cm above the crop.

Blue Takitrap (Syngenta Bioline).

Site details

Site: Field 1 (3rd year Albion, Table 1).

Date: 25-26 August 2011

Traps per treatment: 20

Trap spacing within rows: 11 m along the tunnel

Trap spacing between rows: 13 m (every second tunnel)

Thrips occupancy of flowers: 100%.

Thrips species: >90% WFT.

Results and conclusions

The maximum and minimum temperatures and humidities during experiment 1.3 (1a) are shown in Table 1.3.1 and the mean trap catch with and without pheromone on different trap colours is shown in Figure 1.3.2.

Table 1.3.1. Environmental conditions within the plastic house during experiment 1.3 (1a).

	Minimum	Maximum
Temperature (°C)	12.5	20.5
Relative humidity (%)	63	87.5

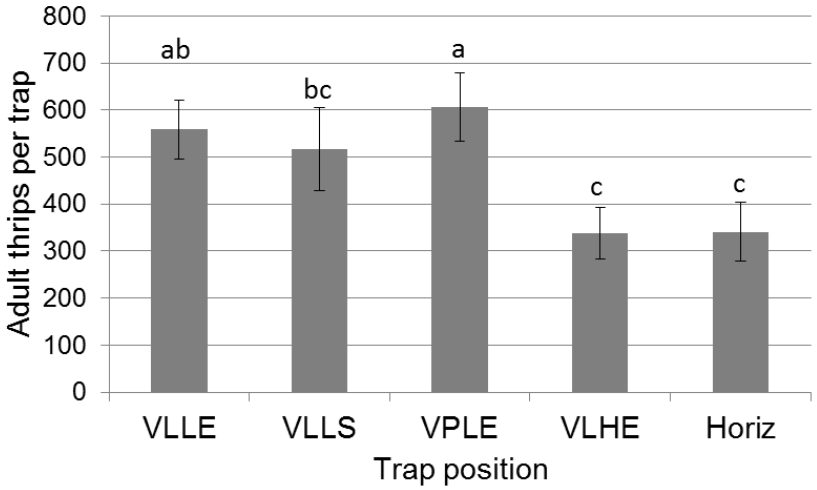

Figure 1.3.2. Mean trap catch ± S.E. of thripids at different trap positions. Bars with the same letter are not significantly different. VLLE = vertical, landscape, low, east facing; VLLS = vertical, landscape, low, south facing; VPLE = vertical, portrait, low, east facing, VLHE = vertical, landscape, high, east facing; Horiz = horizontal, low.

Trap placement had a significant effect on trap catch ($F_{(4, 76)}$=14.63, P<0.001). Traps caught most thrips when suspended vertically, with the base approximately 10 cm above the crop. Placing the traps horizontally or higher above the crop significantly reduced trap catch (x 0.6, Figure 1.3.2). The orientation of the trap did not affect trap catch. The slightly lower numbers of thrips on traps which were orientated north/south may be explained by the weather conditions over the course of the experiment which was overcast or raining for most of the day followed by a warm period of evening sunshine which may have increased trap catch on the east/west orientated traps (because the east/west traps were lit by the evening sunshine). Trap orientation was therefore repeated over a week in experiment 1.3 (1b).

1.3.(1b) Does trap orientation affect trap catch of F. occidentalis? (KU)

Introduction

In experiment 1.3 (1a) there was no significant difference in trap catch on north/south facing traps and east/west facing traps over 24 hours. The weather during this experiment was raining during the day followed by warm evening sunshine which may have biased the trap catch in favour of east/west facing traps, therefore these trap orientations were tested again over the course of a week.

Methods – For full methods see Objective 1, General Methods.

Treatments

S-N = Vertical trap with landscape orientation, 10 cm above the crop, north/south facing.
E-W = Vertical trap with landscape orientation, 10 cm above the crop, east/west facing.
Trap type = Blue sticky traps (Russell IPM).

Site details

Site: Field 2 (second year Finesse, Table 1).
Date: 9-16 May 2012.
Traps per treatment: 17
Trap spacing within rows: 4.4 m along the tunnel.
Trap spacing between rows: 16 m (every second tunnel).
Thrips occupancy in flowers: 27%, 0.13 adults thrips/flower, 29.4 flowers/plant.
Thrips species: 70% WFT.

Results and conclusions

The maximum and minimum temperatures and humidities during experiment 1.3 (1c) are shown in Table 1.3.2 and the mean trap catch on different trap orientations is shown in Figure 1.3.3.

Table 1.3.2. Environmental conditions within the plastic house during experiment 1.3 (1c).

	Minimum	Maximum
Temperature (°C)	6.0	26.0
Relative humidity (%)	40	94

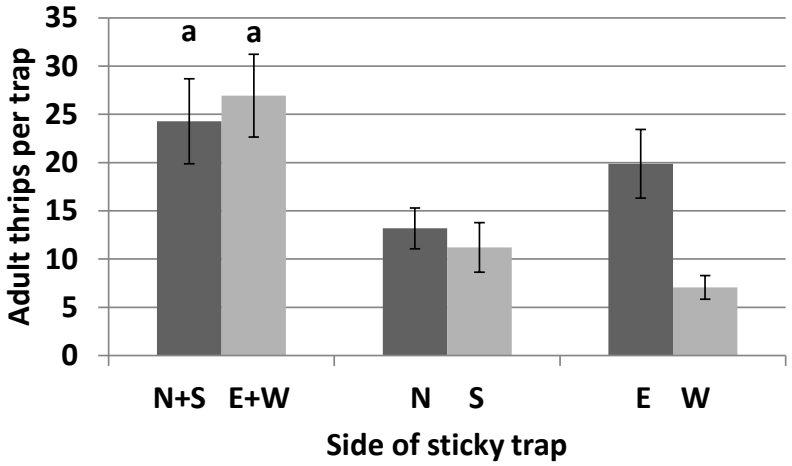

Figure 1.3.3. Mean trap catch ± S.E. of thripids at different trap orientations. Bars with the same letter are not significantly different.

There was no significant difference between total trap catch on north/south or east/west facing traps ($F_{(1, 16)}$=0.14, P=0.71 ns) which is consistent with the results in experiment 1.3 (1a). This indicates that the orientation of the trap is not critical to trap catch.

Although the trap orientation did not affect total trap catch, the thrips were not evenly distributed between the two sides of the traps. In this experiment the weather was generally cool and wet with short periods of sunshine and 54% of the thrips were on the North side of the N/S traps (typically about 83% of thrips are on the North facing side in still, sunny conditions, e.g. experiment 1.3.2b) and 74% were on the east side of the E/W traps, suggesting that the thrips are either more attracted to the traps when the light is behind (i.e. they are flying towards the background light) or flying around to the shaded side of the trap before landing.

1.3.(1c) Do traps placed in the leg areas between the strawberry tunnels catch as many thrips as traps placed above the crop beds? (KU)

Introduction

Traps placed within strawberry beds are vulnerable to damage and soiling by tractors or during crop work such as spraying and picking. Traps placed away from beds in the spaces between tunnels would be easier to erect and check and less vulnerable to damage, although they would be more exposed to rain and direct sunlight if placed directly under the gap in the tunnel plastic. The aim of this experiment was to compare trap catch on traps within strawberry beds to traps between the strawberry rows/tunnels in the leg area (Figure 1.3.4.).

Figure 1.3.4. UK field trial site showing trap placement in crop beds and in the legs between beds/tunnels.

Methods – For full methods see Objective 1, General Methods.

Treatments

Bed traps= 10 cm above the crop, south facing.

Leg traps = 50 cm above the ground (at same height as the bed traps), south facing.

Trap type = Blue sticky traps (Russell IPM).

Site details

Site: Field 2 (second year Finesse, Table 1).

Date: 6-10 August 2012.

Traps per treatment: 18 (nine pairs in one tunnel and nine pairs in the adjacent tunnel).

Trap spacing within pairs: 3 m along tunnels

Trap spacing between pairs: 3 m, with the bed traps alternating left or right from the leg traps and 8.8 m between the tunnels.

Thrips occupancy in flowers: 100%, 9.5 adults thrips/flower, 3.4 flowers/plant.

Thrips species: 97% WFT.

Analysis of variance was carried out considering the different sexes within the same trap as split plots. Where the treatment x sex interaction is significant (as in this case) this indicates a different response between the sexes to trap position. The different sexes were then analysed separately.

Results and conclusions

The maximum and minimum temperatures and humidities during experiment 1.3 (1c) are shown in Table 1.3.3 and the mean trap catch on different trap orientations is shown in Figure 1.3.5.

Table 1.3.3. Environmental conditions within the plastic house during experiment 1.3 (1c).

	Minimum	Maximum
Temperature (°C)	14.0	25.5
Relative humidity (%)	53	87

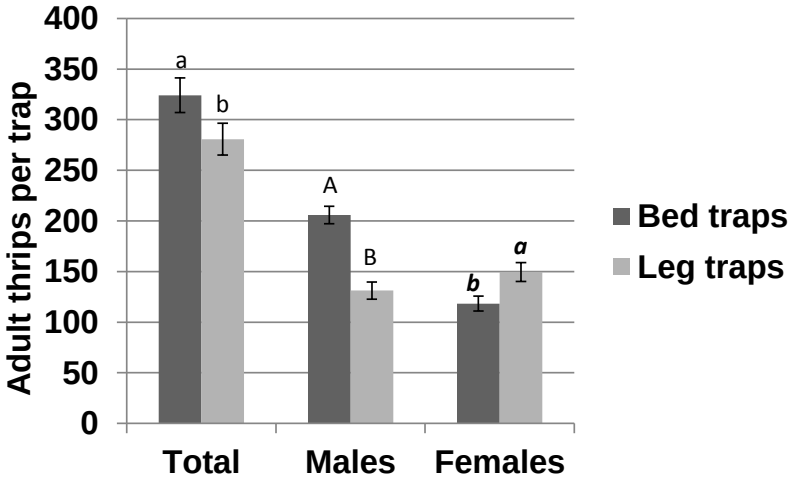

Figure 1.3.5. Mean trap catch ± S.E. of thripids in bed or leg positions. Bars within pairs of either total thrips, males or females, with the same letter are not significantly different

There were more thrips caught on traps placed in beds (x1.15) than when placed in the leg area between tunnels ($F_{(1, 17)}$=7.24, P=0.016), although the difference was less than might be expected as a result of the bed traps being beside the flowers where the thrips feed. However there was significantly interaction between sex and trap placement ($F_{(1, 34)}$=60.69, P<0.001) showing a different response to trap placement between the sexes. There were significantly more female thrips on traps in the leg area (x1.3, $F_{(1, 17)}$=15.59, P<0.001) but significantly more males in the bed traps (x1.6, $F_{(1, 17)}$=30.17, P<0.001).

Placement of traps in the leg area may be the best position for mass trapping because reducing the numbers of females will have a greater effect on population development and traps placed in the leg areas between the strawberry tunnels are less vulnerable to knocking, damage and soiling during crop work.

Task 1.3 (2/3) Trap design to maximise trap catch (KU)

Different types of trap tested are shown in Figure 1.3.6.

(a) Blue and white sticky traps

(b) Cylinder trap

(c) Yellow funnel trap

(d) Blue water trap with lure

(e) White water traps

(f) Ferolite trap

Figure 1.3.6 UK field site showing the different trap types tested

1.3(2a) Does trap colour affect trap catch in outdoor and protected strawberry? (KU)

Introduction

Trap colour has been identified as a key component in thrips trapping. Blue traps of a specific shade are considered the most attractive to *F. occidentalis* (Brødsgaard, 1989; Gillespie & Vernon, 1990) and blue traps caught more thrips than yellow, clear or black traps in 2011 experiments (Sampson and Kirk, 2012). The literature suggests that white traps are also attractive, particularly in outdoor crops (Moffitt, 1964: Yudin, Mitchell & Cho, 1987; Hoddle, Robinson & Morgan, 2002). The aim of this experiment was to compare trap catch white and blue traps in protected and outdoor strawberry with a view to identifying the most attractive colour for leg row traps, which may be exposed to direct sunlight.

Methods – For full methods see Objective 1, General Methods.

Treatments

Blue sticky trap (Russell IPM, 16 cm x 10 cm) in a semi-protected strawberry crop.

White sticky trap (Russell IPM, 16 cm x 10 cm) in a semi-protected strawberry crop.

Blue sticky trap (Russell IPM, 16 cm x 10 cm) in an outdoor strawberry crop.

White sticky trap (Russell IPM, 16 cm x 10 cm) in an outdoor strawberry crop.

Site details

Sites: Field 3 and field 4 (both first year Camarillo crops, Table 1)

Date: 6-10 August 2012.

Traps per treatment: 15.

Trap spacing within blocks: 2.2 m along the beds.

Trap spacing between blocks: 2.2 m along beds and between beds.

Thrips occupancy, protected crop: 100%, 9.5 thrips/flower, 2.5 flowers /plant.

Thrips occupancy, outdoor crop: 90%, 3.2 thrips/flower, 4.5 flowers / plant.

Thrips species: Protected crop, 69% WFT: outdoor crop, 20% WFT.

Results and conclusions

The outdoor crop trial site and traps are shown in Figure 1.3.6a. The maximum and minimum temperature and humidity during experiment 1.3 are shown in Table 1.3.4 and the mean trap catch in outdoor and protected strawberry on different trap colours is shown in Figure 1.3.7.

Table 1.3.4. Environmental conditions within the plastic house during experiments 1.3 (2a).

	Outdoor crop		Protected crop	
	Minimum	Maximum	Minimum	Maximum
Temperature (°C)	14	37	16	40
Relative humidity (%)	27	88	36	91

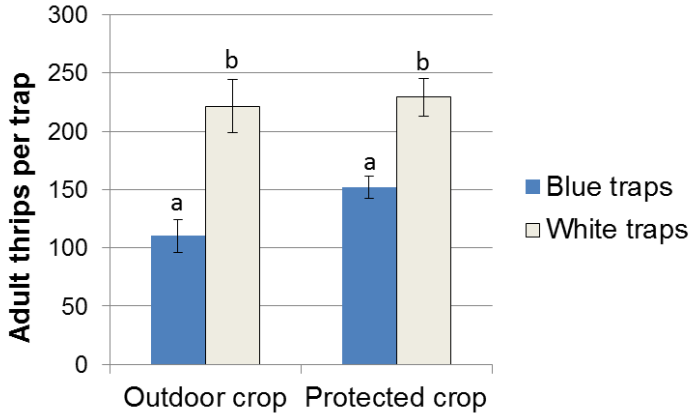

Figure 1.3.7. Mean catch ± S.E. of thripids on blue or white sticky traps in outdoor or semi-protected strawberry crops.

The white traps attracted significantly more thrips (mixed species) than the blue traps in the outdoor crop (x2, $F_{(1,14)}$=49.4, P<0.001), and the protected crop (x1.5, $F_{(1,14)}$=16.02, P=0.002). The white traps were a very bright white as compared to the blue tested and thrips are known to be attracted to bright colours. Although the thrips were very easy to see on the white traps one disadvantage could be that the white traps attract a wider range of insect species including predators which could contaminate the traps. Further assessment will be done to quantify this.

1.3 (2b) Does the trap thickness affect thrips trap catch? (KU)

Introduction

The aim of this experiment was to help inform whether trap thickness affects the trap catch of thrips. Thrips are most frequent on the shaded side of traps and to bright colours and it is possible that they are most attracted to traps that are brighter (more light shining through them) or with more contrast to the background.

Methods – For full methods see Objective 1, General Methods.

Treatments

Control = blue sticky trap, 0.5 mm thick (10 cm x 25 cm, Russell IPM).
Thick = three blue sticky traps stuck together, 1.5 mm thick (10 cm x 25 cm, Russell IPM).

Site details

Site: Field 2 (second year Finesse, Table 1).
Date: 21-24 June 2012
Traps per treatment: 18.
Trap spacing within rows: 4.4 m along a tunnel.
Trap spacing between rows: 8.8 m.
Trap orientation: South facing.
Thrips occupancy: 100%, 11 thrips /flower, 0.2 flowers /plant.
Thrips species: 88% WFT.

Results and conclusions

The weather was largely overcast maximum and minimum temperature and humidity during experiment 1.3 (2b) are shown in Table 1.3.5 and the mean trap catch on standard or thick trap types is shown in Figure 1.3.8.

Table 1.3.5 Environmental conditions within the plastic house during experiment 1.3 (2b).

	Minimum	Maximum
Temperature (°C)	13	24.5
Relative humidity (%)	65	88

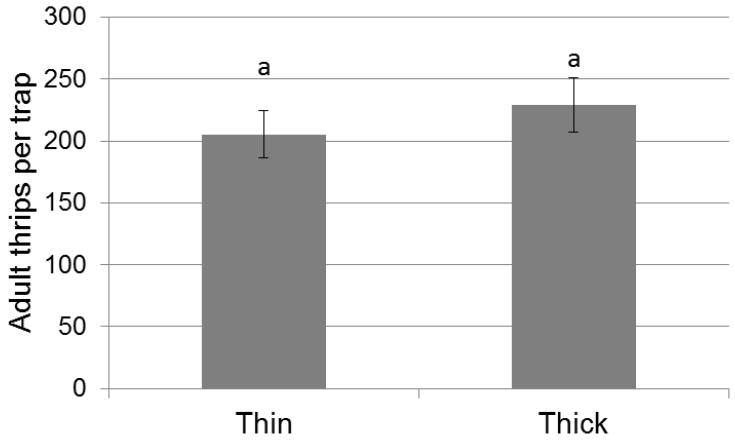

Figure 1.3.8 Mean trap catch ± S.E. of thripids on thick or thin traps. Bars with the same letter are not significantly different.

Trap thickness did not affect trap catch ($F_{(1, 17)}$=1.45, P=0.245 ns), although the weather was overcast, so there may have been less contrast between the trap types. On both trap types 83% of the thrips were caught on the northern side of the traps.

1.3 (2c) Does a cylinder trap catch more F. occidentalis than a flat trap? (KU)

Introduction

The aim of this experiment was to help inform whether a cylinder trap affects the trap catch of *F. occidentalis*. As more thrips have been found on the shaded side of traps and thrips show cryptic behaviour, a cylinder trap may increase trap catch by offering shelter from the sun at all times of the day or by ensuring it faces in all directions.

Methods – For full methods see Objective 1, General Methods.

Treatments

Control = blue sticky trap (10 cm x 25 cm, Russell IPM).

Cylinder = blue sticky trap (10 cm x 25 cm, Russell IPM) clipped into a cylinder shape (10 cm high x 7.5 cm diameter, Figure 1.3.6b)

Site details

Site: Field 2 (second year Finesse, Table 1).

Date: 21-24 June 2012.

Traps per treatment: 11.

Trap spacing within rows: 4.4 m along a row

Trap spacing between blocks: 8.8 m.

Thrips occupancy in flowers: 100%, 11 thrips /flower, 0.2 flowers /plant.

Thrips species: 88% WFT.

Results and conclusions

The maximum and minimum temperature and humidity during experiment 1.3 (2c) are shown in Table 1.3.6 and the mean trap catch on standard or thick trap types is shown in Figure 1.3.9.

Table 1.3.6 Environmental conditions within the plastic house during experiment 1.3 (2c).

	Minimum	Maximum
Temperature (°C)	13	24.5
Relative humidity (%)	65	88

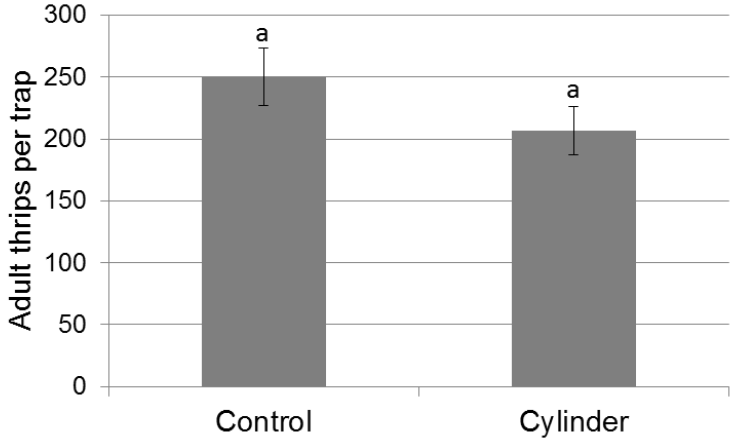

Figure 1.3.9 Mean trap catch ± S.E. of thripids on flat or cylinder traps. Bars with the same letter are not significantly different.

Fewer thrips were found on the cylinder traps (x 0.83), although the difference was not statistically significant ($F_{(1, 10)}$=3.77, P=0.08 ns). The cylinder traps show a smaller area of blue to the thrips which might explain the lower thrips catch. 83% of thrips were found on the north side of the flat traps and 87% of thrips were found on the outside of the cylinder traps, so relatively few thrips were flying inside the cylinder traps. Flat traps are therefore recommended as they are easier to erect and observe.

1.3 (2d) Do water or funnel traps catch more F. occidentalis than sticky traps? (KU)

Introduction

Thrips are able to escape from sticky traps, so the aim of this experiment was do determine whether alternative designs would increase trap catch by preventing escapes.

Methods – For full methods see Objective 1, General Methods

In this experiment the traps were placed in the leg area between strawberry tunnels.

Treatments

Control = blue sticky trap (10 cm x 25 cm, Russell IPM) 50 cm off ground.
Blue water trap = a blue water trap placed on the ground (Figure 1.3.6d) (45 cm diameter, Russell IPM), containing soapy water, approx. 2 cm deep.
White water trap = a white water trap placed on the ground (Figure 1.3.6e) (45 cm diameter, Russell IPM), containing soapy water, approx. 2 cm deep.
Yellow funnel trap = a translucent funnel with a bright yellow funnel lid (Figure 1.3.6c), containing soapy water, approx. 2 cm deep.

Site details

Site: Field 2 (second year Finesse, Table 1).
Date: 22–23 August 2012
Traps per treatment: five.
Trap spacing within rows: 4.4 m along a tunnel.
Trap spacing between blocks: 8.8 m.
Thrips occupancy of flowers: 100%, 20.6 adult thrips/flower, four flowers /plant.
Thrips species: 97% WFT.

Results and conclusions

The maximum and minimum temperature and humidity during experiment 1.3 (2d) are shown in Table 1.3.7 and the mean trap catch using different trap types is shown in Figure 1.3.10.

Table 1.3.7 Environmental conditions within the plastic house during experiment 1.3 (2d).

	Minimum	Maximum
Temperature (°C)	14.5	23
Relative humidity (%)	67	86

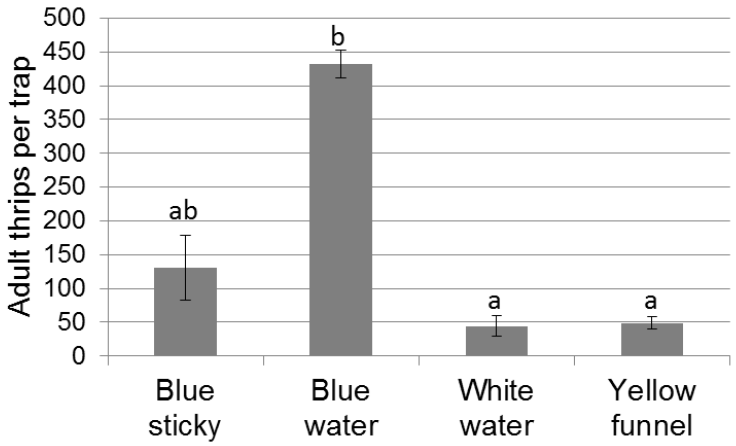

Figure 1.3.10 Mean trap catch ± S.E. of thripids in different trap types. Bars with the same letter are not significantly different.

The blue water trap caught x3 more thrips than the blue sticky traps, x9 more thrips than the yellow funnel traps and x10 more thrips than the white water trap ($F_{(3, 12)}$=10.19, P=0.001). Although the blue water trap caught x3 more thrips than the blue sticky trap, it also had approximately x3 more exposed trapping surface area (1590 cm^2 vs 500 cm^2), therefore the thrips catch related directly to the area of blue rather than the trap design and either design could be used equally effectively.

In contrast to experiment 1.3.2a, where white sticky traps caught more thrips than blue sticky traps, blue water traps caught more thrips than white water traps. This may be because the 'white' water traps (figure 1.3.6e) were a dull translucent plastic unlike the bright white of the sticky trap tested (figure 1.3.6a). Colour brightness is important in trap catch as well as colour wavelength in attracting thrips. Although many thrips were observed landing on the attractive yellow colour of the funnel trap, relatively few were drawn inside and experiment 1.3.2g tested whether semiochemicals would draw the thrips into the funnel traps.

The best choice of trap may depend on cost and practicality, rather than type, but consistent with previous experiments the trap colour is the most important factor for attraction (specific shades of blue and bright white being the most attractive) and the larger the area of that colour, the more thrips are caught.

1.3 (2e) Do LED lights increase F. occidentalis trap catch? (KU)

Introduction

Thrips are known to aggregate on bright surfaces. The aim of this experiment was to determine whether the addition of LED lights would increase trap catch.

Methods – For full methods see Objective 1, General Methods.

In this experiment the traps were placed in the legs between strawberry tunnels

Treatments

Control = blue water trap (Ferolite, Russell IPM, figure 1.3.6f) with LED light turned off.
LED (Light emitting diodes) = a blue water trap (Ferolite, Russell IPM) with LED light turned on.
The Ferolite trap is a solar powered light (wavelength to add) trap made of polypropylene. The water trap base is 45 cm diameter and the light is 12 cm above the base. The solar panel charges during the day, then a sensor turns the light on in the evening in response to low light levels.

Site details

Field: 2 (second year Finesse, Table 1).
Date: 22-23 August 2012
Traps per treatment: five.
Trap spacing within rows: 4.4 m along a tunnel.
Trap spacing between rows: 8.8 m.
Thrips occupancy: 100%, 20.6 adult thrips/flower, four flowers /plant.
Thrips species: 97% WFT.

Results and conclusions

The maximum and minimum temperature and humidity during experiment 1.3 (2e) are shown in Table 1.3.8 and the mean trap catch using different trap types is shown in Figure 1.3.11.

Table 1.3.8. Environmental conditions within the plastic house during experiment 1.3 (2e).

	Minimum	Maximum
Temperature (°C)	14.5	23
Relative humidity (%)	67	86

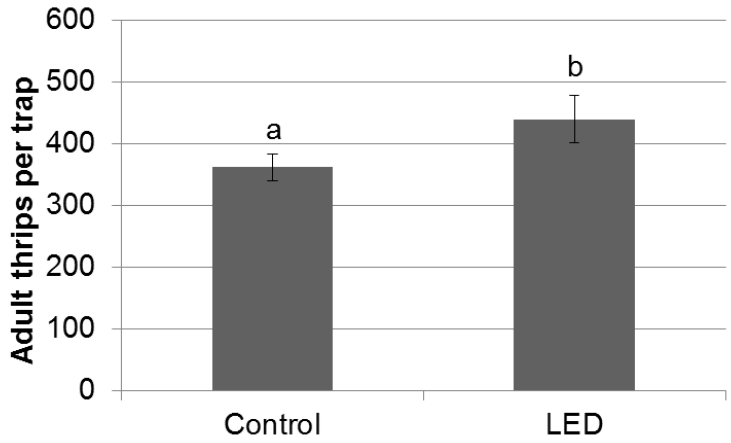

Figure 1.3.11 Mean trap catch ± S.E. of thripids in water traps with or without LED lights. Bars with the same letter are not significantly different.

The blue water trap with LED lights caught more thrips (x1.2) than blue water traps without LED lights ($F_{(1, 4)}$=9.68, P=0.036). LED lights could be used to increase trap catch and the results confirm the importance of light in thrips attraction. The increase in trap catch with LED lights was similar to that with added scents, therefore the best option for growers to maximise trap catch will depend on cost and practicality.

1.3 (2f) Does the trap type affect response to pheromone? (KU)

Introduction

Pheromone increases trap catch, but thrips can escape from sticky traps and it is possible that the pheromone could increase escape by making the thrips more active. The aim of this experiment was to determine whether increased trap catch is higher in water traps with pheromone, where escape is less likely, than with sticky traps with pheromones.

Methods – For full methods see Objective 1, General Methods.

In this experiment the traps were placed in the leg areas between strawberry tunnels

Treatments

Water trap control = blue water trap (Ferolite, Russell IPM) with blank septum.
Water trap NSMB = blue water trap (Ferolite, Russell IPM) with 30 µg neryl (*S*)-2-methylbutanoate (in 30 µl hexane) in septum.
Sticky trap control = blue sticky traps with blank septum (30 µl hexane).
Sticky traps NSMB = blue sticky trap with 30 µg neryl (*S*)-2-methylbutanoate (in 30 µl hexane) in septum.

Site details

Site: Field 2 (second year Finesse, Table 1).

Date: 22–23 August 2012

Traps per treatment: 13.

Trap spacing within rows: 4.4 m along a tunnel.

Trap spacing between rows: 8.8 m.

Thrips occupancy: 100%, 21 adult thrips/flower, four flowers /plant

Thrips species: 97% WFT.

Results and conclusions

The maximum and minimum temperature and humidity during experiment 1.3 (2f) are shown in Table 1.3.9 and the mean trap catch using different trap types is shown in Figure 1.3.12.

Table 1.3.9 Environmental conditions within the plastic house during experiment 1.3 (2f).

	Minimum	Maximum
Temperature (°C)	14.5	23
Relative humidity (%)	67	86

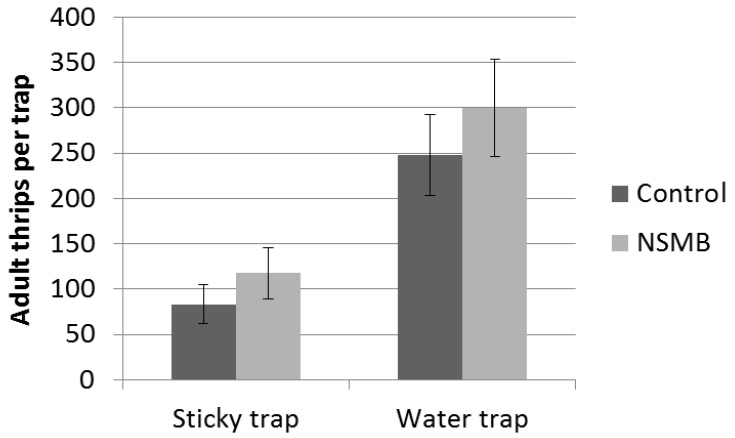

Figure 1.3.12 Mean trap catch ± S.E. of thripids in blue water traps or on blue sticky trap with or without pheromone. NSMB=neryl (*S*)-2-methylbutanoate

The pheromone increased trap catch in both trap types (x1.4 sticky traps, x1.2 water traps), although the differences were not statistically different ($F_{(1,18)}$=0.9, P=0.356) because the variance between the trap types masked the variance between traps with and without scents. The water traps caught more thrips than the sticky traps (x1.3, $F_{(1,18)}$=38.48, P<0.001). There was no difference in response to pheromone between the trap types (interaction between trap type x presence of scent, $F_{(1,18)}$=0.0, P=0.96) therefore both sticky traps and water traps are equally effective, consistent with previous experiments.

1.3 (2g) Do semiochemicals draw thrips into the yellow funnel traps? (KU)

Introduction

Thrips were observed aggregating in large numbers on the outside lid of funnel traps, attracted to the bright yellow colour, however few were caught inside the traps. The aim of this experiment was to see whether semiochemicals (pheromone or plant volatile) would draw the thrips into the funnel traps to increase trap catch.

Methods – For full methods see Objective 1, General Methods.

In this experiment the traps were placed in the leg areas between strawberry tunnels

Treatments

Control = Funnel trap (Russell IPM) with empty lure cage hung inside the trap on a string.
NSMB = Funnel trap (Russell IPM) with 30 µg neryl (*S*)-2-methylbutanoate (in 30 µl hexane) in septum hung inside the traps.
MIN = Funnel trap (Russell IPM) 250 µl neat methyl isonicotinate in a sachet hung inside the trap

Site details

Site: Field 2 (second year Finesse, Table 1).
Date: 22–23 August 2012
Traps per treatment: seven.
Trap spacing within rows: 4.4 m along a tunnel.
Trap spacing between rows: 8.8 m.
Thrips occupancy: 100%, 21 adult thrips/flower, four flowers /plant.
Thrips species: 97% WFT.

Results and conclusions

The maximum and minimum temperature and humidity during experiment 1.3 (2g) are shown in Table 1.3.10 and the mean trap catch using different trap types is shown in Figure 1.3.13.

Table 1.3.10 Environmental conditions within the plastic house during experiment 1.3 (2g).

	Minimum	Maximum
Temperature (°C)	14.5	23
Relative humidity (%)	67	86

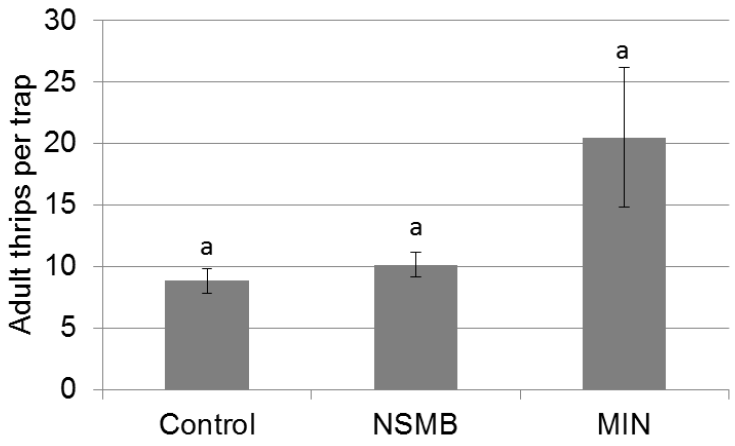

Figure 1.3.13 Mean trap catch ± S.E. of thripids in funnel traps with or without scents. Bars with the same letter are not significantly different.

In this experiment there was no significant overall effect ($F_{(2,10)}$=3.46, P=0.072), although there were more than twice as many thrips in the traps with methyl isonicotinate as in control traps. There was a possible small increase in trap catch (catching 20 thrips/day), but still not enough to match the trap catch with blue sticky or water traps (catching 100 to 400 thrips/day in the same field and on the same date). Yellow funnel traps are not recommended for trapping of thrips.

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

Summary

To advise growers on the areas that were of greatest risk to thrips and therefore where to sample for thrips, further information was required about the distribution of thrips within and between fields. *Frankliniella occidentalis* was shown to overwinter in senescent/dead strawberry flowers and weeds, such as chickweed, groundsel and dandelion. This 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 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 populations had established in fields, they were found throughout the crops monitored, but the number of thrips was greater in the mid to top sections of the fields (excluding the tunnel ends and sides). The distribution of thrips correlated with temperatures, which were higher in the top/middle sections of the polytunnels.

Before flowering, the use of blue sticky traps (vertical orientation) with a pheromone lure placed on canes 10 cm above the crop bed was the most effective monitoring method. The addition of pheromone increased trap catch by x3. From first flowering, counts of adult thrips in medium aged open flowers a more accurate monitoring method than trap counts. Comparison of population estimates by four samplers demonstrated that, following a short training session (5 minutes) on identification using a hand-out, farm staff counted adult thrips in flowers accurately. Analysis of the spatial variation in flower count and thrips density within commercial crops was used to estimate the numbers of flower samples necessary to estimate thrips numbers at levels around the damage threshold.

It is proposed that counts of thrips in 10-20 flowers would be sufficient for growers to get a good idea of thrips numbers in a particular area, but further analysis is needed to recommend a sampling programme. The possibility of reducing sampling time by using binomial (presence/absence) sampling was tested. Thrips occupied all flowers when the mean thrips/flower was approximately 4 thrips/flower in the variety Camarillo, which may be a useful indicator of damage in high risk situations (e.g. in second year crops without predators, in hot/dry conditions). However this method would not be sensitive enough at higher thresholds. Further development of this threshold scoring will be done in 2013.

To help determine the relationship and timing between thrips per flower and fruit damage, the distribution of thrips on strawberry plants and timing of fruit damage was examined. On strawberry plants, 74% of adult thrips were found in the flowers, with the rest spread between fruit of different stages of ripeness. Larvae were mostly on flowers (40%) and young fruit (38%), with the rest on mature fruit and very few thrips were present on leaves. All stages of flowers and fruit were damaged by both adult and larval *F. occidentalis*, with larvae doing about twice as much damage as adults, possibly because they do more feeding than adults. The greatest amount of damage to fruit occurs at the end of flowering when the flowers are senescent and larval numbers are at their highest, although further damage occurs throughout fruiting. The influence of flower flushes was identified as a key factor in the timing of damage, damage occurring soon after the end of flower flushes when thrips are concentrated into fewer flowers, but further work will be done in 2013 to examine damage thresholds further. Fruit damage occurred when thrips damage was approximately between four and eight adult thrips per flower, however there were crops with high damage and low thrips numbers and crops with high thrips numbers and low damage. Further work will be done to separate factors affecting fruit damage, as well as quantifying the amount of damage that results in downgrading of fruit.

1.4.1 Flower monitoring

In 2011 we concluded that counting adult thrips per flower gave a better correlation with fruit damage than trap counts, and that medium aged flowers (avoiding newly opened and senescent flowers) should be sampled. In order to advise growers how many flowers to sample, when to start monitoring and where to take samples from, further information was required on the distribution of thrips within and between fields. Following a short training session, differences between samplers was analysed to confirm that the sampling method was effective and easy to use for growers. Analysis of spatial variation in flower count and thrips density within crops was used to show how many flowers are needed for monitoring and to examine the possibility of using binomial (presence/absence) sampling to reduce sampling time.

1.4 (1a) Monitoring overwintering thrips populations. (KU)

Introduction

The aim of this monitoring was to determine whether sticky traps (with or without pheromone) provide a useful early season monitoring tool (before flowering), and to determine when thrips become active in the season, so that growers can plan monitoring and control methods.

Methods

Site details: Three fields were monitored (Table 1):

Field 2 (second year Finesse).

Field 4 (first year Camarillo).

Field 5 (second year Camarillo).

Visit dates: 8 Nov 11, 18 Nov 11, 29 Nov 11, 6 Dec 11, 15 Jan 12, 22 Jan 12, 3 Feb 12, 22 Feb 12, 21 March 12.

Trap monitoring

Two pairs of blue sticky traps (25 cm x 10 cm, Russell IPM) were set up in each of the three monitoring fields. Each pair consisted of one trap with and one trap without a pheromone lure (Thripline AMS, Syngenta Bioline). Traps were placed at least 20 m in from the ends of the tunnels to reduce sunlight and edge effects with at least 20 m between pairs and with 10 m between traps within a pair. The trap positions (with and without pheromones) within a polytunnel were alternated within each pair, with the first position chosen randomly on the first monitoring date. The traps were stuck vertically onto bamboo canes with the base of the traps about 10 cm above crop (landscape orientation). The canes were pushed into the ground so that the tops of the posts would fit under a tractor. The pheromone lures were placed in green plastic lure-holders with slits (25 mm diam., 50 mm long, Russell IPM) slotted over the bamboo canes with a small wire loop (see Year 2 report) with the cage hanging on the north side of the trap shaded from direct sunlight.

The controls used a cage containing a blank natural rubber septum identical to that used for the pheromone (6.3 mm diam. × 10.8 mm long; International Pheromone Systems Ltd.) that had been solvent cleaned and dried in an oven at 50°C. All traps were south facing with the printed grid side of the trap facing north. Traps and lures were replaced on each visit and the traps placed in a polythene wrapper and stored in a freezer. The numbers of thripids were counted and sexed under a binocular microscope in the Keele laboratory. Aeolothripid (with broad wings) and phlaeothripid thrips (with a tube at the end of the abdomen) were excluded from the counts. Lascar data loggers were placed in white delta traps (to shade from the sun) in the canopy, 5 cm above the bed in each polytunnel to record temperature and humidity.

Comparison was made between pheromone and control traps used Wilcoxon matched-pairs signed-ranks tests. Statistical analysis was carried out with Minitab 16.

Plant monitoring

On each site visit, five dead strawberry flowers (flowers that had not set at the end of the 2011 season) and samples of five dandelion, groundsel and chickweed plants were collected where present (these were the most common weed species identified during the 2011 field season). The flowers were placed in a tube with 80% industrial methylated spirits. Thrips were extracted later and placed on slides for identification.

Results and conclusions

Overwinter temperatures in the strawberry canopy at the monitored farm in Staffordshire are shown in Table 1.4.1, showing that maximum air temperatures were largely below 15°C from December 2011 to February 2012. The mean numbers of thrips on blue sticky traps, with and without pheromones and the presence of *F. occidentalis* in weeds and strawberry flowers is shown in Table 1.4.1.

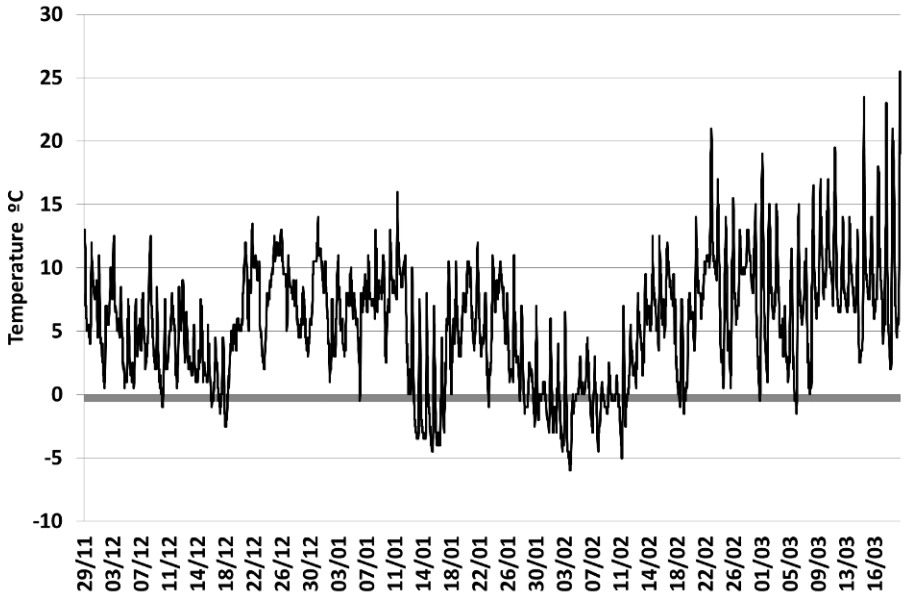

Figure 1.4.1. Overwinter temperatures at Manor Farm, Staffordshire 2011-2012.

Table 1.4.1. Mean numbers of thripidae on blue sticky traps with or without pheromone (n=6) and presence or absence of *F. occidentalis* in collected flowers (weeds or dead strawberry). Minimum and maximum temperatures are shown.

Week Number	**44**	**48**	**4**	**5-7**	**8-11**
MaxTemp (°C)	15.5	12.5	11	12.5	25.5
Min Temp (°C)	4	1	-4.5	-6	-1.5
Mean thrips/trap (control)	3.5	0	0	0	5.83
Mean thrips/trap (+ pheromone)	16.5	0.5	0.2	0	10.5
Presence of *F. occidentalis* in weeds or dead strawberry flowers*	✓	✓	✓	✓	✓

*_Frankliniella occidentalis_ were also collected and identified from flowers of the following weed species within strawberry fields during September 2011: groundsel (_Senecio vulgaris,_ Asteraceae), chickweed (_Stellaria media,_ Caryophyllacae), dandelion (_Taraxacum officinale_, Asteraceae), sowthistle (_Sonchus asper_, Asteraceae), speedwell (_Veronica persica_, Scrophulariacae), hedge mustard (_Sisymbrium officinale,_ Brassicacae), white clover (_Trifolium repens,_ Fabaceae), mayweed (_Tripleurospermum inodorum_, Asteraceae), rape (_Brassica napus,_ Brassicacae), pineappleweed (_Matricaria matricarioides,_ Asteraceae).

Only adult female _F. occidentalis_ were found on traps or in flowers between mid-December and mid-March. No adult males or larvae were found during this time.

Frankliniella occidentalis appears to overwinter as adult females, confirming HDC report SF 80 (Bennison and Fitzgerald, 2009). Live females were found in flowers of weeds and overwintering strawberry plants throughout the winter period, which are therefore a source of thrips in the following season. The use of blue sticky traps to monitor thrips activity before flowering was easy and practical. Trap catch was low or absent between December and February when temperatures were at or below 12.5°C. Pheromone traps caught three times more thrips than blue sticky traps alone, although the difference was not statistically significant (P=0.10). Thrips activity and trap catch increased in March, when maximum canopy temperatures exceeded 20°C. In second year crops, adult _F. occidentalis_ were observed in strawberry flowers as soon as they opened in late March and larvae were widespread in flowers soon after (e.g. 12 April 2012). It is therefore recommended that the thrips population model is started from first flowering of a crop as this is when thrips invade flowers and start to breed.

1.4 (1b) How are thrips distributed between fields? KU

Introduction

Frankliniella occidentalis overwinter in semi-protected strawberry crops and weeds (1.4 (1a)). The aim of this monitoring was to determine whether the carry-over of thrips from first to second year crops affected thrips densities.

Methods

Four first-year and four second-year crops were monitored monthly from May to July 2012 (Table 1.4.2). In each field, flower samples were taken from the same 2.2 m section of bed, at least 22 m in from the edge of the crop. On each occasion ten medium-aged flowers were selected at random and the numbers of adult thrips per flower were recorded.

Table 1.4.2. First and second year crops monitored to compare thrips numbers, 2012.

First year crops			Second year crops		
Field No.	**Variety**	**Field name**	**Field No.**	**Variety**	**Field name**
6	Finesse	5 acre	2	Finesse	12 acre
7	KG EME	KG	9	Finesse	Quarry
4	Camarillo	Taylor's	5	Camarillo	Roadside
8	Camarillo	a	10	Camarillo	b

Results and conclusions

The mean numbers of thrips adults per flower ± SEM in first and second year crops is shown in Figure 1.4.2. On all sample dates there were significantly more thrips in second year crops than in first year crops (Mann-Whitney tests, May *P*=0.027; June *P*=0.029; July *P*=0.029).

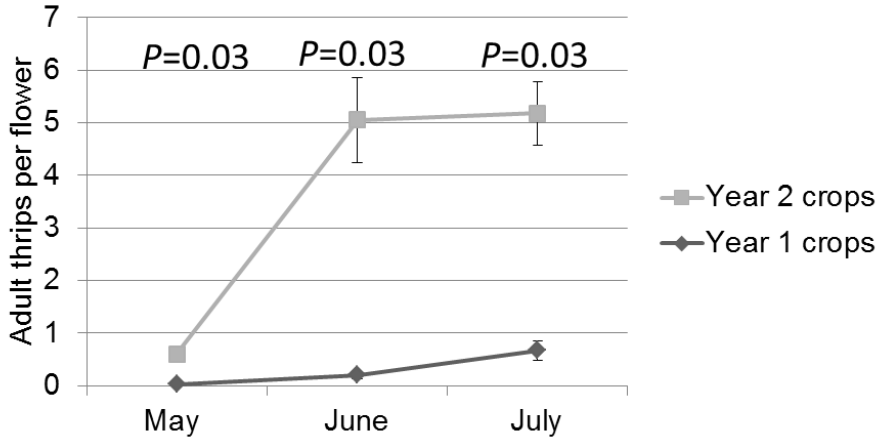

Figure 1.4.2 Mean numbers of adult thripids per flower ± S.E. in first and second year crops.

The overwinter carry-over of thrips from first to second-year crops resulted in significantly more thrips in second year crops compared to first year crops from May to July. On farms with different aged crops, the differences were less pronounced at the end of the season as movement of thrips between fields during August resulted in a more even distribution between fields (Sampson, pers. obs 2012). Growers could reduce thrips risk by growing only first year crops or by reducing the overwintering thrips population.

1.4. (1c) How are thrips distributed within fields? (KU)

Introduction

Fields were monitored in order to identify factors that affect within-field distribution of thrips, to help growers locate the areas which are most at risk of thrips damage and where to sample.

Methods

Early season distribution of thrips in first and second year crops

Two first year and two second year crops (sites a-d below) were monitored on 12 April, around two weeks after first flowering. As no thrips were found in the first year crops in April, the monitoring was repeated on 14 and 23 May. The length and breadth of each crop was divided into ten equal divisions, then sampled in a Z pattern (Figure 1.4.4), so that all areas of the crop was sampled. At each sample point, ten medium-aged flowers were selected arbitrarily and the numbers of thrips per flower counted using a x7 optivisor head lens.

Mid-season distribution of thrips in a second year crop

A second year crop with an established thrips population was monitored on 6 June 2012 (site e below). Samples were taken from five areas, equally spaced, down every six rows of the crop (Figure 1.4.5). At each sample point, five medium-aged flowers were selected at random and the numbers of adult thrips per flower counted. The differences between means were compared by ANOVA on log (n+1) transformed data using Minitab. Figures show untransformed data.

Distribution of thrips across tunnel beds, before and after weeding

Weeds support thrips populations (1.4.1a, Figure 1.4.3b) and a second year crop with an established weed population in the legs between tunnels (Site f, Figure 1.4.3a) was monitored on 9 July 2012, before weeding took place on 16 July and approx. three weeks after weeding on 8 August 2012. Three plots (17.6 m x 11 m) in three separate tunnels were monitored. In each plot, eight medium aged flowers were selected at random from each of five rows within the tunnel, and the numbers of adult thrips per flower were counted. The differences between means were compared by ANOVA on log transformed data using Minitab. Figures show untransformed data.

Site details(for full details see Table 1).

Field 2 (second year Finesse).

Field 4 (first year Camarillo).

Field 5 (second year Camarillo).

Field 8 (first year Camarillo).

Field 10 (second year Camarillo).

(a) **(b)**

Figure 1.4.3 Weeds growing (a) between tunnels in a second year crop and (b) in a planting hole of a grow bag during the winter.

Results and conclusions

The mean numbers of thrips (adults and larvae) per flower from zig-zag monitoring of first and second year crops early in the season is shown in Figure 1.4.4. Thrips are predominantly around the edge of first year crops. Thrips are present throughout the crops in second year crops, with a tendency towards more thrips in the mid/upper areas of the crop.

The distribution of thrips in a second year crop with an established thrips population on 6 June 2012 is shown in Figure 1.4.5. Thrips were found throughout the crop, with the exception of one area, which was right at the bottom of the crop in a cool area, shaded by trees. There was a trend towards increasing thrips numbers with increasing height of the tunnel with fewer thrips at the bottom and near some crop edges ($F_{(19, 80)}$=12.32, P<0.001). Thrips numbers were similar throughout the middle/top areas of the crop and there was no significant difference between thrips numbers in 14 of the 20 monitoring points (figure 1.4.5).

The distribution of thrips across tunnels before and after weeding, in a crop with many weeds in the leg area between tunnels, is shown in Figure 1.4.6. Before weeding, there were significantly more thrips on the outside beds, beside the weedy sections between tunnels ($F_{(4,113)=}$4.58, *P*=0.001**). Three weeks after weeding, the thrips were more evenly distributed with no bias towards the outside beds ($F_{(4,113)=}$1.46, *P*=0.218 ns).

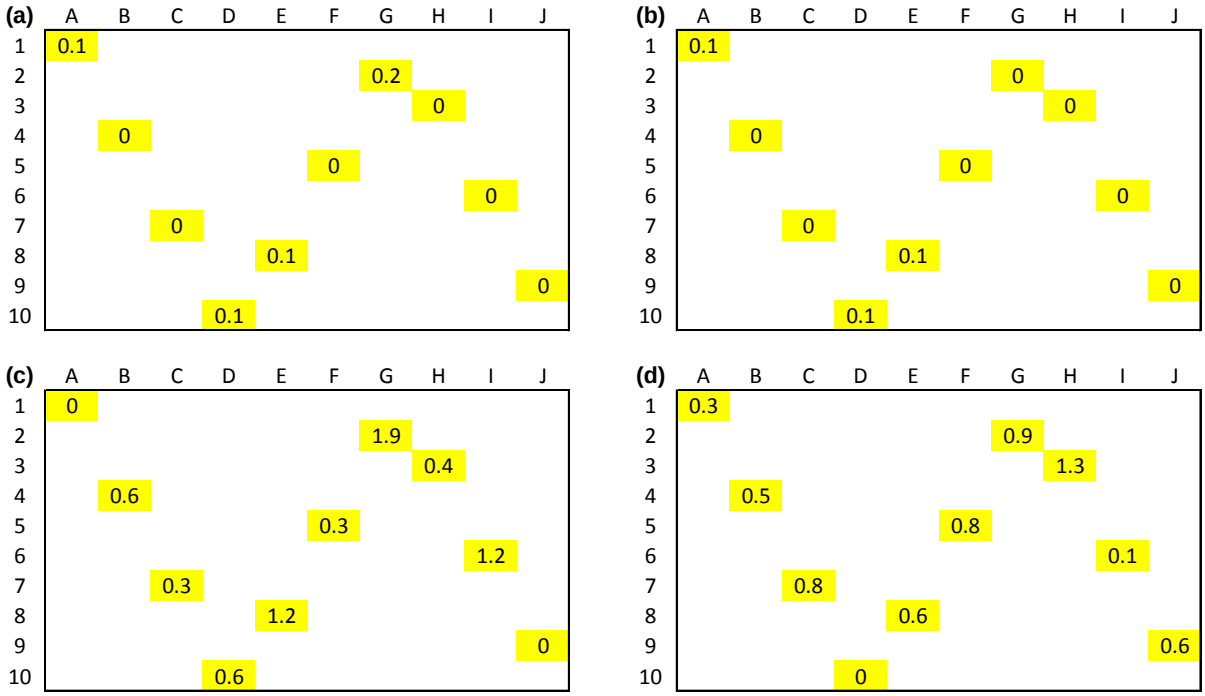

Figure 1.4.4. Mean numbers of thrips adults and larvae per flower (n=10) at each sampling point (marked in yellow) in four different crops (a) first year crop cv Camarillo, Stafford, 14 May 2012 (b) first year crop cv Camarillo, Tamworth, 23 May 2012 (c) second year crop cv Finesse, Tamworth 12 April 2012 (d) second year crop cv Camarillo, 12 April 2012. Tunnel direction is up the page.

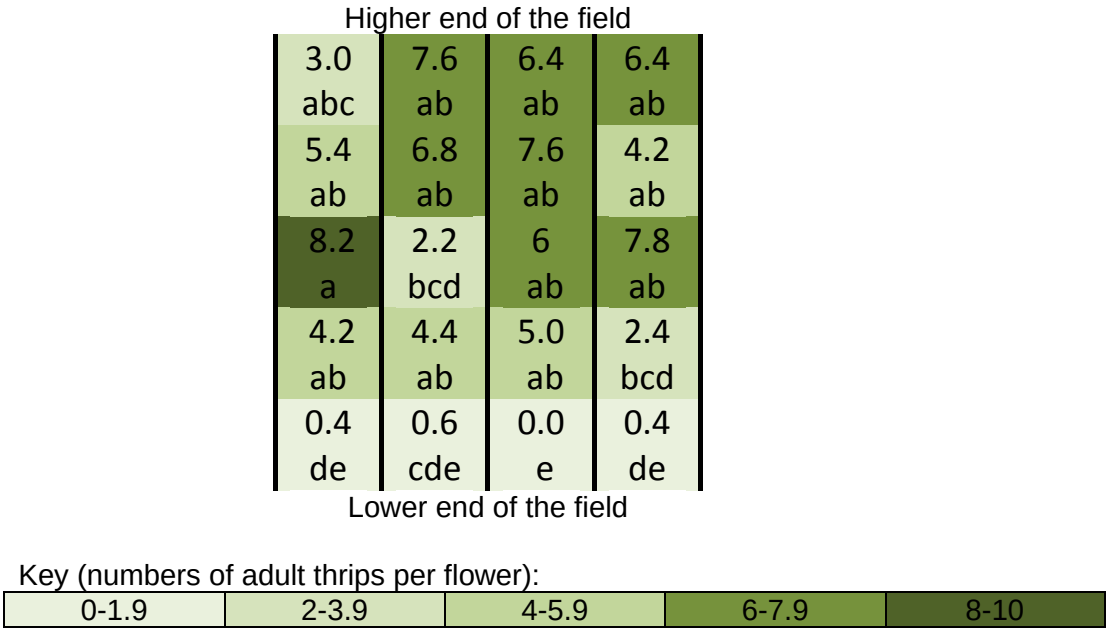

Figure 1.4.5 Distribution of thrips in a second year crop on 6 June, showing mean numbers of adult thrips per flower (n=5). Numbers followed by the same letters are not significantly different. The crop was approx. 1 ha, 64 m wide (8 tunnels x 8 m) by 189 m (86 leg sections x 2.2 m). Tunnel direction is up the page.

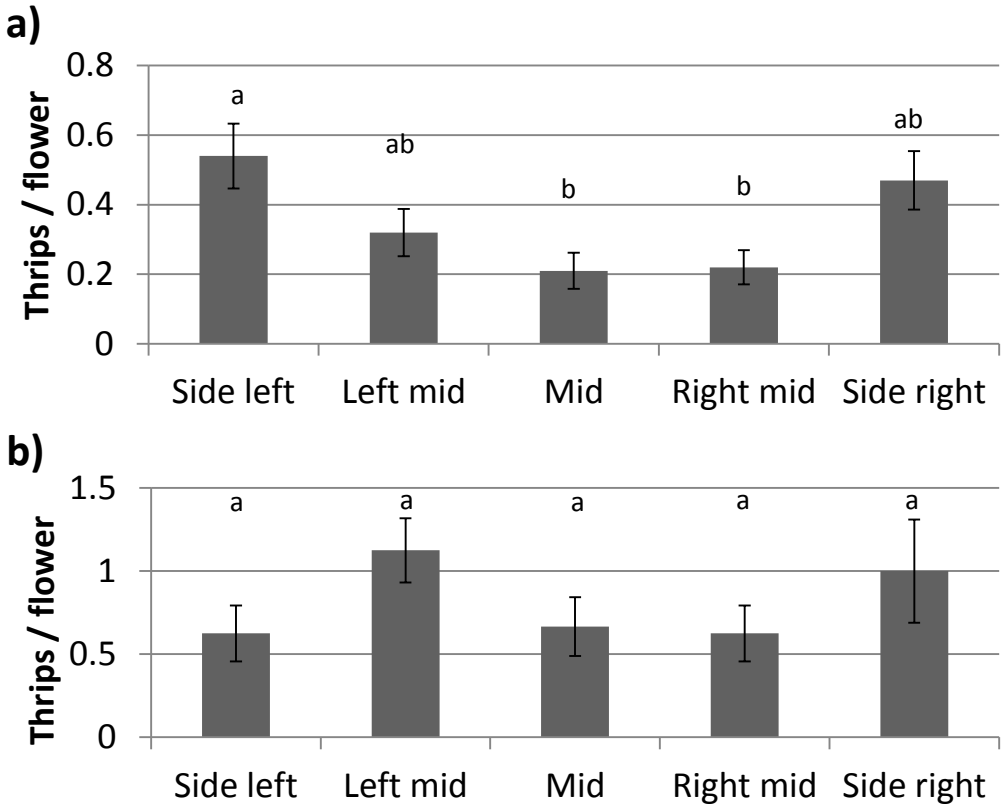

Figure 1.4.6. Distribution of thripids across tunnels (a) before weeding and (b) three weeks after weeding, showing mean thrips adults± SEM per flower. Columns with the same letters are not significantly different.

In the first year crops monitored, no thrips were found in 100 flowers sampled soon after first flowering in April. In May, thrips were concentrated around the edges of the polytunnel, suggesting that most thrips had invaded from outside the crop (Figure 1.4.4 a,b). *Frankliniella occidentalis* was identified from weeds in the field margins as well as in nearby second year crops, so these are the most likely sources of infestation.

In second year crops, thrips were found throughout the polytunnels soon after first flowering (Figure 1.4.4.c,d) confirming that they had over-wintered in the field. Higher numbers of thrips were found towards the middle/upper areas of sloping crop with increasing thrips higher up the tunnels (Figure 1.4.5) and lower numbers of thrips at the lower ends and edges of the tunnels. This trend was observed in other crops, and may be related to maximum temperatures, which increase up the tunnel and are cooler near the tunnel edges. This was examined further in 1.4 (1d) below. Although growers are advised to survey thrips distribution and identify hot-spot areas for each individual field, highest thrips numbers might be expected in the top half of sloping fields, away from the edges in second year strawberry crops.

The distribution and abundance of weeds within and around fields may affect thrips numbers within crops. The monitoring showed that there were more thrips in strawberry beds beside weedy areas between tunnels (Figure 1.4.6). It is likely that thrips breed up in the untreated weeds between strawberry beds and move into the adjacent strawberry plants, increasing the thrips numbers in the side rows. This is a potential problem if using flowering Alyssum as a banker plant for *Orius* spp. or as a trap plant for *Lygus* spp. The availability of flowers is a key factor in the population growth of thrips, so it follows that good weed control would reduce thrips carry-over between crops as well as build-up of thrips numbers within crops.

1.4 (1d) Do temperature gradients within a field affect thrips numbers and distribution?

Introduction

Strawberry crops are grown on slopes to aid irrigation. During sunny periods hot air moves up the polytunnels with resulting higher temperatures towards the top of the tunnels (excluding the open tunnel ends which are cooled by the outside air). The aim of this experiment was to determine whether temperature gradients within tunnels might explain the thrips distribution patterns within polytunnels (see Figure 1.4.5). This would help growers to identify areas of greatest risk to thrips damage and therefore where to sample and/or treat.

Methods

Four tunnels (each 16 m apart, approx. 158 m long) were monitored on 13 September 2012, 12.00 to 1.00 pm. Each tunnel was monitored at 8 positions up the tunnel; 2 m from the bottom end of the tunnel, then at 22 m intervals with the final monitoring point 2 m from the top end of the tunnel. At each monitoring position the height above sea level was measured (Garmin satnav), temperature was recorded at bed level (digital thermometer placed in a delta trap to shade from the sun, recorded after 5 min in situ) and the numbers of adult thrips per flower were counted from five medium aged flowers. The weather was cloudy with occasional periods of sunshine. The differences between means were compared by ANOVA on log transformed data using Minitab. Figures show untransformed data.

Three data loggers were placed at bed level in delta traps near the bottom (95 m), middle (101 m) and top of a tunnel (107 m) on 2 September to 5 October 2012. All data loggers were at least 20 m from the edge of the tunnel. Temperatures were recorded at 30 minute intervals.

Site details: Field 5, second year Camarillo (Table 1).

Results and conclusions

The mean number of thrips ± SEM, mean temperatures on 13 September (12 to 1pm) and mean altitude (m) at different positions up the tunnels is shown in Figure 1.4.7. Thrips numbers increased with the height above sea level ($F_{(7, 152)}$=43.4, P<0.001), but dipped at the exposed tunnel ends. There was no significant difference in thrips numbers between the four tunnels sampled ($F_{(3, 156)}$=0.45, P=0.71 ns). When thrips numbers were regressed against temperatures up the tunnel at the time of sampling there was a significant correlation between mean thrips numbers and temperature ($F_{(2,7)}$=30.73, P=0.002; r^2=89.5%).

The daily maximum and minimum temperature from top, middle and bottom positions up the tunnel from 24 September to 5 October are shown in Figure 1.4.8. Over the 13 day period, the mean maximum temperatures were significantly higher in the middle (25.7°C, 101 m) and top (27.5°C, 107 m) parts of the tunnel than at the bottom of the tunnel (21.9°C, 95 m) ($F_{(2, 36)}$ =13.11, P<0.001). Temperature gradients were reversed at night (Figure 1.4.8).

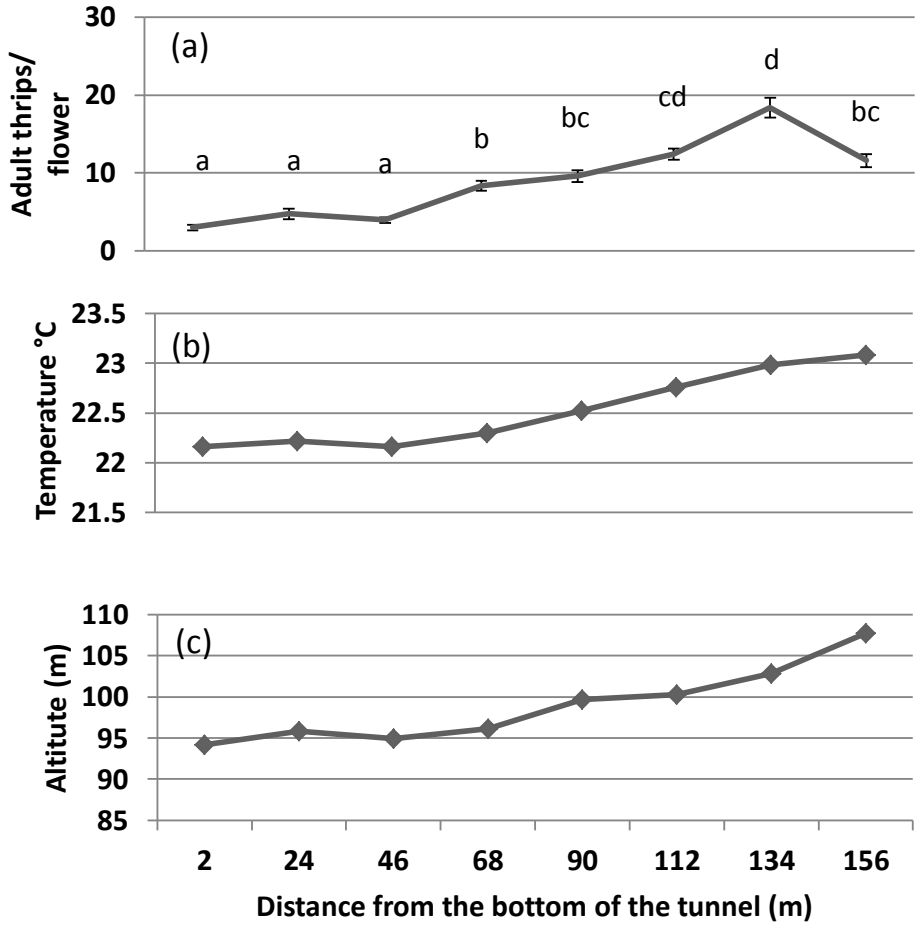

Figure 1.4.7. (a) The mean number of thripids ± SEM, (b) the mean temperature on 13 September, 12-1pm and (c) the mean altitude at different positions up the tunnels.

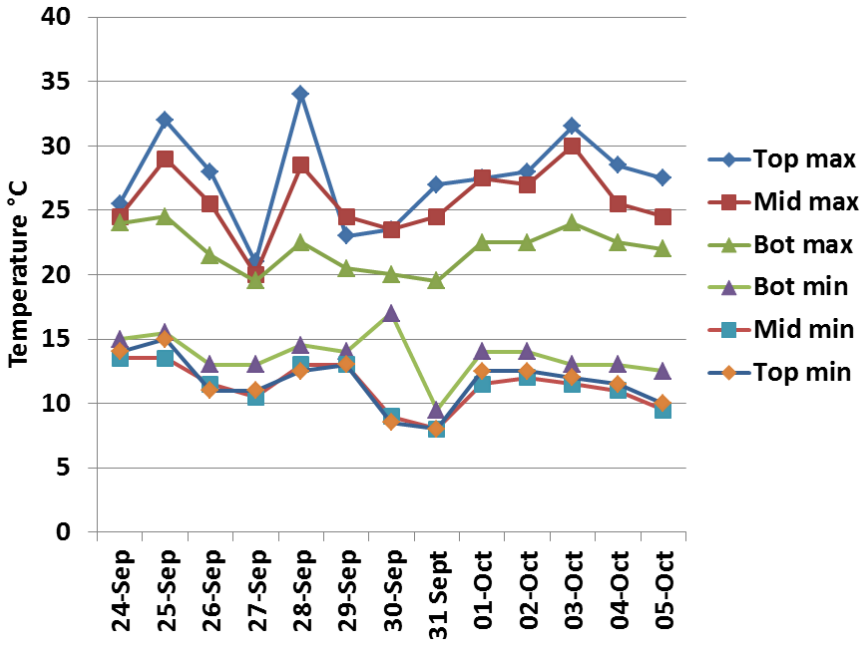

Figure 1.4.8. The daily maximum and minimum temperatures from top (107 m above sea level), middle (101 m) and bottom (95 m) positions up a tunnel from 24 September to 5 October 2012.

Thrips numbers increased with increasing altitude and maximum temperatures up the tunnels (excluding the open end at the top of the tunnel which is cooled by outside air). Over a 13 day period, mean maximum temperatures were 5.6°C higher 22 m from the top end of the tunnels than at 22 m from the bottom. Higher temperatures increases thrips egg-laying/activity and decreases generation time, explaining the higher thrips numbers. In addition, the thrips may get blown up the tunnels on rising warm air-currents when the sun comes out. In all four second year crops monitored, thrips were at higher densities in the upper/mid areas of crops, away from the open tunnel ends. Individual fields have other influences and specific hot-spots (e.g. adjacent crops, prevailing wind, weed control, spraying etc), but tunnel temperature has significant effect on thrips numbers. Highest thrips numbers are predicted to be near the top of the tunnels at least 20 m from the open ends/side tunnels.

1.4. (1e) Is flower sampling easy to use and accurate? (KU)

Introduction

The aim of this experiment was to determine whether counting thrips per flower in the field with a x10 hand lens gives a reliable estimate of thrips numbers and whether this method can be used by farm staff following a short training. If reliable, this quick and easy method could be used to determine damage thresholds.

Methods

A training hand-out was given to four samplers (two experienced advisors and two inexperienced farm staff) with instructions on how to count the numbers of adult thrips per flower. The hand-out explained which flowers to sample and what to count, with pictures of thrips to aid identification. Each sampler examined 30 separate flowers and recorded the number of adult thrips per flower. At the same time 30 flowers were placed into tubes of alcohol and the number of thrips counted later under a binocular microscope. The first samples were taken about 15 m from the open end of the tunnel and samplers moved down the tunnel together so that flowers were taken from the same area of crop. Two crops were sampled, one with high and one with low numbers of thrips. Data were transformed to log (n+1) for analyses with ANOVA using Minitab.

Site details (for full details see Table 1):
Field 2, high thrips numbers (second year Finesse).
Field 4, low thrips numbers (first year Camarillo).
Date: 6 June 2012, alcohol samples assessed on 7 June 2012.

Results and conclusions

The mean number of adult thrips ± SEM recorded by different samplers and alcohol counts, from two fields is shown in Table 1.4.3.

Table 1.4.3. The mean numbers of adult thripids ± SEM per flower and comparisons between different samplers compared to counts from flowers in alcohol, from fields with low and high thrips numbers. Means followed by the same letter within each row are not significantly different.

Field (cv)	Mean numbers ± SEM of thrips per flower					Comparison between samples
	Experienced samplers		Inexperienced samplers		Alcohol samples	
	1	2	3	4		
12 acre (Finesse)	7.0 ± 0.50 a	3.2 ± 0.50 b	6.0 ± 0.78 a	6.6 ± 0.67 a	5.7 ± 0.69 a	$F_{(4, 145)}$=8.24 P<0.001
Taylors (Camarillo)	0.07 ± 0.06 a	0.10 ± 0.05 a	0 ± 0 a	0 ± 0 a	0.03 ± 0.03 a	$F_{(4, 145)}$=1.48 P=0.21 ns

Power analysis

30 samples gave a power of 0.99. Including counts from sampler 2, 21 flowers samples would be needed for a power of 0.8.

With the exception of sampler 2 in the field with higher thrips numbers, none of the estimates by different samplers were significantly different from the absolute thrips counts from flowers placed in alcohol. Sampler 2 (an experienced advisor) was deliberately estimating thrips numbers quickly as done when crop walking and was not doing an exact count of thrips above 10 per flower, which brought down the mean for high thrips densities. The samplers were able to count adult thrips numbers per flower accurately with a minimum of training and it was concluded that this method would be reliable for field monitoring. Feedback on the training sheet indicated that the addition of photographs of insect species that look similar to thrips should be added (e.g. springtails). Further analysis of the numbers of samples required to estimate populations (sample size) and the possibility of using binomial (presence/absence) sampling to reduce sampling time is investigated in 1.4 (1f).

1.4. (1f) Sample size (KU)

Introduction

Thrips are known to aggregate and can have a patchy distribution. Analysis of spatial variation in flower count and thrips density within commercial crops was used to estimate how many flowers are needed for monitoring.

Methods

Sampling methods and site details

Four Camarillo crops (Table 1.4.4) were monitored monthly from April to August 2012. On each sample date, the length and breadth of each crop was divided into ten equal divisions, then sampled in a Z pattern (Figure 1.4.4), so that all areas of the crop were sampled. At each sample point, ten medium-aged flowers were selected arbitrarily and the numbers of adult thrips per flower counted using a x7 optivisor head lens. In total 2000 individual Camarillo flowers were sampled.

Analysis of data from 2011 in the variety Camarillo and from 2012 in the variety Finesse is ongoing.

Table 1.4.4. Fields used for trapping and monitoring experiments in UK strawberry.

Field No.	Location (field name)	Area (ha)	No. of tunnels	Growing system	Variety	Crop year
4	Tamworth (Taylor's)	2.1	14	Growbags	Camarillo	1
5	Tamworth (Road)	2.4	22	Beds	Camarillo	2
8	Stafford (a)	21.4	40	Beds	Camarillo	1
10	Stafford (b)	21.4	40	Beds	Camarillo	2

Sub-samples of thrips will be identified to species from the different fields and sample dates over the winter period (see General Methods).

Analysis of spatial distribution and sample size

Aggregation indices were calculated using Taylor's power law (Taylor, 1961) which has been used extensively to describe thrips populations (e.g. Steiner and Goodwin, 2005; Navarro-Campos *et al.*, 2012). Taylor's power law relates mean density (m) to variance (s^2) by the equation $s^2 = a\ m^b$, where s^2 is the sample variance, m is the sample mean density, 'a' is a scaling factor relating to sample size and b is Taylor's index of aggregation. A regression after log-log transformation ($\log s^2 = \log a + b \log m$) is used to estimate the coefficients (a and b). An aggregation index above 1 indicates clumped populations. Taylors' coefficients were then used to calculate the minimum sample size (n) required to estimate density at 2 precision levels (80% and 90% accuracy) using $n = a\ m^{b-2}/D^2$ (Green, 1970) where D=0.2 or 0.1.

The possibility of using binomial sampling was investigated by comparing the mean number of thrips per flower with percentage flowers infested. The mean value (m) was adjusted using the equation $m^{1-0.5b}$ (Southwood, 1978) to give a linear relationship when graphed against percentage flowers occupied.

Results and conclusions

The relationship between mean thrips/flower and variance for the Camarillo crops which estimates Taylors' coefficients a=0.1021 and b=1.114, is shown in Figure 1.4.9. The number of flower samples needed for sampling thripids in strawberry flowers (cv Camarillo), based on the number of thrips per flower, to achieve a fixed precision level of 0.2 or 0.1 is shown in Figure 1.4.10 for means from the fields sampled and for specific thrips densities in Table 1.4.5. The relationship between numbers of thrips per flower and percentage of occupied flowers is shown in Figure 1.4.11.

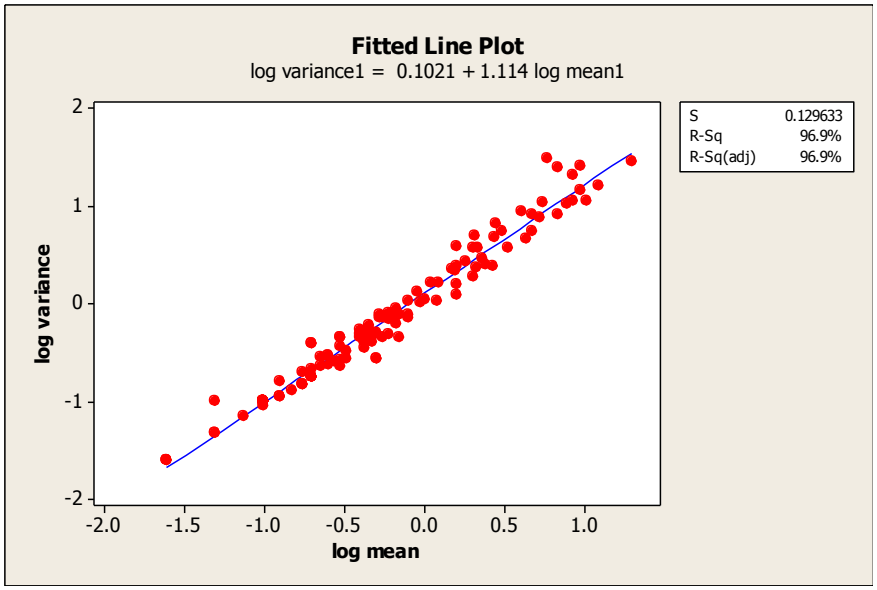

Figure 1.4.9 Taylor's power law for adult thripids in strawberry flowers, cv Camarillo (10 units per sample) from April to August in 4 fields during 2012.

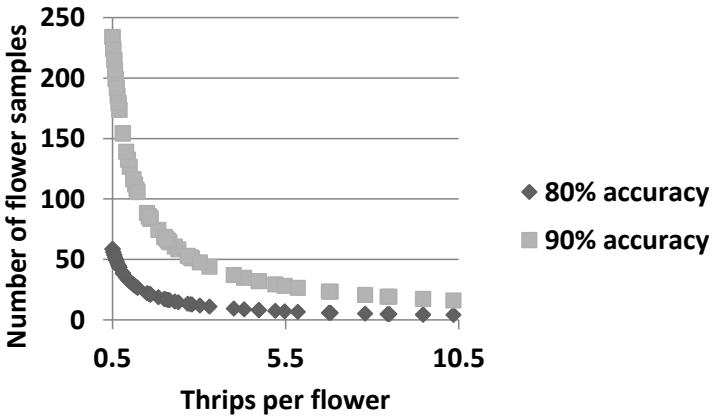

Figure 1.4.10. Number of flower samples required for sampling thripids in strawberry flowers (cv Camarillo), based on the number of thrips per flower, to achieve a fixed precision level of 0.2 or 0.1. Each sample point represents an actual mean from the field populations.

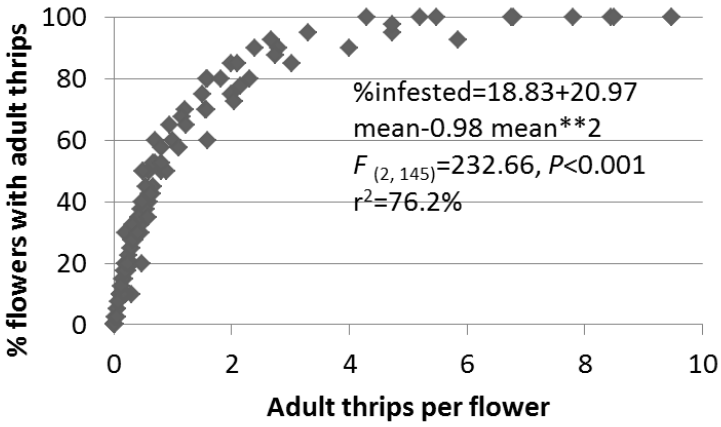

Figure 1.4.11. shows the relationship between the numbers of adult thripids per flower and the percentage of flowers infested in Camarillo crops.

Table 1.4.5. Numbers of samples required for sampling thripids in strawberry flowers (cv Camarillo), to achieve a fixed precision level of 0.2 or 0.1 at specific numbers of thrips per flower.

Precision level	Number of samples needed at different thrips densities: 1	2	4	8	16
0.2	31	17	9	5	3
0.1	127	68	37	20	11

The value of coefficient b of Taylor's power law was 1.114, indicating an aggregated population distribution, similar to those found in the literature. This value was used to determine the number of flower samples needed to monitor adult thripids in strawberry flowers. For growers, who are monitoring to determine damage or action thresholds, the assessment of 10 to 20 flowers would be sufficient to estimate the population with 80% accuracy around proposed damage threshold levels of four to eight adult thrips per flower (table 1.4.5). At lower thrips numbers, this level of accuracy would not be necessary since the thrips would be below damaging levels.

The possibility of reducing sampling time by using binomial (presence/absence) sampling was tested. When the mean was adjusted to a linear relationship (using $m^{1-0.5b}$), the % of flowers infested = -8.066 + 59.55 x transformed mean. Thrips reached 100% flower occupation when the mean thrips/flower was just under 4 thrips/flower (4 adult thrips/flower equates to 102% occupancy). This may be a useful indicator of damage in high risk situations (e.g. in second year crops without predators, in hot/dry conditions). However this method would not be sensitive enough at higher thresholds. Further development of threshold scoring using data sets from different years and varieties will be done in 2013.

1.4.2 The relationship between flower counts and damage

Summary

To help define damage thresholds the distribution of thrips on flowering/fruiting strawberry plants and timing of fruit damage was examined. On strawberry plants, 74% of adult thrips were found in the flowers, with the rest spread between fruit of different stages of ripeness. Larvae were mostly on flowers (40%) and young fruit (38%) with the rest on mature fruit and very few thrips were present on leaves. All stages of flowers and fruit were damaged by both adult and larval *F. occidentalis*, with larvae causing about twice as much damage as adults, possibly because they do more feeding than adults. The greatest amount of damage to fruit occurs at the end of flowering when the flowers are senescent and larval numbers are at their highest, although further damage occurs throughout fruiting.

1.4. (2a) What stage(s) of Frankliniella occidentalis cause fruit damage and when does that damage occur? (KU)

Introduction

Fruit bronzing correlated with numbers of thrips/flower in 2011 experiments. The aim of this experiment was to determine the timing of fruit damage under controlled conditions and to identify which thrips stage(s) cause damage. By combining this information with the distribution of thrips between different strawberry stages in the field, we can determine when damage occurs in strawberry and therefore the time lag between thrips in the crop and fruit damage. This in turn will help define damage thresholds.

Methods

Timing of damage and stage of thrips causing damage

Strawberry plants (cv: Camarillo) were grown in coir growbags (10 cm x 100 cm), each containing ten plants, in an open sided polytunnel in Staffordshire. Planting date: 12 February 2011. The experiment was set up on 15 August and 26 August 2012 with 5 replicates on each date (n=10).

Using a randomised block design, four stages of strawberry (mid-aged open flowers, green fruit, white fruit and red fruit) were infested with six second instar *F. occidentalis* larvae, six adult female *F. occidentalis* or without thrips (control) then enclosed using a cage made of horticultural fleece, clipped to the stem using a metal clip. Thrips were collected from a culture at Keele University reared on chrysanthemum plants. Any invertebrates observed in the flowers were removed before the thrips were released. After one week the fleece covers and all thrips were removed using a damp paintbrush and then every three days until

harvest. All the fruit were harvested when they reached the red fruit stage. Fruit damage was assessed by counting the number of seeds surrounded by bronzing. Temperature and humidity were recorded using a Lascar data logger placed in a white delta trap for shade, hung at flower height.

Distribution of thrips on strawberry plants and timing of damage

Ten plants were selected at random from a 10 m section of bed on 10 August (field 5, Table 1), 22 August (field 2, Table 1) and 13 September (field 4, Table 1) (n=30). One fully expanded leaf, one open flower, one senescent flower, one button fruit, one green fruit, one white fruit and one red fruit was selected from each plant and placed separately into pots of 70% alcohol. In the laboratory, insects were washed off the samples and the number and stage of thrips was counted. The thrips species will be identified over the winter period.

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

The proportion of thrips on different plant parts was worked out by multiplying the numbers of thrips (adults or larvae)/plant part by the numbers of those parts per plant at the time of monitoring. The proportion of each was then calculated as a percentage. The damage index was calculated by taking the mean number of adult and larval thrips on each strawberry stage from the field monitoring, then applying a weighting of x1.8 to the numbers of larvae to allow for the extra damage from larvae (from the damage experiment, Figure 1.4.13).

Results and conclusions

Timing of damage and stage of thrips causing damage

The maximum and minimum temperatures and humidities are shown in Table 1.4.5. The amount of fruit bronzing from *F. occidentalis* adults or larvae infested on different strawberry stages for seven days is shown in Figure 1.4.13. Larvae caused nearly twice as much damage as adults for the same time period (x1.8, $F_{(3,100)}$=77.63, P<0.001). There was a trend towards more damage when flowers were infested with thrips compared to the different fruit stages, although the differences were not statistically significant (x2, $F_{(2,100)}$=1.48, P=0.23) and there was no interaction between stage x treatment ($F_{(6,100)}$=0.54, P=0.78).

Table 1.4.5. Environmental conditions within the polytunnel.

	Minimum	Maximum
Temperature (°C)	7	26
Relative humidity (%)	75	98

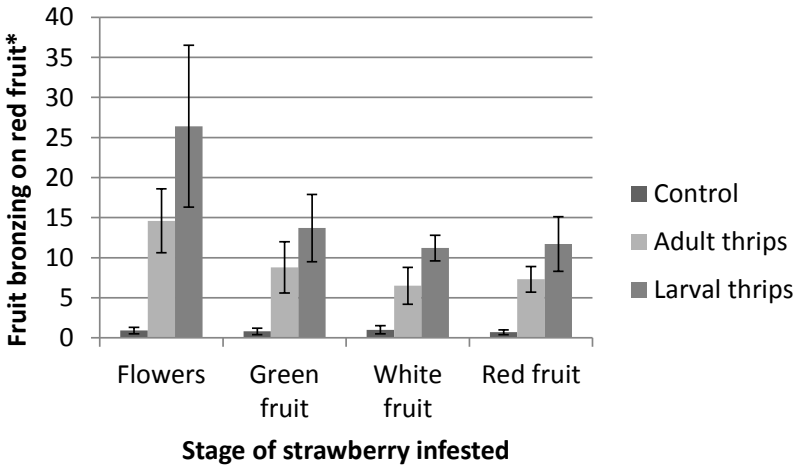

Fig.1.4.13. Mean numbers of seeds surrounded by bronzing /fruit ± S.E. following infestation of strawberry flowers, green fruit, white fruit or red fruit with adult female or second instar larval *F. occidentalis.* *Bronzing represents the numbers of seeds surrounded by bronzing at harvest.

Distribution of thrips on strawberry plants and timing of damage

The distribution of thrips adults and larvae on different strawberry parts is shown in Figure 1.4.14. There were significantly more thrips in the flowers than on the fruit and more on fruit than on leaves ($F_{(6,201)}$=36.11, P<0.001). Adult thrips were concentrated in the flowers (74%) with the rest spread between fruit of different stages of ripeness. Larvae were mostly on flowers (40%) and young fruit (38%) (Table 1.4.6). Very few thrips were present on leaves. Nearly 60% of damage occurs in the flower stages, although further damage occurs at all stages of fruit development (Table 1.4.7).

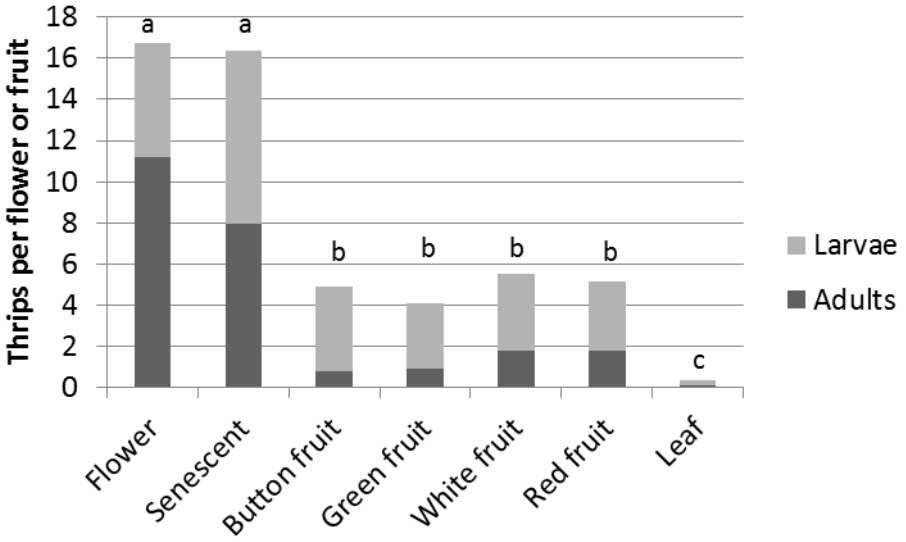

Fig. 1.4.14. Distribution of thrips adults and larvae between different strawberry parts.

Table 1.4.6. Percentage of the adult or larval thripid population on different parts of the strawberry plant.

	Open flowers	Button and green fruit	White and red fruit	Leaves
Adult thrips (%)	74.24	11.66	12.81	1.11
Larval thrips (%)	40.29	38.44	18.10	2.08
Mean no. of part/plant*	5.5	9.88	7.13	7.88

*Mean number of flowers, fruit or leaves /plant at the time of sampling.

Table 1.4.7. The proportion of damage done to each strawberry stage by adult and larval thripids and percentage of total thrips damage done at each stage.

	Open flower	Sene-scent	Button fruit	Green fruit	White fruit	Red fruit
Adult damage	11.22	7.98	0.78	0.91	1.82	1.81
Larval damage	9.89	15.08	7.43	5.73	6.70	6.08
Damage index	21.11	23.06	8.21	6.64	8.52	7.89
% damage	28	31	11	9	11	10

All stages of flowers and fruit were damaged by both adult and second stage larval *F. occidentalis*, with larvae doing about twice as much damage as adults, possibly because they do more feeding than adults. The greatest amount of damage to fruit occurs at the end of flowering when the flowers are senescent and larval numbers are at their highest. Fruit damage in harvested fruit might be expected to correlate best with numbers of thrips per flower about five weeks previously. However damage continues to occur throughout fruiting, so the current thrips population will also affect damage, particularly in when a thrips population is increasing. This relationship will be analysed further using 2012 and 2013 data so that damage thresholds can be defined.

1.4. (2b) What is the relationship between the numbers of adult female Frankliniella occidentalis per flower and fruit damage? (KU)

Introduction

Field monitoring in 2011 showed that counting the numbers of adult thrips per flower gave a better correlation with thrips damage than thrips per trap, as trap counts varied with temperature. Initial monitoring suggested that fruit damage occurred when there were an average of between four and eight adult thrips per flower and that greater numbers of thrips were tolerated without damage in sites with more natural enemies. The aim of 2012 monitoring was to test this damage threshold over different farms, cultivars and crop ages.

Methods

Monitoring of thrips per flower, fruit damage (to red and white fruit) and flowers per plant was done periodically between April and September 2012 in the fields detailed in Table 1 and a large amount of data was collected. The variability between fields and farms was such that further analysis is required before the data can be presented to the consortium. A few main conclusions and points of interest are bullet pointed below.

Initial observations, results and conclusions

- There was a significant correlation between adult thrips per flower and fruit bronzing in everbearer strawberry varieties Camarillo ($F_{(1,179)}$=86.72, P<0.001) and Finesse ($F_{(1,21)}$=12.0, P<0.001).

- Damage thresholds can only be a guideline and there were occasions where fruit bronzing could not be explained by thrips, and other instances where thrips numbers above 8/flower did not result in the expected fruit damage. These instances will be examined further before conclusions are made. Possible explanations include:
    - Some bronzing was caused by early season wind or spray damage;
    - Where predators reduced numbers of thrips larvae, this reduced fruit damage;
    - High humidity is known to reduce fruit damage;
    - Low temperatures reduce thrips feeding and thrips damage.

- The amount of fruit bronzing (number of seeds surrounded by bronzing) on red and white fruit on the same date was quantified on 10 occasions. The mean damage on red fruit was approximately 21% of that seen on white fruit.

- The flowering pattern of the crop plays an important part in predicting fruit damage. Consistent with 2011 data, there was a big increase in fruit damage at the end of the first flower flush, in some second-year crops with overwintering thrips populations. For example in a second year Finesse crop, fruit damage increased after flower numbers reduced from 30 flowers/plant to <3 flowers/plant, thrips/flower increased because they were concentrated into fewer flowers (Figure 1.4.15).

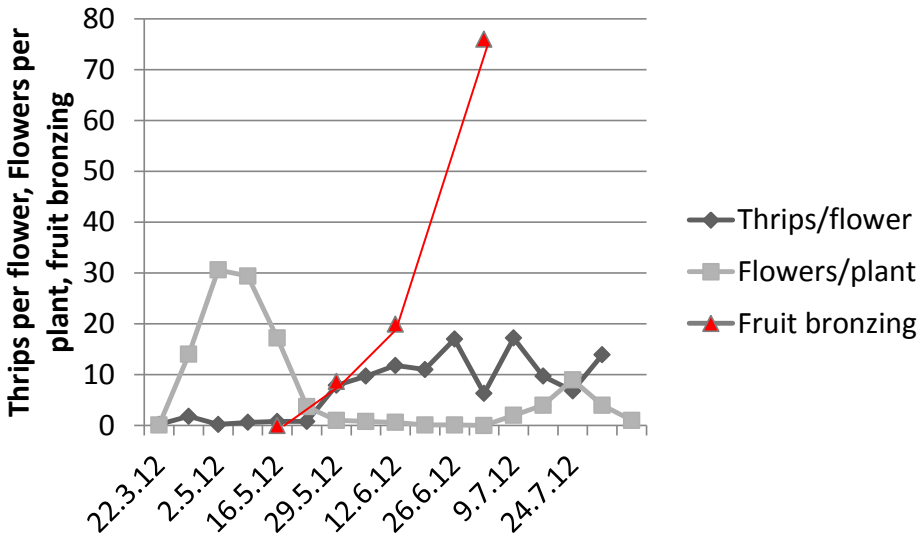

Figure 1.4.15 Thrips/flower, flowers/plant and fruit bronzing in a second year strawberry crop showing that fruit damage started at the end of the first flower flush. *Bronzing represents the numbers of seeds surrounded by bronzing at harvest.

- *Neoseiulus cucumeris* played an important part in reducing thrips numbers and fruit damage. For example in a field where part of the field was treated with a non-compatible acaricide against spider mites (etoxazole, Borneo), the presence of predatory mites on fruit reduced from 33% to <1% and a resurgence of thrips resulted (Figure 1.4.16).

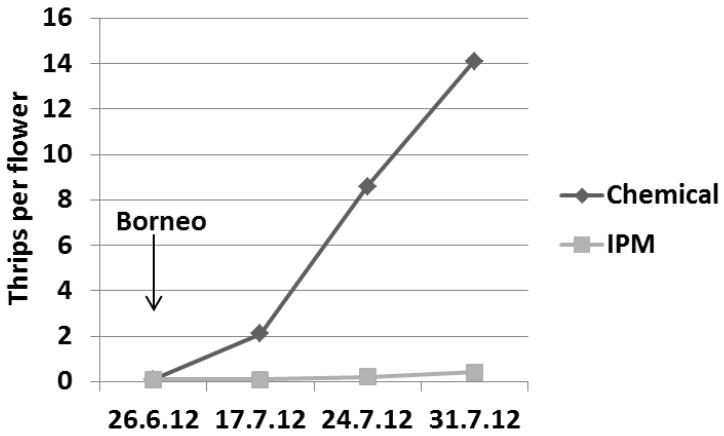

Figure 1.4.16 Mean number of thrips/ flower comparing parts of a field that had been treated with etoxazole to part of a field where IPM was used.

- Further data from different areas (especially warmer drier areas such as Kent and East Anglia), varieties and growing systems are required in the 2013 season.

1.4. (1c) How much damage results in fruit downgrading? (KU)

Introduction

To define a damage threshold for thripids on strawberry it is necessary to know how much thrips damage is tolerated on Class 1 fruit and how much results in downgrading.

Methods

On the last pick of the season (2 October 2012), when fruit quality was at its poorest, packhouse staff selected punnets of first, second and waste fruit from a Camarillo crop (field 5, Table 1) that had moderate numbers of thrips/flower (approx. 5/flower) and a Finesse crop (field 2, Table 1) that had high numbers of thrips/flower (approx. 10/flower). For each fruit class, the number of seeds surrounded by bronzing, fruit weight (g) was recorded for 25 fruit. The presence of bruising, disease or misshapen fruit was also recorded.

Results and conclusions

The amount of fruit bronzing and weight of first, second and waste fruit from two fields at the end of the season is shown in Figure 1.4.17. In the Finesse crop there was more fruit bronzing in Class 2 and waste fruit than in Class 1 fruit ($F_{(2, 69)}$=17.21, P<0.001). In the Camarillo crop there was more bronzing on waste fruit than on Class 1 and 2 fruit ($F_{(2, 63)}$=22.3, P<0.001). In the Finesse crop, waste fruit was heavier than Class 2 fruit with Class 1 fruit intermediate ($F_{(2, 72)}$=3.62, P=0.032). In the Camarillo crop, Class 1 fruit was heavier than Class 2 fruit, with waste fruit intermediate ($F_{(2, 68)}$=27.2, P<0.001).

None of the Class 1 fruit from either field showed symptoms of disease or capsid damage. In Class 2 fruit there was 32% capsid damage on Finesse fruit and 20% capsid damage on Camarillo fruit with only one fruit showing disease symptoms. The waste fruit was downgraded for various reasons, including bronzing, powdery mildew, capsid damage and bruising. 62% of the waste Camarillo fruit showed symptoms of powdery mildew.

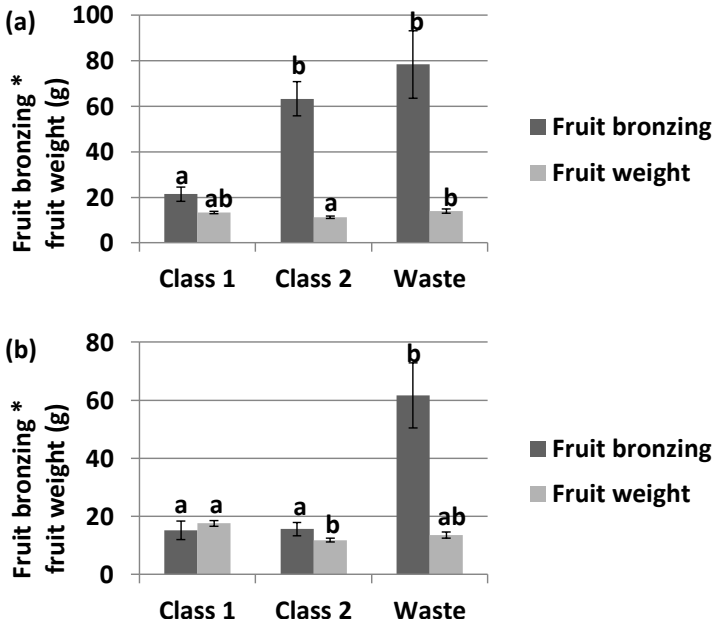

Figure 1.4.17. The amount of fruit bronzing and fruit weight of strawberry fruit from the pack house from a) a Finesse crop with high thrips numbers and b) a Camarillo crop with moderate thrips numbers. *Bronzing represents the numbers of seeds surrounded by bronzing at harvest.

Class 1 fruit is being sold with some bronzing caused by thrips. In the example above, Class 1 fruit had an average 21 and 15 seeds surrounded by bronzing (mean 5-7%, range 0-20% bronzing per fruit) and there were no rejections from the supermarket. In the Class 2 Finesse fruit that had been downgraded due to bronzing, bronzing averaged 60 seeds surrounded by bronzing (mean 20% bronzing, range 5-66% bronzing per fruit). Capsid damage and powdery mildew were also main reasons for downgrading. The differences in fruit weight did not relate to thrips damage. Small fruit were often graded as Class 2. Some waste fruit was larger because they were fruit that had been missed during picking and were therefore swelling for longer and had gone over.

Further assessment of fruit damage will be collected in order to determine thrips damage thresholds during the 2013 season.

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

1.5. (1ab) Can mass trapping be used to reduce thrips numbers and crop damage in a) a first year crop starting with a low thrips population and b) a second year crop with an established thrips population? (KU)

Introduction

The aim of this experiment was to see whether traps could be used to reduce thrips numbers and fruit damage. Blue sticky traps caught large numbers of thrips in UK strawberry crops (over 2,000/trap/week at times, Year 2 report) and the addition of scents used for precision monitoring (pheromone or plant volatiles) increased trap catch further. Placement of sticky traps along the legs, between strawberry tunnels, was shown to be an effective trapping method, catching more female thrips than traps in the beds. In this 'proof of principle' experiment a high density of traps was used, which was not necessarily economic. The experiment was set up in two crops concurrently; in a first year crop with lower thrips numbers at the start of the season, and in a second year crop with an established thrips population.

Methods

Site details (for full details see Table 1, General Methods):

Field 4, first year Camarillo crop in growbags.

Field 5, second year Camarillo crop in raised beds.

Plot details: In each field there were four matched pairs of treated and untreated plots (Figure 1.5.1). Each plot was 17.6 m long and 6.5 m (one tunnel) wide, with 24 m (three tunnels) in between each pair. Plot length was determined by the length of available roller trap and the distance between tunnel legs, to which the traps were attached. The treatment position within the first pair was chosen randomly, but the treatment for the rest of the pairs was alternated, so that the treated plots were as far away from each other as possible to reduce interference. There were 10 plants per metre length of row and four beds of strawberry per tunnel.

Treatments

Trap details: In treated plots in April, blue sticky roller traps (Optiroll, 100 m x 30 cm, Russell IPM, cut to plot length) were placed along each side of the plots in three, 4.4 m sections, with 2.2 m (distance between legs) between each section (Figure 1.5.2a). The traps were clipped onto the legs of the polytunnels using polytunnel securing clips (20 mm wide, 30 mm

diameter) protected by a polythene strip (approx. 30 mm x 80 mm, Figure 5.1.3) with the base of the trap level with the crop canopy (30 cm). Within the plot, blue sticky traps (25 cm x 10 cm Russell IPM) were placed down the two middle beds of strawberry at 2.2 m intervals (9 per bed). When the roller traps were replaced in June, they were replaced in a continuous run along each side of the plot (17.6 m, Figure 1.5.2b), with two clips holding the trap in place at every leg.

Scents: Pheromone lures, each containing 30 µg neryl (S)-2-methylbutanoate (source Thripline ams, Syngenta Bioline) were placed in the string hole of each central trap and at 2.2 m intervals down the roller traps (Figure 1.5.3) (Total of 36 lures, 1080 µg). Four plant volatile sachets, each containing 250 µl methyl isonicotinate (source NRI) were stapled onto traps with one on each roller trap and one in each central bed (Total of four lures, 1000 µl). Control plots had no traps or lures.

Set up and assessment dates:

Pre-trial assessment:	a) 12 April 2012	b) 19 April 2012
Traps and lures put up:	a) 23 April and 27 June	b) 19 April and 27 June.
Assessments:	a) 23 May, 21 June, 18 July, 13 Aug	
	b) 16 May, 12 June, 11 July, 10 Aug.	

Assessments: On each assessment date 10 flowers and five white fruit (when available) were chosen arbitrarily from each bed within the plots (n=40 flowers, n=20 fruit). The numbers of adult and larval thrips were counted per flower. The numbers of seeds surrounded by bronzing were counted per fruit. The numbers of flowers per plant was counted on 10 plants at each trial site at each assessment date.

Figure 1.5.1 Photos from UK field site showing approx location of plots in a) first year crop (cv Camarillo) b) second year crop (cv Camarillo). White = control plots, red = treated plots.

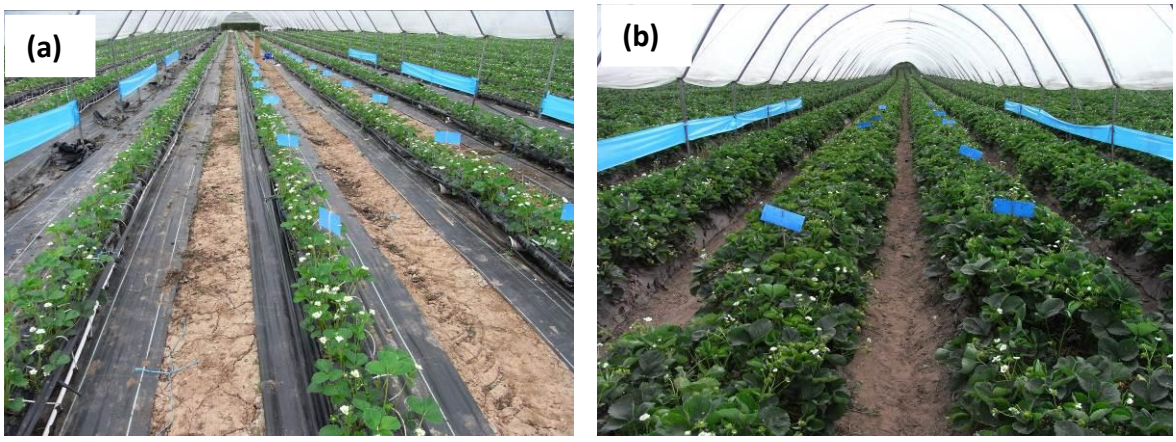

Figure 1.5.2 Treated plots in a) first year Camarillo crop in April b) second year Camarillo crop in July.

Figure 1.5.3 Method of clipping the traps onto the legs of the tunnels.

Lascar data loggers were placed in white delta traps (to shade from the sun) in the canopy and air (5cm above the crop) in each polytunnel to record temperature and humidity.

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

Results and conclusions

The temperature during the experiment is shown in Figure 1.5.4. Temperatures were generally cool before the end of May, although sufficient for thrips flight (>20°C) for short periods on most days. Mean thrips per flower with and without traps is shown in Figure 1.5.5. Mean fruit damage with and without traps is shown in Figure 1.5.6. The overall effects of trapping on thrips numbers and fruit damage and estimated thrips per plot and on

traps is shown in Table 1.5.1.

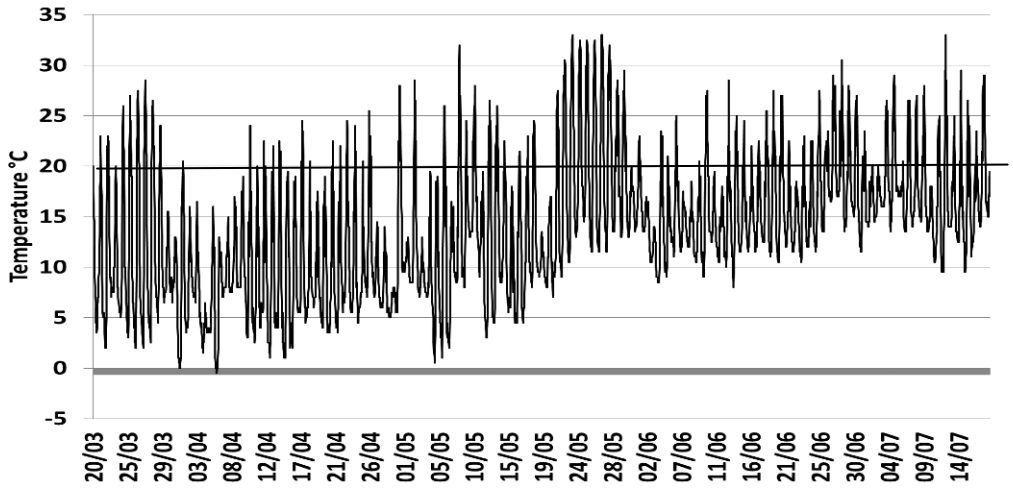

Figure 1.5.4 Temperature records in plot 2 in experiment b, showing typical temperatures in the polytunnels at the trial site during 2012.

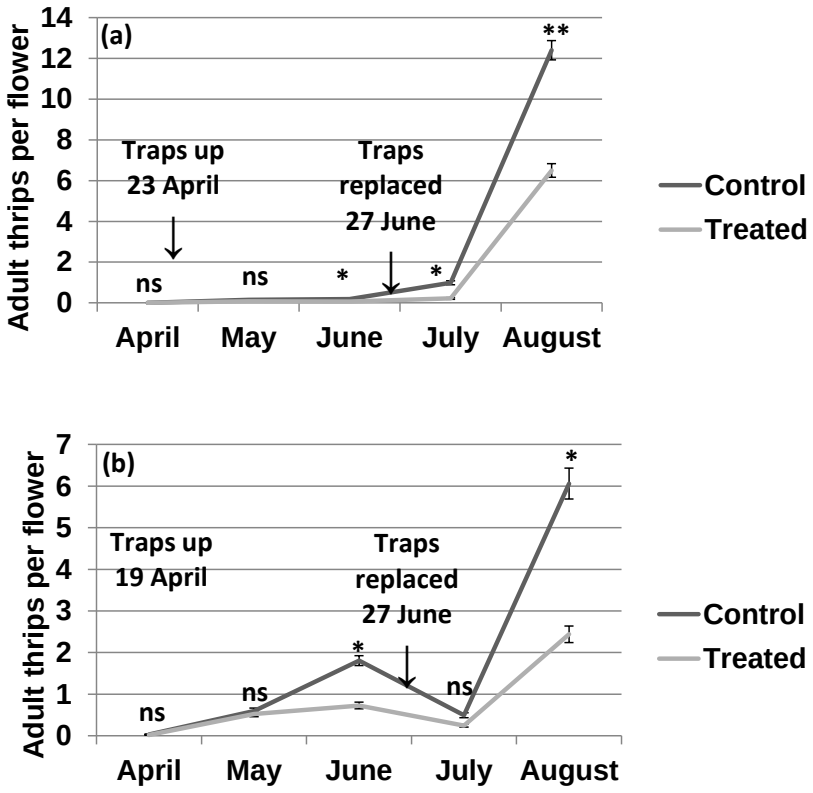

Figure 1.5.5. Mean thrips per flower ± SE with or without traps in a) a first year b) a second year crop (n=4). Comparisons between control and treatment plots are shown by asterisks for each assessment date. Key: ns = not significant; * *P*<0.05; ** *P*<0.01.

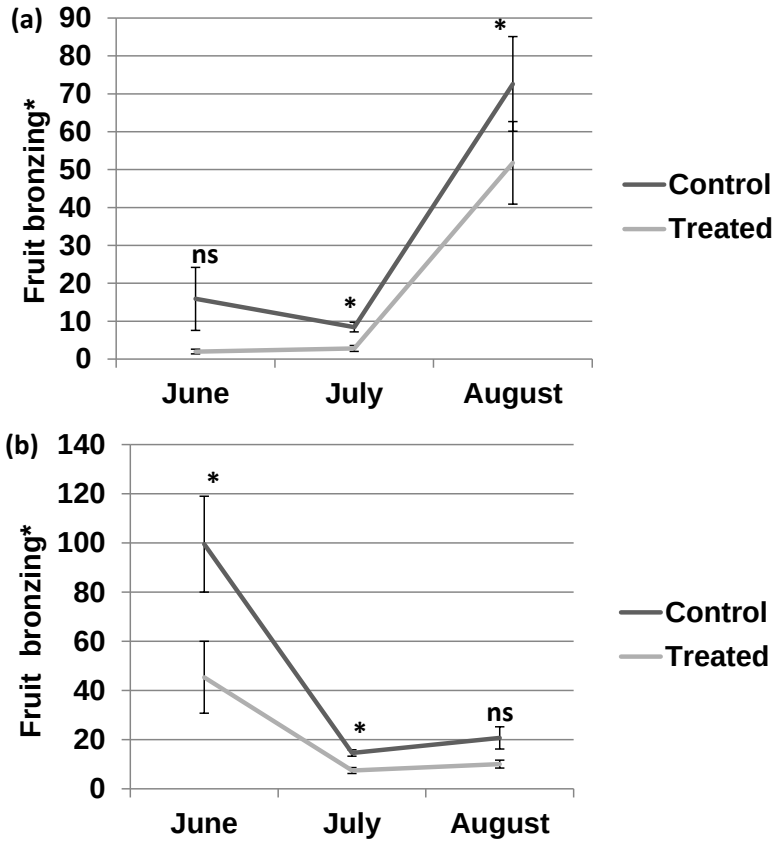

Figure 1.5.6. Mean fruit damage ± S.E. with or without traps in a) a first year b) a second year crop. Comparison between control and trapped plots are shown by stars for each assessment date. *Fruit bronzing is the number of seeds surrounded by bronzing on swollen white fruit. Key: ns = not significant; * P<0.05.

Table 1.5.1 Estimated thrips numbers in flowers per plot and on traps during experiment 1.5.1a, b and comparison between thrips numbers in treated and untreated plots.

	First year crop				Second year crop				Comparison of thrips/flower between treated and untreated plots[*3]	
	Estimated thrips/plot*[1]		% reduction	Thrips /roller trap*[2]	Estimated thrips/plot*[1]		% reduction	Thrips /roller trap*[2]		
	Control	Treated			Control	Treated			$F_{(1,10)}$	P
April	0	0	-		26	16	38		0.76	0.404 ns
May	74	37	50		2383	2107	12		0.58	0.464 ns
June	428	142	67	813	1526	612	60	2189	13.97	0.004**
July	2370	527	78		1182	584	51		7.37	0.022*
August	24443	12813	48	30646	10666	4224	60	14850	8.99	0.013*

*1. Estimated thrips/plot=Thrips/flower x flowers/plant x plants/plot (704).
*2. Estimated thrips/trap=Thrips counts on trap sections x Trap length (x132 and x176).
*3. Analysis of treatment effect using analysis of variance in both fields together.

The thrips were distributed evenly through the plots, with no significant difference between

thrips numbers per flower or fruit damage between edge beds (near the roller traps) or mid-bed. For example, in the first year crop in August; Mean thrips numbers were 9.24/flower in side beds and 9.69/flower in mid beds ($F_{(1,318)=}$0.45, P=0.50). Mean fruit damage was 66.2 seeds surrounded by bronzing in mid beds and 58.2 in side beds ($F_{(1,158)=}$0.23, P=0.63).

Roller traps remained in place for the duration of each experiment and the method of attaching them to the legs was practical and easy to apply. Although the traps are designed for outdoor use with non-drying glue, placement in the leg area meant that they were subject to heavy rainfall from the tunnel plastic which washed off thrips and glue in some areas (during this exceptionally wet season). Thrips were seen walking over the traps in areas where the glue had been washed away. Traps placed within strawberry beds on bamboo canes were vulnerable to tractor damage. After one month an average (between the two sites) of 29 out of 72 traps within beds were still in place (40%). After two months an average five out of 72 traps were still in place (5%). Those that remained were often soiled, broken and no longer sticky. Therefore placing traps in strawberry beds was not considered practical for mass trapping.

The use of blue sticky roller traps with semiochemicals from mid-April resulted in a significant reduction in thrips numbers from June to August, in first and second year crops, by 48-78% (mean reduction 61%) (June, $F_{(1,10)=}$13.97, P=0.004; July, $F_{(1,10)=}$7.37, P=0.022; August, $F_{(1,10)=}$8.99, P=0.013). This in turn resulted in reduced fruit damage (29-88% reduction, mean 57%). The reduction may be explained by the estimated numbers of thrips caught on the roller traps (Table 1.5.1).

The roller traps did not significantly reduce thrips numbers from mid-April to mid-May, when thrips numbers were below 1/flower, temperatures were mostly below 20°C and the crops were in full flower flush, consistent with experiments 1.2b and 1.2c. This may be because the low temperatures reduced flight and because the semiochemicals were in competition with scents or food sources present in a mass of strawberry flowers.

Placement of roller traps attached to the tunnel legs was practical and did not interfere with crop work. In this exceptionally wet year, rain washed off the glue on some areas of the traps over the course of two months, although parts of the trap were still sticky.

1.5.2 Can roller traps, with or without semiochemicals, placed in the legs between tunnels reduce thrips numbers and crop damage? (KU)

Introduction

As replacement of traps is time consuming and expensive, experiment 1.5.2 was done to test whether trapping from early July would be sufficient to reduce thrips numbers and test the benefit of the presence of semiochemicals used for monitoring. Placement of traps within strawberry beds was shown to be impractical, so only roller traps were used. The aim of this experiment was to determine whether roller traps alone, deployed from early July and placed along the legs between tunnels, would reduce thrips numbers and fruit damage and whether there is added benefit of semiochemicals. Note that wider tunnels were used than in experiment 1.5.1.

Methods

Site details: Field 10 (second year Camarillo, Table 1).
Thrips species: 9 July 2012, 33% WFT; 8 Aug, 69% WFT, 10 Sept 2012, 99% WFT.

Plot details: Each plot (Figure 1.5.7) was 17.6 m long and 8.5 m (one tunnel) wide, with 33 m between plots. All plots were located at least 40 m in from the end of the polytunnel.

Treatments

There were three treatments, each with three replicates arranged regularly, so that the same treatment did not appear twice in the same tunnel:

1. Control - without any traps or lures.
2. Traps - Blue sticky roller traps (Optiroll, 100m x 30 cm, Russell IPM, cut to plot length) along the legs along the edge of each plot (Figure 1.5.7). The traps were clipped onto the legs of the polytunnels using polytunnel securing clips (20 mm wide, 30 mm diameter) protected by a polythene strip (approx. 30 mm x 80 mm, Figure 1.5.3) with the base of the trap level with the crop canopy (30 cm) and two clips per leg.
3. Traps with pheromone – Roller traps as in treatment 2, with additional pheromone lures at 2.2 m intervals, each containing 30 µg neryl (S)-2-methylbutanoate (source Thripline ams, Syngenta Bioline) (Total of 18 lures per plot, 540 µg pheromone). The lure were pushed into a hole made in the roller trap with a hole punch (Figure 1.5.3.).

Set up and assessment dates:

Pre-trial assessment: 9 July 2012
Traps and lures put up: 9 July 2012
Assessments: 8 August 2012, 10 September 2012.

Assessments: On each assessment date and in each plot, 8 mid-aged open flowers were sampled from each row and 10 swollen white fruit were sampled from outside rows (five from each side) and 10 from the central row (n=40 flowers, n=20 fruit). The numbers of adult and larval thrips per flower were counted by eye using a x7 head lens. The numbers of seeds surrounded by bronzing were counted per fruit. The number of flowers per plant was counted on 10 plants on each assessment date.

Figure 1.5.7 Photograph of a treated plot (in the fog!).

A lascar data logger was placed in a white delta traps (to shade from the sun) in the canopy and air (5cm above the crop) in the centre of the trial area to record temperature and humidity.

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

Results and conclusions

The temperature exceeded 20°C on all but three days during the experiment (Figure 1.5.8). Mean thrips per flower in plots without traps, with roller traps alone and with roller traps plus semiochemicals is shown in Figure 1.5.9. Mean fruit damage without traps, with roller traps alone and with roller traps plus semiochemicals is shown in Figure 1.5.10. Estimated thrips per plot and on traps is shown in Table 1.5.2.

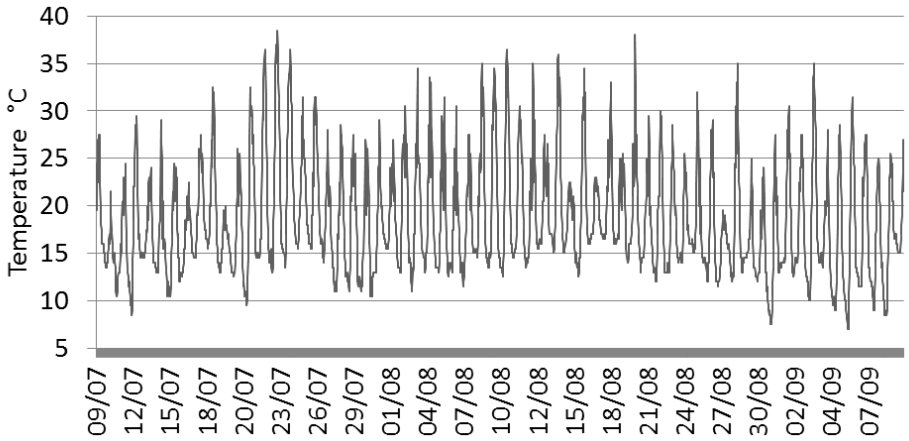

Figure 1.5.8. Temperature records during experiment 1.5.2.

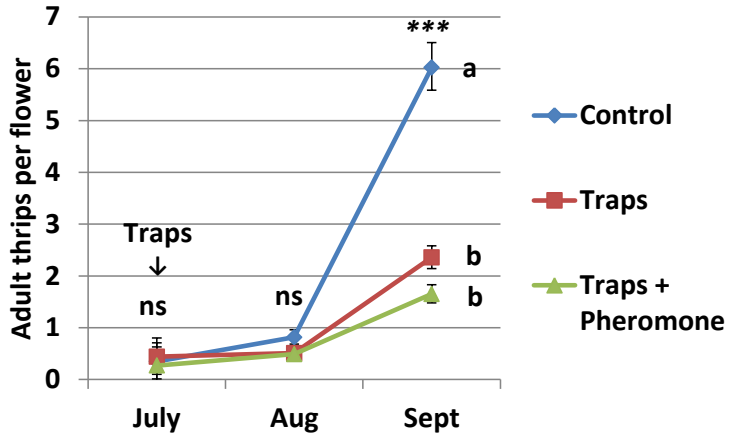

Figure 1.5.9. Mean thrips per flower ± SE using back-transformed data. Comparison between treatments on each sample date are shown by *P* values (n=3). Values with the same letter are not significantly different. Key: ns = not significant; *** *P*<0.001.

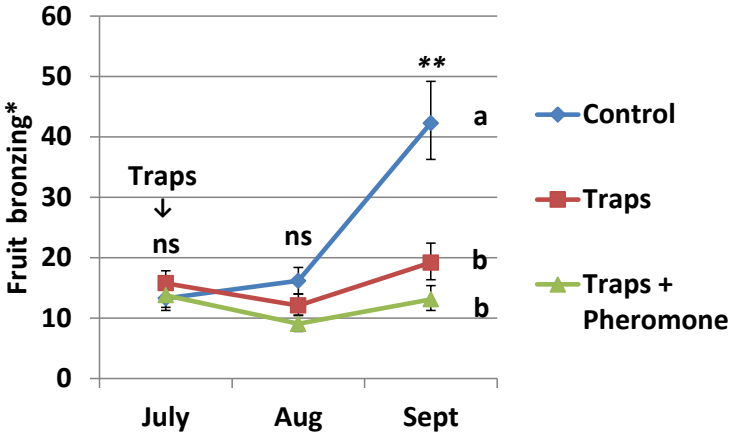

Figure 1.5.10. Mean fruit damage ± SE using back-transformed data. Comparison between treatments on each sample date are shown by *P* values. Values with the same letter are not significantly different. *Fruit bronzing is the number of seeds surrounded by bronzing on swollen white fruit. Key: ns = not significant; ** *P*<0.01.

Table 1.5.2 Estimated thrips numbers per plot and on traps during experiment 1.5.1ab and comparison between thrips numbers in treated and untreated plots.

	Estimated thrips/plot*[a]			% reduction	
	Control	Traps only	Traps +NSMB	Traps only	Traps +NSMB
August	2229	1391	1337	38	40
September	13200	5187	3630	61	72
Thrips/trap*[b]		6688	12877		

*a. Estimated thrips/plot=thrips/flower x flowers/plant x plants/plot (880).
*b. Estimated thrips/trap=thrips counts on trap sections x trap length (x176).

Fruit damage was reduced more in beds beside the roller traps than in central beds (Table 1.5.3.). For example, by September, traps with pheromone had reduced fruit damage by 42% in the central beds but by 80% in the beds beside the roller traps. In control plots there was a trend towards more damage in beds beside legs where there were many weeds, in plots with traps alone damage was more evenly spread and in plots with traps and pheromone there was less damage in the beds beside the traps, reversing the trend observed in the control (Table 1.5.3).

Table 1.5.3. Comparison of fruit damage between mid and side rows in September.

Treatment	Fruit damage (numbers of seeds surrounded by bronzing)		Comparison between damage in mid and side beds	
	Mid beds	Side beds	$F_{(1,176)}$	*P*
Control	31.5±3.1	54.3±11.8	3.95	0.052 ns
Traps	22.2±4.4	18.7±2.03	0.52	0.474 ns
Traps +pheromone	18.1±2.7	10.6±1.4	6.17	0.016*

The placement of roller traps along the legs of the tunnels was practical and did not interfere with crop work. All traps were still in place after two months in the field, although they were contaminated with a range of insect species (especially Diptera, but including capsids) and areas of glue had washed off the traps where water drained off the tunnel covers (Figure 1.5.11).

Figure 1.5.11 Trap after two months in the field showing trap catch and area under the plastic where glue and insects have washed off.

The use of roller traps attached to the tunnels legs reduced thrips adults/flower by 61% and fruit damage by 55%. Roller traps with the aggregation pheromone reduced thrips adults/flower by 73% and fruit damage by 68%. The trapping method was practical and did not interfere with crop work. In 8 m wide tunnels damage reduction was greatest in the beds beside the traps than in the central bed (4 m from traps), so maximum effect would need traps down every tunnel.

The cost of treating all tunnel legs in a 1 ha block in 8.5 m tunnels with 30 cm wide traps (Optiroll, Russell IPM) would be approximately £577/ha (13 rolls x 100 m @ £25/roll + £252 labour). Return on investment using blue roller traps, calculated by the increased sales of Class 1 fruit minus the cost of trapping would be approximately £2,354/ha in this eperiment.

The cost of additional aggregation pheromone in current formulation and prices, at the frequency tested for monitoring, would not increase grower returns further. However, the aggregation pheromone could potentially be added under the glue of roller traps cheaply and effectively as only a very small volume of is required to attract *F. occidentalis*. This could be pursued if agreed by the patent owner and licensees. The pheromone is currently used for precision monitoring and would need registration in order to be used as a control agent.

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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 (Yrs 1-3, EMR)

A prototype model has been developed (see Year 2 report). We have further modified the model by combining another additional set of data WFT on cucumber leaves. Weather data from EMR over the last four years was used to run the model. It shows that distinguishing different generations may be difficult because of overlapping generations (short generation time).

Task 2.2. Obtaining new data for model validation (Yrs 1-4, EMR)

We are particularly interested in how WFT development is affected by the low temperatures experienced in the spring because previous research on WFT was primarily done on glasshouse crops with temperatures > 15°C. Experiments were done at controlled fluctuating temperatures in the lab. This aimed to identify the extent of non-linear relationships at low temperatures, which may cause considerable prediction errors around these temperature ranges.

Methods

Experiments are in progress to investigate the effects of fluctuating temperatures on WFT development. Experiments are being done on weaned strawberry plants derived from micropropagated plants. This experimental design was chosen after several other designs with leaf disc material had failed to enable us to obtain reliable data on thrips development from egg to adult over the extended period required at these low temperatures. The plants were weaned in vermiculture at 22°C until well rooted. They were then transplanted into pots consisting of rigid plastic tubing with the bottoms covered in fine mesh. The mesh enabled the plants to be watered by capillary action. The pot was sealed by placing another similar tube, also with a mesh bottom, on top of it and sealing the two tubes together with parafilm.

The gauze top then allowed ventilation to the plants and prevented loss of any thrips on the plants. The set-up is shown in Figure 2.2.1.

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

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

Results

Table 2.2.1 and Figure 2.2.2 show the time for egg development in the five temperature regimes. The results clearly showed that WFT developmental rate at 10°C is not zero as assumed by all previous studies (minimum temperature for development was said to be around 10°C). For instance, the egg hatching period is between 8-9 days under the constant temperature of 16°C as predicted by the model. However under the 16/10°C, the length is between 9-10 days, which is much shorter than the predicted 14-15 days (assuming the developmental rate is zero at 10°C). Similarly for the 14/10°C regime, the predicted length is around 18 days, compared to the observed 12-13 days.

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

Treatment	Days after oviposition												Total hatched
	4	5	6	7	8	9	10	11	12	13	14	15	
Constant 20°C	38	167	7	8									220
16/10°C					1	32	48	13	6	7			107
Constant 16°C				1	12	26	15	4					58
14/10°C							2	7	3	12	3	8	35
Constant 14°C							20	25	8				53

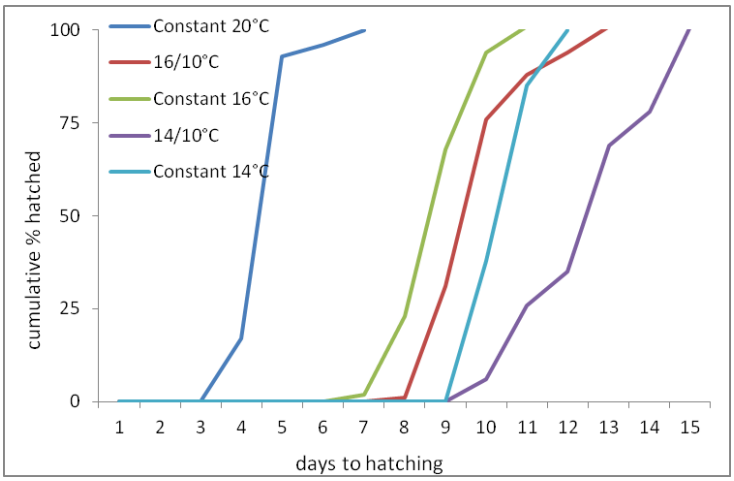

Figure 2.2.2. Cumulative WFT egg hatch at different temperatures

Experiments to determine the development time of larvae from egg hatch to adult are ongoing.

These data will be used to validate and refine the prototype model. Further work may be needed to assess thrips development around 35-38°C.

Task 2.3. Field WFT monitoring (Yrs 1-4, EMR)

Methods

An experiment was done to obtain information on the timing of first catches of WFT in pheromone traps in the spring and at what temperature. Commercial pheromone lures and blue sticky traps were posted to six strawberry growers in different areas of England to enable them to monitor first catches of thrips. Traps were sent out at the beginning of March. Temperature loggers were also dispatched to enable the growers to record the temperature at the site of the traps. Instructions were given to the growers to change the traps every two weeks and send them to EMR for assessment of thrips presence and to enable the identity of the species present to be determined. Traps catches were recorded from March to mid-May.

Results

No WFT were caught on the sticky traps that were returned to EMR from the six commercial sites. The model predicted overwintered adult flight (activity) to start in late April and the first generation of adults to appear in late May.

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 Objective 1 in this report. A literature search is being made to determine if developmental data for the two thrips species commonly found has been published and if so if there are similarities between these and WFT development rates. If this was the case the information could be incorporated into the model and the data reported in Objective 1 used to validate a general thrips development model. If WFT are to be identified from samples taken during the work undertaken in Objective 1 these data could be included in the model for WFT.

Task 2.4. Adapting, validating and modifying the model (3-5)

This will be done in years 4 and 5.

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 and 3.2 were completed in Years 1 and 2

Guided by these results, a further experiment was done by both ADAS and EMR in task 3.3.2 to further refine combined release strategies for both predators for optimum WFT control.

Task 3.3.2 Combine Neoseiulus cucumeris and Orius laevigatus release strategies for improved WFT control

Task 3.3.2 ADAS Experiment

Materials and Methods

Host grower and site: Paul Harrold, Sunclose Farm, Milton, Cambridge.

Everbearer variety: Eve's Delight

Growing system: Bags of substrate on raised beds covered with woven ground-cover matting.

Risk of WFT: This was a third year crop, the same crop used for the ADAS experiment in task 3.2.3 in 2012. In the 2012 experiment, the majority of thrips species confirmed in the strawberry flowers were WFT, although onion thrips (*Thrips tabaci*) also occurred. Thus the risk of overwintered WFT in this experiment was high. WFT were confirmed in the first few open strawberry flowers in the crop on 28 March, when this site was selected for the experiment.

Treatments:

1. Untreated control
2. *Neoseiulus cucumeris* at one sachet per 2m length of row before full flowering (4 April), repeated at six-week intervals (16 May and 26 June)
3. *N. cucumeris* at one sachet per 2m length of row before full flowering (4 April), followed by loose product at 25 per plant after 6 weeks (16 May) and thereafter every two weeks (31 May, 15 June, 28 June, 12 July and 26 July).
4. Untreated with *N. cucumeris*. *Orius laevigatus* at 0.5 adults per m^2 at first flower flush on 10 May, one adult per m^2 on 17 May and at 0.5 adults and three young nymphs per m^2 at second flower flush on 26 July.
5. *N. cucumeris* as in treatment 2, plus *O. laevigatus* as in treatment 4.

6. *N. cucumeris* as in treatment 3, plus *O. laevigatus* as in treatment 4.

There were four replicate plots for each of the six treatments, in a randomised block design within the assigned tunnels.

Experiment layout

- Four Spanish tunnels were used for the experiment, two tunnels in each of two adjacent blocks of tunnels (Figure 3.3.2.1)
- Tunnels 3 and 4 in the right-hand block were used for treatments 1-3.
- Tunnels 1 and 2 in the left-hand block were used for treatments 4-6. This allowed three tunnels to separate the treatments including *O. laevigatus* from those without, in order to reduce the risk of migration of *Orius* adults into treatments 1-3 as much was practically possible.
- Each tunnel was approximately 100 metres long and 8.3 metres wide.
- Each tunnel had five beds of strawberry plants.
- There were five plants in each bag and each bag was one metre long.
- Each plot was 16 metres long and 8.3 metres wide, containing 80 bags of plants (400 plants per plot).
- Only the central six metre length of each plot and the middle three rows of plants in each plot were used for assessments, to leave a 'guard' area in between sampling areas, as a precaution against *N. cucumeris* migrating between plots (Figure 3.3.2.2).

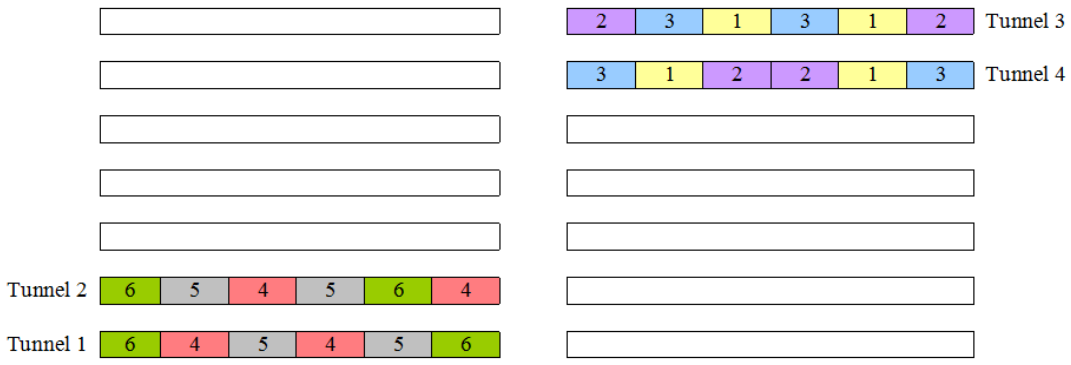

Figure. 3.3.2.1. Trial layout showing treatment numbers for each plot in tunnels 1-4 (for details of treatments 1-6 see Treatment list).

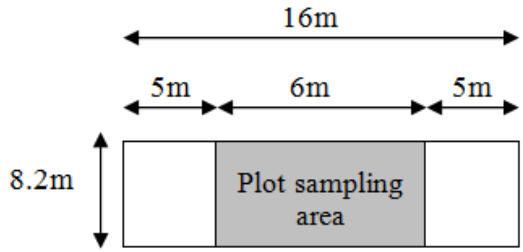

Figure 3.3.2.2 Plot area and sampling area

Integration of pesticides:

If necessary, other pests and diseases were as far as possible controlled with pesticides least harmful to *N. cucumeris* and *O. laevigatus*. Any pesticides to be used were discussed with the grower before use, and application dates were recorded.

Thrips, predatory mite and Orius assessments

Assessments were done immediately before the first release of *N. cucumeris* on 4 April and every two-four weeks thereafter until 9 August. On predator release dates, flowers were always sampled immediately before release. Assessments were done on 10 strawberry flowers per plot, except on 4 and 20 April and on 31 May, when they were done on five flowers per plot. Fully open, upward-facing, middle-aged flowers were selected, with fresh white petals and yellow anthers with pollen. The flowers from each plot were collected into tubes of 70% alcohol, except on 20 April and 31 May, when assessments of thrips and *Orius* numbers were done in the field by tapping the flowers onto a white tray. The flowers collected into alcohol from each plot were washed and sieved using thrips-proof mesh in the laboratory, to enable numbers of thrips adults, larvae, predatory mites and *Orius* adults and nymphs to be counted on the mesh under a binocular microscope. All the predatory mites found and a sub-sample of eight thrips adults per plot were mounted on microscope slides and identified to species.

Assessment of mean numbers of flowers per plant

On each assessment date, three random strawberry plants per assessment plot were assessed for numbers of open flowers.

Fruit damage assessments

Thrips damage to fruit was recorded on 10 randomly selected ripe fruit and 10 white fruit per plot on 28 June, 12 and 25 July and 9 August. Percentage damaged fruit and severity of damage was recorded. Severity of damage was scored as:

- Absent (no damage)
- ‘Slight’ (bronzing around one-five seeds)
- ‘Potentially downgraded’ (bronzing around more than five seeds, as agreed with the host grower)
- On 25 July and 9 August, to give consistentcy with fruit damage scoring carried out by Keele University, the ‘potentially downgraded’ score was sub-divided into ‘bronzing around 5-50 seeds’ and ‘bronzing around more than 50 seeds’. The decision on downgrading Class 1 fruit can vary during the season, according to how much fruit is available on the market.

Crop canopy temperatures

Crop canopy temperatures were recorded in each of the four tunnels throughout the trial period. Four replicate USB dataloggers were used, in a secure position. The dataloggers were shaded with ventilated white shades to reflect any direct sunlight.

Results and Discussion

Mean numbers of flowers per plant

Mean numbers of flowers per plant in each treatment on each assessment date are shown in Figure 3.3.2.3. On the first release date for *N. cucumeris,* the overall mean numbers of flowers per plant in the four trial tunnels was 0.4. There were two main flower flushes during the season, one peaking in early May (overall mean 9.4 per plant on 2 May) and the other in late July. (overall mean five per plant on 25 July). Thus there were plenty of flowers with pollen available for *O. laevigatus* feeding on the dates of release (10 and 17 May and 26 July). However, during June there were very few flowers present. Numbers of flowers were lower in tunnels 3 and 4 (used for treatments 1-3) than in tunnels 1 and 2 during April and May.

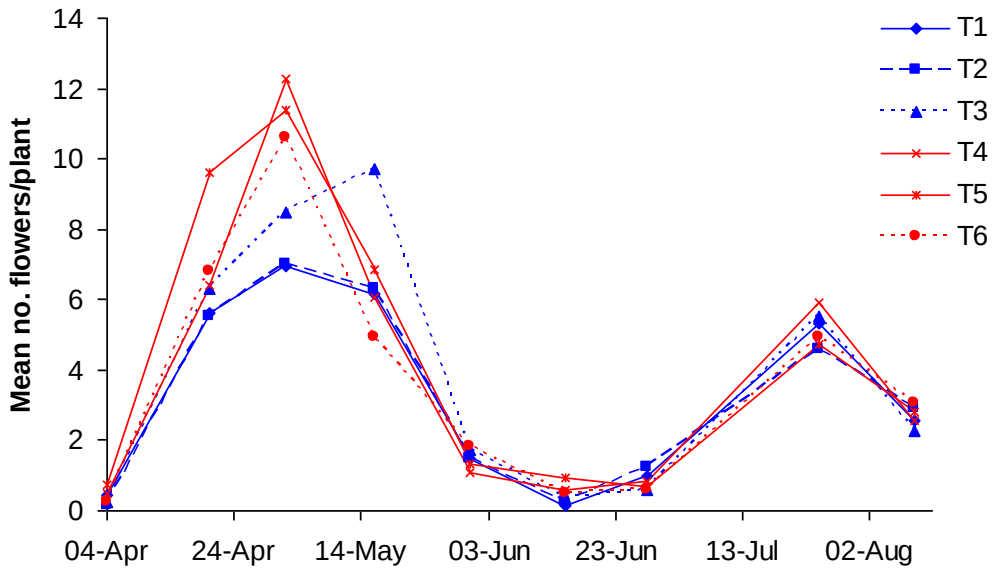

Figure 3.3.2.3. Mean number of flowers per plant. T1-3 (blue) are *N. cucumeris* treatments, T3-4 (red) are *N. cucumeris* plus *Orius* treatments.

Thrips species

On all assessment dates, the thrips were all confirmed as western flower thrips (WFT), *Frankliniella occidentalis*. This contrasted with the species found at the same site and field in the 2011 trial, when 74% were WFT and the majority of the remaining thrips were the onion thrips, *Thrips tabaci*.

Mean numbers of thrips adults and larvae per flower

Mean numbers of thrips adults and larvae per flower are shown in Figure 3.3.2.4 and Figure 3.3.2.5 respectively. At the start of the trial on the first date for *N. cucumeris* release, there was an overall mean of 0.4 WFT adults and 2.3 WFT larvae per flower. The intention was to start releasing *N. cucumeris* before flowering and before the first thrips were active in the crop. This trial started slightly later than planned due to another grower deciding not to host the trial as previously agreed, therefore we approached the second grower, who kindly agreed to host the trial as in 2011, at short notice. The first grower was approached as the project consortium had asked us to site the trial on a farm with a history of a very high population of WFT, to put the biological control programme under higher thrips pressure than the trial in 2011.

Numbers of thrips adults and larvae per flower increased during the trial period. Mean numbers of adults peaked on 28 June at a mean of 20 adults per flower in tunnels 3 and 4 (used for treatments 1-3) and at a mean of 7.8 adults per flower in tunnels 1 and 2 (used for treatments 4-6). Although there were consistently less thrips adults in tunnels 1 and 2 than

tunnels 3 and 4, this was due to a tunnel effect rather than a treatment effect, i.e. it was not due to *O. laevigatus* being released to tunnels 1 and 2. Nor was there a treatment effect of either of the *N. cucumeris* treatments used (treatments 2 and 3, 5 and 6 respectively) with numbers of thrips adults being similar to those in untreated controls in the same tunnel pairs (treatments 1 and 4 respectively). The peaks in numbers of thrips per flower corresponded with periods when there were fewer flowers per plant (see Fig. 3.3.2.3). This is likely to be due to adult thrips flying to and congregating in the few flowers available during June and early July.

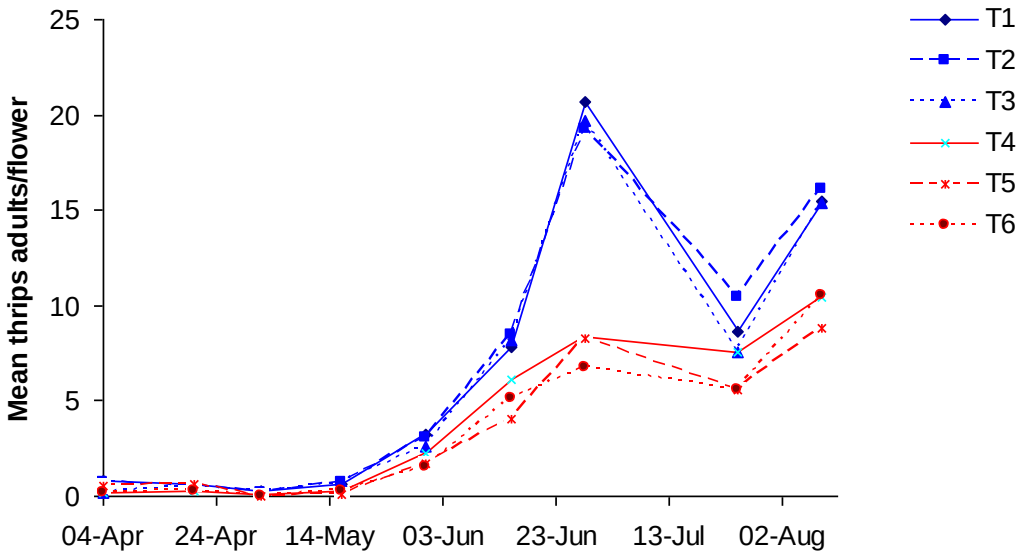

Figure 3.3.2.4. Mean number of thrips adults per flower. T1-3 (blue) are *N. cucumeris* treatments, T3-4 (red) are *N. cucumeris* plus *Orius* treatments.

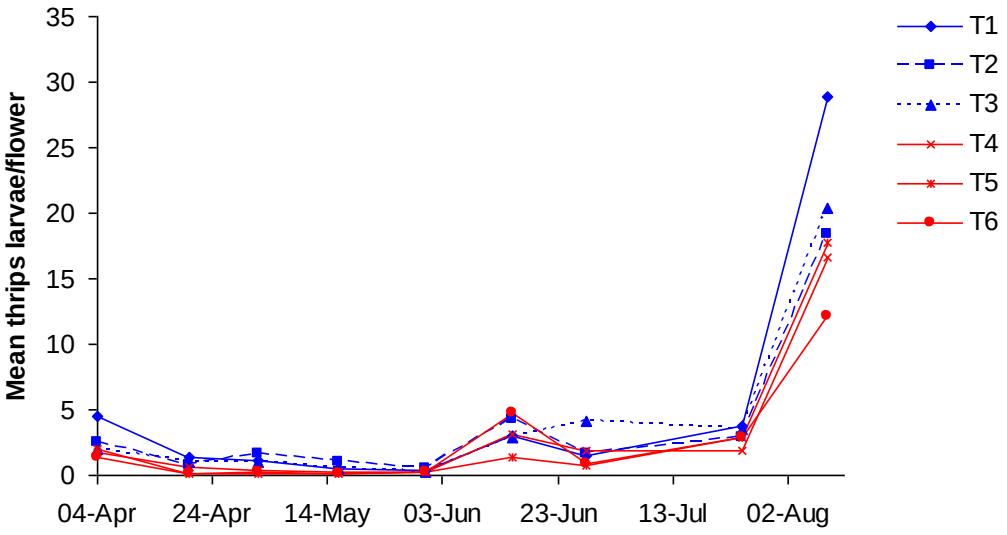

Figure 3.3.2.5. Mean number of thrips larvae per flower. T1-3 (blue) are *N. cucumeris* treatments, T3-4 (red) are *N. cucumeris* plus *Orius* treatments.

Mean numbers and species of predatory mites per flower

The main species of predatory mites recorded in the flowers were *N. cucumeris* (Figure 3.3.2.6). However, *Amblyseius andersoni* were also frequently recorded (Figure 3.3.2.7) and lower numbers of *N. californicus* were also found. All three species were found in some flowers on 4 April before any *N. cucumeris* were released. This indicated that they all occurred naturally in the crop. The same field and crop had been used for the trial in 2011, thus some of the 2011 *N. cucumeris* probably overwintered from those released and established in the previous crop. The only date when numbers of *N. cucumeris* were significantly different in any of the treatments was on 28 June, when there were significantly higher numbers (mean 0.63 per flower) in treatment 5 (three sequential releases of sachets at six-week intervals on 4 April, 16 May and 26 June) than in all other treatments ($P<0.05$, Figure 3.3.2.6). As *N. cucumeris* were found in untreated plots (treatments 1 and 4) in similar numbers to all other treatments on all other dates, this explains why there was no effect of either of the *N. cucumeris* strategies on thrips numbers throughout the trial.

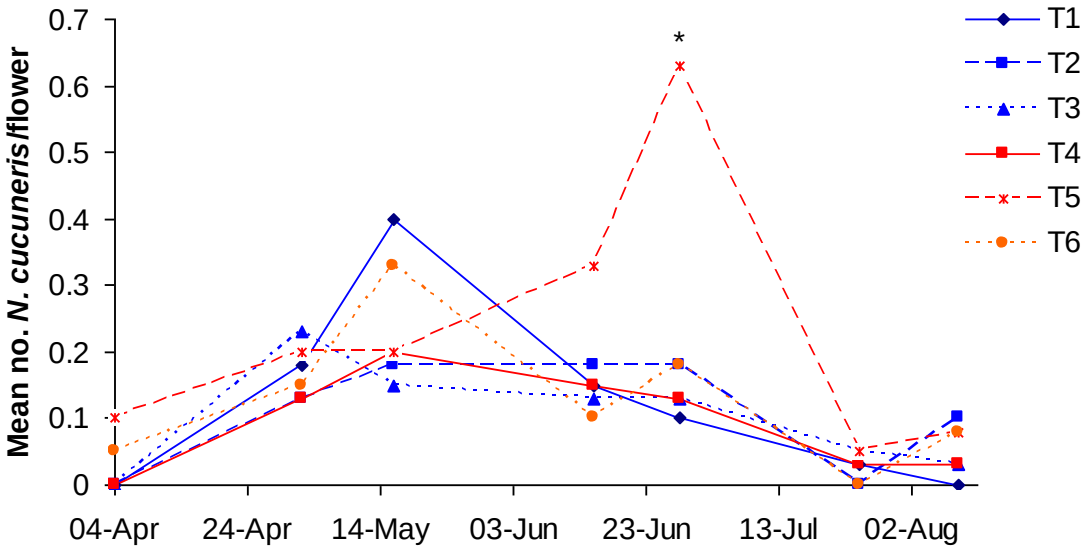

Figure 3.3.2.6. Mean number of *N. cucumeris* per flower. T1-3 (blue) are *N. cucumeris* treatments, T3-4 (red) are *N. cucumeris* plus *Orius* treatments. * significantly more in T 5 than in all other treatments ($P<0.05$).

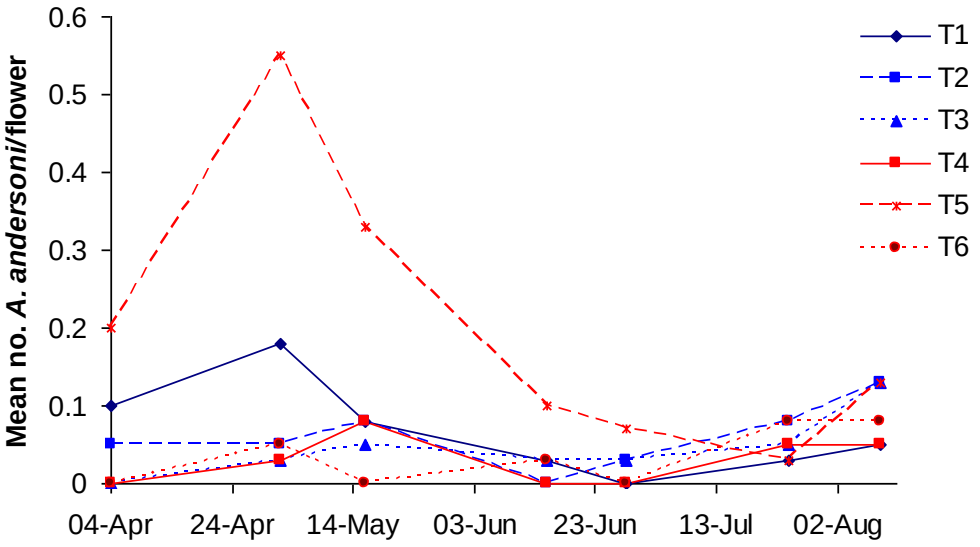

Figure 3.3.2.7. Mean number of *A. andersoni* per flower . T1-3 (blue) are *N. cucumeris* treatments, T3-4 (red) are *N. cucumeris* plus *Orius* treatments.

Mean numbers of O. laevigatus per flower

Very low numbers of *O. laevigatus* were recorded throughout the trial period, with means of less than 0.1 per flower and less than 0.2 per plant, when taking into account mean numbers of flowers per plant (Table 3.3.2.1 and Figure 3.3.2.8). The majority of them were nymphs, indicating that there was some breeding in the flowers after releases of adults on 10 and 17 May. On 28 June and 25 July, nymphs were found in treatments where *O. laevigatus* had not been released. This could have been due to some migration from the release plots, or could have been due to natural *O. laevigatus* occurring (*Orius* spp. are often noticed on this farm by the grower), or to overwintering of some predators surviving from the 2011 trial. However, the predators failed to establish in any treatment and this explains why there was no effect of their release on numbers of thrips per flower.

Table 3.3.2.1 Mean numbers of *O. laevigatus* adults and nymphs per flower

Treatment	31 May	28 June	25 July	9 August
1	0	0	0.03 nymphs	0
2	0	0.05 nymphs	0	0
3	0	0	0.03 nymphs	0
4	0.05 nymphs	0.08 nymphs	0	0.02 nymphs
5	0.05 nymphs	0.05 nymphs	0.03 adults	0.03 nymphs, 0.03 adults
6	0.05 nymphs	0.03 nymphs	0	0.03 nymphs

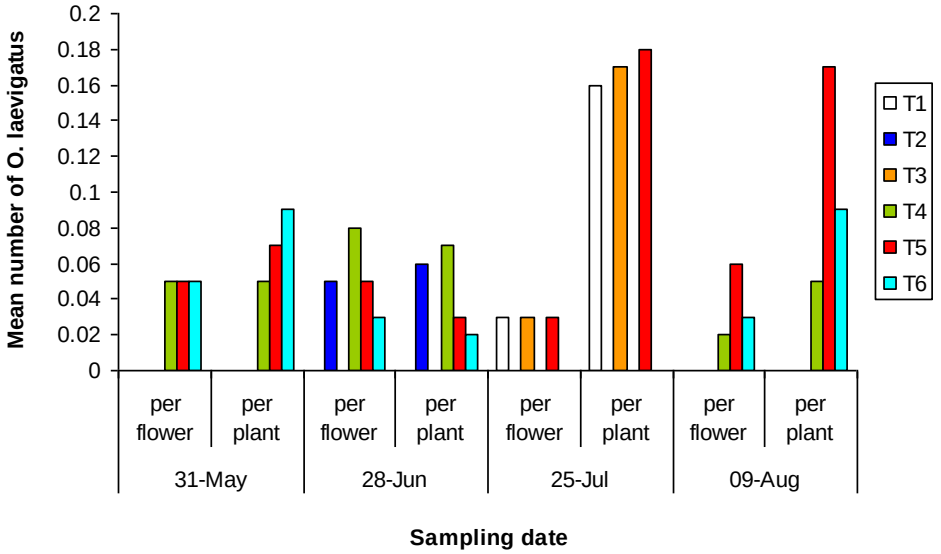

Figure 3.3.2.8 Mean numbers of *O. laevigatus* adults and nymphs per flower and per plant (adjusted for the mean numbers of flowers per plant on each date in each treatment)

Fruit damage

Mean percentage fruit with bronzing around five or more seeds on the two assessment dates where a significant effect was given is shown in Figures 3.2.3.9 and 3.2.3.10. As in previous trials in this and other projects, more damage was visible on white than ripe fruit on all dates. On 28 June, which was the date when peak numbers of WFT adults per flower were recorded, the percentage of white fruit with bronzing around five or more seeds was statistically similar in all treatments. On the same date, significantly less damage was recorded on ripe fruit in treatments 4-6 (with *Orius*) than in treatments 1-3 (without *Orius*), but this was due to a significant tunnel effect rather than a treatment effect. On 25 July, four weeks after the date when peak numbers of WFT adults were recorded, the percentage of ripe fruit with bronzing around five or more seeds was statistically similar in all treatments.

On the same date, significantly less damage to white fruit occurred in treatments 4-6 (with *Orius*) than tunnels 1-3 (without *Orius*) but again this was due to a significant tunnel effect rather than a treatment effect. These results indicated that on 28 June when mean numbers of WFT adults peaked at 20 per flower in treatments 1-3, the mean percentage ripe fruit with bronzing around more than five seeds was 24%. On the same date, when mean numbers of WFT adults peaked at eight per flower in treatments 4-6, the mean percentage ripe fruit with bronzing around more than five seeds was 9%. Four weeks later on 25 July, when ripe fruit would have developed from the flowers in which peak numbers of WFT were recorded on 28 June, the mean percentage of ripe fruit with bronzing around more than five seeds was 10% in treatments 1-6. On 25 July, no ripe fruit had damage around 50 or more seeds

per fruit. Further work is needed to correlate the numbers of thrips per flower with fruit damage on different everbearer varieties in future experiments in this project.

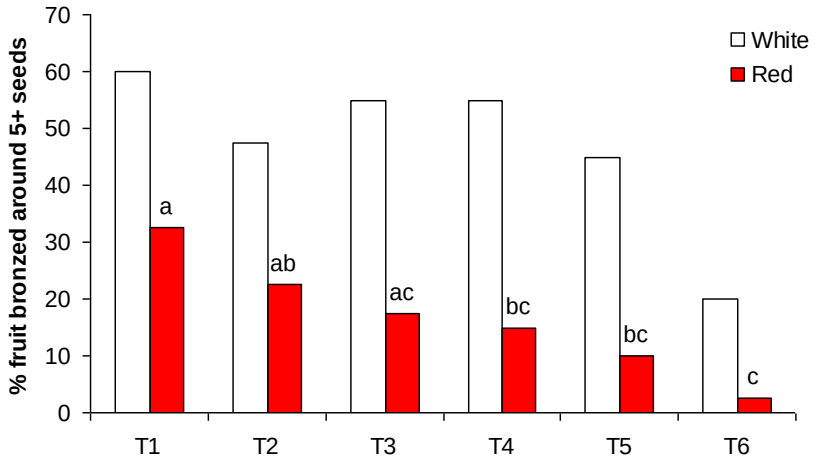

Figure 3.3.2.9. Mean % red and white fruit with bronzing around 5+ seeds on 28 June. Bars with no shared letters above them are statistically different (*P*<0.05).

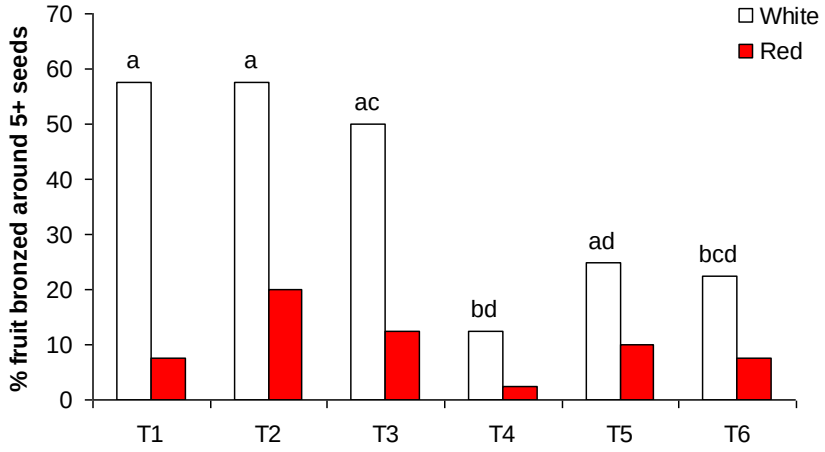

Figure 3.3.2.10. Mean % red and white fruit with bronzing around 5+ seeds on 25 July. Bars with no shared letters above them are statistically different (*P*<0.05).

Crop canopy temperatures

Mean minimum, maximum and mean crop canopy temperatures in the four experimental tunnels during the experiment are shown in Figure 3.3.2.11. Mean daily temperatures were frequently below 15°C between 10 and 21 May, after the first two releases of *O. laevigatus* adults. This is the minimum temperature for *O. laevigatus* egg-laying. Mean and minimum temperatures during this period were cooler than in the 2011 trial, in which better establishment of *O. laevigatus* occurred. Mean maximum temperatures reached 20-30°C on

most days after the first *O. laevigatus* release, were below 20°C on 20 May, 3 and 11 June, unlike in 2011 when mean maximum temperatures reached 20-30°C on all dates after *O. laevigatus* release. Mean numbers of hours per day above 15°C are shown in Figure 3.3.2.12. Unlike in the 2011 trial when temperatures exceeded 15°C for over 10 hours per day throughout the experimental period, in 2012, they were frequently below 10 hours per day during the first two weeks after *O. laevigatus* release. These cooler temperatures are likely to have contributed to the poorer establishment of *O. laevigatus* in 2012 than in the 2011 trial.

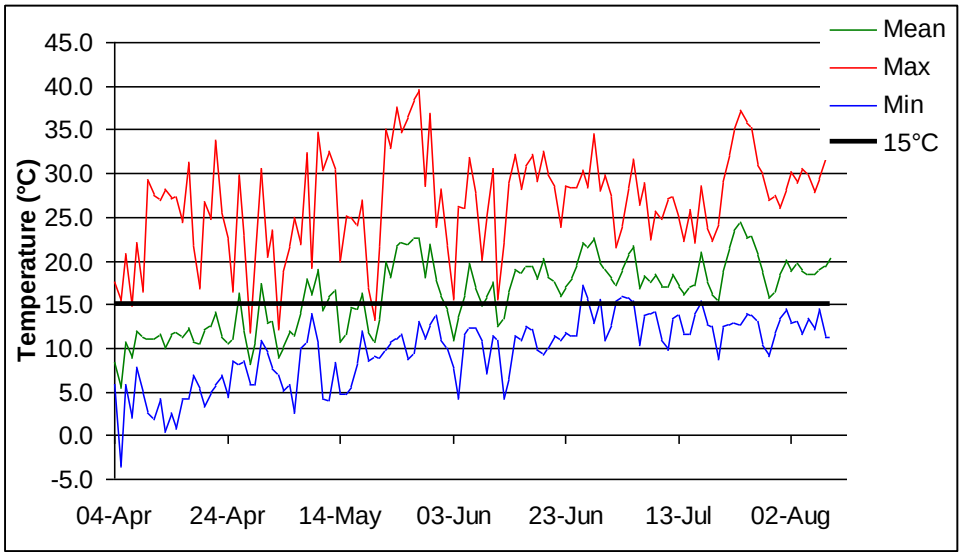

Figure 3.3.2.11. Mean minimum, maximum and mean temperatures recorded in the four trial tunnels during the experiment

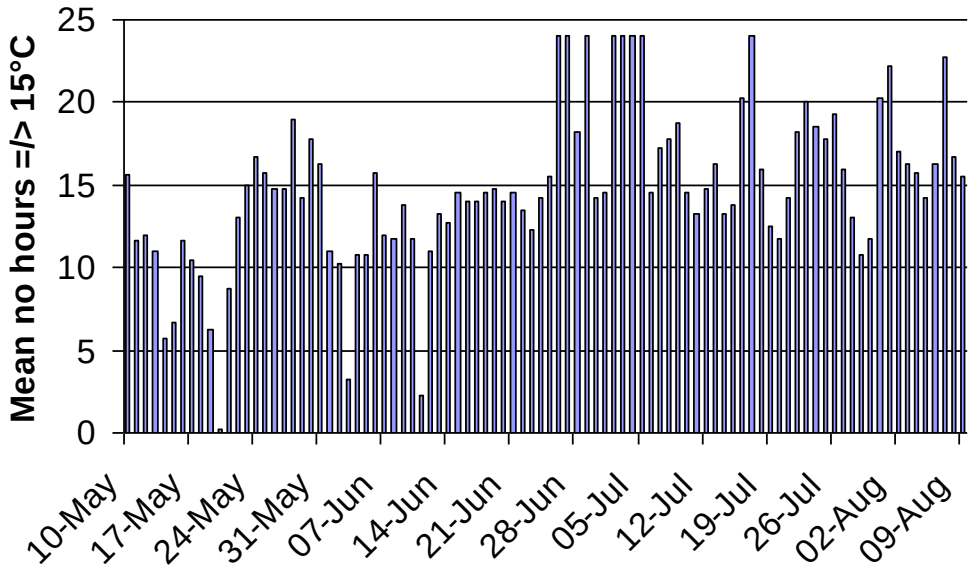

Figure 3.3.2.12. Mean numbers of hours per day at or above 15°C recorded in the four trial tunnels during the experiment

Pesticide applications

Of the pesticides applied to the experimental crop, the following had potential adverse effects on *N. cucumeris* and/or *O. laevigatus*:

Thiacloprid (Calypso): This pesticide is moderately harmful to *N. cucumeris* and harmful to *O. laevigatus*, with both side effects lasting for up to two weeks after application (Table 3.3.2.1). Calypso was applied to the crop for aphid control before the host grower agreed to host the trial, and the first release of *N. cucumeris* and *O. laevigatus* were not until 4 April and 10 May respectively, they should not have been adversely affected.

Pirimicarb (Phantom): This aphicide is moderately harmful to *N. cucumeris* for up to three days after application and slightly harmful to *O. laevigatus* nymphs for up to five days after application. Phantom was applied on 27 April and 16 May, so is likely to have impacted both predators. However, as *N. cucumeris* were released regularly after these dates (either from sachets or from repeated releases of loose product), it is unlikely that Phantom had undue effects on this predator. In the 2011 trial on the same field, Phantom was used earlier in the season on 8 and 22 April, before *O. laevigatus* was first released on 12 May. Thus the timing of this pesticide should be taken into account when using in an IPM programme, particularly if *O. laevigatus* is being used.

Cyprodonil plus fludioxonil (Switch): This fungicides is reported as being harmful to *O. laevigatus* adults and nymphs (www.biobest.be) and cyprodinil as an individual fungicide is reported as being harmful to *O. laevigatus* (www.iobc-wprs.org). Switch was applied on 26 May, after *O. laevigatus* adults had been released on 10 and 17 May, thus this fungicide is likely to have had an impact on early *Orius* establishment. In the 2011 trial, Switch was applied on 13 July, and *O. laevigatus* established in the crop from mid-July to late August. It is possible that Switch had less impact in the 2011 trial as it was applied when more *O. laevigatus* were present and when temperatures were suitable for reproduction. The persistence of Switch against *O. laevigatus* is not reported and this information would be useful to allow better timing of this fungicide in IPM programmes which include this predator.

Table 3.3.2.1. Pesticides applied to all experimental plots from 21 February to 10 August 2012. S = safe (kills<25%). SH = slightly harmful (kills 25-50%). H = harmful (kills>75%. Persistence (if information available) against biocontrols given in brackets. Data compiled from Biobest, Koppert and IOBC-wprs websites.

Date	Insecticide active ingredient (product name)	Effect on *N. cucumeris*	Effect on *O. laevigatus*	Fungicide active ingredient (product name)	Effect on *N. cucumeris*	Effect on *O. laevigatus*
21 March				dimethomorph (Paraat)	No info.	MH
23 March	thiacloprid (Calypso)	MH (2 wks)	H (2 wks)			
7 April	*Bacillus thuringiensis* (Dipel DF), pymetrozine (Chess)	S S	S SH (1 wk)			
27 April	*Bacillus thuringiensis* (Dipel DF), pirimicarb (Phantom)	S MH (3 days)	S S (adults) SH nymphs (5 days)			
16 May	Pirimicarb (Phantom)	MH (3 days)	S (adults) SH nymphs (5 days)			
26 May				Myclobutanil (Systhane 20EW), cyprodinil + fludioxonil (Switch)	No info No info	S H (adults & nymphs)
2 June				Penconazole (Topas), pyrimethanil (Scala)	No info S	S S (adults & nymphs)
8 June				*Bacillus subtilis* (Serenade), sulphur	S SH (3 days)	S S (adults), SH (nymphs)
15 June				*Bacillus subtilis* (Serenade), bupirimate (Nimrod), fenhexamid (Teldor)	S S	S SH (0 days)
23 June				*Bacillus subtilis* (Serenade), sulphur	S SH (3 days)	S S (adults), SH

						(nymphs)
28 June				*Bacillus subtilis* (Serenade), sulphur	S SH (3 days)	S S (adults), SH (nymphs)
5 July	*Bacillus thuringiensis* (Dipel DF)			Myclobutanil (Systhane), mepanipyrim (Frupica SC)	No info	S
10 July	*Bacillus thuringiensis* (Dipel DF)			*Bacillus subtilis* (Serenade), sulphur		
20 July	*Bacillus thuringeinsis* (Dipel DF)			cyprodonil + fludioxonil (Switch), penconazole (Topas)	No info	S
27 July	*Bacillus thuringeinsis* (Dipel DF)			*Bacillus subtilis* (Serenade), sulphur		
3 August				*Bacillus subtilis* (Serenade), sulphur		
9 August	*Bacillus thuringeinsis* (Dipel DF)			sulphur, bupirimate (Nimrod), fenhexamid (Teldor)	No info	SH
10 August	Spinosad (Tracer)	H (1-2 wks)	H (1-2 wks)			

Conclusions from ADAS experiment in 3.3.2

- None of the *N. cucumeris* strategies, used with or without *O. laevigatus,* controlled WFT. This contrasts with the 2011 trial in this project on the same field and crop, when a combination of *N. cucumeris* (one sachet per 2m row on 31 March and 12 May) and *O. laevigatus* (used with or without alyssum 'banker plants' gave good control of WFT throughout the season.
- *N. cucumeris* was confirmed in strawberry flowers before the first release date, indicating that they had either occurred naturally or overwintered from the previous season. *N. cucumeris* were recorded in untreated plots in similar numbers to plots treated with the predators and thus there was no effect of *N. cucumeris* on WFT numbers throughout the trial period.
- Cooler temperatures during May 2012 than in May 2011 are likely to have contributed to poor *O. laevigatus* establishment in 2012.
- The use and timing of Phantom and Switch may have adversely affected *O. laevigatus* establishment in the 2012 trial.

- Mean numbers of WFT adults per flower peaked on 28 June, with a mean of 20 adults per flower in tunnels 3 and 4.
- Mean percentage of ripe fruit with damage around five or more seeds was 2.5-32.5% on 28 June and 2.5-12.5% four weeks later on 25 July.
- The grower decided to apply spinosad (Tracer) for control of WFT on 10 August. WFT are still susceptible to this pesticide on this farm.

3.3.2. EMR experiment

This combined *Neoseiulus* (*Amblyseius) cucumeris* and *Orius laevigatus* release strategies to improve WFT control with the following objectives:

- To determine whether *N. cucumeris* is more effective as repeated releases in sachets every six weeks, or as a pre-flowering release of sachets followed six weeks later by loose product every three weeks;
- To determine whether releases of *O. laevigatus* improve control of thrips when used in combination with releases of *N. cucumeris*.

Methods

Experimental design

This experiment was done at J R Clarke and Partners, Manor Farm, Hints, Staffordshire B78 3DW. (Manager Simon Clarke; Office: 01543 483308; Mob: 07798 740209).

Treatments were:

1. *N. cucumeris* at one sachet per 2-metre length of row, before flowering on 5 April and repeated after six weeks on 17 May
2. *N. cucumeris* at one sachet per 2-metre length of row, before flowering on 5 April and repeated every six weeks until 10 August
3. *N. cucumeris* at one sachet per 2-metre length of row, before flowering on 5 April, followed by loose product at 25 per plant, every three weeks, starting on 17 May, six weeks after the first release of sachets until 10 August.
4. Untreated control
5. As treatment 1, plus *O. laevigatus* as in 8
6. As treatment 2, plus *O. laevigatus* as in 8.
7. As treatment 3, plus *O. laevigatus* as in 8.
8. No *N*. *cucumeris* (as in treatment 4), but treated with *O. laevigatus* at 1 per m^2 on 17 May, 6 weeks after the first release of *N. cucumeris* (when the plants were flowering). A second application scheduled for 8 June was not done as the grower was about to spray the whole planting with Calypso. *O. laevigatus* was then released on 28 June, 21 July and 10 August.

The experiment used two tunnels of the Berry Gardens Growers cultivar EME 676 planted on 1 March 2012 in re-used coir bags in Bottom Meadow Field. The tunnels were circa 250 and 270 m long and 6 m wide. The treatment tunnels were separated by six tunnels which were managed by the grower according to his normal practise. Plants were not fleeced. Tunnels were erected on 7 March. Plants were de-blossomed to leave 50% of flower clusters on 11 May.

There were eight treatments replicated four times. *N. cucumeris* treatments were randomly assigned within blocks. *O. laevigatus* releases were made to one entire tunnel in an attempt to reduce the potential effects of dispersal of this predator into the no-release *Orius* plots. The 'no-*Orius* release' tunnel was adjacent to newly planted 60 day plants (planted mid-May). The '*Orius* release' tunnel was adjacent to grassland. Plots were circa 14 m long and contained four beds of 14-15 bags. Strawberries were planted eight to each 1 m coir bag in each bed. Thus each plot contained circa 450 plants.

Neoseiulus cucumeris sachets were released at one per 2 m length of bed in the appropriate plots. All beds in the plot were treated. The first release was made on 5 April and the second on 17 May. The third release in treatments 2 and 6 was on 28 June and the forth on 10 August. Loose product was released on the relevant plots, after calculating how much volume of product was needed per plot for the required release rate and transferring this volume into separate tubes for each plot. The first loose release was made on 17 May by sprinkling the required volume evenly over the plants in the bed. Further releases were made every three weeks until 10 August.

O. laevigatus were supplied as adults in buckwheat carrier in plastic bottles. Each bottle contained 500 predators. Predators were released every five metres down tunnel 8, to strawberry leaves in the middle two beds of plants. Predators were released by calculating the volume of carrier required to dispense the required number of individuals assuming they were evenly distributed through the carrier. Bottles were emptied into a larger container and well mixed before each dispensing. Predators were dispensed using a small spoon and actual numbers dispensed assessed by counting numbers present in 6 aliquot spoonsful. The first release was made on 17 May and subsequent releases on 28 June, 21 July and 10 August.

The predator release treatments were in addition to the grower's standard pest and disease management programmes which used pesticides safe to beneficial mites and insects in the

experimental tunnels where possible. *Hypoaspis miles* was released to each bag in all treatments by the grower in early May. Full records of treatments applied were kept by the host grower. A data logger was placed in each tunnel to take half hourly records of temperature in the crop.

Assessments

An estimate of the average number of flowers per plant was made on each sampling occasion by recording the number of open flowers on each of 25-50 plants.

20 open strawberry flowers were taken from each plot and placed into pots containing 70% alcohol. The flowers were taken from the central 2 beds and from the central area (6 m length) of each plot. Flowers were of similar age, fully open with fresh white petals. The numbers of adult and larval thrips and predatory mites and insects present were assessed in the laboratory at EMR using a washing method to extract the arthropods from each sample followed by counting under a binocular microscope. A sub sample of thrips adults and predatory mites were mounted on microscope slides and identified to species under a compound microscope. The % adult WFT present was estimated. Tap samples of 75 plants were made in each tunnel after *O. laevigatus* release.

Thrips damage to fruit was recorded on 10 randomly selected ripe fruit per plot on each of four picking dates in July and August. In the final two assessments 10 white fruit were also inspected in each of the untreated control plots. The damage scoring system was that used in previous years (none; low; moderate; severe).

Statistical analysis

Numbers of *N. cucumeris* and thrips larvae and adults were square root transformed and compared by ANOVA.

Results

There was no consistent effect of releasing *O. laevigatus* on numbers of *N. cucumeris* recorded in samples of 20 flowers, so no evidence that released *O. laevigatus* were consuming *N. cucumeris*. No *O. laevigatus* were recorded in tap samples from plants after release.

There were significant differences in numbers of *N. cucumeris* recorded in the different release treatments ($P<0.001$). Overall transformed means of numbers in treatments over all dates were 2.13, 2.53, 1.97 and 1.25 for treatments 1-4 respectively. These results confirm

those reported in the second year of the project, where higher numbers of mites were found where multiple deployments of sachets were made. In 2012 highest numbers were found over the season in the multiple sachet treatment (Figure 3.3.2.12). Table 3.3.2.2 give the results for mite numbers on each sample date. Placing out sachets every 6 weeks ensured that these predators were still abundant at the end of the season. Numbers were low in the 'no-release' treatment in the first two samples but after that it was apparent that the mites had dispersed onto the untreated plots. There appeared to be two main flower flushes in the variety used in this experiment (Figure 3.3.2.12). The apparent reduction in numbers of *N. cucumeris* in August may partly be due to dilution effects resulting from this flush of flowers. Fruit from this field was picked until October.

Table 3.3.2.2 Square root transformed numbers of predatory *N. cucumeris* recorded from flower samples in different release treatments compared to the no-release control

Treatment	Sampling date					
	17 May	8 June	28 June	21 July	9 Aug	19 Sept
Early sachets repeated after 6 weeks	2.37	2.42	3.96	2.56	0.59	0.88
Early sachets repeated every 6 weeks	2.12	2.87	3.23	4.19	1.47	1.32
Early sachets followed by loose product	2.41	2.93	2.50	2.40	0.80	0.81
No release	0.50	0.77	1.13	2.49	1.48	1.15

sed (21 df) = 0.185

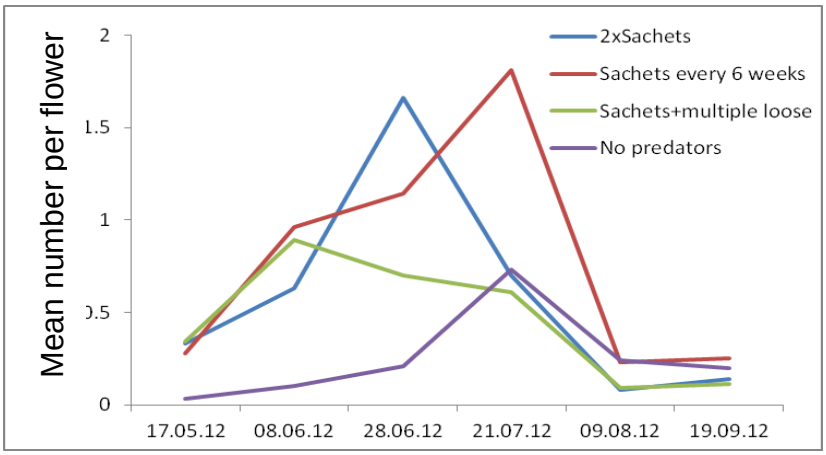

Figure 3.3.2.12. Mean number of *N. cucumeris* per flower in the different release treatments

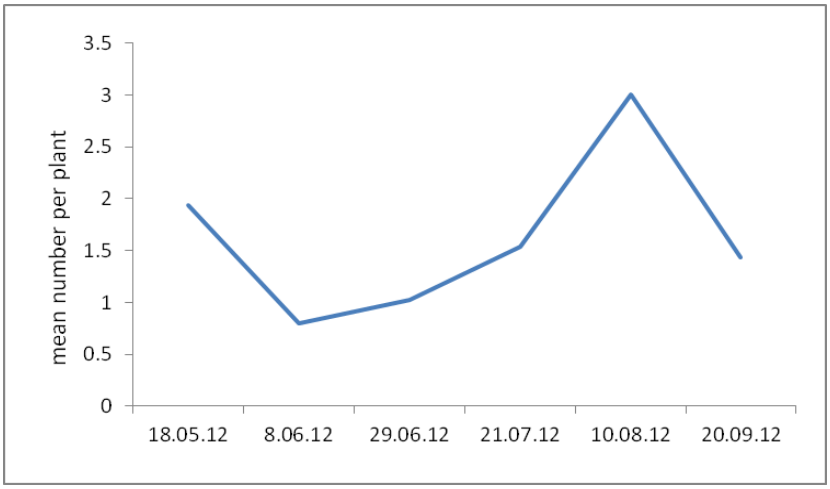

Figure 3.3.2.13. Mean number of flowers per strawberry plant at time of sampling

For thrips larvae and adults no effect of *O. leavigatus* release was seen until the last sample date in September when numbers were significantly lower for both stages in the *O. laevigatus* release plots (P=0.002) (Figures 3.3.2.13 and 3.3.2.14). The dip in numbers of thrips larvae seen in Figures 3.3.2.14 and 3.3.2.16 may be due to an application of Calypso (thiacloprid) that was made over the whole planting on 8 June to control strawberry blossom weevil; this is likely to have only had an effect on *T. major* and *T. tabaci*. This insecticide application had no detectable effects on *N. cucumeris* numbers (Figure 3.3.2.12 and Table 3.3.2.2).

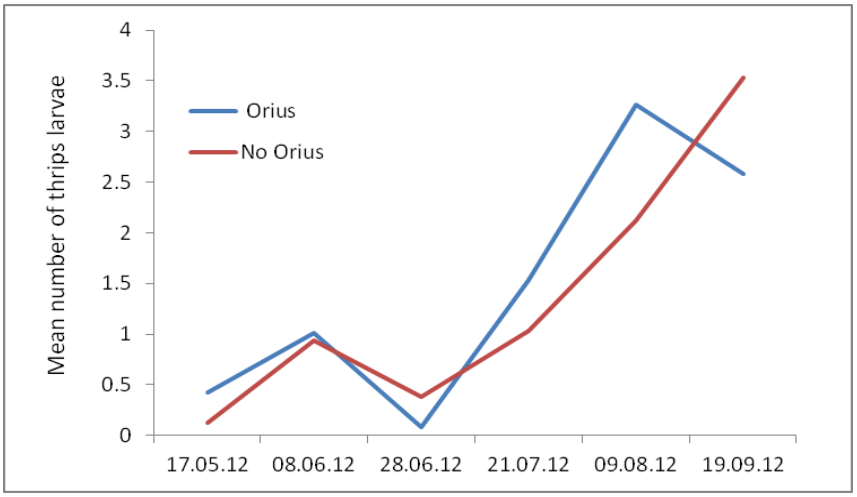

Figure 3.3.2.14. Square root transformed mean number of thrips larvae in plots with or without *O. laevigatus* release

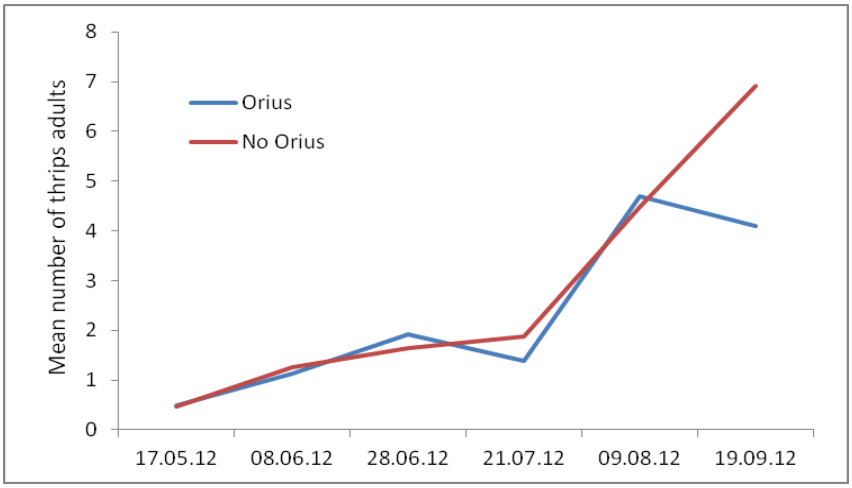

Figure 3.3.2.15. Square root transformed mean number of thrips adults in plots with or without *O. laevigatus* release

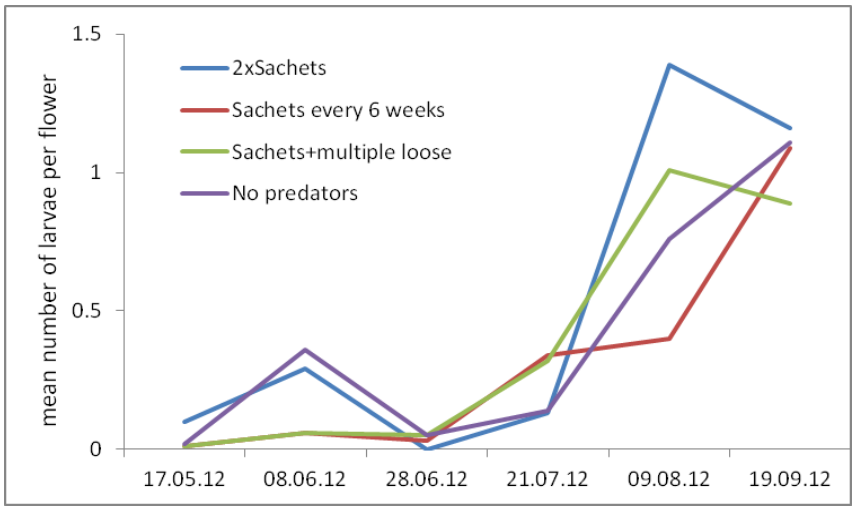

Figure 3.3.2.16. Mean number of thrips larvae in plots treated with different releases of *N. cucumeris*

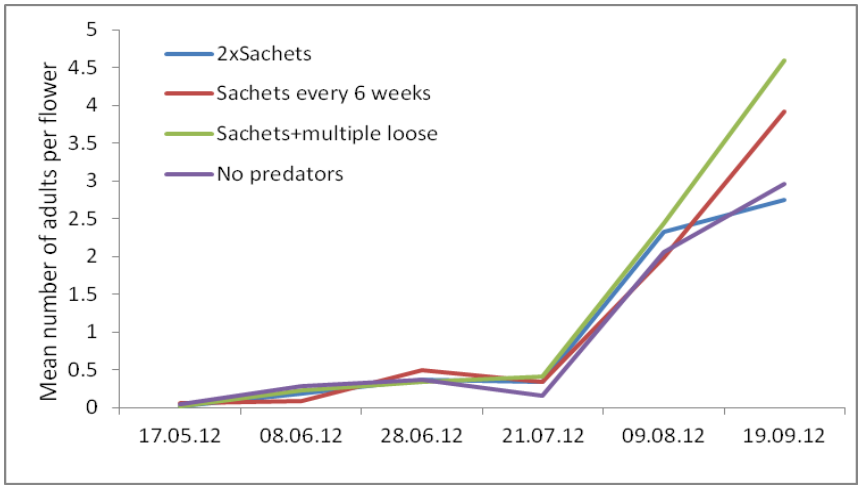

Figure 3.3.2.17. Mean number of thrips adults in plots treated with different releases of *N. cucumeris*

All the predatory mites identified from flower samples were *N. cucumeris*. Of the thrips adults identified from flowers throughout the season, 39% were WFT, 23% were *Thrips major* and

23% were *T. tabaci*. The remaining 16% consisted of three-four other species which have not yet been identified. The proportions of the three main species were similar throughout the season from early June to August.

There was no significant effect ($p<0.05$) of any of the *N. cucumeris* release strategies on numbers of thrips larvae or adults in 2012 (Figures 3.3.2.16 & 3.3.2.17). There were lower numbers of thrips larvae in the multiple sachet release treatment on 9 August ($p<0.1$).

There was no thrips damage to ripe or white fruit in samples inspected in the field in 2012, and the grower did not downgrade any fruit due to thrips damage.

Temperature and humidity data for the tunnels during the experiment are shown in Figure 3.3.2.18.

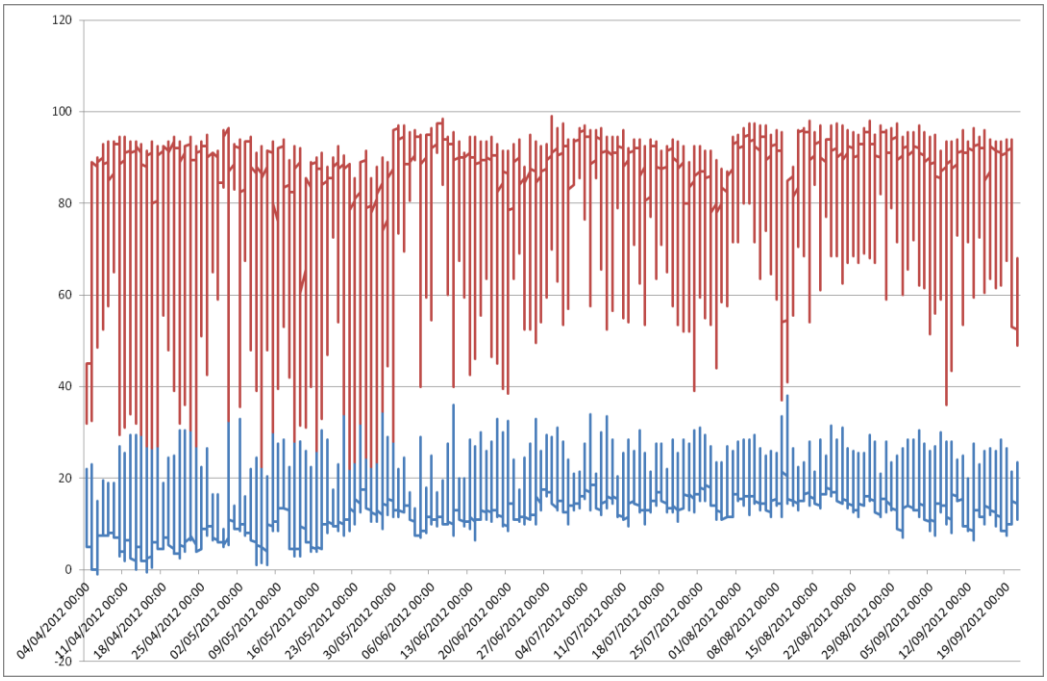

Figure 3.3.2.18. Temperature (lower trace) and humidity recorded in experimental tunnel during the trial at Manor Farm

The spray programme used by the host grower in the experimental tunnels is shown in Table 3.3.2.3. The only insecticide applied to these tunnels was Calypso (thiacloprid) on 9 June for control of strawberry blossom weevil and an overall cleanup application on 21 September.

Table 3.3.2.3. Spray programme in experimental tunnels

Date	Fungicide
20 April	Teldor
	Stroby
3 May	Fenomenal

Date	Fungicide
4 May	Teldor
	Fortress
14 May	Signum
23 May	Stroby
4 June	Teldor
	Fortress
9 June	Teldor
	Mantra
26 June	Serenade
	potassium bicarbonate
	sulphur
9 July	Systhane
	Rovral
10 July	potassium bicarbonate
	sulphur
31 July	Nimrod
	Teldor
11 August	Borneo
	Kindred
16 August	Switch
	Systhane
29 August	Switch
	potassium bicarbonate
1 September	Topas
	Scala
7 September	sulphur
	potassium bicarbonate
16 September	Switch
	Nimrod
21 September	Scala
	Hortiphyte
	potassium bicarbonate

Discussion

There were very low numbers of thrips in this first year planting at the beginning of the experiment in April and numbers only began to increase in July. The initial plan to release *O. laevigatus* early in the season had to be abandoned when the grower decided that he needed to treat the crop for strawberry blossom weevil; thiacloprid is not safe to *O. leavigatus*. Although three releases of *O. laevigatus* were made from late June to early August, when thrips numbers were increasing, none were found in tap samples of plants. Therefore it is unlikely that they established successfully in the planting, even though there was the suggestion that numbers of thrips larvae were lower in the *O. laevigatus* release treatment on the last sample occasion. More work needs to be done to determine what is preventing establishment of this predator in commercial strawberry crops.

In this experiment, multiple releases of sachets and loose product ensured that *N. cucumeris* were present until later in the season than was seen in other years in this project. However,

there was no evidence to suggest that any of the *N. cucumeris* release strategies had any effect on thrips populations; this is contrary to the results found in 2010 and 2011 (see previous reports). The reason for this is unclear as it is apparent from the counts of mites in flowers that they established well on the plants. Also in 2012, despite the relatively large populations of thrips seen later in the season (means of 2.5-4.5 adults per flower), there was no damage to fruit from thrips feeding in this planting. Figures 3.3.2.19 and 3.3.2.20 summarise the thrips populatons recorded in the *N. cucumeris* release experiments over the three years of this project. It is clear that populations were much larger in 2010 and 2011, so the lower populations seen in 2012, in particular at the beginning of the season, may have been below the threshold for causing visible damage to the crop. Also the fruit cultivar grown in the experiment each year was different (Jubilee; Camarillo; EME 676 in the three years respectively), and it is possible that some varieties are more resistant or tolerant to thrips feeding than others.

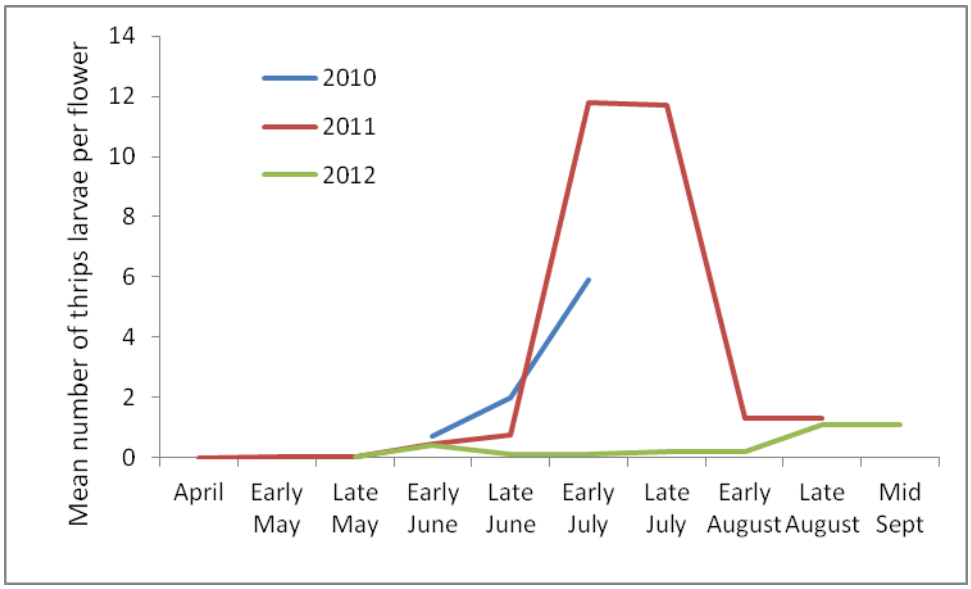

Figure 3.3.2.19. Mean number of thrips larvae per flower in the untreated plots at Manor Farm over three seasons

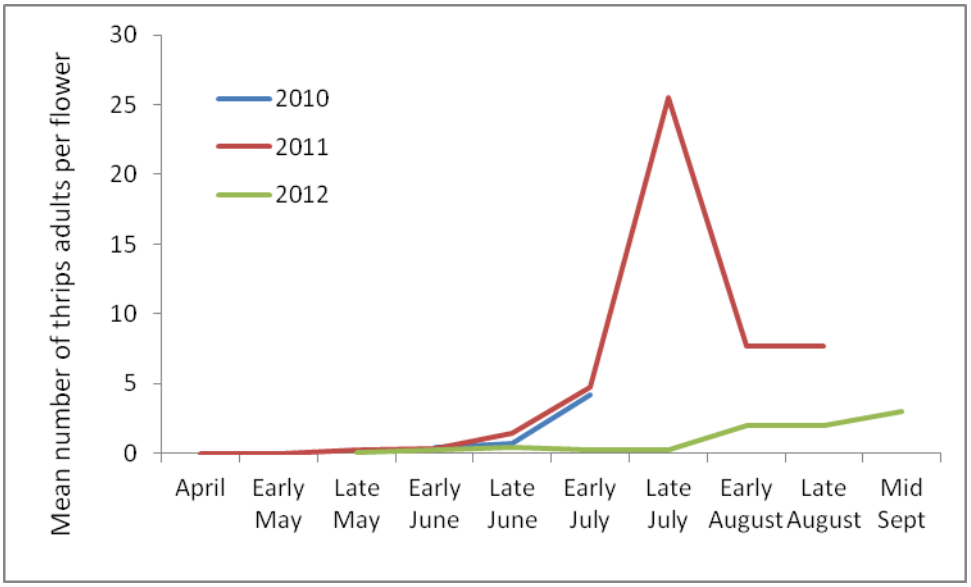

Figure 3.3.2.20. Mean number of thrips adults per flower in the untreated plots at Manor Farm over three seasons

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

This task will begin in Year 4.

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

In the tap samples of plants taken to determine if *O. laevigatus* had established in the commercial crop at Manor Farm by EMR, very low numbers of arthropods were recovered. In 375 plants sampled over three sample dates only 26 spiders were recorded; no other predators were seen. From this and other observations in previous years in this project it seems unlikely that there will be high numbers of naturally occurring predators in first year commercial crops. Plants will be sampled from second year crops in 2013 to determine if naturally occurring predators disperse into these crops.

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

The aim of this Objective is to evaluate novel insecticide treatments and proprietary fungal biopesticides on a commercial crop. Experimental design, analysis and interpretation will be done by the team at Warwick HRI, while execution of the experiment and data collection will be done by the team at EMR.

Task 4.2-4.3. Evaluation of entomopathogenic fungi applied as soil drenches (Yr2) and consistency of effect (Yr 3) EMR, Warwick HRI

Methods

In 2012 four products including three fungal biopesticides and one botanical insecticide (Table 4.1) were evaluated as either a foliar spray or a soil drench and compared with a standard foliar spray insecticide treatment (Tracer, Dow Agrosciences) and an untreated control.

Table 4.1: Treatments

	Product	Application	Parent company	Active substance and formulation
1	Untreated		-	-
2	Mycotal	Foliar spray	Koppert BV	*L. muscarium* strain Warwick HRI 19.79
3	Naturalis L	Foliar spray	Intrachem	*B. bassiana* strain American Type Culture Collection 74040
4	Naturalis L	Soil drench	Intrachem	*B. bassiana* strain American Type Culture Collection 74040
5	Met 52	Soil drench	Novozymes Inc	*M. anisopliae* Bipesco 5/F52
6	Neem	Foliar spray	Neemco	Azadirachtin A
7	Neem	Soil drench	Neemco	Azadirachtin A
8	Tracer	Foliar spray	Dow Agrosciences	Spinosad

All of the foliar treatments were applied with an adjuvant, Attracker (Koppert BV) which was tank mixed with each product prior to spraying. The foliar treatments were applied at a volume rate of 500 l/ha with a CP 20 pump knapsack sprayer according to the manufacturers' recommendation. All plots were fleece lined cages so no drift could occur between plots. The drench treatments were applied at a rate of 100 ml/pot applied directly to the soil around the plant, avoiding the crown of the plant.

The treatments were randomly assigned to the fleece cages according to a randomised split plot design with five replicates of the eight treatments (40 treatment applications in total). Each cage (1 x 0.5 x 0.5 m) contained eight strawberry plants (var Finesse) in 3L pots (Figure 4.1).

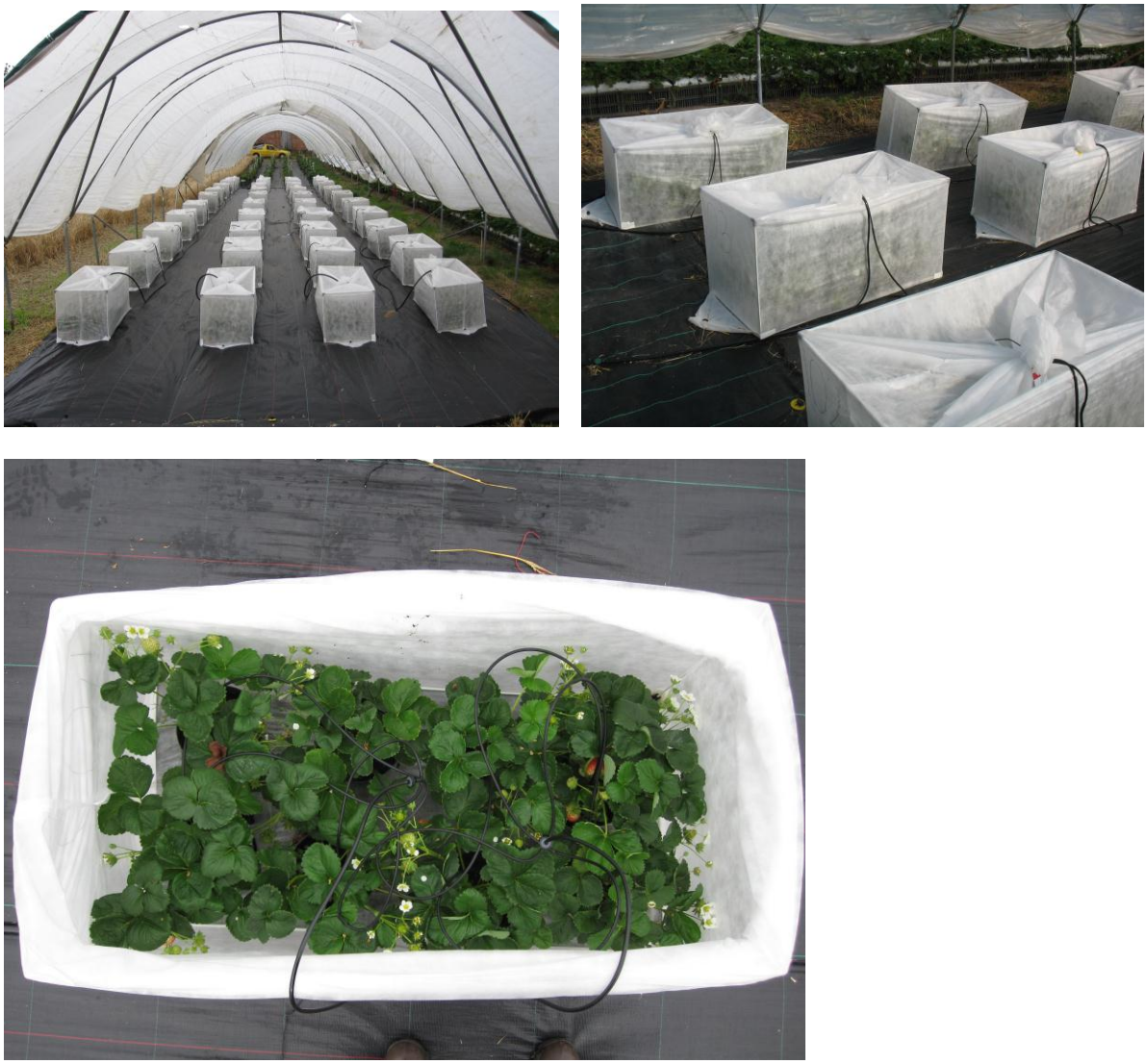

Fig 4.1: Trial site

The treatments were applied four times at seven day intervals and the numbers of live WFT (adults and juveniles) were counted and flower and fruit damage assessed on 6 September, 13 September and 20 September 2012 (Table 4.2).

Wet and dry bulb temperature, wind speed and direction were recorded before and after spraying. In addition, a USB-502 logger was used to take hourly temperature and humidity readings inside the cages and polytunnel throughout the duration of the trial.

Table 4.2 Timetable of spray applications and assessments

Day	Action	Date
0	Pre spray assessment of WFT	13.08.12 and 21.08.12
3	First treatment applications	24.08.12
10	Second treatment applications	31.08.12
16	First post spray assessment	06.09.12
17	Third treatment applications	07.09.12
23	Second post spray assessment	13.09.12

24	Fourth treatment applications	14.09.12
30	Third post spray assessment	20.09.12

A pre-spray assessment of the natural thrips population was done 10 days prior to the first application. Ten flowers from each cage were randomly sampled and agitated in alcohol (SOP:780 Sampling and assessing thrips numbers in flowers. (C Jay, EMR, June 2010)) and the number of WFT counted under a binocular microscope at low magnification and recorded. There was considerable variation between the cages and so one plant from higher infested cages was swapped with one in a lower infested cage and all cages left for a further week to allow the WFT population to build up further.

Assessments of treatment effects were done on 6, 13 and 20 September 2012, 13, 20 and 26 days after the first treatment applications. The degree of thrips control achieved in the trial was determined by counting numbers of WFT adults and nymphs on young flowers. On each sampling occasion, a sample of young open flowers was collected from each cage and placed into screw top tubes containing 70% ethanol, one tube for each plot, for storage. (SOP: 780 Sampling and assessing thrips numbers in flowers. (C Jay, EMR, June 2010)). Numbers of thrips (nymphs and adults) were counted under a binocular microscope at low magnification. Data were analysed by ANOVA following a square root transformation. Flower and fruit damage were assessed on five flowers and 10 fruits per treatment according to the SOP: WFT damage to strawberry flowers and fruit (Jude Bennison, ADAS, 2010). WFT damage to flowers was recorded as present or absent. WFT damage to fruit was recorded as follows: (1) Absent (i.e. free from damage); (2) 'slight' bronzing (one patch of bronzing or russetting around 1-3 seeds); (3) 'moderate' bronzing (up to 50% of the fruit surface area damaged); (4) 'severe' (more than 50% of the fruit surface area damaged).

Analysis and results

The total number of WFT per cage were aggregated to give sums of count per flower and a variance stabilising transformation (logarithm +0.5) applied to the numbers before analysis of variance (Genstat, 2007). The total numbers of WFT (nymphs plus adults) per flower were variable both within and between cages ranging from 0 to 96 WFT per flower (mean = 30.6; se = 3.76). The total numbers counted consisted largely of nymphs. The adults and nymphs were analysed separately and combined but no difference in the results were observed, therefore the total WFT (adults + nymphs) data is presented. There was no significant difference between mean numbers of WFT per flower prior to application of spray treatments (Table 4.3). There was no significant effect of any of the treatments on WFT populations (Table 4.4). There was a large variation in WFT numbers between replicate plots, particularly for the untreated control. This may well have masked any effect of

treatments. There were indications of a trend of declining WFT populations over time for the Naturalis foliar application and two drench treatments (Naturalis and Neem) (Figure 4.2).

Flower damage data was subject to a variance stabilising transformation (logarithm +0.5) applied to the numbers before analysis of variance (Genstat, 2007). The average number of flowers damaged ranged from 30 - 90% at the end of the trial. The Naturalis drench, the Neem foliar application and Tracer all significantly (P=0.10) reduced the overall amount of flower damage compared to the water control. No significant increase (P=0.10) in damage was observed in consecutive assessment dates and the interaction between treatment and timing was not significant (Table 4.5; Figure 4.3). After the first flush of flowers the crop didn't flower very heavily so thrips may have become concentrated in the few available flowers, masking any effects of the treatments.

Fruit damage score data was aggregated as a percentage and angular transformed prior to analysis of variance (Genstat, 2007). None of the treatments had significantly less fruit damage than the untreated control (Table 4.6; Figure 4.4). There was significantly greater fruit damage observed (P=0.10) on consecutive assessments. The interaction between treatment and timing was not significant

Conclusions

Although there was no significant reduction in WFT populations following treatments there were indications of a trend of declining WFT populations over time for the biopesticide Naturalis and the botanical Neem applied as a drench. This method of application is worth investigating further as it could suggest that WFT do not receive a sufficient dose on the crop for lethal fungal infection with foliar applications. Another explanation could be connected with environmental conditions. Entomopathogenic fungi require high humidity and moderate temperatures for activity (the optimum temperature for fungal infection is c. 23°C). In the tunnels the minimum temperatures ranged from 4.5 to 17°C and the maximum temperatures ranged from 23 to 42.5°C (Figure 4.5). The high temperatures within the tunnels may be detrimental to foliar sprays of fungal biopesticides.

Table 4.3: Mean total No. of WFT (nymphs and adults) per flower (pre-treatment assessment)

Treatment	Application	Mean WFT per flower (log10 +0.5 transformed)	Mean WFT per flower (back transformed)
Naturalis	Foliar	0.7342	4.92
Naturalis	Drench	0.5356	2.93
Met52	Drench	0.7809	5.54
Mycotal	Foliar	0.8942	7.33
Neem	Foliar	0.6021	3.50
Neem	Drench	0.8351	6.34
Tracer	Foliar	0.5369	2.94
Untreated		0.7257	4.82
LSD (p<0.10)		**0.4203**	

Table 4.4: Mean (backtransformed) number of WFT per flower after treatment on three assessment dates (log transformed data in parentheses).

Treatment	Application	Timing		
		06.09.12	**13.09.12**	**20.09.12**
Naturalis	Foliar	3.740 (0.6273)	3.345 (0.5849)	1.257 (0.2449)
Naturalis	Drench	3.407 (0.5919)	2.155 (0.4241)	1.472 (0.2949)
Met52	Drench	4.229 (0.6747)	1.504 (0.3018)	1.626 (0.3277)
Mycotal	Foliar	1.167 (0.2219)	2.209 (0.4328)	1.353 (0.2679)
Neem	Foliar	2.732 (0.5095)	3.919 (0.6454)	2.030 (0.4030)
Neem	Drench	2.924 (0.5345)	1.479 (0.2964)	0.429 (0.0319)
Tracer	Foliar	0.994 (0.1742)	2.491 (0.4759)	1.411 (0.2813)
Untreated		0.727 (0.0887)	0.781 (0.1076)	2.462 (0.4716)
LSD (p<0.10)			**0.4203**	

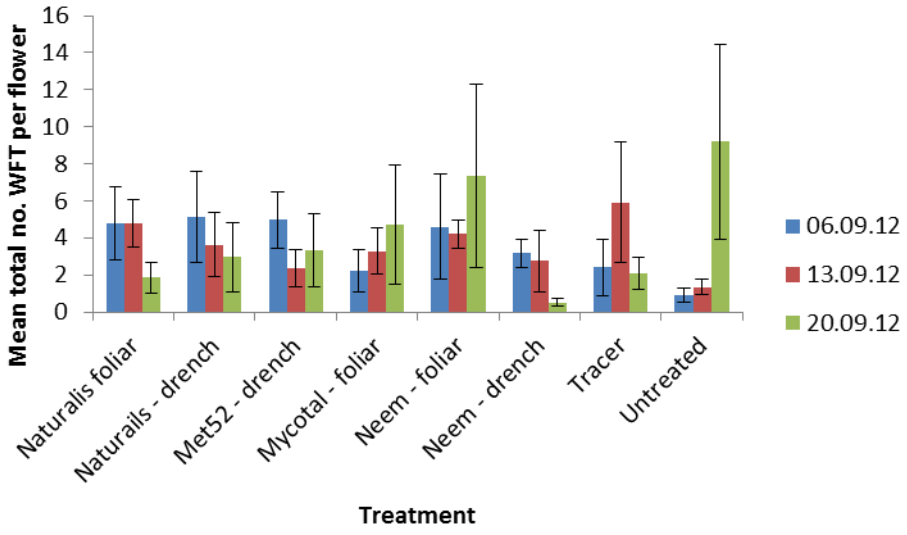

Figure 4.2: The mean number of WFT per flower after treatment on three assessment dates. Error bars represent the standard error of the mean

Table 4.5: The mean number of flowers damaged or not damaged after treatment (log +0.5 transformed data in parentheses).

Treatment	Application	Undamaged	Damaged
Naturalis	Foliar	1.190 (0.228)	2.550 (0.484)
Naturalis	Drench	1.559 (0.314)	1.810 (0.364)
Met52	Drench	1.304 (0.256)	2.586 (0.489)
Mycotal	Foliar	0.414 (-0.039)	4.036 (0.657)
Neem	Foliar	2.458 (0.471)	1.217 (0.234)
Neem	Drench	0.891 (0.143)	3.031 (0.548)
Tracer	Foliar	2.574 (0.488)	0.966 (0.166)
Untreated		0.554 (0.023)	3.841 (0.638)
LSD (p<0.10)		**0.2248**	**0.2248**

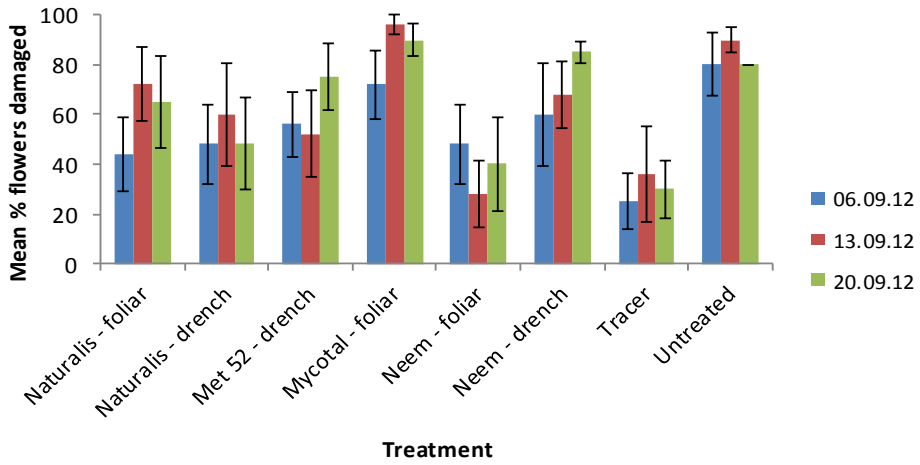

Figure 4.3: The average % number of flowers damaged after treatment on 3 assessment dates. Error bars represent the standard error of the mean.

Table 4.6: The average fruit score of 50 fruits per treatment

Treatment	Application	Average fruit score
Naturalis	Foliar	2.342 (62.07)
Naturalis	Drench	1.610 (47.10)
Met52	Drench	2.071 (56.18)
Mycotal	Foliar	1.582 (46.57)
Neem	Foliar	1.504 (45.07)
Neem	Drench	1.741 (49.62)
Tracer	Foliar	1.839 (51.53)
Untreated		1.816 (51.07)
LSD (p<0.10)		**9.34**

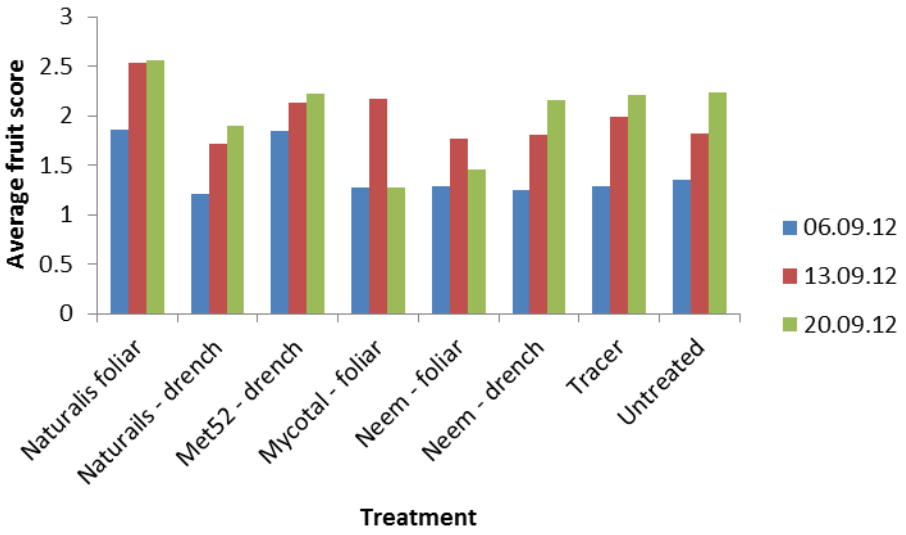

Figure 4.4: The average fruit score per treatment on three assessment dates.

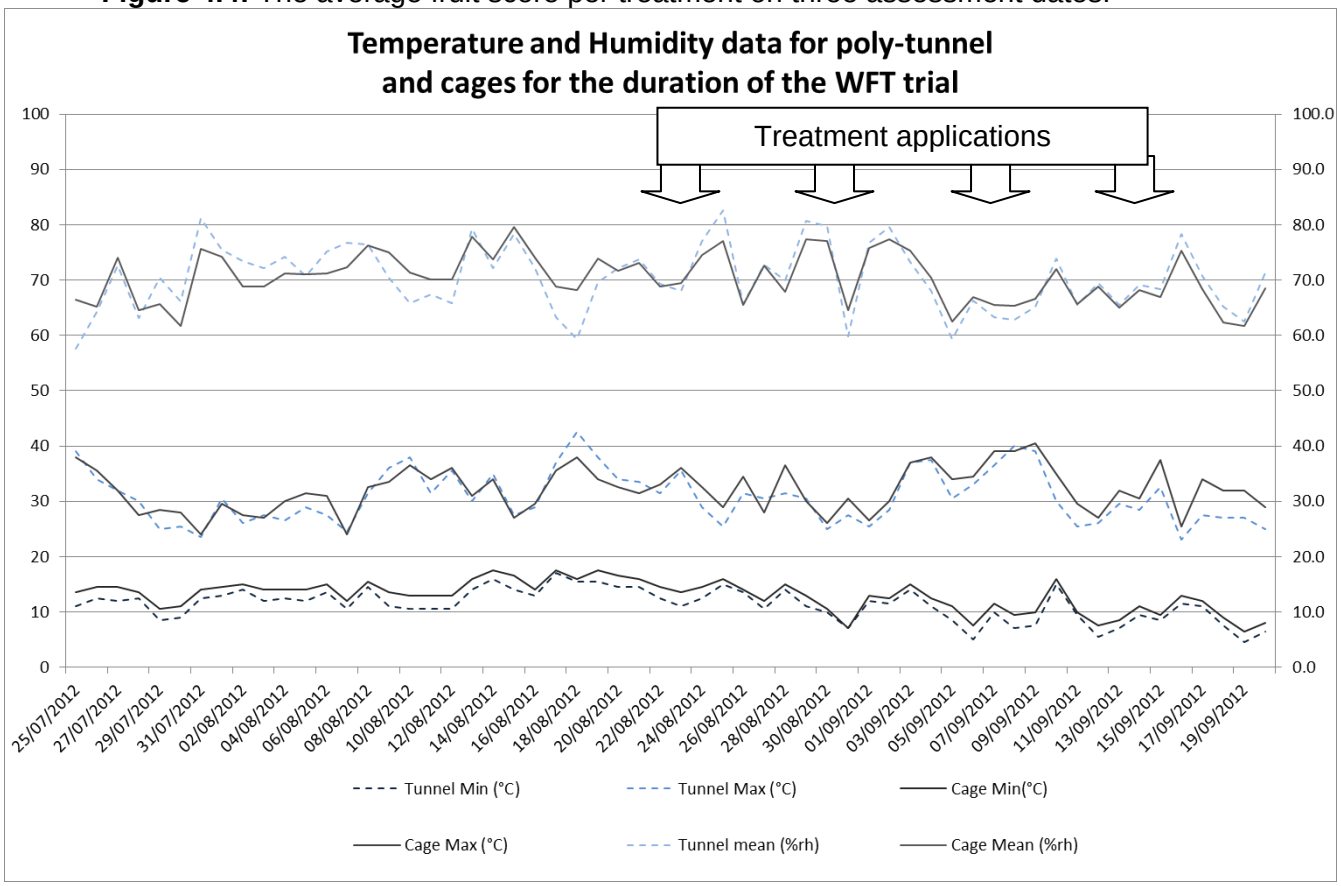

Figure 4.5: Meteorogical data from trial site

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

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

A draft IPM programme has been produced for discussion with the consortium members.

Task 5.2. - Test IPM in commercial crops (Years 4-5; EMR, ADAS and grower partners)

This work will begin in Year 4 of the project. The IPM strategy devised in 5.1 and agreed by the consortium will be tested in the final two years of the project, in comparison with the standard commercial programme used at the time by the host grower at four sites, two in Kent (EMR), one in Herefordshire (ADAS) and a fourth in East Anglia (ADAS). The WFT IPM programme and the 'standard commercial programme' control will each be applied to one large plot (> 0.5 ha) of protected everbearer strawberries at each site. The host growers will apply the treatments under direction and supervision of the science partners (EMR in Kent, ADAS in Herefordshire and East Anglia). The project researchers will make regular assessments of populations of thrips in monitoring traps and in the crop and flowers, of natural enemies and other pests as well as crop damage by these. Labour and materials costs will be recorded to provide data for an economic assessment. A cross-site statistical analysis will also be done if appropriate.

Task 5.3. - Prepare best practice guidelines (Year 5; all partners)

This will be done in Year 5

Task 5.4. Economic and environmental impact analysis (EMR, PO and grower consortium members, Year 5)

This will be done in Year 5.

SIX MONTHLY REPORT TO HORTICULTURE LINK PROGRAMME MANAGEMENT COMMITTEE
(Due 31 March 2013)

Project Number:	HL01107
Project Title:	Biological, semiochemical and selective chemical management methods for insecticide resistant western flower thrips on protected strawberry
Project Partners:	East Malling Research, ADAS Boxworth, Warwick HRI, University of Keele, Natural Resources Institute, Agriculture & Horticulture Development Board; Tesco Stores Ltd; K G Growers Ltd; Berry World Ltd; CPM Retail Ltd; Syngenta Bioline Ltd, Certis UK; Russell IPM Ltd; Belchim Crop Protection Ltd; Bayer Crop Science Ltd; East Malling Ltd
Report Written by:	J Bennison, J V Cross, J Fitzgerald, W Kirk, C Sampson, X Xu
Project Start/Completion Dates:	1 April 2010 – 31 March 2015
Reporting Period:	30 September 2012-31 March 2013
Number of Months Since Commencement:	30
Date of Last Management Meetings:	2 February 2012
Dates of Next Management Meetings	7 Feb 2013

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	
P1.5	31 Mar 2015	Damage thresholds established for thrips flower counts	
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	
P2.4	31 Mar 2015	A final model for WFT on strawberry completed	
P3.1	31 Mar 2011	First trial on release strategy for *N. cucumeris* completed	Y
P3.2	31 Mar 2011	Banker plant for *O. laevigatus* selected	Y
P3.3	31 Mar 2013	Efficacy of combined releases of *N. cucumeris* and *O. laevigatus* determined	
P3.4	31 Mar 2015	Role of WFT attractant with banker plants determined	
P3.5	31 Mar 2015	Analysis of gut content of naturally occurring predators completed.	
P4.1	31 Mar 2013	Effective pesticides and EPFs identified	
P5.1	31 Mar 2013	IPM programme for thrips for evaluation in yrs 4 and 5 devised	
P5.2	31 Mar 2015	Thrips IPM programme evaluated in commercial crops for two seasons	
P5.3	31 Mar 2015	Best practice guidelines for thrips IPM prepared	
P5.4	31 Mar 2015	Economic and environmental impact analysis of thrips IPM completed	
S1.1	31/03/11	Data on release rates of pheromone components by WFT obtained	Y
S1.2	31/03/12	Initial designs to exclude other insects tested	Y
S1.3	31/03/13	Optimum flower sampling methods determined	Y
S1.4	31/03/14	Optimum trap density and spacing determined	Y
S1.5	31/03/15	Feasibility of using traps to control WFT determined	Y
S2.1	31/03/11	Experimental protocols for lab experiments established	Y
S2.2	31/03/14	Sufficient amount of field data on WFT obtained	
S2.3	31/03/15	A model for a specific BCA incorporated with the WFT model	
S3.1	30/09/10	Emergence of *N. cucumeris* from sachets quantified	Y
S3.2	31/07/10	Pilot experiment with *O. laevigatus* establishment completed	Y
S3.3	31/03/11	Protocol for trial with release rates of both predators agreed	Y
S3.4	31/03/13	Protocol for using thrips attractant with banker plants agreed	
S3.5	31/01/12	Protocol for collection of natural predators agreed	
S4.1	31/03/11	First field trial evaluating pesticides and EPF sprays completed	Y
S4.2	31/03/12	Second field trial evaluating pesticides and EPF soil treatments completed	Y
S4.3	31/03/13	Confirmatory field trial testing most effective pesticide and EPF treatments completed	
3.	**Milestones for the six month period:** (from project proposal, or other more recently approved planning document)		
		None were due in the reporting period	
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

WFT was shown to overwinter as adult females in senescent/dead strawberry flowers and weeds, such as chickweed, groundsel and dandelion within fields and in field margins. Overwintering in crops resulted in significantly more thrips in second year crops than in first year crops at the beginning of the season. Adult thrips moved into strawberry flowers and started to lay eggs at first flowering. In first-year crops, the first thrips were observed around the outside of crops, particularly near weedy field margins, demonstrating the need for good weed control to reduce thrips risk. In general there was a mix of species early in the season (mainly WFT, *Thrips major* and *Thrips tabaci*) with increasing proportion of WFT (>90%) from July, especially after insecticide treatments. Before flowering, the use of blue sticky traps placed on canes (vertical orientation) 10 cm above the crop bed, with a pheromone lure was the most effective monitoring method. The addition of pheromone increased trap catch by x3. From first flowering, a count of adult thrips in medium-aged open flowers was a more accurate monitoring method than using trap counts. Significant damage that might result in downgrading of fruit corresponded to an average of about four to eight adult thrips per flower with lower thresholds in hot/dry conditions without predators and higher thresholds in cool, humid conditions with predators. The pheromone neryl (S)-2-methylbutanoate and the plant volatile methyl isonicotinate increased trap catches by small amounts (between x1.2 and x1.6) in UK strawberry crops during June and August, but there was no synergistic response. Three large-scale, replicated field trials demonstrated that placement of blue roller traps along the legs between tunnels reduced thrips numbers and fruit damage. The use of traps alone (30 cm wide, 100 m long, Optiroll, Russell IPM) reduced thrips numbers by 61% and fruit damage by 55%. The use of roller traps with WFT aggregation pheromone, reduced thrips numbers by 73% and fruit damage by 68%. Roller traps should be put out about 3-4 weeks before damage is predicted (e.g. between late May and early July according to the cropping system). They remain sticky for at least two months, although sections of glue can be washed off the trap.

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

New data have been obtained on the rates of development of WFT on strawberry at fluctuating temperatures in the laboratory. These data are being used to validate the model developed in years 1 and 2.

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

An experiment was carried out by EMR on a first year strawberry planting in an attempt to identify the most effective strategy for release of predatory mites in combination with releases of *Orius laevigatus*. There were eight treatments replicated four times. *O. laevigatus* releases were made to one entire tunnel in an attempt to reduce the potential effects of dispersal of this predator into the no-release *Orius* plots. The treatments were: (1) *N. cucumeris* at one sachet per 2-metre length of row, before flowering in early April and repeated after six weeks; (2) as 1 and repeated every six weeks; (3) *N. cucumeris* sachets in early April, followed by loose product at 25 per plant every three weeks, starting six weeks after the first release of sachets; (4) untreated control; (5) as treatment 1, plus *O. laevigatus* as in 8; (6) as treatment 2, plus *O. laevigatus* as in 8; (7) as treatment 3, plus *O. laevigatus* as in 8; (8) no *A. cucumeris* (as in treatment 4), but treated with four releases of *Orius laevigatus* at 1 per m^2 six weeks after the first release of *N. cucumeris*. Thrips larvae and adults were present in similar numbers in all treatments throughout the season, including the no predator release control. Several species were present with 38% of those identified being WFT. No *O. laevigatus* were found in samples taken in the release tunnel. Highest numbers of *A. cucumeris* were found in the plots where sachets had been released every six weeks; the peak in predator numbers was also later in this treatment (end of July rather than end of June). However this appears to have had no effect on thrips numbers in the flowers. There was no thrips feeding damage seen in samples taken by EMR at harvest and the grower did not downgrade any of this crop from the experimental tunnel.

A second experiment carried out by ADAS tested the same strategy for using *N. cucumeris* in combination with *Orius laevigatus*. No alyssum 'banker' plants were used to aid establishment of Orius. The treatments were: (1) Untreated control. (2) *N. cucumeris* at one sachet per 2-metre length of row before flowering on 4 April, repeated at six-week intervals (on 16 May and 26 June), (3) *N. cucumeris* at one sachet per 2-metre length of row before flowering on 4 April, followed by loose product at 25 per plant after six weeks (on 16 May) and thereafter every two weeks (on 31 May, 15 June, 28 June, 12 July and 26 July), (4) untreated with *N. cucumeris* with releases of *Orius laevigatus* adults at 0.5 per m^2 at first flower flush on 10 May, and again at second flower flush, together with nymphs at 3 per m^2 , (5) *N. cucumeris* as in treatment 2, plus *O. laevigatus* as in treatment 4, (6) *N. cucumeris* as in treatment 3, plus *O. laevigatus* as in treatment 4. Numbers of thrips (predominantly WFT) increased during the experiment in all plots and *O. laevigatus* did not establish well. Very little fruit was downgraded due to thrips damage, but the host grower decided to apply spinosad (Tracer) on 9 August as mean numbers of WFT had reached very high numbers (16 adults per flower). Spinosad resistance has not yet developed on this farm.

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

Programmes of four weekly applications of sprays versus drenches at seven day intervals of 3 EPF and a novel botanical product were evaluated in comparison with a standard programme of four spinosad sprays at weekly intervals and an untreated control in Bugdorm cages covered with horticultural fleece to prevent WFT emigration or immigration. WFT populations declined over time for drenches of one EPF and the botanical product but there was no statistically significant treatment effect. The failure to gain significant control of WFT with EPFs in this and the previous experiments in the project contrasts with very high levels of control observed in other crops. EPFs are known to infect WFT. Possible reasons for poor control include poor spray coverage, lack of secondary pick up of spores, inadequate persistence of EPFs on foliage and environmental conditions.

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

No work on this objective was done in the reporting period.

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.

None

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

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.

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