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Date project commenced:	01 April 2015
Date project completed (or expected completion date)	31 March 2020

DISCLAIMER

[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

AUTHENTICATION

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

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GROWER SUMMARY

This project addresses the main pest problems reported by the UK strawberry industry, except for spotted wing drosophila (SWD), which is covered in other projects. Within this project, it was planned to work on five objectives over the five-year duration. A sixth objective was added during the life of the project to investigate *Thrips fuscipennis* which developed as an industry problem after the start of the project:

1. Develop effective biological methods for managing western flower thrips, *Frankliniella occidentalis* (WFT), compatible with pesticide use against SWD, improve the reliability of biocontrol of WFT with predatory mites, and develop effective approaches to the use of entomopathogenic fungi (EPF) for control of WFT.
2. Refine pest control programmes on strawberry, integrating pesticides with phytoseiid mites.
3. Develop IPM compatible controls for European tarnished plant bug (*Lygus rugulipennis*), common green capsid (*Lygocoris pabulinus*) and strawberry blossom weevil (*Anthonomus rubi*).
4. Improve insecticide control of the potato aphid, *Macrosiphum euphorbiae,* so as to be more compatible with IPM programmes.
5. Improve the control of aphids through the growing season.
6. Fill key gaps in knowledge on *Thrips fuscipennis* biology in strawberry crops so that IPM strategies can be developed.

All of these objectives were explored and the majority led to significant outcomes and actions that growers can implement to improve pest management in commercial strawberry crops. In some cases, additional studies were done as problems arose through the duration of the project.

For ease of reading, this Grower Summary report is split into sections for each of the objectives being worked upon. The Science Section of this report contains research carried out in year 5 (2019/20), the final year of the project. Details of previous year’s studies can be found in Annual Reports 1-4 (2016, 2017, 2018 and 2019).

Objective 1. Develop effective biological methods for managing western flower thrips, *Frankliniella occidentalis* (WFT), compatible with pesticide use against SWD, improve the reliability of biocontrol of WFT with predatory mites, and develop effective approaches to use of entomopathogenic fungi (EPF) for control of WFT.

Task 1.1. Determine the distribution of *Neoseiulus cucumeris* on commercial strawberry plants, after introduction, for WFT management.

Headline

- The presence of WFT as prey in strawberry plants increases the number *of N. cucumeris* on flowers and button fruits.

Background and expected deliverables

In the first year of the project, the major target was western flower thrips (WFT). At present, growers rely on introductions of the predatory mite *Neoseiulus cucumeris* (formerly called *Amblyseius cucumeris*) to control WFT. It is relatively inexpensive to mass produce and can be introduced in large numbers but only predates first-instar WFT larvae. However, biocontrol with *N. cucumeris* sometimes fails. This is usually due to insufficiently early or frequent introductions, poor predator viability and/or adverse effects of crop protection programmes. For effective biocontrol, a high proportion of flowers must contain *N. cucumeris*. Growers find it difficult to assess whether *N. cucumeris* populations have established adequately and whether they are in balance with their prey. It is crucial to develop grower-friendly methods for estimating WFT and *N. cucumeris* populations in relation to fruit damage and to develop attendant predator-prey ratio thresholds for interpreting relative populations.

In 2016, when multiple releases of high numbers of *N. cucumeris* were made in small field plots, very few predators were recovered from flowers or button fruit after release. A study was set up to determine; where mites disperse when released onto the plant; the influence of WFT on *N. cucumeris* distribution, and the diurnal movement of *N. cucumeris* on strawberry button fruits and flowers.

Summary of the project and main conclusions

To gain the background information needed to develop effective sampling strategies and treatment thresholds for WFT, samples of individual flowers and ‘button’ fruit were collected from two commercial crops, where *N. cucumeris* were being released, every two weeks from April to September. In addition, replicate samples of different plant parts, from unopened flowers to ripe fruit, were collected twice from each of two plantings to determine the distribution of pest and predator over the plant. One-off collections of flowers and fruit were also made from 12 crops that had different levels of WFT on the plants. Numbers of WFT and *N. cucumeris* were extracted and recorded in the laboratory and the data used to determine the most effective sampling strategy for *N. cucumeris* and to model the interaction between pest and predator.

In a glasshouse experiment, to assess the distribution of *N. cucumeris* on strawberry plants after release, eighteen plants were placed in each of two glasshouse compartments at NIAB EMR. WFT from laboratory cultures were released onto plants in one compartment at approximately 20 mixed stages per plant; the second compartment had no WFT released. Five days after WFT release *N. cucumeris,* from a commercial supplier, was released onto each plant in both compartments at a rate of ~200 mites per plant. One, four and seven days after release, six plants were randomly selected from each treatment. Numbers of each plant part at the time of sampling were recorded and the plants were destructively sampled in the glasshouse; all plant parts were separated into closed containers. Plant parts assessed were: old leaves, recently expanded leaves, folded leaves, flowers, button fruit, remaining fruit, developing fruit clusters and the crown. In addition, a sample of the *N. cucumeris* carrier material from the leaf surfaces of each plant was taken. Numbers of *N. cucumeris* and WFT were counted from the different plant parts to assess distribution over the plant after release and the data analysed to determine if there were differences in *N. cucumeris* distribution when prey was present.

Most WFT were found on the strawberry flowers and fruits. Most *N. cucumeris* had dispersed from the carrier material within one day of release, but around 50% of the total numbers of mites released were not recorded on the plants. *N. cucumeris* were recorded on all assessed plant parts but there were low numbers on the leaf samples. In the overall analyses of the results the presence of prey affected the distribution of *N. cucumeris* on the plants; there were significantly higher numbers of *N. cucumeris* on both flowers and fruits in the treatment where WFT had been released. These results confirmed earlier work that button fruit were the most effective plant parts to assess populations of *N. cucumeris* in the crop and highlights that the presence of prey (WFT) has a significant effect on the distribution of the predator.

Button Fruit: Some senescing petals may be visible on some fruits

In a following field experiment on a commercial crop to determine if there is a diurnal pattern of movement of *N. cucumeris* over the plant, several introductions of *N. cucumeris* were made. Data loggers were used to record temperature and humidity throughout the experimental period, and the photosynthetically active light levels (400-700 nm) were also monitored. Button fruit and flower samples were taken five times during the day; 09.00; 12.00; 15.00; 18.00 and 21.00. Sampling was repeated on three days, with a one day gap between the first two samples and a four day gap between the second and third sample to allow the plants to recover and produce more open flowers and button fruits. Each assessment unit consisted of 10 flowers or 10 button fruit. These bulk samples were collected into ethanol and arthropods were extracted using our standard laboratory washing technique. Numbers of *N. cucumeris,* thrips adults and larvae and *Orius* adults and nymphs were counted. Arthropods recorded on the sample units in relation to sampling time and date, position within the tunnel, and environmental conditions (mean temperature and mean light intensity for the 60 mins before each sample) were analysed.

There was a diurnal pattern of movement of arthropods on strawberry. In the overall statistical analyses of the data, the mean temperature in the hour prior to sampling significantly affected the number of arthropods recorded in samples of flowers and button fruits. No other variable tested had any effect on arthropod distribution. Numbers of *N. cucumeris* declined by around 3% for every 1°C increase in mean temperature calculated per hour, over the range recorded in the experiment (18-33°C). Predatory *Orius* adults and WFT adults were recorded in higher numbers as the mean temperature increased whereas WFT larvae decreased in abundance. Numbers of *N. cucumeris* were also lower in flowers and button fruit at higher temperatures. Therefore if very low numbers are recorded in samples it would be worth revisiting the plantation when temperatures have decreased to confirm establishment of the predator.

In a subsequent, late season experiment, five daily time points were selected (09.00; 12.00; 15.00; 18.00; 20.00) to achieve varying temperatures, then samples of 20 button fruits were placed in the extraction device at each time point in the field. The percentage of arthropods extracted from the button fruits at each time point and corresponding temperature were analysed. Findings showed that *N. cucumeris* extraction was not linked to time of day, or average temperature, however mean percent extraction did appear to follow a pattern, whereby it was lowest at the beginning and end of the day when average temperatures were coolest, and highest mid-afternoon when average temperature was warmest (average temperatures ranged from 13.9°C at 20:00 to 20.7°C at 15:00). The highest mean percent of *N. cucumeris* extracted was 44.5% at 15:00. Hence, when using the device to estimate numbers of *N. cucumeris* in the crop, temperature should be taken into consideration.

Main conclusions

- The presence of WFT as prey in strawberry plants increases the number *of N. cucumeris* on flowers and button fruits.
- Sampling button fruit rather than flowers gives a more reliable estimate of *N. cucumeris* establishment.
- Ambient temperature can affect the numbers of predatory mites observed in strawberry flowers and fruits.

Financial benefits

Western flower thrips (*Frankliniella occidentalis*) causes bronzing of fruit. It has become difficult to control because of resistance to crop protection products and a lack of effective alternative biological controls. Financial losses can be high, exceeding £15m to the UK industry alone in 2013. This project has investigated and developed new approaches to monitoring and control of WFT whilst maintaining control of other pests, particularly by conserving and improving efficacy of introduced arthropod biocontrol agents and entomopathogenic fungi in the crop.

Action points for growers

- Sample button fruit to detect *N. cucumeris* in the crop.
- Thrips are also found in button fruit, but numbers are higher in flowers using the extraction device (Task 1.2).
- Take into consideration numbers of WFT as there are more likely to be more *N. cucumeris* in flowers and fruits where there are high numbers of WFT.

- If temperatures are high, it is likely that fewer *N. cucumeris* will be found in the fruitlets and flowers and re-sampling to ascertain establishment may be needed.
- Avoid sampling for *N. cucumeris* in the mid-day heat in mid-season.

Task 1.2. To 1) develop an easy-to-use extraction device for monitoring *N. cucumeris* and WFT in commercial strawberry crops, and determine methods of using Calco Red to stain *N. cucumeris* in culture so they can be more easily identified in the field.

Headline

- An extraction device has been developed to improve detection and monitoring of *Neoseiulus cucumeris,* thrips, *Orius,* and predatory thrips in strawberry crops, and can be produced for grower and agronomist use.

Background and expected deliverables

Some commercial growers report finding very few or no predators in flowers or on fruit after multiple releases. In order to make rational decisions on release and sampling strategies for *N. cucumeris*, it is important to determine whether the mites are present on the plant, or if they are not surviving in the crop. This objective examined the distribution of *N. cucumeris* and WTF on strawberry flowers and fruits, aimed to dye mites to make them easier to identify in the crop and develop an easy-to-use extraction device to assist with the detection of predatory mites in strawberry.

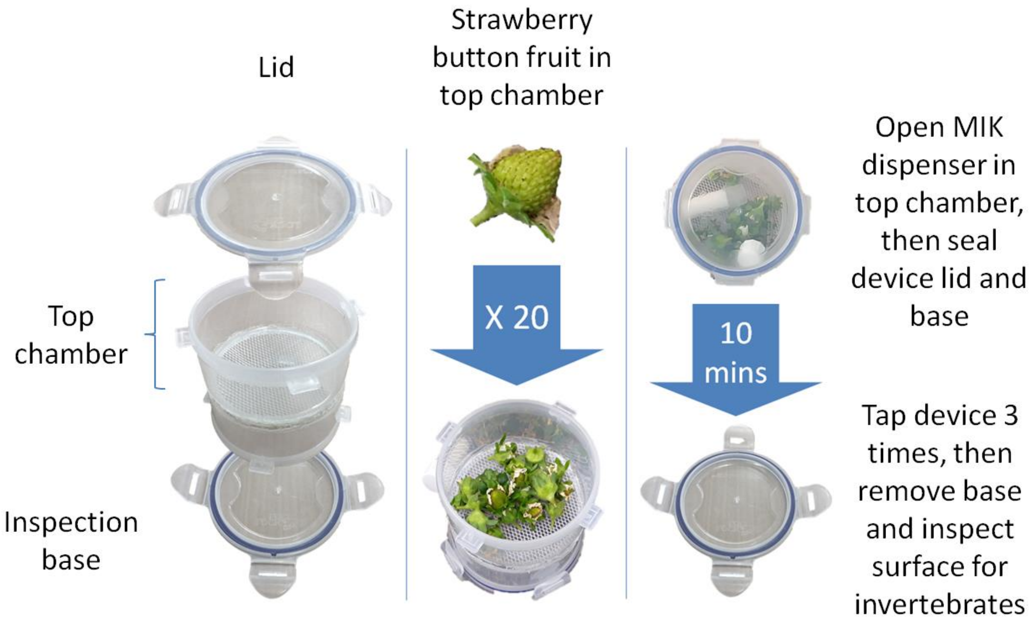
Summary of the project and main conclusions

In 2015, to develop a field-based extraction/monitoring system, three fumigants were tested in replicated experiments for their efficacy in extracting WFT and *N. cucumeris* from flowers and fruit. The most effective fumigant, methyl isobutyl ketone (MIK) was used successfully in a prototype extraction/monitoring device in the field. In subsequent years work was done to refine and optimise its use and calibrate the device.

Button fruit (young fruits where the petals had withered and/or fallen off), (see Task 1.1) yielded higher numbers of *N. cucumeris* in the extraction device compared to 'by eye' assessments of flowers or fruitlets.

Three prototype monitoring devices, making use of this fumigant extraction method, were constructed and tested. Following grower/advisor feedback on the different designs and prototypes, a 'food container' design with a metal grid was chosen for further development based on its robustness, ease of use and transparency.

Following initial laboratory studies to assess the efficacy of the device in extracting thrips and mites from button fruit, further laboratory and field experiments calibrated the device for detection of *N. cucumeris*. Fruits collected from commercial crops were initially inspected using a hand lens, then arthropods extracted using MIK in the extraction device before washing the fruit back in the laboratory with ethanol to remove remaining arthropods. In the laboratory, after inoculating button fruits with known numbers of predatory mites, ~57% of predatory mites were recovered using the device by counting under a microscope. In the field, using a hand lens the recovery of mites was closer to 27%. However, this was significantly higher than direct visual inspection of the button fruit where the majority of predatory mites were missed (in most cases no predatory mites were observed by inspecting button fruit in the field with a hand lens – although this will vary depending on the expertise of the assessor). *Orius* on both button fruit (direct observation 26%; extraction device 85%) and flowers (direct observation 55%; extraction device 94%) was also easier to detect with the extraction device.



Schematic diagram of extraction device and how to use it. The device should be operated in a well-ventilated area and a full Risk Assessment completed before use

Further improvements to the MIK release tube were made. These new dispensers gave a higher release rate and were subsequently field tested for different exposure times (1, 3, 5, 10 and 20 minutes) on samples of 20 strawberry button fruits per device. The percent of arthropods extracted was compared for each exposure. Overall, for *N. cucumeris*, pale thrips and dark thrips, numbers extracted increased up to a 10 minute exposure time. After this time, there was no significant increase in arthropod numbers. The mean percent *N. cucumeris* extracted in the laboratory was 57% - similar to the earlier studies. *Orius* and aphids were also observed in the extractions, but were too few in number for statistical analysis. Hence, a 10 minute exposure period was recommended for extraction of predatory mites from button fruits. In addition, the MIK dispensers were effective for at least 57 uses (providing lids were replaced after each use).

In another study, early on in the project, we tested whether a method could be developed to enable *N. cucumeris* to be more easily visualised on plants. Laboratory experiments were undertaken to assess the efficacy of staining the mites with CalcoRed, but this proved to be ineffective.

Financial benefits

Western flower thrips (*Frankliniella occidentalis*) causes bronzing of fruit. It has become difficult to control because of resistance to crop protection products and a lack of effective alternative biological controls. Financial losses can be high, exceeding £15m to the UK industry alone in 2013. This project has investigated and developed new approaches to monitoring and control of WFT whilst maintaining control of other pests, particularly by conserving and improving efficacy of introduced arthropod biocontrol agents and entomopathogenic fungi in the crop.

Action points for growers

- The extraction devices developed for this research can be purchased directly from Adrian Harris at NIAB EMR should growers or agronomists wish to employ them as an aid to their crop monitoring for WFT, *N. cucumeris* and other predatory mites.
- Before using or transporting the extraction device, ensure that a full risk assessment is carried out, as MIK is a solvent. Ensure the MIK tube and extraction device are fully closed when not in use and only open/use in a well-ventilated area (i.e. cropping area).
- This device will not replace crop monitoring but will assist in determining numbers of predatory mites in the crop and inform the need to make further predatory mite applications.
- Compare the practicality of the extraction device to your existing methods for detecting *N. cucumeris* and thrips in the crop.
- To determine numbers of *N. cucumeris* in the crop it is better to sample the button fruit and leave the extraction device for 10 minutes for each 20 button fruit sample.
- MIK tubes can be used at least 57 times.

Task 1.3 Develop effective biological methods for managing western flower thrips, *Frankliniella occidentalis* (WFT), compatible with pesticide use against SWD

Headline

- Met52 EC is unlikely to have adverse effects on the survival of the commercially available pest control products Thripor-L, Ervipar, Aphiscout, Aphidalia and Chrysopa.

Background and expected deliverables

This task explored sprays of entomopathogenic fungi (EPF) as a second-line-of-defence against WFT. For effective control of a target pest, spores of an EPF strain need to adhere to the pest's cuticle, then germinate and penetrate the cuticle to cause mycosis. Efficacy requires an adequate number of spores to adhere to vulnerable parts of the body, then adequate high humidity and temperature for a sufficient period for spore germination and infection to take place. Mortality occurs after a few days, but insects stop feeding, moving and reproducing well before death.

Four main studies took place as part of this task;

1) The EPF formulation of Met52 OD (Fargro), as a foliar spray, was tested in a laboratory bioassay against adult female WFT using a direct dosing method.
2) The addition of adjuvants was tested to determine if improved spore distribution, adhesion and biological efficacy of EPF (Naturalis L) against WFT could be achieved.
3) A literature review on the effects of *Metarhizium brunneum* strain F52 (the active ingredient of Met52) against WFT and natural enemies was compiled.
4) Bioassays were carried out, testing Met52 against three commercially produced natural enemy products (Chrysopa, Aphidalia and Ervipar), to fill a knowledge gap so that growers may best know how to utilize it within their growing systems.

Summary of the project and main conclusions

Efficacy of Met52 OD: In two laboratory experiments there was 44% higher WFT mortality after 6 days, and over 40% WFT mortality after 6 days and nearly 70% mortality after 8 days, at the highest label dose, compared to the untreated control, respectively. However, there was also around 40% WFT mortality in a blank oil control.

Adjuvant addition: No significant difference in deposition/retention of spores was identified between adjuvants following spraying. However significantly higher deposition/retention was observed on flowers compared to leaves in all treatments. The addition of adjuvants significantly improved spore distribution, adhesion and biological efficacy of EPF (Naturalis L) against WFT in laboratory bioassays and replicated field experiments.

The literature review highlighted that Saito and Brownbridge (2016) tested the compatibility of soil dwelling predators to Met52 EC and found that only *Dalotia coriaria* (Greenhouse rove beetle), was killed by the Met52 EC at a significantly different rate compared to the control. In addition, EFSA (2012) Annex IIM 8; HIM 10 showed evidence that direct application to *Orius majusculus* (*insidious* flower bug) (dripping onto the insect at a rate of 5.1 x 108 CFU /mL) causes 70% mortality after 7days. In addition, mortality was noted for *Chrysoperla carnea* (common green lacewing), through dietary exposure at 4.2 x 105 CFU/mL, as 37% after 12 days and *Hippodamia convergens* (convergent ladybird) (Coccinellidae) as 31% after 22 days. This review showed that some work on the effects of Met52 EC on beneficials had been done, so the experimental studies in this project focussed on the main beneficials used in the UK strawberry system.

Firstly, the active ingredient of Met52 EC was tested on five natural enemy products by a ‘dipping assay’ method, and, secondly, ‘spray contact assays’ were performed on the three products that showed kill in the dipping assay. All experiments were carried out at the field recommended rate for Met52 EC. The results for the dipping assay, where the insects were submerged in recommended dose of *M. brunneum* spore suspension showed that Aphiscout and Chrysopa had around 50% kill. For Thripor-L and Aphidalia there was around 65% mortality and 70% mortality in Ervipar three days after treatment. This was a worst-case scenario and is unlikely to happen in the field. The spray contact assays consisted of a recommended rate tank mix of Met52 EC sprayed onto strawberry leaves using a Burkard Computer sprayer, allowed to dry prior to insects being placed on the leaves for three days before removing the leaf. Three products; Chrysopa, Aphidalia and Ervipar, were tested. The results showed that there was around 20% death of the Chrysopa and Aphidalia treatments and less than 10% death of the Ervipar treatment after three days. The conditions used in the assays were the best for fungal growth and hence in the field it is likely that these effects will not be as high as in this experiment.

It was therefore concluded that Met52 EC will have insignificant effect on the survival of the commercially available pest control products Thripor-L, Ervipar, Aphiscout, Aphidalia and Chrysopa when used in UK strawberry production systems.

Financial benefits

Western flower thrips (*Frankliniella occidentalis*) causes bronzing of fruit. It has become difficult to control because of resistance to crop protection products and a lack of effective alternative biological controls. Financial losses can be high, exceeding £15m to the UK industry alone in 2013. This project has investigated and developed new approaches to monitoring and control of WFT whilst maintaining control of other pests, particularly by conserving and improving efficacy of introduced arthropod biocontrol agents and entomopathogenic fungi in the crop.

Action points for growers

- The biocontrol product Met52 EC is recommended for use in UK strawberry production and has been shown to have minimal adverse effects on other beneficial organisms.

Objective 2. Refine pest control programmes on strawberry, integrating pesticides with phytoseiid mites.

Task 2.1. Investigation of how to minimize the adverse effects of pesticides on *Neoseiulus cucumeris*, used as a biocontrol of WFT.

Headline

- Repeated applications of some fungicides can cause significant reductions in predatory mite populations although this can be alleviated by further introductions of *N. cucumeris.*

Background and expected deliverables

Predatory mites such as *Neoseiulus cucumeris* can form a very successful part of Integrated Pest Management (IPM) strategies. However, they can be vulnerable to plant protection products, including, potentially, fungicides. In addition, increased use of plant protection products against other pests, such as SWD, can potentially interfere with IPM. Although some plant protection products have been shown to be safe or only slightly harmful to *N. cucumeris* in single applications, in the field, products are applied multiple times, and in tank mixes. The work in this objective explored whether 1) sprayer tank mixes are harmful to *N. cucumeris* on strawberry, and 2) if Calypso (thiacloprid) and potassium bicarbonate+Activator90, products commonly used by the industry, are harmful to *N. cucumeris* over multiple applications or in tank mixes, compared to Nimrod+Teldor applications. In addition, we tested whether a second release of *N. cucumeris* after spraying could mitigate the effects of harmful spray treatments.

Summary of the project and main conclusions

Experiment 1: To determine if the reduction in *N. cucumeris* numbers in commercial crops is due in part to applications of various crop protection products, the effect of repeated applications of three commonly used tank mixes of fungicides were compared to an application of spinosad and an untreated control in a replicated field experiment. *N. cucumeris* predatory mites were released onto the plants before the trial began and three applications of the fungicide mixes were applied, with assessment of *N. cucumeris* numbers made after each application. Significant reductions in *N. cucumeris* populations were recorded after the third spray application of tank mixes of Nimrod/Teldor and Signum/Systhane.

Experiment 2: *N. cucumeris* predatory mites were released onto strawberry plants before the field trial began and three applications of plant protection products were applied, with assessments made of adult and immature *N. cucumeris* numbers on button fruit after each application. No evidence was found that Calypso, potassium bicarbonate+Activator90, or Nimrod+Teldor had a detrimental effect on *N. cucumeris* populations. An additional release of *N. cucumeris* after the second spray treatment led to an increase in adult *N. cucumeris* in the crop. Neither Calypso nor the secondary addition of *N. cucumeris* had a significant effect on thrips numbers. However, there were significantly lower numbers of thrips in the potassium bicarbonate+Activator90 treated plots compared to the water controls. The reason for this was not clear.

Financial benefits

WFT can cause fruit losses close to 20% if not adequately controlled. For a crop yielding 30 tonnes/ha, this equates to 6 tonnes/ha and at a value of £2,400 per tonne, losses of £14,400 per hectare. Frequent introductions of high numbers of *N. cucumeris* are costly both to purchase and to introduce to the crop. Potential damage or disruption to the mites caused by the use of harmful fungicide mixes or other crop protection products will lead to reduced efficacy of control and hasten the onset of WFT induced damage, resulting in further financial losses. It is therefore vital that growers are better informed of those fungicide mixes or other products that may have an adverse effect on the expensive predatory mites which have been introduced.

Action points for growers

- Carefully monitor strawberry crops for pest and predator numbers both before and after applications of fungicide tank mixes to determine if populations have been adversely affected.
- Careful thought needs to be given to the tank mixes used.
- Consider reducing the frequency of tank mixes of fungicides, or only spraying single products as the former may be harmful to introduced predatory mites.
- Be prepared to make additional releases of predatory mites as required to maintain control of pests such as WFT and tarsonemid mite.
- Ensure that populations of thrips and tarsonemid mite are adequately controlled before SWD enters the crop and requires treatment.

Task 2.2. In field, effect of insecticides commonly used to target spring aphids on the establishment of *N. cucumeris*

Headline

- A one-year study demonstrated that the persistence of Hallmark and Calypso in strawberry applied in early spring did not reduce numbers of the predatory mite *N. cucumeris.*

Background and expected deliverables

This field study explored the effect that insecticides, commonly used to target spring aphids, have on the establishment of *Neoseiulus cucumeris* and other predators. In order to make rational decisions on release of this predator, during the spring months it is important to determine whether *N. cucumeris* predatory mites are affected by plant protection products applied for aphid control. Data on the introduction of *N. cucumeris* following a pesticide application is generally based on laboratory side-effects tests and does not consider timing, temperature or leaf expansion.

Summary of the project and main conclusions

The experiment was set up on a commercial table-top of 2nd year Junebearer strawberry. On 7 March plots were sprayed with either field rates of lambda-cyhalothrin (Hallmark) or thiacloprid (Calypso), and compared to an untreated control. The experiment was set up with a randomised block design with six replicates of each treatment including an untreated control. *N. cucumeris*, releases were made at a rate of 200 mites per plant.

On 23 February, a pre-assessment was done; then three assessments post spray application. At each assessment the numbers of *N. cucumeris* adults, nymphs and eggs on either, leaves, flowers or button fruits (depending on availability) were recorded by collecting 30 samples from each plot. At the beginning of this trial the weather was unusually cold for the time of year. During the trial, no thrips were recorded, but tarsonemid mites were found in the young folded leaves, providing a source of food for *N. cucumeris*. The establishment of *N. cucumeris* adults, immature forms and eggs were not affected by one application of either Hallmark or Calypso applied to target spring aphids. Indeed following three releases of *N. cucumeris* the population indiscriminately increased over time in the control and treated plots.

The newly emerging folded leaves and flowers where *N. cucumeris* was detected had very little or no target pesticide residue potentially enabling the predatory mites to establish and reproduce (evidenced by the presence eggs and nymphs). Hallmark, which is suggested to have a persistence of activity against *N. cucumeris* of between 8 and 12 weeks in the laboratory, had no adverse impact on mite numbers in the field, in this trial.

Main conclusions from this work

The findings from the two years of work in this objective (Tasks 2.1 and 2.2) are in contrast in that repeated applications of fungicide mixes in Task 2.1 had adverse effects on the numbers of *N. cucumeris* while application of the insecticides Calypso and Hallmark in Task 2.2 appeared to have little impact. However, it should be remembered that only one application of Calypso and Hallmark were made in Task 2.2 and not repeated applications. In addition, spray coverage of young unfurling strawberry leaves is rarely complete and with later leaf expansion, there is usually sufficient plant leaf area free from deposit to allow the predators to survive single applications.

Financial benefits

Growers invest substantial sums in the purchase and release of biocontrol agents. Knowledge that an early spring spray targeted against aphids is unlikely to affect subsequent releases of *N. cucumeris* is helpful to encourage biocontrol as soon as possible and before numbers of thrips and tarsonemid mite proliferate.

Action points for growers

- Make early releases of *N. cucumeris* in crops, using slow release sachets when no or few strawberry flowers are available.
- Aim to get early control of aphids with insecticides, if needed, so that sprays are not necessary later in the season, when introduced and wild natural enemies are more active.
- *N. cucumeris* should be released into the crop frequently through the growing season.
- Releases of parasitoids for aphid control and *Orius* for thrips control can mitigate the need for later insecticide applications which disrupt WFT control.
- Growers need to couple this with control of SWD and control of non-WFT species (see Objective 6).

Objective 3. Develop IPM compatible controls for European tarnished plant bug, *Lygus rugulipennis*, common green capsid, *Lygocoris pabulinus*, and strawberry blossom weevil, *Anthonomus rubi*.

Task 3.1. To investigate the potential of a multi-pheromone blue sticky trapping system for *Lygus rugulipennis*, *Lygocoris pabulinus* and *Frankliniella occidentalis*

Headline

- Blue sticky traps combined with pheromones were compatible for capturing WFT and capsids, but also captured natural enemies including hoverflies.

Background and expected deliverables

In strawberry, western flower thrips, *Frankliniella occidentalis* (WFT), causes bronzing of the fruit. It has become difficult to control because of resistance to crop protection products and lack of effective alternative biological controls. Financial losses can be high, exceeding £15m to the UK industry alone in 2013. From June onwards European tarnished plant bug, *Lygus rugulipennis*, becomes a damaging pest of strawberry requiring routine control. Feeding in flowers and on green fruits can cause up to 80% crop loss, rendering production uneconomical. Traditional crop protection products used for control can disrupt biological control agents and increase residues in fruits. *Lygocoris pabulinus* (common green capsid) is also a damaging pest, which tends to be sporadic in appearance and locally distributed within the crop.

Blue sticky traps are currently employed for WFT control. These can be enhanced with a WFT aggregation pheromone, which can typically double the catch. If these could also be used in conjunction with capsid pheromones, this would potentially provide in-crop control of three pest species. *L. rugulipennis* is currently trapped using a *Lygus* sex pheromone lure within a green bucket trap and cover; catches, including of females, can be increased with the addition of the plant volatile phenylacetaldehyde (PAA). The trapping system for *L. pabulinus* uses the same pheromone lure, but attached to a blue sticky trap placed vertically in the crop. We investigated whether *L. rugulipennis* and *L. pabulinus* can be attracted to blue sticky traps with the addition of a *Lygus* sex pheromone lure + PAA only or whether the *Lygus* pheromone

+ PAA can be used in conjunction with the WFT pheromone, and, finally, if beneficial arthropods are also attracted to the trapping system.

Summary of the project and main conclusions

Experiments were set up in multiple strawberry crops in mid- to late- June for two months in 2017. Treatments included: 1) Blue dry sticky trap board - 25 cm x 10 cm, 2) blue dry sticky trap board + WFT pheromone lure, 3) blue dry sticky trap board + *Lygus* sex pheromone lure + PAA, or 4) blue dry sticky trap board + WFT pheromone lure + *Lygus* sex pheromone lure + PAA. Traps were placed 10 m apart in a randomised block design.

L. rugulipennis and *L. pabulinus* were attracted to a blue sticky trap with *Lygus* sex pheromone + PAA. However, 20% of capsids could detach themselves from the blue sticky traps. The *Lygus* sex pheromone lure + PAA was compatible with the WFT pheromone and thrips catches were always higher when a WFT lure was present. The PAA lure also appeared to attract lacewings and syrphids. PAA is essential to increase catches of the female *L. rugulipennis.* However, the floral component may be detrimental to some beneficial species, including hoverflies.

Main conclusions

Although the combined use of blue sticky traps, pheromones and PAA have potential for the control of both WFT and capsid pests in strawberry, the capsids ability to detach themselves from the traps is a flaw in the system, so the scientists turned their attention to a different control strategy using a ‘push-pull’ system described in Task 3.2 below.

Financial benefits

Lygus rugulipennis (European tarnished plant bug) and *Lygocoris pabulinus* (common green capsid) are serious pests on everbearer strawberries causing crop losses by feeding on developing fruits which become deformed and unmarketable. Over 50% of fruit may be downgraded as a result of capsid feeding in unsprayed crops. This results in loss of profitability of the crop. The crop protection products currently used to control capsids can have an adverse effect on IPM control strategies used for other pests such as WFT, tarsonemid mite and aphids, so a novel IPM compatible control system is desperately needed by growers.

Action points for growers

- No immediate action points for growers arose from this work.

Task 3.2. To investigate the potential of a push-pull system for control of capsids in strawberry

Headline

- A synthetic semiochemical capsid push-pull strategy has been developed for commercial strawberry which significantly reduced capsid numbers in the crop and reduced damage to the fruits.

Background and expected deliverables

In late-season UK strawberry crops, the European tarnished plant bug (*Lygus rugulipennis*) is considered to be the major cause of fruit malformation 'cat-facing' (Easterbrook 1997). One *L. rugulipennis* per 40 plants is considered enough to cause economic loss (Jay et al. 2004) and if left uncontrolled, over 50% fruit can potentially be downgraded (Fitzgerald et al. 2011). The common green capsid (*Lygocoris pabulinus*) may also be a damaging pest. Control usually requires several crop protection sprays from June onwards in everbearer crops. However, products currently used for control can disrupt biological control agents and increase occurrence of residues in fruits.

Push-pull is an IPM strategy with potential to control capsids that damage UK strawberries. The technique uses a stimulus to repel the capsids from the crop (push), in combination with another stimulus (pull) which attracts them to traps surrounding the crop where they are concentrated and eliminated. In a previous project we showed that synthetically produced hexyl butyrate can be repellent to *L. rugulipennis* and therefore used as a potential push. We also showed that synthetically produced *L. rugulipennis* female sex pheromone can be used to attract *L. rugulipennis* males to baited traps, along with males of the common green capsid *L. pabulinus* (Fountain et al. 2014); also associated with strawberry plant damage (Alford 1984). Another attractant has also been shown to encourage the capture of female *L. rugulipennis* (Fountain et al. 2010; Koczor et al. 2012), and a standard green bucket trap (Unitrap) with green cross-vanes and no bee excluder grid was found to be the most effective trap for *L. rugulipennis* (Fountain M. 2015); all three components combining to offer a potential pull.

Summary of the project and main conclusions

Replicated field studies on large plots in commercial strawberry were done in 2017, 2018 and 2019. In the first year, the study in Kent showed significantly reduced numbers of capsids and damage to fruits in crops where the push was applied (either alone or in combination with a pull). In 2018, capsid numbers in the target crops were too low for statistical analysis, believed to be because of the very hot and dry conditions.

In 2019, the objective was to generate data to support the 2017 push-pull result and test two methods to improve the push. Field trials were done in seven strawberry plantations in Kent and Herefordshire (including crops known to have high capsid numbers). The experiment was conducted between June and September in seven tunnel grown commercial strawberry plantations. To compare the different push-pull variations, each plantation (except the WET centre at NIAB EMR), was divided into the following four equal sized plots; 1) push-pull (same as 2017 – repellent units inside the plots with pheromone bucket traps around the perimeter of the plots), 2) a push-pull, with double the number of repellent units in the push, 3) a push-pull with the same number of repellent units as 2017, but each with double the concentration and 4) a control plot with no push or pull. The pull was the same as 2017 and 2018, consisting of traps holding a lure and a killing agent, positioned at 8 m intervals around the perimeter of the push-pull plots. The WET centre at NIAB EMR tested plot 2 against a control. We also tested whether the push-pull strategy had side effects on numbers of beneficials, or if the repellent caused phytotoxicity to strawberry plants.

Fortnightly assessments were made in all plots at each of the seven plantations. Assessments per plot consisted of 1) tap samples of 100 or 50 strawberry plants (depending on capsid numbers), counting capsids and natural enemies within the plots, 2) counts of capsids in traps around the perimeter of push-pull plots, 3) damage assessments of approximately 100 strawberries within the plots and 4) a phytotoxicity assessment after one month attachment of the repellent to strawberry plants.

In plantations where there were more capsids, all push-pull treatments significantly reduced numbers of capsids in the crop and damage to fruit by more than 80%. Treatments had no noticeable adverse effect on numbers of beneficials counted in the crop therefore this push-pull strategy shows IPM compatibility. The repellent did not cause any detectable phytotoxic effects when applied close to the strawberry crown. Increasing the level of repellent did not improve the push so future work could investigate reducing the level of repellent for cost effectiveness. Numbers of capsids in Kent 2019 were again too low to analyse.

Financial benefits

Lygus rugulipennis (European tarnished plant bug) and *Lygocoris pabulinus* (common green capsid) are serious pests on everbearer strawberries causing crop losses by feeding on developing fruits which become deformed and unmarketable. Over 50% of fruit may be downgraded where capsids are not adequately controlled. The ‘push-pull system’ will help to reduce reliance on traditional plant protection products, further reducing disruption to other IPM strategies for other pests.

Action points for growers

To protect everbearer strawberry from *L. rugulipennis* using this method of push-pull:

- Use a standard green bucket trap (Unitrap) with green cross-vanes (no bee excluder grid) baited with synthetic attractants and water with a drop of detergent as a drowning solution.
- Position traps around the edge of the crop (not within) to intercept the primary invasion of adults from late spring and draw capsids out of the crop.
- Repellents could be deployed in the crop throughout the growing season to deter adult capsid immigration.
- Potentially earlier applications of repellents from early spring could further reduce capsid numbers in heavily affected crops.
- Good management of weeds in and around the crop is recommended as *L. rugulipennis* can breed in these.
- Most *L. rugulipennis* likely overwinter outside strawberry fields, and even those that stay in the crop appear to leave in the spring to feed on weeds or other crops.
- Weed hosts include; Groundsel, Mayweed, Fat-hen, Nettles, Dock and Common mugwort. Adults migrate into strawberry fields in June/early July, although many remain on suitable weed hosts. In Southern England there are two generations of *L. rugulipennis* a year.

Objective 4. Improve insecticide control of the potato aphid, *Macrosiphum euphorbiae,* so as to be more compatible with IPM programmes.

Task 4.1. Investigate the potential of garlic grown in strawberry bags to reduce pests in the crop.

Headline

- Planting garlic in a strawberry crop may reduce the numbers of aphid, namely strawberry aphid in the crop.

Background and expected deliverables

In 2017, a grower of a Hampshire-based strawberry business reported that intercropping garlic and breaking garlic leaves onto the strawberry crop, could reduce the prevalence of thrips. This effect had not been quantified alongside an untreated crop. There is experimental evidence in other crops showing that garlic intercropping can reduce the prevalence of pests. To investigate the pest control potential of garlic intercropping, during summer 2018, NIAB EMR conducted a garlic trial on a commercial everbearer strawberry plantation in Kent. During the trial, a group of strawberry plots were intercropped with garlic and garlic leaves were broken fortnightly and laid on to the crop. Alongside these were another group of strawberry plots without garlic. Assessments were made fortnightly in both groups of plots to determine if the garlic treatment could deter the main strawberry pests, without adversely affecting beneficials. Here we aimed to determine if this method of intercropping garlic is a feasible pest control option for commercial everbearer strawberry.

Summary of the project and main conclusions

The trial was set up in a commercial strawberry plantation in Kent in everbearer varieties. The plantation was divided into two sections according to strawberry plant age: 1st or 2nd year. Within each plant age, four plots were intercropped with garlic and four comparable plots were not intercropped. In garlic plots, garlic cloves were planted in mid-May, then approximately a month later a garlic leaf from every plant was snapped off and laid on to the strawberry plants. This continued fortnightly until the end of the trial on 23 August.

Assessments were divided into two phases: pre-assessments and full assessments. Pre-assessments occurred between the planting of garlic cloves and the snapping of garlic leaves. Full assessments occurred during the period that garlic leaves were being snapped. Assessments were made in all plots, with and without garlic, and involved; examining 20 strawberry plants for the presence of aphids, examining 20 strawberry button fruits for the presence of *N. cucumeris* and thrips, and tap sampling 20 strawberry plants for capsids and natural enemies. Throughout the assessment period, the main aphid species found was the strawberry aphid (*Chaetosiphon fragaefolii*).

Of the key findings, fewer *C. fragaefolii* occurred in 1st year strawberry plantings than second year plantings. More mummified aphids, parasitoids and predatory spiders were also present in the older crop. The garlic treatment significantly reduced *C. fragaefolii* in strawberry compared to untreated strawberry. Breaking garlic leaves possibly releases compounds which repel aphids and control is sustained by the continuous presence of garlic plants in the crop. However, this is yet to be confirmed. It is also unclear whether this reduction is sufficient to reduce *C. fragaefolii* damage to the crop.

More predatory spiders were counted in garlic treated strawberry than the untreated strawberry. Garlic possibly provides a structure on which to spin webbing, but this remains to be confirmed.

Encouragingly garlic did not significantly affect numbers of the predatory phytoseiid mite, *N. cucumeris*, indicating that garlic does not have a negative impact on this natural enemy. However, thrips numbers (adults and larvae) were also unaffected, challenging observations made by the grower who employs this approach. Differences between our approach and the grower's approach were the climatic conditions, the variety of garlic planted and possibly the higher frequency at which the grower's staff break garlic leaves.

Garlic plant growing in strawberry bag and breaking the garlic leaf fortnightly and dropping onto strawberry plants in the same grow bag.

Financial benefits

The estimated cost of applying this garlic treatment is £263-395/ha per year. This includes purchase, splitting, planting, breaking-leaves, harvesting and labour. However this can be more expensive. Another grower with experience of intercropping garlic has informed us that it can cost up to £1,000/ha (personal contact). In our trial there was no loss to the grower in terms of spaces taken up in grow bags for garlic, because two spaces were free in each, but this should also be considered.

Action points for growers

NOTE: during this trial although there is evidence of a reduction in aphid numbers, it is unclear whether this resulted in less aphid damage, so if adopting the following actions points, do so with caution. Be guided by these action points if you would like to try this on an area of strawberry on your farm:

- If planning to test garlic intercropping to control thrips, plant a hard neck variety such as ‘Violet’ in autumn for control the next year, although control of thrips using this method is still anecdotal.
- For maximum effect, consider planting at a spacing of every 1 m.
- When garlic is established, snap leaves at least fortnightly and lay on the strawberry crop.
- Continue to apply *N. cucumeris* and other pest control products at the usual rate in garlic treated strawberry.
- Renew strawberry plantings each year to reduce the chance of aphid numbers building up.

Task 4.2. Determine the effect of low and fluctuating temperatures on the ability of aphid parasitoids to parasitize the potato aphid, *Macrosiphum euphorbiae*.

Headlines

- The parasitoids *Aphidius ervi* and *Praon volucre* require minimum temperatures of 8°C and 12°C respectively to effectively parasitize the potato aphid.

Background and expected deliverables

Several species of aphid are regularly found affecting strawberry crops. Five of the most frequently found and most damaging are the strawberry aphid (*Chaetosiphon fragaefolii*), the melon and cotton aphid (*Aphis gossypii*), the shallot aphid (*Myzus ascalonicus*), the glasshouse-potato aphid (*Aulacorthum solani*) and the potato aphid (*Macrosiphum euphorbiae*).

In recent years the control of early season aphids such as the potato aphid has become more problematic due to the withdrawal of commonly used insecticides. The remaining chemical options often have limited efficacy (AHDB Projects SF 140 and 156) and there is little evidence that biological controls are effective at the low temperatures experienced in early spring. The potato aphid causes damage to the crop through the production of honeydew and cast skins which result in sooty moulds and make the fruit unmarketable. Feeding action of these aphids can also result in distortion of the leaves and fruit. The species may breed all year round on strawberry crops if conditions allow and populations can build up rapidly in the spring.

Two aphid parasitoid species (*Aphidius ervi* and *Praon volucre*) commonly found in strawberry crops are known to readily parasitize potato aphid and may contribute to control. Both species occur naturally in the environment but can be introduced as biological control products as either a single species in the case of *A. ervi* or as part of a mix of six parasitoid species (*Aphidius colemani, A. ervi, A. matricariae, Praon volucre, Ephedrus cerasicola* and *Aphelinus abdominalis*).

Temperature is a key factor in determining the developmental time of insect species. Current knowledge suggests that the lower developmental threshold of *P. volucre* from the egg to mummy stage is 3.8°C and for mummy to adult development is 5.5°C. In comparison, the lower developmental thresholds for egg to mummy development and mummy to adult development of *A. ervi* in *Sitobion avenae* are 2.2°C and 6.6°C respectively. Although parasitoid development at low temperatures is extremely slow, *A. ervi* has been found to have a negative effect on pea aphid reproductive capacity following oviposition. This suggests that even if the parasitoid larvae do not kill the adult aphids as quickly early in the season, they may still be effective at reducing aphid populations.

Temperature can also affect the ability of the parasitoid to successfully locate and parasitize the aphid. Previous work has shown that oviposition by *A. ervi* and *P. volucre* on the grain aphid remained low below 10°C in both species. Flight and walking activity both increased with temperature, with *A. ervi* being consistently more active than *P. volcure*. The lower flight threshold was 10°C for both species and walking activity continued down to 8°C. This suggests that these parasitoid species would still be capable of locating aphids at low temperatures early in the season.

The aim of this work was to determine the effect of low and fluctuating temperatures on the ability of *A. ervi* and *P. volucre* to parasitize the potato aphid.

Potato aphid, *Macrosiphum euphorbiae*, on strawberry leaf petiole

Summary of the project and main conclusions

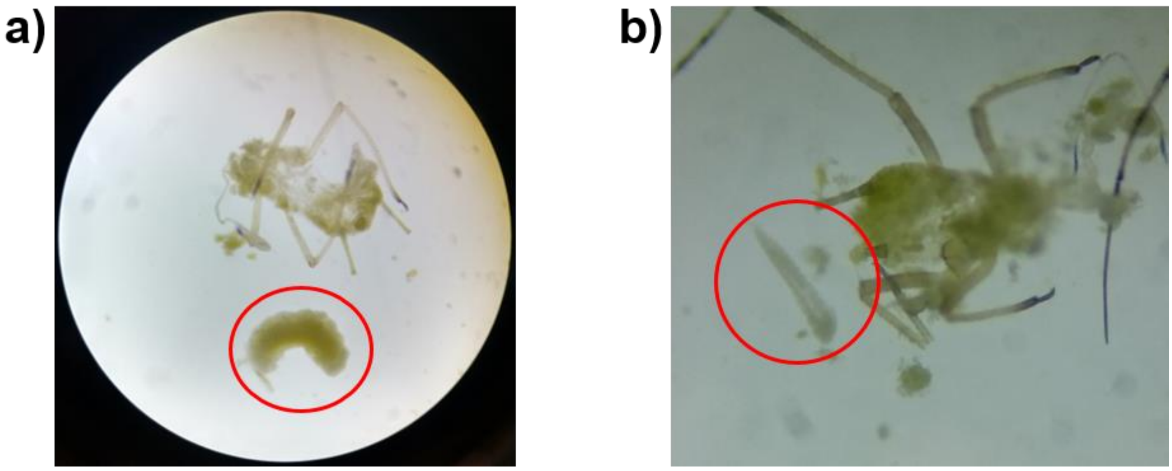
Air temperatures recorded in a polytunnel and an unheated glasshouse located in West Sussex confirmed that from early in the year, temperatures were above minimum thresholds for parasitoid activity. In the studied polytunnel, air temperatures rose above 12°C for at least 18% of the time in the month of February 2014, increasing to 33% in March and 52% in April. In the studied unheated glasshouse, air temperatures rose above 12°C for at least 11% of the time in the month of February 2015, increasing to 33% in March and 82% in April.

A series of experiments were completed under controlled temperature conditions. Each experiment used an unfurled strawberry leaf placed in a glass Petri dish with the stem immersed in 2.5 ml of water. The leaf was infested with 10 potato aphid nymphs and conditioned at the treatment temperature for 24 hours prior to the start of the experiment. Mated female parasitoids were separated out into a different glass Petri dish with access to a 20% sugar solution and conditioned similarly. Two female parasitoids were introduced to each dish of aphids and left for 24 hours at the treatment temperature. The parasitoids were then removed and the aphids were maintained on the strawberry leaf at 20°C for a further seven days before they were dissected to determine if parasitism had occurred. To confirm parasitoid larval development at low temperatures, additional replicates of parasitized aphid treatments and 20 mummies of each species were maintained at the lowest constant temperature at which parasitism was previously observed.

The minimum temperature at which parasitism of potato aphid by *A. ervi* occurred under constant conditions was 8°C. The minimum temperature at which parasitism of the same aphid species by *P. volucre* occurred under constant conditions was 12°C. There were a greater number of dishes with parasitism occurring in *A. ervi* compared to *P. volucre* as a result of the lower temperature threshold. Development of parasitoid larvae inside the aphid host was confirmed for both species of parasitoid in aphids maintained at constant low temperatures for two weeks. Similarly, adult emergence from aphid mummies was also confirmed at these constant low temperatures for both species.

Where temperatures fluctuated between 2°C and then eight hours at 8, 13 or 18°C, the minimum temperature at which parasitism by *A. ervi* occurred was 8°C. The minimum temperature at which parasitism by *P. volucre* occurred under fluctuating conditions was 13°C.

Both parasitoid species responded to higher temperature fluctuations (8°C for *A. ervi* and 13°C for *P. volucre*) and parasitized aphids in less than two hours when switched from 2°C.



Microscope images of *Aphidius ervi* larva dissected from *Macrosiphum euphorbiae* after a) 7 days at 20°C and b) 14 days at 8°C

Main conclusions

- The parasitoids *Aphidius ervi* and *Praon volucre* require minimum temperatures of 8°C and 12°C respectively to effectively parasitize the potato aphid.
- Fluctuating temperatures had no effect on the ability of the parasitoids to parasitize *M. euphorbiae* and both species were able to respond to short periods, as little as two hours, of higher temperatures.
- Both species have the potential to be used as early season biological control in polytunnels or glasshouses.
- The slow development of parasitoid larvae at low temperatures means that evidence of parasitism in the form of mummified aphids may not be apparent.
- Early season applications of control products may reduce the efficacy of natural and introduced biological control agents.

Financial benefits

Potentially, if not controlled, aphid infestations can lead to complete crop loss. No quantitative data on industry average losses resulting from aphid infestation is available but conservatively assuming that 1% of the crop is lost, this is equivalent to 507 tonnes of strawberries; worth £2.1 million per annum. Improved control as a result of this work would reduce the scale of these losses considerably.

Action points for growers

- Consider autumn applications (post-harvest) of insecticides for aphid control as these have been shown to reduce populations of aphids found in crops the following year.
- Carefully monitor both aphid numbers and their associated natural enemies within crops in order to determine the need for control sprays. Do not treat all fields the same. Consider the species of aphid prevalent and the damage it may cause, including plant virus spread.
- Where spring applications of spray products are considered necessary, growers should ensure that there is good spray coverage, in particular the undersides of leaves and the crown of the plant. Consider the use of water sensitive papers to visualise how effectively spray applications achieve this.
- Some populations of aphid pests e.g. the melon and cotton aphid (*Aphis gossypii*) have developed insecticide resistance. Growers should ensure that they follow insecticide resistance management guidelines on the product label and rotate between products with different modes of action.

- Carefully consider the compatibility of the available product options with aphid natural enemies as well as the biological control programmes used to control other pests of strawberry crops.
- Consider early season releases of *Aphidius ervi* to control potato aphid when daytime temperatures exceed 8°C regularly for at least part of the day. *Praon volucre* is currently only available as part of a mix of parasitoid species (including also *A. ervi*) and may also be considered for releases when daytime temperatures exceed 12°C regularly for at least part of the day.
- Although aphid parasitism may occur at low temperatures, the development of the aphid parasitoid will be very slow at these temperatures and may take several weeks to complete. The absence of mummified aphids does not, therefore, reliably indicate lack of parasitoid activity. Carefully monitor aphid populations within crops for presence of adult parasitoids. If possible, move some aphid infested plants to a warmer environment for 7-10 days, checking regularly for presence of mummified aphids.

Task 4.3. Improve insecticide control of the potato aphid, *Macrosiphum euphorbiae* and melon-cotton aphid, *Aphis gossypii*, to be more compatible with IPM programmes.

Headline

- A single application of the approved product Batavia or the coded insecticide AHDB 9966 (= HDCI 108) gave durable (up to 3-week) and effective control of both melon-cotton aphid and potato aphid.

Background and expected deliverables

Several species of aphid are regularly found infesting strawberry crops. Five of the most frequently found and most damaging are the strawberry aphid (*Chaetosiphon fragaefolii*), the melon-cotton aphid (*Aphis gossypii*), the shallot aphid (*Myzus ascalonicus*), the glasshouse-potato aphid (*Aulacorthum solani*) and the potato aphid (*Macrosiphum euphorbiae*).

In recent years the control of early season aphids such as the potato aphid has become more problematic due to the withdrawal of commonly used control products. The remaining chemical options often have limited efficacy (AHDB Projects SF 140 and 156) and there is little evidence that biological controls are effective at the low temperatures experienced in early spring. The potato aphid causes damage to the crop through the production of honeydew and cast skins which result in sooty moulds and make the fruit unmarketable. Feeding action of these aphids can also result in distortion of the leaves and fruit. The species may breed all year round on strawberry crops if conditions allow and populations can build up rapidly in the spring.

Outbreaks of melon-cotton aphid are also a concern for strawberry growers, as this species causes similar problems (feeding damage and contamination with honeydew and cast skins) as potato aphid. In addition, melon-cotton aphids are known to be resistant to multiple classes of insecticides, so this species can be very difficult to control.

The aim of this work was to assess the potential of plant protection products (without current approvals for strawberries) to control potato aphid and melon-cotton aphid. Comparisons were made with untreated control plants and with plants treated with approved products:

In 2016: Hallmark (lambda-cyhalothrin), Chess (pymetrozine) or Calypso (thiacloprid) with and without Silwet L-77 were compared to Silwet only or an untreated control.

In 2018/19: AHDB coded products, Batavia (spirotetramat) and Flipper (fatty acids) (both trials), Met52 OD (Metarhizium anisopliae) and Majestik (maltodextrin) (melon-cotton aphid trial), Benevia 10 OD (cyantraniliprole) and Spruzit (pyrethrins) (potato aphid trial) were compared to water only or unsprayed plots.

Summary of the project and main conclusions

2016 Semi-field trial on potato aphid:

Hallmark or Hallmark + Silwet gave 100% control, whilst Calypso or Calypso + Silwet gave moderate control initially (approx. 75% reduction in aphids numbers three days after spray application), but aphid numbers started to increase again eight days later. Chess, Chess + Silwet, Silwet, and the water control did not reduce potato aphid numbers on strawberry plants.

2016 Controlled environment room (20^{o}C and 60% RH) trial on potato aphid:

Each replicate consisted of a single aphid infested strawberry leaf. In the first bioassay, uninfested fully expanded strawberry leaves were sprayed on both surfaces to run-off and allowed to dry by placing the leaves on several layers of tissue paper before infesting each leaf with 20 potato aphid nymphs (1-3 instar). The second bioassay was prepared in the same way; however, leaves were infested with 20 potato aphid nymphs before spraying to run-off and allowing to dry. Calypso, Calypso + Silwet, Hallmark, and Hallmark + Silwet killed all aphids in both bioassays. Hallmark, and Hallmark + Silwet gave 100% kill within 24 hours in both cases whereas Calypso and Calypso + Silwet gave 100% kill within 24 hours only when aphids were directly sprayed. Chess + Silwet and Silwet applied on its own killed all aphids but only when aphids were directly sprayed. Chess applied without Silwet did not kill all aphids.

2018/19: Semi-field trials on melon-cotton aphid and potato aphid:

Single applications of the coded products AHDB 9966 and the approved insecticide product Batavia gave effective control of melon-cotton aphid and potato aphid on strawberries.

Effective control of melon-cotton aphid was also achieved using two applications a second coded product: AHDB 9951. The same product was also effective when tested against potato aphid (with just one application).

The other products tested were not associated with statistically significant reductions in aphid numbers. These included “softer” products such as Flipper, Majestik and Met52 OD. However, growers are likely to apply these products at shorter spray intervals than were used in some of the experimental treatments.

Main conclusions

- Hallmark gave 100% control of potato aphids with prolonged control while Calypso gave moderate control with reduced longevity. Control with Calypso is improved when the product contacts the aphids. Chess controlled potato aphids but only when mixed with Sliwet and when the spray contacted the aphids.
- A single application of the approved product Batavia or the coded product AHDB 9966 (= HDCI 108) gave durable (up to 3-week) and effective control of both melon-cotton aphid and potato aphid.
- A second coded product (AHDB 9951 = HDCI 109) also gave effective control of both melon-cotton aphid and potato aphid, following a single application (potato aphid trial) and two applications (melon-cotton aphid trial).
- The product coded AHDB 9966 was particularly effective against melon-cotton aphid, resulting in complete clean-up of aphids from plants. The same product was effective at controlling potato aphid, and even reduced numbers in the colonies that were hidden away on young, expanding leaves in the crowns of plants.

Financial benefits

Potentially, if not controlled, aphid infestations can lead to complete crop loss. No quantitative data on industry average losses resulting from aphid infestation is available but conservatively assuming that 1% of the crop is lost, this is equivalent to 507 tonnes of UK grown strawberries; worth £2.1 million per annum. Improved control as a result of this work would reduce the scale of these losses considerably.

Action points for growers

- Consider autumn applications (post-harvest) of insecticides for aphid control as these have been shown to reduce populations of aphids found in crops the following year.
- Carefully monitor both aphid numbers and their associated natural enemies within crops in order to determine the need for control sprays.
- Where spring control applications are considered necessary, growers should ensure that there is good spray coverage, in particular on the undersides of leaves and the crown of the plant. Use water sensitive papers to visualise how effectively spray applications achieve this.
- Some populations of aphid pests e.g. the melon and cotton aphid (*Aphis gossypii*) have developed insecticide resistance. Growers should ensure that they follow insecticide

resistance management guidelines on the product label and rotate between products with different modes of action.

- It is important to carefully consider the compatibility of the available product options with aphid natural enemies as well as the biological control programmes used to control other pests of strawberry crops.
- Useful information on the compatibility of available products is provided on biocontrol manufacturer websites including: https://www.koppert.com/side-effects/ or http://www.biobestgroup.com/en/side-effect-manual to help inform product selection.
- Since the trials were carried out in 2016, pymetrozine (Plenum or Chess) has lost its approval on strawberry and thiacloprid will not be approved for use from 2021. Hallmark is still effective and can be considered for early season control applications.
- Batavia provides effective control of melon-cotton aphid, potato aphid and other aphid species damaging strawberries. However, application of this product to strawberry crops (both protected and unprotected) is restricted to use up until 14 days before flowering or again after harvest and a maximum of two applications is permitted per season.

Objective 5. Improve control of aphids through the growing season.

Task 5.1. Thresholds for aphids and natural enemies; assessments to demonstrate confidence in control strategies.

Headline

- Before June, there are very few natural enemies in strawberry crops and therefore other control measures should be employed to supress aphid populations until natural numbers build.

Background and expected deliverables

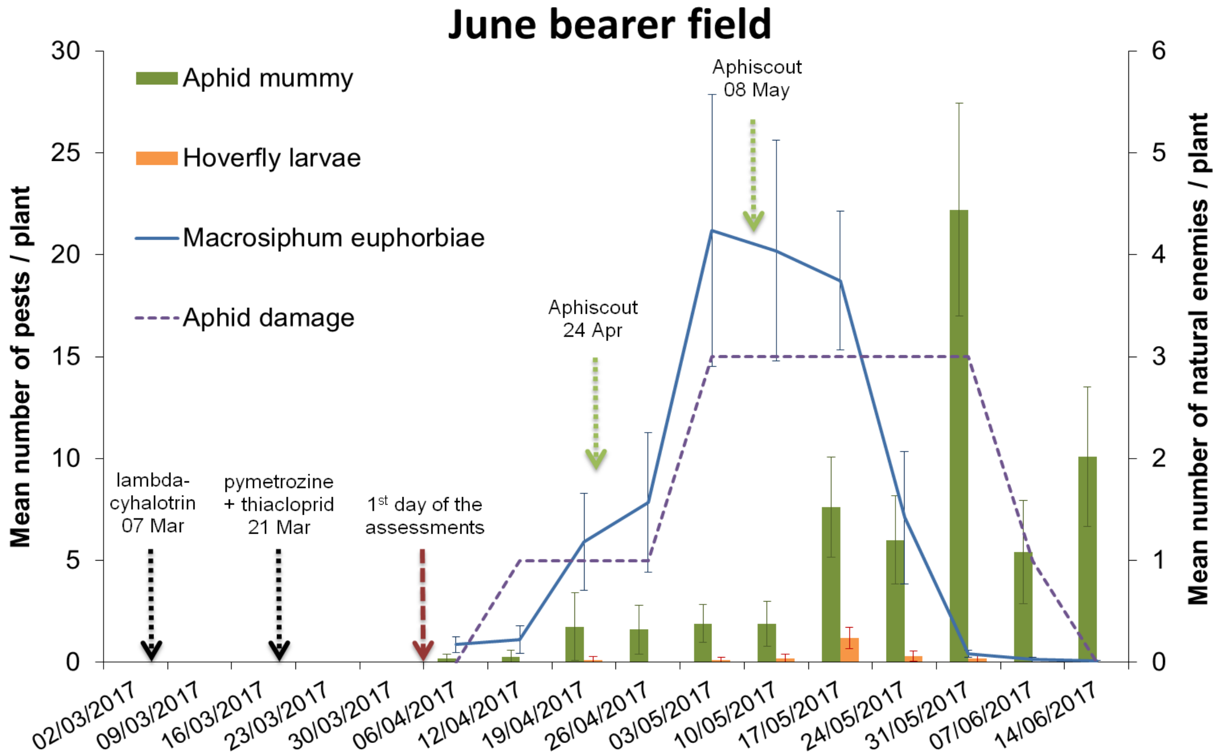
Strawberry crops are affected by a range of aphid pests. The most difficult to control is the potato aphid, *Macrosiphum euphorbiae*, as populations often resurge after spray application, probably due to incomplete control as shown in AHDB Project SF 140. In this project, it was also found that aphid numbers in the untreated plots had a tendency to decline rapidly by the end of the experiments because of the increases in natural enemies.

Crop protection sprays can be harmful to natural enemies which might otherwise be controlling pests in the crop. Often there is a lag between the build-up of the pest and the immigration and build-up of the predators and parasitoids. This lag period is often a critical time for the build-up of the natural enemies, but a time when sprays for aphids are more likely to be applied.

The aim of this study was to monitor and demonstrate the importance of naturally occurring aphid enemies in everbearer and Junebearer strawberry crops. We compared three crops in both Junebearer and everbearer fields for aphid build-up in the crop, in relation to natural enemy appearance. We also aimed to demonstrate the effects of pest spray programmes on potato aphid and natural enemies and show the relationship between population 'peaks and toughs' of pest and natural enemies. Studies were made on two farms with historically different degrees of aphid and natural enemy numbers. On each farm, three Junebearer and three everbearer fields were selected. To obtain an overall picture of the changes in natural enemy populations throughout the year, fields were chosen within the same or as similar a landscape as possible on the farms. Hence they had the same potential pool of pests and natural enemies.

Summary of the project and main conclusions

Both farms were visited each week from 5 April until 30 August. At each visit, 25 plants were thoroughly searched in a different central row of the cropping area and the numbers and species of aphids and natural enemies were counted and plotted.

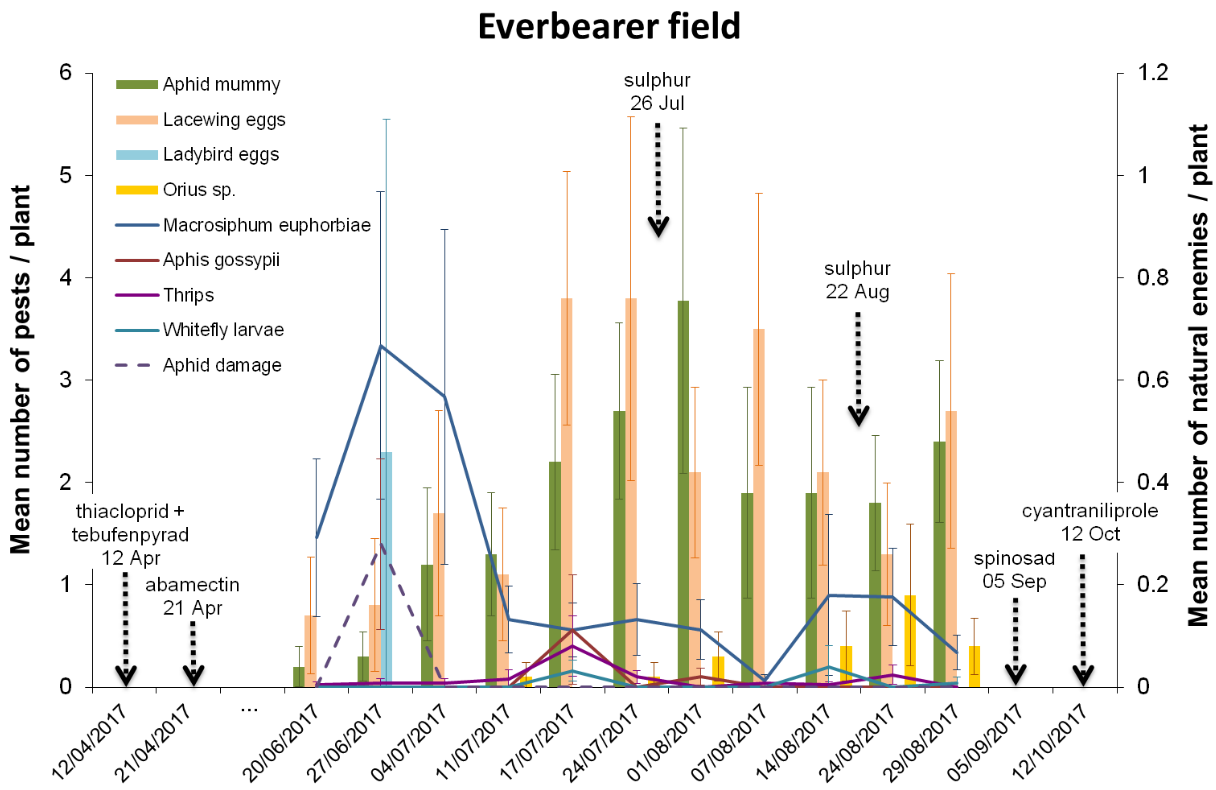


Aphids, parasitized aphids (mummies), lacewing eggs and hoverfly larvae per strawberry plant in a June bearer field. Maximum aphid damage is also shown; 0 – *none*, 1 – *slight* – some aphid skins, 2 - *moderate* – some aphid skins and honeydew but confined to leaves and 3 – *severe* – fruit/flowers affected, possible sooty moulds

There was a high variability in aphid species and numbers between farms and between crops in the same landscape. The main pest was potato aphid although other pests (*Aphis gossypii*, thrips, two-spotted spider mites and glasshouse whitefly) were present. Winged aphids peaked on 9 June. The main aphid predators recorded were the green lacewing and hoverfly larvae. Hoverfly larvae were present in low numbers across the two farms through the season and green lacewing larvae became more prevalent from 4 July. It is known that a single larva of the marmalade hoverfly (*Episyrphus balteatus*) can consume 660-1,140 aphids during development and a single green lacewing larva, 566-789 aphids before pupating. Other predators, such as spiders, ladybirds and *Orius* were also observed in low numbers.

The parasitoids *Praon* sp. and *Aphidius* sp. were the main species parasitizing aphids. *Aphelinus* sp. parasitism was also present but at a lower incidence.

The pest and natural enemy fauna was more diverse in the ever-bearers than in the June bearers. In both crop types, there were delays in the natural enemy population growth compared to the pest population growth. However, with the increase of natural enemies, the number of aphids declined. It is evident from this study, that before June there are very few natural enemies in strawberry crops and therefore other control measures should be employed to supress aphid populations until natural numbers build. Controls introduced by growers should be sensitive to the natural enemies likely to enter the crop later in the season.



Aphids, parasitized aphids (mummies), lacewing eggs and hoverfly larvae per plants in an ever-bearer field. The maximum aphid damage value is also given; 0 – *none*, 1 – *slight* – some aphid skins, 2 - *moderate* – some aphid skins and honeydew but confined to leaves and 3 – *severe* – fruit/flowers affected, possible sooty moulds

Financial benefits

Potentially, if not controlled, aphid infestations can lead to complete crop loss. No quantitative data on industry average losses resulting from aphid infestation is available but conservatively assuming that 1% of the crop is lost, this is equivalent to 507 tonnes of strawberries, worth

£2.1 million per annum. Improved control as a result of this work would reduce the scale of these losses considerably.

Action points for growers

- Each season, carefully consider choice of early-season aphid control products and wherever possible, select those that are likely to be less harmful to aphid parasitoids and *N. cucumeris* that may or may not be obvious within the crop. Use helpful information on commercial biocontrol suppliers' websites: https://www.koppert.com/side-effects/ or http://www.biobestgroup.com/en/side-effect-manual to help inform product selection.

Objective 6. Fill key gaps in knowledge on *Thrips fuscipennis* biology in strawberry crops so that IPM strategies can be developed

Headline

- During 2018 and 2019, adults of five thrips species that can damage strawberry fruit were confirmed at five sites.

Background and expected deliverables

Western flower thrips (WFT, *Frankliniella occidentalis*) is a serious pest of strawberry, feeding on flowers and developing fruits leading to damaged bronzed fruits which are unmarketable. In recent years, before work in this project began, ADAS identified the presence of rose thrips (*Thrips fuscipennis*) in strawberry flowers where fruit bronzing is occurring. Often rose thrips has been the predominant species in mixtures including the rubus thrips (*Thrips major*). At sites where fruit damage attributed to rose thrips has occurred, some growers have been using IPM programmes based on *Neoseiulus cucumeris* and good control of WFT has been achieved. However, at the same sites, rose thrips has not been controlled and growers have needed to apply plant protection products including spinosad (Tracer) to prevent further fruit damage. There is concern that, like WFT, rose thrips could develop resistance to Tracer and other chemical plant protection products. In addition, the number of Tracer applications permitted on each crop is limited and growers may prefer to reserve these for control of spotted wing drosophila (SWD).

The adult females of rose thrips and other *Thrips* species are darker than WFT but the species can only be identified using a microscope and specialist expertise. Fruit damage often seems to occur soon after 'dark' thrips adults are noticed in the flowers, so it is possible that rose thrips and possibly other thrips species adults are migrating into the crop and damaging the fruit before they start reproducing. Adult thrips would not be controlled by *N. cucumeris* which only feeds on first instar WFT larvae. The predatory bug *Orius laevigatus* will feed on thrips adults as well as larvae. However, *O. laevigatus* needs high temperatures to establish and they are sensitive to chemical plant protection products. In 2018 and 2019, the objectives were:

1. Determine when adult thrips activity starts and identify peaks in numbers between April and August inclusive.
2. Determine what species of thrips larvae develop in strawberry flowers.
3. Record fruit damage associated with rose thrips (*Thrips fuscipennis*) and other thrips species in flowers.

4. (2019 only) Determine colour attraction (using coloured water traps) of thrips species for potential development of a mass monitoring system.

Summary of project and main conclusions

Adults of five thrips species that can damage strawberry fruit were recorded at five sites in 2018 and 2019 where fruit damage attributed to rose thrips had occurred during the previous one or two seasons. These were the rose thrips (*T. fuscipennis*), rubus thrips (*Thrips major*), onion thrips (*Thrips tabaci*), flower thrips (*Frankliniella intonsa*) and western flower thrips (WFT, *F. occidentalis).*

In 2018, the earliest thrips species recorded during May in the June-bearer crops were the onion thrips, *Thrips tabaci* and the rubus thrips, *Thrips major*. Mean numbers were less than one per flower and only slight fruit damage occurred. In the June-bearer crops in 2019, *T. tabaci, T. major* and the rose thrips, *T. fuscipennis* were recorded from May and the flower thrips, *Frankliniella intonsa* was recorded from early June. Rose thrips were the most numerous reaching a mean of 1.2 adults per flower and only slight fruit damage occurred.

In 2019, numbers of the combined species peaked on 26 June in the two outdoor everbearer crops in Essex and Bucks at 2.2 and 3.5 adults per flower respectively and these were mainly rose thrips, *Thrips fuscipennis*. This differed from in 2018 when although rose thrips was the main species occurring during June, peak numbers of thrips adults peaked on 11 July at both sites and the predominant species was the flower thrips, *Frankliniella intonsa*.

In 2019, in the two tunnelled everbearer crops in Kent, numbers of thrips adults peaked on 11 June, in similar numbers to those in the two outdoor crops at around two and four adults per flower respectively and these were mainly WFT at Site 5 and rose thrips at Site 3. This differed from in 2018 in two tunnelled crops in Kent when peak adult numbers occurred in August and September and were mainly WFT. However, as in 2018, WFT was the predominant species at both sites in July and August.

In 2019, adults of the onion thrips, *Thrips tabaci* and the rubus thrips, *Thrips major* had similar patterns of activity to those in 2018 with a long period of activity between April/May and July/August. These species usually occurred in lower numbers than *T. fuscipennis* and, in the two tunnelled crops in Kent, than WFT, although at one of the Kent sites numbers of *T. major* were higher than those of *T. fuscipennis* and WFT in late May and late June.

Adults of the flower thrips, *Frankliniella intonsa* were found in higher numbers than usual in 2018. Very low numbers were found at the four monitoring sites in 2019. However, high numbers were recorded during 2019 in a different crop not monitored in this project, in the

West Midlands and it has been recorded as damaging strawberry fruit in Denmark. This species is native to the UK but is thought to be more adapted to the more extreme climate in central Europe, so with climate change it could become a more common pest of UK strawberry crops.

In 2019, as in 2018, thrips larvae were recorded in lower numbers per flower than thrips adults in the two outdoor crops and were found mainly during July. Thrips species larvae confirmed in the two outdoor crops were the predatory banded wing thrips (*Aeolothrips* sp.), *T. tabaci, T. major* and *F. intonsa.* In the two tunnelled crops in Kent, greater numbers of larvae than adults per flower were recorded during August, when the species confirmed were mainly *F. intonsa* and WFT.

No larvae of *T. fuscipennis* were identified in strawberry flowers from any of the sites in either 2018 or 2019 and it is possible that this species does not breed in strawberry flowers. This could explain why *N. cucumeris* does not seem to control rose thrips, as this predatory mite feeds only on young thrips larvae and not on adults.

In both 2018 and 2019, fruit damage was only slight in the two outdoor everbearer crops. Damage was more severe at the two tunnelled sites in Kent but was well below a mean of 10% fruit area damaged which is usually considered as the ‘threshold’ above which fruit is downgraded. In 2019, fruit damage may have been caused by a mixture of *T. fuscipennis*, *T. tabaci, T. major* and *F. intonsa* adults in the two outdoor everbearer crops although *T. fuscipennis* was the predominant species. Fruit damage is likely to have been caused mainly by WFT in one of the tunnelled crops in Kent where it was the predominant species and by a mixture of WFT, *T. fuscipennis*, *T. major*, *T. tabaci* and *F. intonsa* in the other tunnelled crop. Peak numbers of thrips adults (all species combined) per flower did not exceed four per flower at any site in both years so it can be concluded that on the everbearer varieties monitored (Favori, Finesse, Katrina and Murano), mean numbers of thrips adults per flower would need to be higher than this to cause severe fruit damage.

In both 2018 and 2019, numbers of thrips are likely to have been kept below damaging levels by a combination of released and naturally-occurring predators and by plant protection products applied for the control of strawberry blossom weevil and SWD.

An effective IPM programme needs to be developed for control of a range of thrips species other than WFT that are known to cause fruit damage. *Orius* is likely to feed on both adults and larvae of all thrips species but it needs warm temperatures to establish and these do not occur every year. In addition, *Orius* is very susceptible to some of the products applied for control of other pests such as SWD. *Aeolothrips* sp. is known to feed on thrips larvae but it is not known whether they also predate thrips adults. Although most thrips species other than

WFT still seem to be susceptible to insecticides, there is a risk of pesticide resistance developing so reliance on control with chemical plant protection products is not sustainable.

In 2019, significantly more *T. fuscipennis* adults were caught in blue water traps than in yellow or green in one of the tunnelled crops in Kent. This result might lead to the opportunity to develop an IPM strategy for this species incorporating blue sticky traps for mass monitoring. No significant differences between the different coloured water traps were given in numbers of any of the other thrips species known to damage strawberry.

Financial benefits

Financial annual losses to the UK strawberry industry due to WFT damage exceeded £15m before an effective IPM programme was developed. Financial loss values due to other thrips species are not yet available but these species have the potential to cause severe losses if effective IPM strategies are not developed.

Action points for growers

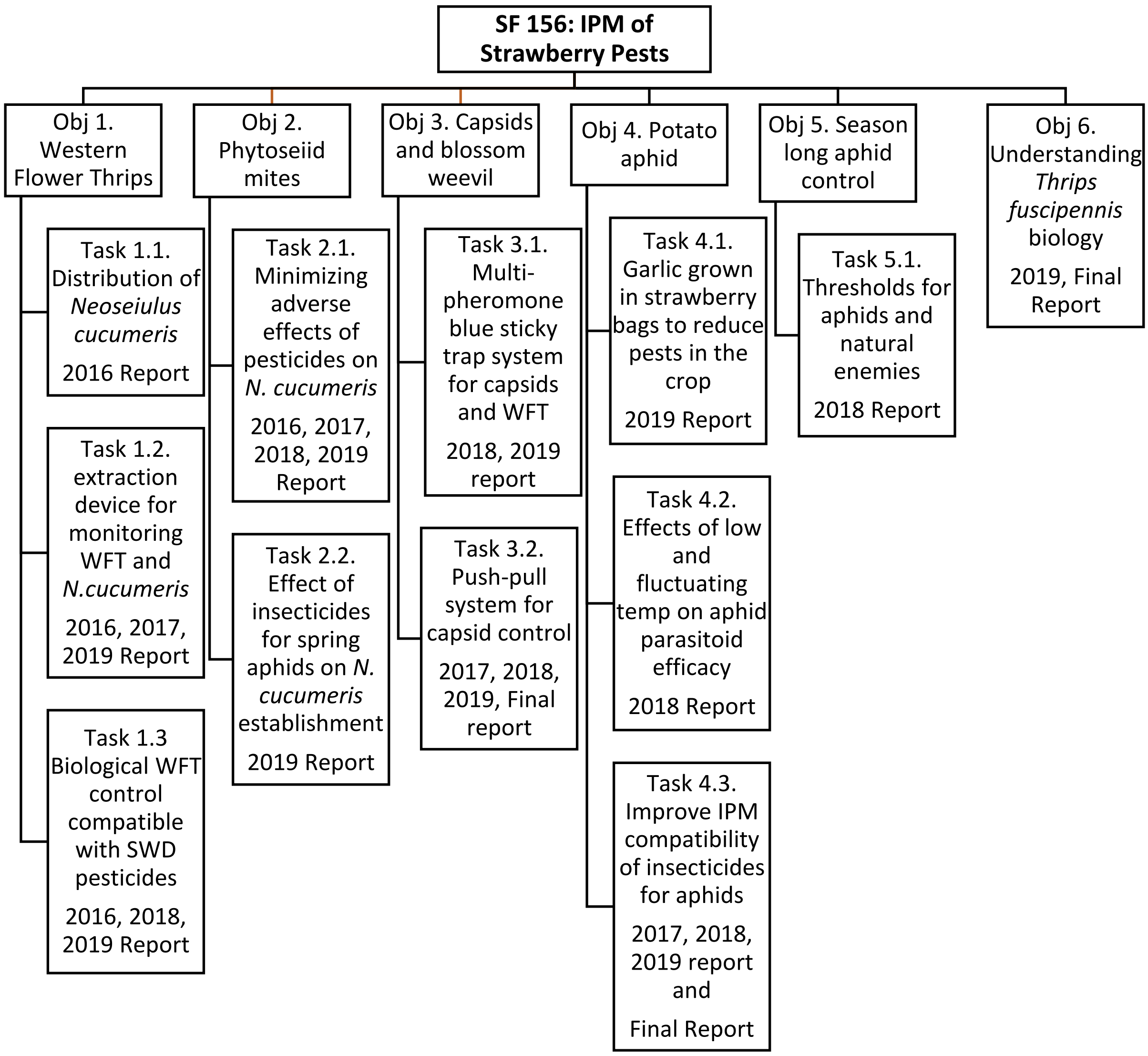
- Thrips control should be planned as part of an Integrated Pest Management (IPM) programme. Until effective strategies are developed for thrips species other than WFT, the IPM programme should be the same as that commonly used against WFT. Further details are set out in AHDB Factsheet 14/15, but are summarised below.
- Release the predatory mites *Neoseiulus cucumeris* throughout the season from first flowers. The minimum release rate should be 25 per plant every week or fortnight, increasing to 50 per plant if numbers of thrips start to increase. This predator feeds only on young thrips larvae so it may not control rose thrips which might not breed in strawberry flowers.
- Apply the ground-dwelling predatory mites *Statiolaelaps scimitus* (formerly known as *Hypoaspis miles*) once at about 10 per plant. It is not yet known how effective these are against larvae of thrips species other than WFT that might drop to the ground to pupate, but as they are effective against WFT it is a sensible option.
- Release *Orius laevigatus* in addition to *N. cucumeris* once temperatures are suitable. This predator needs a minimum of 15°C for egg laying and over 20°C for good establishment. Commonly used release rates are a minimum of 0.25 to one *Orius* per plant, repeated after two weeks. *Orius laevigatus* is very sensitive to plant protection products so avoid using any that are harmful (consult your supplier or adviser).
- Some growers use blue roller traps in the leg rows to help control WFT adults in strawberry but there is no evidence yet that these also help to control other thrips

species adults. Limited initial results of using coloured water traps in 2019 indicated that at one site, more rose thrips adults were caught in blue traps than in yellow or green.

- If fruit bronzing is seen, consider using an IPM-compatible plant protection product for control. Options include spinosad (Tracer) but growers may wish to reserve this for control of SWD. Do not use Tracer if only WFT are present as they are likely to be resistant to this product. Thrips species can only be confirmed using a high power microscope and specialist expertise. Consult your adviser on getting the thrips species identified and choice of plant protection product if required.

SCIENCE SECTION

The Grower Summary of this report gives a summary of all the objectives which were investigated as part of this 5-year IPM programme of research. The Science Section of this final project report only covers the research which was conducted in the final year. Below is an organogram of all the research which was conducted as part of this programme of research. The annual report where the tasks are reported is listed should the reader wish to refer to any of the experiments in more detail.



Objective 3. Develop IPM compatible controls for European tarnished plant bug, *Lygus rugulipennis*, common green capsid, *Lygocoris pabulinus*, and strawberry blossom weevil, *Anthonomus rubi*.

Task 3.2. To investigate the potential of a push-pull system for control of capsids in strawberry (2019)

Introduction

Push-pull is a strategy with the potential to control capsids that damage UK strawberries. The technique uses a combination of behaviour-modifying stimuli to manipulate the distribution and abundance of the pest from the protected resource – in this instance the strawberry crop. This is achieved using a stimulus to deter the pests away from the crop (push), whilst another (pull) simultaneously attracts them to a trap where they are concentrated and eliminated. Benefits of the strategy include an increase in control efficacy, efficiency, sustainability, and output, and a reduction in negative environmental impact (Cook et al. 2017). The European tarnished plant bug, *Lygus rugulipennis*, becomes a damaging pest of strawberry requiring routine treatment with insecticides, usually from June onwards in everbearer crops. Pest feeding on developing fruits cause severe malformation with over 50% fruit potentially downgraded in unsprayed crops (Jay et al. 2004). Another capsid *Lygocoris pabulinus* (common green capsid), is also a damaging pest, which tends to be sporadic in appearance and locally distributed within the crop. Chemical plant protection products (PPP) are typically used to control capsids, however these can disrupt biological control agents and increase pesticide residues in fruits. Moreover, there are continuing restrictions on chemical PPP use. For example, in the EU there has been an ongoing review and phase-out of chemical PPPs since the 1980s (pan-europe.info. 2008) and a continuing trend to promote the use of non-chemical alternatives (eur-lex.europa.eu. 2009).

In 2017, this project first demonstrated the control potential of push-pull against capsids in 4 commercial strawberry plantations in Kent (2017 annual report). Significantly reduced numbers of capsids and damage to fruits were counted in plots where a hexyl butyrate (HB) push was applied. The pull (Lygus sex pheromone and phenylacetaldehyde (PAA)) in green cross vane bucket traps around the crop perimeter, appeared to reduce capsid numbers too, and a combination of push and pull components significantly increased percent of fruit with zero capsid damage compared to the control (2017 annual report).

During the subsequent trial in 2018 (also on 4 commercial strawberry plantations), push-pull treatments were not shown to cause a significant reduction of *L. rugulipennis* and fruit damage in crops (2018 annual report), despite re-testing the 2017 push-pull along with an additional repellent (coded) intended to enhance the HB push. The shortcoming was attributed to low numbers of capsids affecting robust statistical analysis possibly due to unfavourable climatic conditions.

In 2019 we set out to reproduce and improve on the 2017 push-pull result by using higher replication of strawberry crops - including those with more capsids – and increasing the level of HB released in the push. The trial was set up on 7 separate strawberry crops, 3 of which were organically grown and reported to have high capsid numbers. The objectives of the trial were to test whether:

- Capsid numbers and strawberry damage could be reduced using the 2017 push-pull treatment
- Capsid numbers and strawberry damage could be reduced further by increasing the number of HB point sources in the push
- Alternatively, capsid numbers and strawberry damage could be reduced further by increasing the level of HB released in the push
- Push-pull causes no side effects on numbers of beneficials
- HB sachets cause no phytotoxicity to strawberry plants

Materials and Methods

Trial sites:

Seven strawberry sites (blocks) were selected; 4 in Kent (Blocks 1 to 4) and 3 in Herefordshire (Blocks 5 to 7) (Fig. 3.2.1). Strawberries were Polytunnel grown, mostly everbearer, with one day-neutral. Varieties were; Amesti (Site 1), Sweet eve 2 (Sites 2 and 3), Malling^{TM} Champion (Site 4), EV2 (Site 5) and Serena (Sites 6 and 7). Polytunnel ends were open at Kent blocks and protected with insect exclusion mesh at Herefordshire blocks. Strawberries were grown conventionally in bags on table tops at Kent blocks and organically in soil beds on the ground at Herefordshire blocks. Weeds noted adjacent to crops at all blocks that could host pest capsids were docks (*Rumex* spp.) and nettle (*Urtica dioica* L, Urticaceae). Others may have been present, but a habitat assessment was not made.

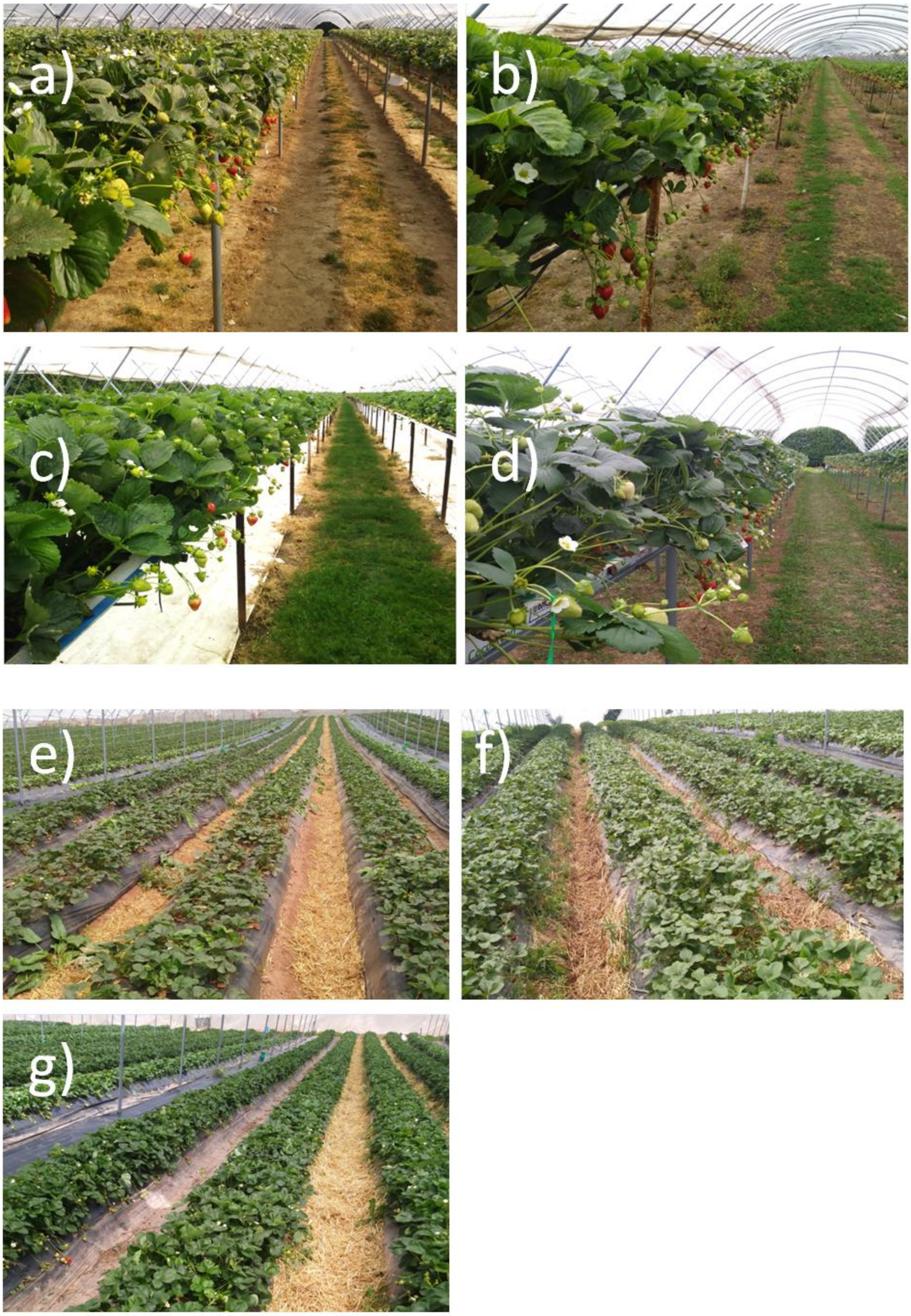


Figure 3.2.1. Photos of capsid push-pull trial blocks 2019; a) Kent Block 1; b) Kent Block 2; c) Kent Block 3; d) Kent Block 4 (WET Centre NIAB EMR); e) Herefordshire Block 5; f) Herefordshire Block 6; g) Herefordshire Block 7

Block layout:

A randomised block design was used. Each block was sub-divided into 4 plots (Fig. 3.2.2), with the exception of the WET centre at NIAB EMR Kent, which was divided into 2 plots (double number of standard concentration HB repellent sachets in the push and a control). All plots were 25 m x 25 m (3 or 4 tunnels wide depending on the tunnel span at each block, i.e. 8 or 6 m tunnel spans) and set up either at the corners of the crop as in Fig. 3.2.2, or in a line along the edge of the crop, depending on block space and pest pressure. Plots were ordered randomly to avoid position affect bias and spaced as far apart as possible to avoid interaction between the treatments.

Treatments:

Control. No push or pull

Treatment 1. Standard push-pull tested in 2017; A central push with 8 rows of 8 standard concentration HB repellent sachets (14 x 14 m grid) stapled to strawberry growbags, 1 every 2 m (64 total) combined with a perimeter pull

Treatment 2. ~ Double the number of HB repellent sachets in push; A central push with 8 rows of 15 (120 total) standard concentration HB repellent sachets (14 x 14 m grid) stapled to strawberry growbags, 1 every 1 m combined with a perimeter pull

Treatment 3. Double concentration HB repellent sachets in push; A central push with 8 rows of 8 (64 total) double concentration HB repellent sachets (14 x 14 m grid) stapled to strawberry growbags, 1 every 2 m, combined with a perimeter pull

HB repellent sachets were stapled to grow bags (Fig. 3.2.3) in a position where they would not contact developing fruit.

The Pull consisted of 12 green cross vane “bucket traps” (Agralan UK, *Lygus rugulipennis* trap system) carrying *Lygus* sex pheromone, female *Lygus* attractant phenylacetaldehyde (PAA) and a drowning solution of dilute liquid detergent. Traps were positioned in a 25 m x 25 m perimeter square surrounding the push, ~5.5 m away to prevent interference between HB and *Lygus* sex pheromone, as HB is a component of the pheromone. Traps were spaced at 8 m intervals and secured in-between two grow bags or at the end of the row in between the metal support and the first grow bag (Fig. 3.2.4).

Semiochemicals were renewed monthly, except mid-August near the end of the trial.

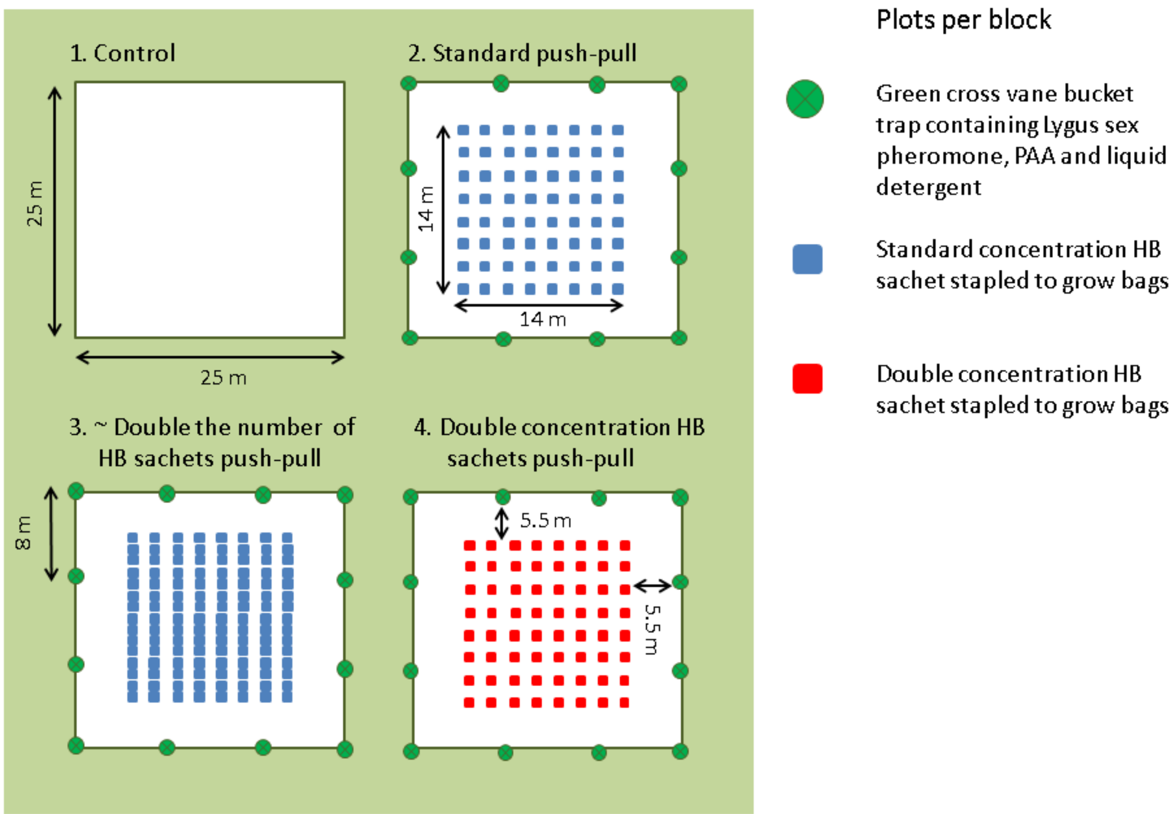


Figure 3.2.2. Diagrammatic representation of an experimental block of the capsid push-pull trial 2019, showing the control and 3 push-pull plots with positions of HB repellent sachets and green cross vane traps containing *Lygus* attractants.

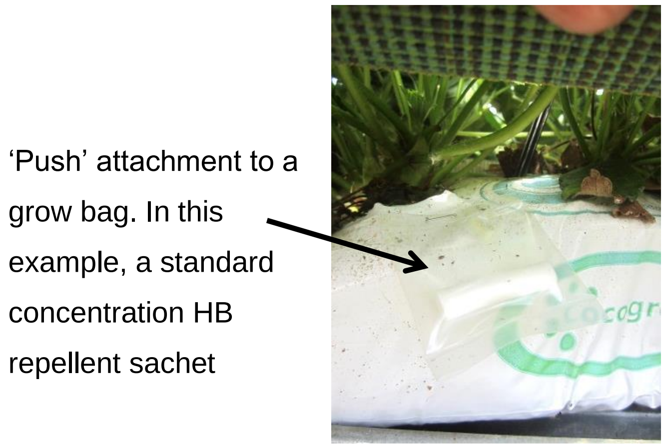


Figure 3.2.3. A standard concentration HB repellent sachet stapled to a strawberry grow bag

Figure 3.2.4. a) Typical position of a green cross vane trap in the plot perimeter b) location of *Lygus* sex pheromone and PAA in the trap

Semiochemical formulations:

For Treatments 1 & 2, HB was formulated in polyethylene sachets (1 ml HB on a dental roll sealed in a polyethylene sachet 50 mm x 50 mm x 120 µm thick).

For Treatment 3, HB was formulated in polyethylene sachets (2 pieces of dental roll with 1 ml HB on each, sealed in a polyethylene sachet 100 mm x 50 mm x 120 µm thick).

Lygus sex pheromone was formulated in 1 ml disposable pipettes (10 mg HB + 0.3 mg (*E*)-2-hexenyl butyrate + 2 mg (*E*)-4-oxo-2-hexenal + 1 mg Waxoline Black in 100 µl sunflower oil on cigarette filter). PAA was formulated in polyethylene sachets (0.5 ml on dental roll in a polyethylene sachet 50 mm x 50 mm x 120 µm thick).

Crop husbandry involved the standard grower practices, including the growers' standard spray programme which differed at each block (Appendix 3.2.1). Growers were advised that insecticide sprays should be avoided to prevent target pests being killed. Data loggers recorded temperature and humidity throughout the experimental period in each crop (Appendix 3.2.2).

Assessments

Tap sampling

To compare numbers of capsids and beneficials in control and treatment plot crops, plants were tap sampled fortnightly in the central 14 x 14 m of each plot within a block and invertebrate numbers counted. Fifty plants were tap sampled at Herefordshire blocks (5 to 7) and 100 at Kent blocks (1 to 4) to increase chances of finding capsids for statistical analysis.

Trap counts

To compare numbers of capsid adults and beneficials caught in perimeter traps of the 3 treatment plots, all 12 traps of each plot within a block were emptied fortnightly and invertebrate numbers counted.

See Table 3.2.1 for tap and trap assessment dates.

Fruit assessment

Flowers were tagged at each visit to relate numbers of pests to subsequent fruit damage. The timing of the first assessment was determined by following tagged flowers to fruit. All fruit at the same development stage on a plant were assessed to prevent bias. Assessments were conducted in the central 14 x 14 m of each plot within a block. Approximately 100 fruits were assessed per plot and categorised according to capsid damage; 0 (zero), 1 (slight), 2 (moderate) and 3 (severe) (Fig. 3.2.5). See Table 3.2.2 for fruit assessment dates.

Phytotoxicity

To determine if HB causes leaf phytotoxicity, at Block 1 Kent, 25 July 2019; 10 standard concentration HB sachets (release rate 18 mg/d at 22°C), 10 double concentration HB sachets (release rate 36 mg/day at 22°C) and 10 sachets containing dental roll soaked in 1ml water, were attached to young leaves close to the crown on separate strawberry plants. A further 10 plants were tagged with no sachets attached. On 3 September 2019, the 4 groups of 10 plants were assessed according to the phytotoxicity key (Appendix 3.2.3) (onlinelibrary.wiley.com. 2006).

The water sachet was formulated in polyethylene sachets (1ml deionised water on a dental roll sealed in a polyethylene sachet 50 mm x 50 mm x 120 μm thick).

Table 3.2.1. Dates for capsid push-pull trial tap and trap assessments at each block, 2019.

Location	Date of experiment set-up	Assessment 1	Assessment 2	Assessment 3	Assessment 4	Assessment 5
Block 1	26-Jun	09-Jul	25-Jul	08-Aug	3-Sep	
Block 2	25&26-Jun	10-Jul	23-Jul	06-Aug	2-Sep	
Block 3	25-Jun	10-Jul	23-Jul	06-Aug	2-Sep	
Block 4	27-Jun	09-Jul	24-Jul	08-Aug		
Block 5	18&19-Jun	02-Jul	16-Jul	31-Jul	15-Aug	29 Aug
Block 6	18&19-Jun	03-Jul	15&16-Jul	30&31-Jul	15-Aug	
Block 7	18&19-Jun	02-Jul	15-Jul	30-Jul	15-Aug	29&30 Aug

Table 3.2.2. Dates for strawberry damage assessments at each block, 2019. *No damage was counted at block 6 on 30 & 31 July due to low numbers of fruit in the crop and on 29 & 30 August due to the grower grubbing and dismantling the trial.

Location	Date of experiment set-up	Damage assessment 1	Damage assessment 2	Damage assessment 3
Block 1	26-Jun	08-Aug	03-Sep	
Block 2	25&26-Jun	06-Aug	02-Sep	
Block 3	25-Jun	06-Aug	02-Sep	
Block 4	27-Jun	08-Aug		
Block 5	18&19-Jun	31-Jul	15-Aug	29 Aug
Block 6	18&19-Jun	N/A*	15-Aug	N/A*
Block 7	18&19-Jun	30-Jul	15-Aug	29&30 Aug

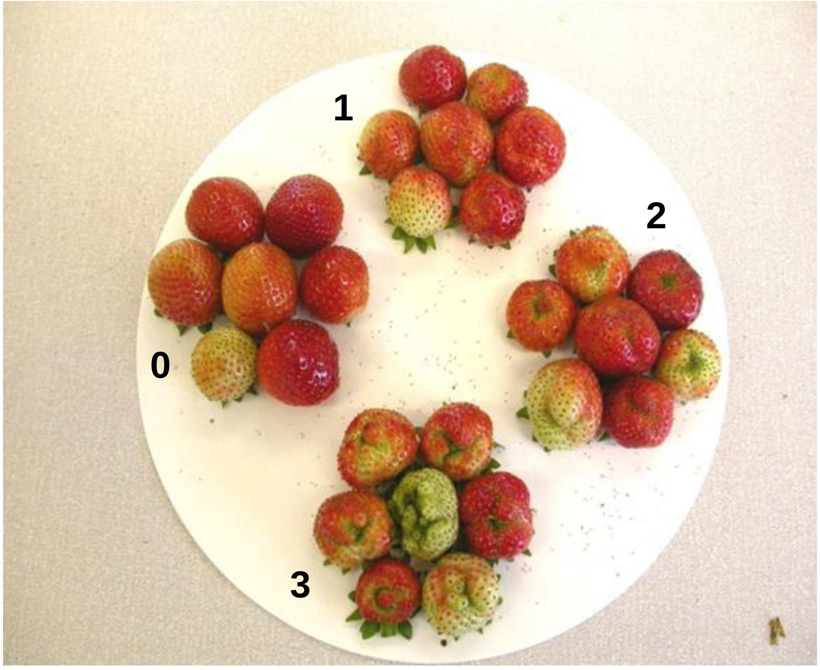


Figure 3.2.5. Capsid damage categories for strawberry fruits; from left working clockwise, 0 = no damage, 1 = slight damage, 2 = moderate damage, 3 = severe damage.

Statistical analyses

All statistical analyses were carried out in R 3.51.

Tap samples

The effect of treatment and assessment on capsid numbers in tap samples was estimated by fitting a generalised linear mixed model (GLMM) with a negative binomial distribution and log link function. Statistically significant effects of treatment, assessment and their interaction were calculated using a likelihood ratio test (LRT test). Post-hoc marginal means and contrasts were calculated using the R emmeans package, with Tukey adjusted p-values to control false discovery rate.

Trap counts

The effect of treatment and assessment on counts of each species caught in traps was estimated by fitting a generalised linear model (GLM) with a Poisson distribution and log link function. If over dispersed the model was refit with a Quasipoisson distribution. Statistically significant effects of treatment, assessment and their interaction were calculated using Analysis of deviance. Post-hoc marginal means and contrasts were calculated using the R emmeans package, with Tukey adjusted p-values to control false discovery rate.

Fruit assessments

As in 2017, data for fruit damage were analysed by firstly calculating a damage score. The damage score was determined for analysis using the formula (%0*0 + %1*1 + %2*2 + %3*3)/3. Values ranged from 0 if all of the fruits are in the '0' category, to exactly 100 if all of the fruits are in the '3' category. Whilst this did not relate directly to the mean % damage, this allowed data between plots to be compared statistically and to be transformed for analysis; in this case an angular transformation multiplied by 180/pi was used prior to ANOVA. Overall effects of the respective 'push-pull' treatments and interactions were examined. Results are presented on the transformed scale.

Results

Fruit assessments

Push-pull treatments significantly reduced capsid damage to fruit compared to the control. Herefordshire blocks had much higher damage scores than Kent blocks so were analysed separately (Grandmean = 36.1 and 7.4 respectively). In Herefordshire, percentage mean fruit damage score was significantly lower in Treatment Plots 1, 2 and 3 compared to the control plot (mean = 27.2, 31.3 and 27.2 and 58.8 respectively, P contrasts = 0.023, 0.023 and 0.042 respectively) (Fig. 3.2.6). Correspondingly mean percent of strawberries with zero capsid damage, was significantly lower in the control plot compared to Treatment Plots 1, 2 and 3 (mean = 10.3 %, 58.8 %, 48.7 % and 58.1 % respectively, P = <.002) (Fig. 3.2.7). At the Kent blocks (including the WET centre) mean damage score was not significantly different between treatments and control. The mean percentage of fruits with damage scores (across date and sites) of 0, 1, 2, and 3 were 69.2 %, 14.0 %, 6.1 %, and 11.0 % respectively.

Tap sample assessments (per 50 plants)

Push-pull treatments significantly reduced the number of capsid nymphs and adults in the crop compared to the control, at the Hereford sites only (very few capsids were observed at the Kent sites). Herefordshire blocks had more capsid nymphs compared to Kent blocks so were analysed separately (Grandmean = 34.4 and 0.3 respectively). At Herefordshire overall marginal mean numbers of capsid nymphs were significantly lower in Treatment Plots 1, 2 and 3 compared to the control (marginal mean = 12.1, 17.9, 14.0 and 53.4 respectively, P = <.001) (Fig. 3.2.8 b). Comparing treatments, the only difference was assessment 3 when there were significantly fewer capsid nymphs in Treatment 1 plots compared to Treatment 3 (mean = 23 and 79 respectively, P = <.001). Early instar capsid nymphs could not be identified to species in the field for practical reasons so were grouped for statistical analysis. Later instars were predominantly *L. rugulipennis* (Table 3.2.3) so most capsid nymphs analysed were assumed to be *L. rugulipennis* also. At Herefordshire overall marginal mean numbers of *L. rugulipennis* adults were significantly lower in treatment plots 1, 2 and 3 compared to the control (marginal mean = 0.15, 0.2, 0.15 and 1.05 respectively, *P* = .019) (Fig. 3.2.8 a). At every assessment there were fewer *L. rugulipennis* adults in treatment plots compared to the control - Treatments 1 and 3 had joint fewest overall.

In Herefordshire push-pull treatments also moderated population fluctuations of capsid life-stages in the crops over the trial period. In control crops, mean numbers of capsid nymphs peaked mid-July and adults early-August (Figs. 3.2.9 and 3.2.10). Between early and late-August damage to fruit increased in relation to the earlier increase in nymphs (Fig. 3.2.12). In the three treatments, peaks of both capsid life-stages were a lot less pronounced, reversing slightly with Treatment 1 (Figs. 3.2.9 and 3.2.10). Subsequent fruit damage did not follow the same pattern, by increasing as with the control, though damage scores were lower in all treatment crops (Fig. 3.2.12). Following a decrease from mid-August, capsid nymphs increased a second time in the control; treatments followed a similar slope of increase, but numbers were still lower (Fig. 3.2.9). Following a decrease, adults remained constant in control crops from mid to late-August. In Treatment 2, adults slightly increased, but in Treatments 1 and 3 numbers decreased (Fig. 3.2.10). Mean numbers of adult *L. rugulipennis* caught per 12 perimeter traps surrounding the three treatments, started high early-July, were lowest mid-July, then peaked mid-August before decreasing to late-August (Fig. 3.2.11).

Kent blocks had no *L. rugulipennis* adults so only Herefordshire blocks were analysed. At Kent blocks overall numbers of capsid nymphs were too low and no *L. rugulipennis* adults were found for statistical analysis. *Liocoris tripustulatus* (common nettle bug) and *L. pabulinus*, were also present in the crops at Herefordshire and Kent, but mean numbers of late instar nymphs and adults were either too low or none were counted for statistical analysis (Table 3.2.3).

At Kent and Herefordshire blocks, treatments had no effect on mean numbers of beneficials counted in the crop compared to the control during the trial.

Trap sample assessments (per 12 traps)

Of the capsids caught in perimeter traps, push-pull treatments only differed significantly on numbers of *L. tripustulatus* at Herefordshire. Herefordshire blocks had more *L. rugulipennis, L. pabulinus* and *L. tripustulatus* adults than Kent blocks (Table 3.2.4) so were analysed separately. At Herefordshire blocks overall marginal mean numbers of *L. tripustulatus* adults caught in perimeter traps was significantly higher in Treatment 1 than 2 and 3 (mean = 2.8116, 1.1508 and 0.9264 respectively, $P = <.001$) (Fig. 3.2.13). At Kent blocks overall numbers of capsid adults were too low for statistical analysis. At Herefordshire blocks treatment had no effect on mean numbers of *L. rugulipennis* and *L. pabulinus* adults caught in perimeter traps.

Treatment also had no significant effect on marginal mean numbers of beneficials counted in perimeter traps at Kent and Herefordshire blocks during the trial. Beneficials counted in the crop with numbers suitable for statistical analysis were parasitoid Hymenoptera spp., Anthocoridae spp., Araneae spp., Hemerobiidae spp., Chrysopidae spp. and Hemerobiidae spp. nymphs, Coccinellidae spp. nymphs.

Phytotoxicity

After attachment close to the crown on separate strawberry plants between 25 July and the assessment; 3 September, the two types of HB sachets used in the 2019 push had no clear adverse effect on strawberry plant foliage compared to plants where water sachets and no sachets were applied (Fig. 3.2.14). During the attachment period mean temperature in the Polytunnel was 19.5 °C ranging from 6.5 to 39 °C (Fig. 3.2.15) and mean humidity was 71.8 %RH ranging from 29.5 to 94.5 %RH (Fig 3.2.16).

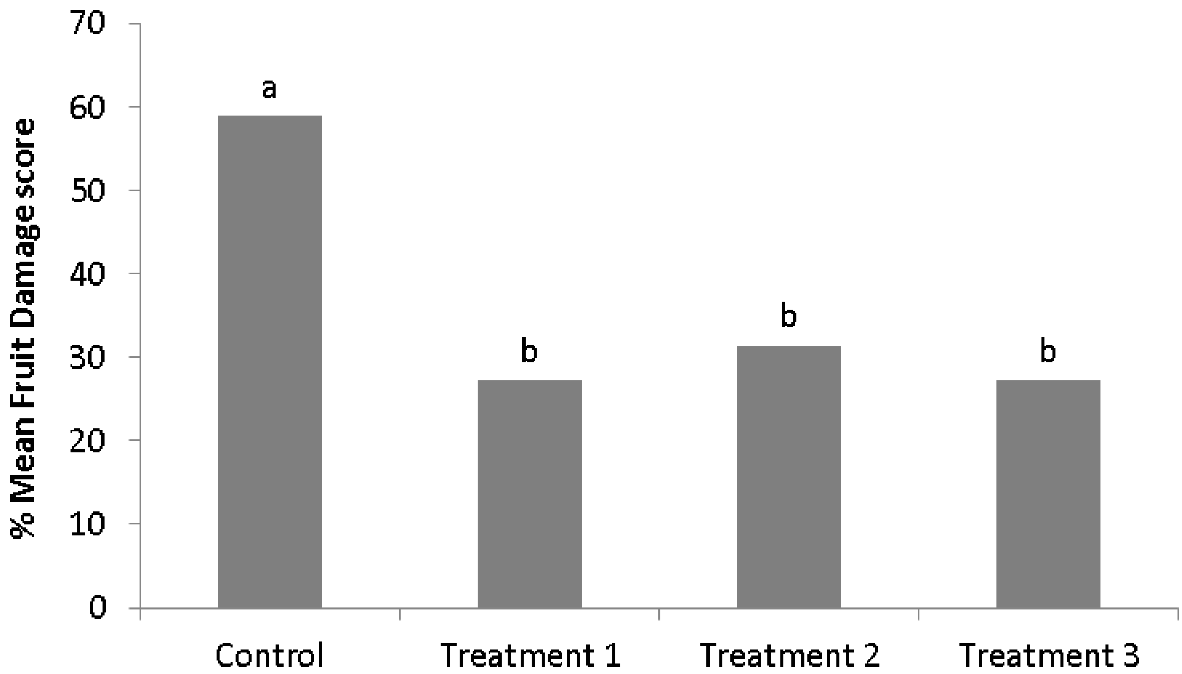


Figure 3.2.6. % Mean damage scores of strawberries assessed in Control, Treatment 1 (standard HB sachet, 64 deployed in push), Treatment 2 (standard HB sachet, 120 deployed in push) and Treatment 3 (double concentration HB sachet, 64 deployed in push) plots at

Herefordshire blocks. A score of 0 = no fruit damage by capsids, 100 = all fruit severely damaged by capsids.

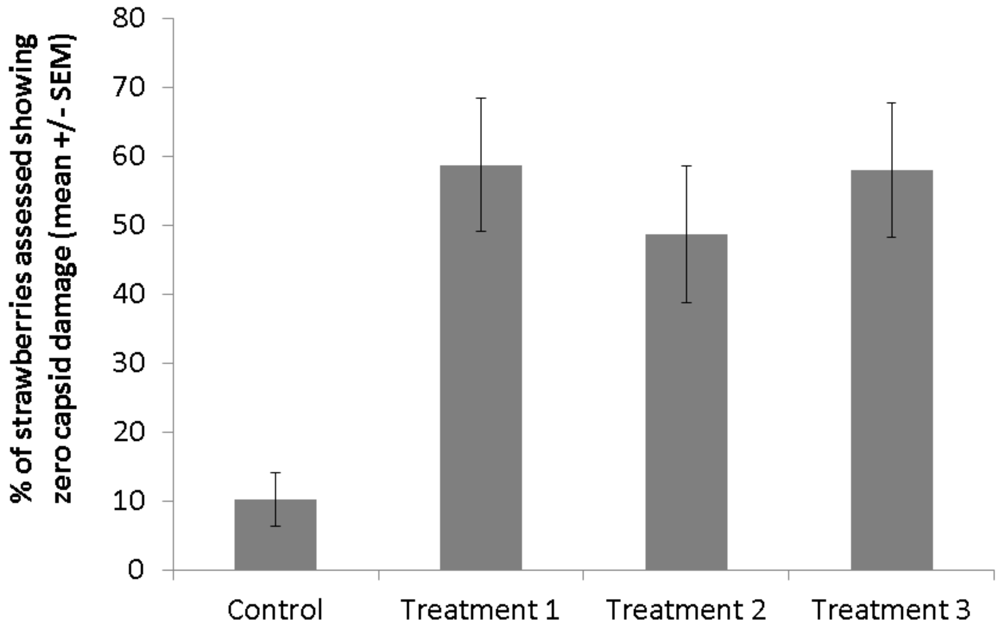


Figure 3.2.7. Mean percent (+/-SEM) of strawberries with zero capsid damage, from fruit assessments in Control, Treatment 1 (standard HB sachet, 64 deployed in push), Treatment 2 (standard HB sachet, 120 deployed in push) and Treatment 3 (double concentration HB sachet, 64 deployed in push) plots at Herefordshire blocks.

a) *L. rugulipennis* adults b) Capsid nymphs

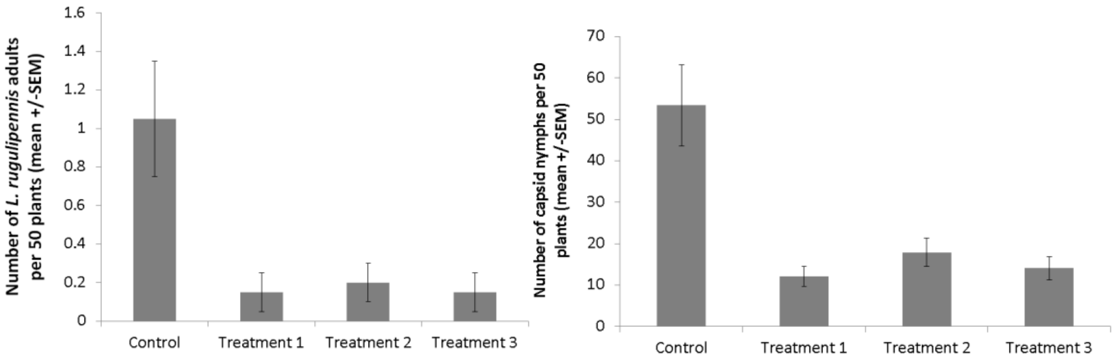


Figure 3.2.8. a) Marginal mean numbers (from statistical model)(+/-SEM) of *L. rugulipennis* adults and b) capsid nymphs per 50 plants from tap assessments in Control, Treatment 1 (standard HB sachet, 64 deployed in push), Treatment 2 (standard HB sachet, 120 deployed in push) and Treatment 3 (double concentration HB sachet, 64 deployed in push) plots at Herefordshire blocks

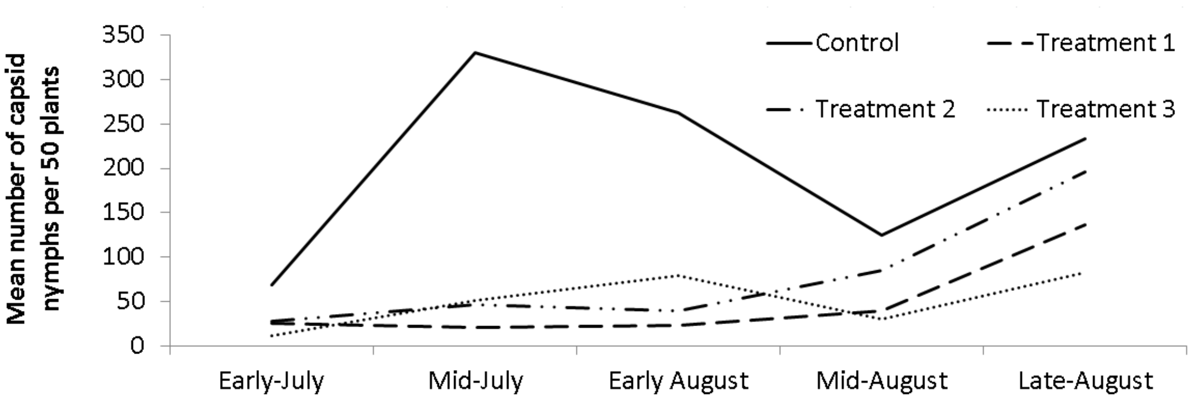


Figure 3.2.9. Mean number of capsid nymphs per 50 plants each tap assessment, in Control, Treatment 1 (standard HB sachet, 64 deployed in push), Treatment 2 (standard HB sachet, 120 deployed in push) and Treatment 3 (double concentration HB sachet, 64 deployed in push) plots at Herefordshire blocks.

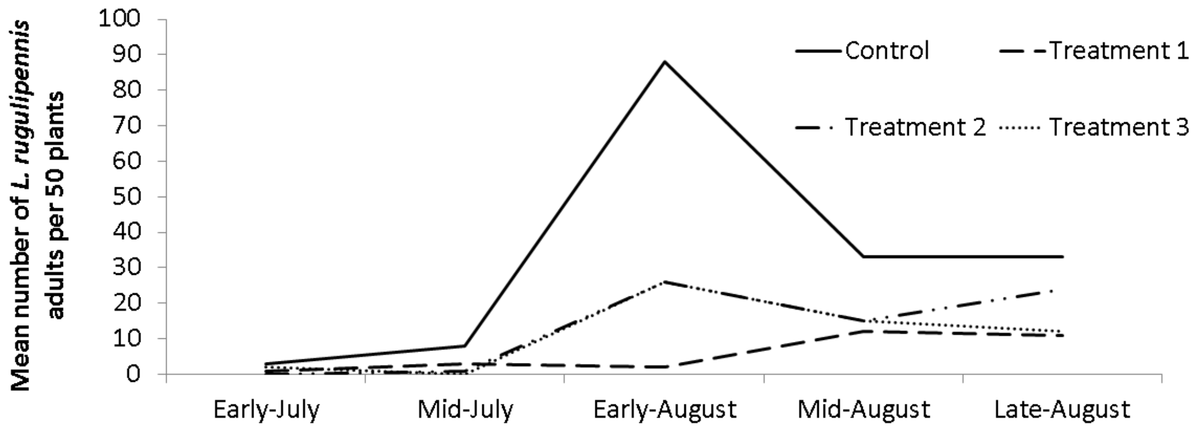


Figure 3.2.10. Mean number of *L. rugulipennis* adults per 50 plants each tap assessment, in Control, Treatment 1 (standard HB sachet, 64 deployed in push), Treatment 2 (standard HB sachet, 120 deployed in push) and Treatment 3 (double concentration HB sachet, 64 deployed in push) plots at Herefordshire blocks.

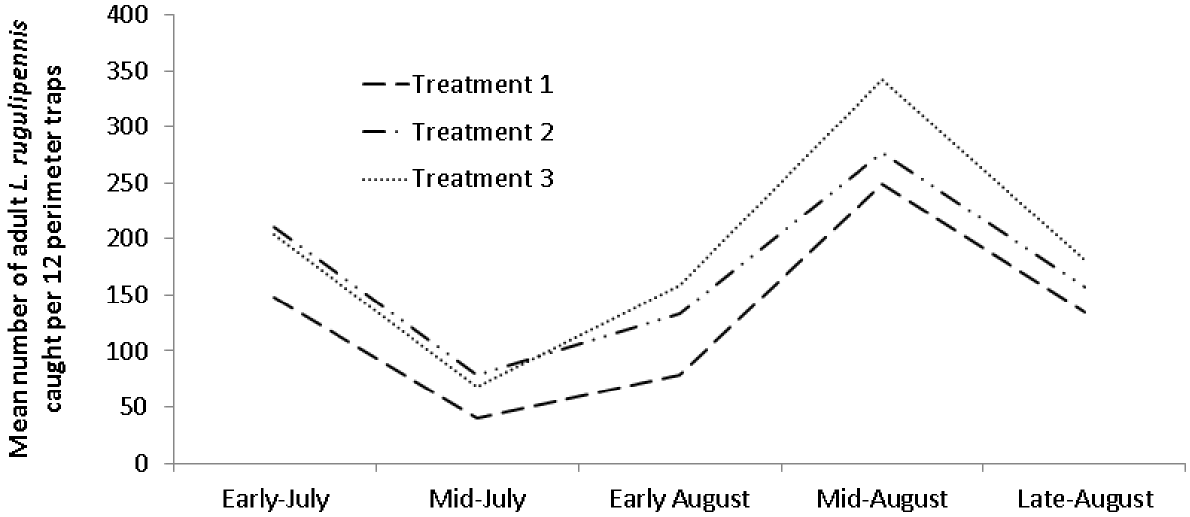


Figure 3.2.11. Mean number of *L. rugulipennis* adults per 12 perimeter traps each assessment, Treatment 1 (standard HB sachet, 64 deployed in push), Treatment 2 (standard HB sachet, 120 deployed in push) and Treatment 3 (double concentration HB sachet, 64 deployed in push) plots at Herefordshire blocks.

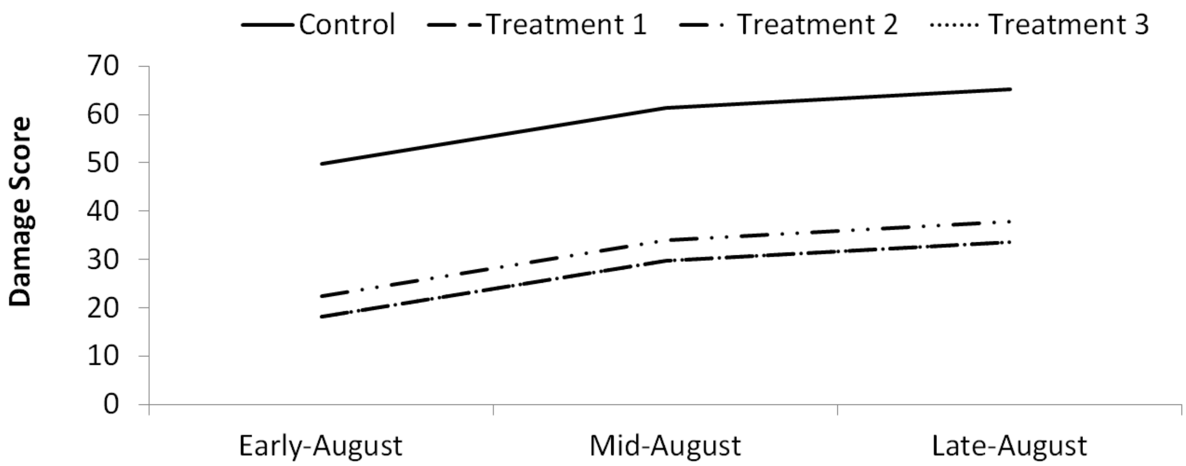


Figure 3.2.12. Damage scores of strawberries each assessment, in Control, Treatment 1 (standard HB sachet, 64 deployed in push), Treatment 2 (standard HB sachet, 120 deployed in push) and Treatment 3 (double concentration HB sachet, 64 deployed in push) plots at Herefordshire blocks. A score of 0 = no fruit damage by capsids, 100 = all fruit severely damaged by capsids.

Table 3.2.3. Mean numbers of capsids (nymphs and adults) counted per 50 plants in experiment blocks, during 3 years of push-pull trials in commercially grown strawberry. LRN & LRA = *L. rugulipennis* nymphs & adults, LPN & LPA = *L. pabulinus* nymphs & adults, LTN & LTA = *L. tripustulatus* nymphs & adults and capsid nymphs = a potential mix of these capsid species that could not be identified in the field.

		LRN	LRA	LPN	LPA	LTN	LTA	Capsid nymphs
2017	Kent	0.3594	0.25	0.25	0.4531	NA	NA	0
2018	Kent	0.0097	0.003	0.0219	0.0156	NA	0.0012	0.48
2019	Kent	0.0004	0.0006	0.0009	0.0015	NA	0.0003	0.30
2019	Herefordshire	0.2189	0.1125	0	0	NA	0.0236	34.25

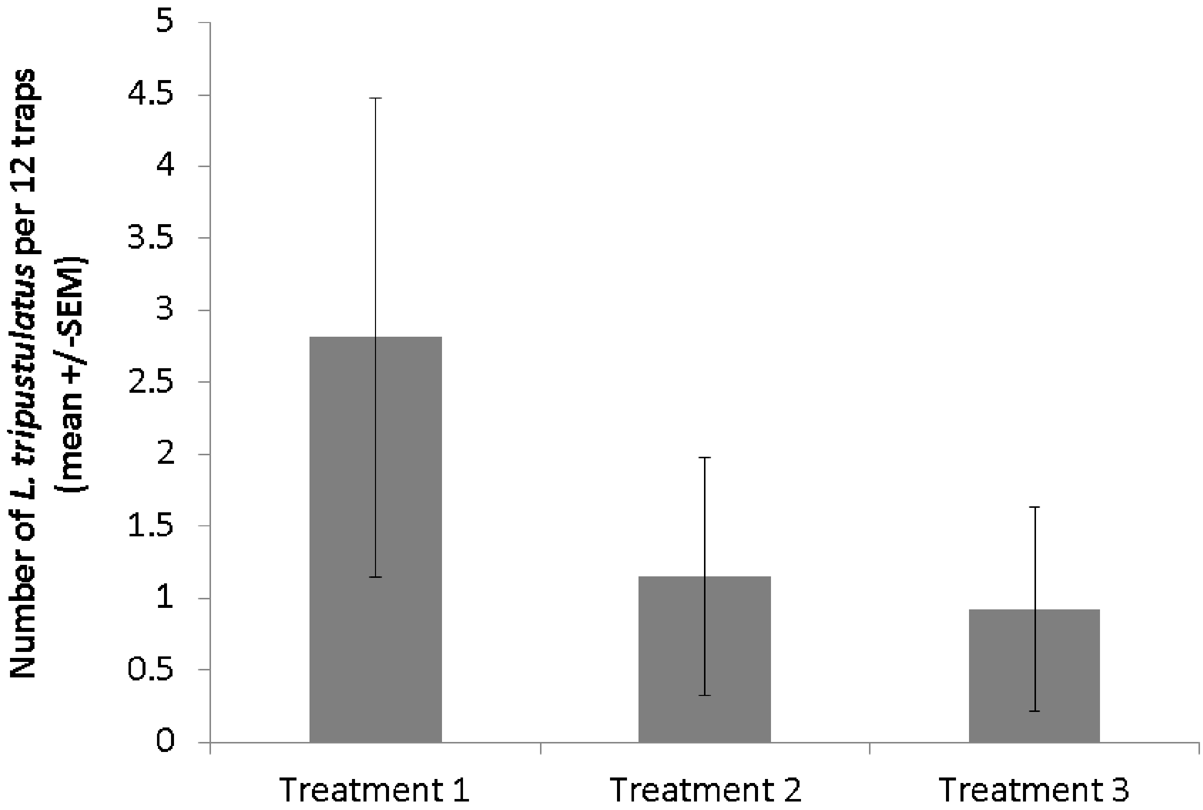


Figure 3.2.13. Marginal mean number (+/-SEM) (from statistical model) of *L. tripustulatus* adults per 12 traps in Treatment 1 (standard HB sachet, 64 deployed in push), Treatment 2 (standard HB sachet, 120 deployed in push) and Treatment 3 (double concentration HB sachet, 64 deployed in push) plots at Herefordshire blocks.

Table 3.2.4. Mean numbers of capsid adults counted per 12 green cross vane perimeter traps in treatment plots per experiment block, during 3 years of push-pull trials in commercially grown strawberry. LRA = *L. rugulipennis* adults, LPA = *L. pabulinus* adults and LTA = *L. tripustulatus* adults.

		LRA	LPA	LTA
2017	Kent	0.2500	0.4531	0
2018	Kent	0.3906	0.0347	0.0052
2019	Kent	0.6389	0	0.0021
	Herefordshire	4.8790	0.0159	0.2738

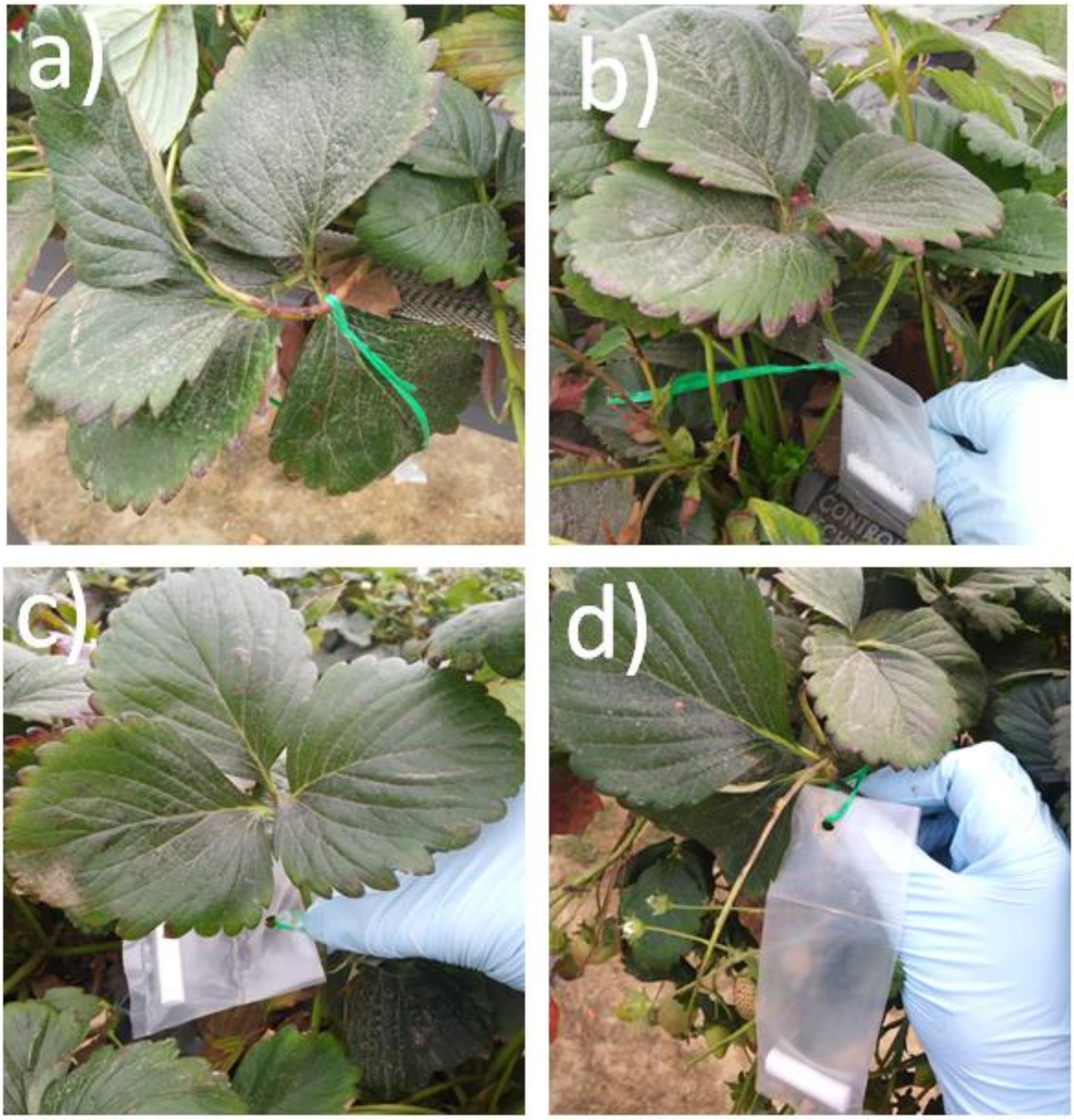


Figure 3.2.14. Sample photos from HB phytotoxicity assessment comparing plant foliage following ~1 month exposure to HB repellent sachets used in the push-pull trial 2017 and 2019: a) control - no sachet; b) sachet containing dental roll soaked in 1ml water; c) standard concentration HB sachet (2017 and 2019 trials); d) double concentration HB sachet (2019 trial).

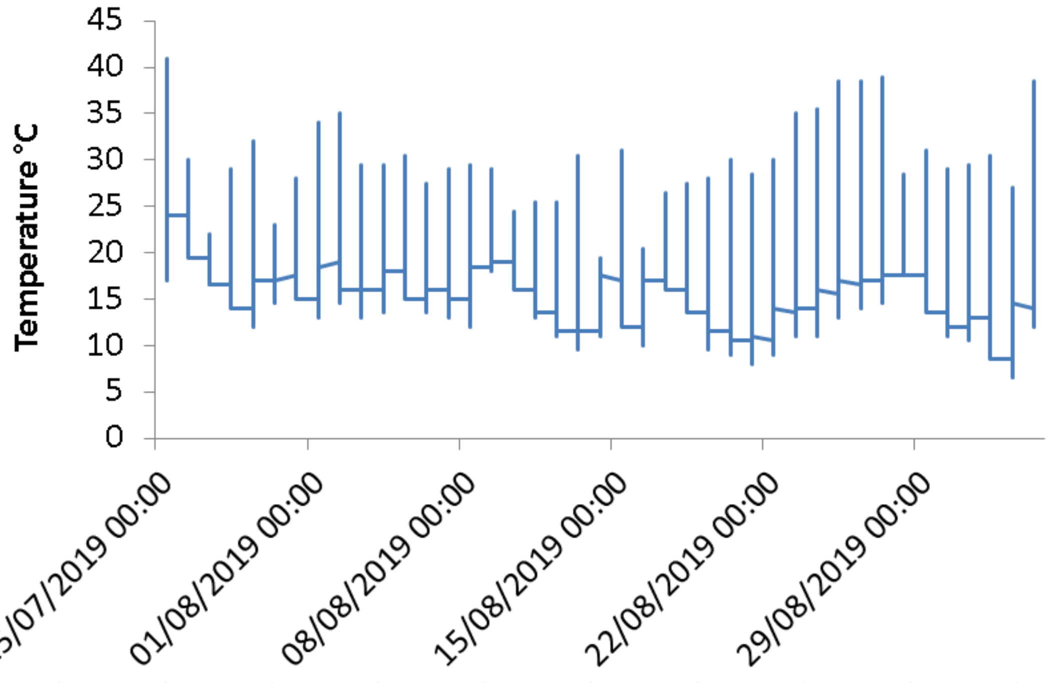


Figure 3.2.15. Temperature (°C) in the Polytunnel during the HB phytotoxicity experiment between 25 July (sachet attachment) and 3 September (phytotoxicity assessment).

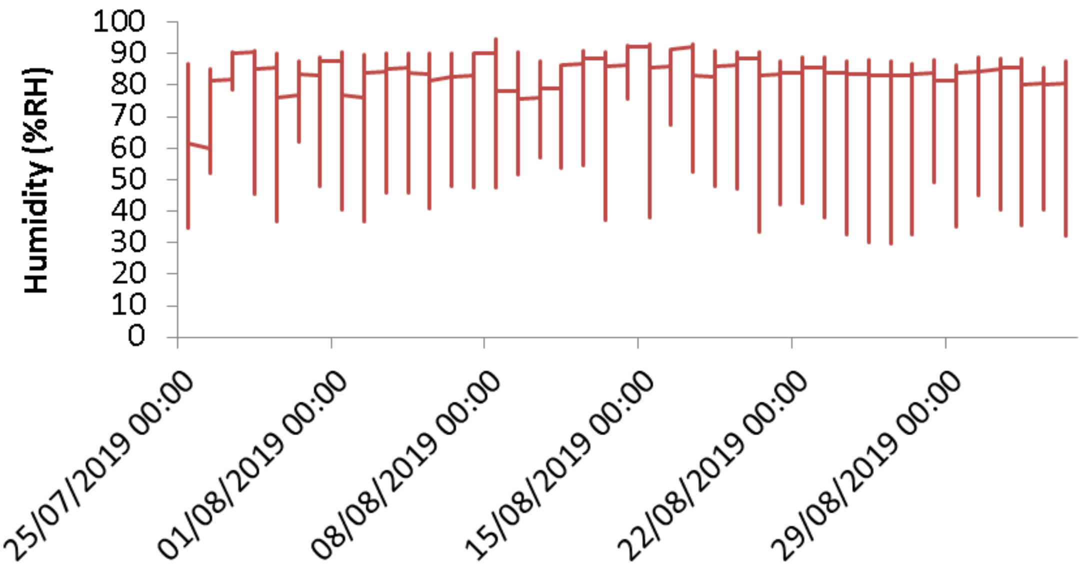


Figure 3.2.16. Humidity (%RH) in the Polytunnel during the HB phytotoxicity experiment between 25 July (sachet attachment) and 3 September (phytotoxicity assessment).

Discussion

During the trial in 2019, push-pull significantly reduced numbers of capsids in the crop and capsid damage to strawberries, reinforcing the 2017 result. Three push-pull treatment variations were compared (the standard method used in 2017 and 2 alterations to increase the push in the crop) alongside an untreated control. In the organic crops at Herefordshire where capsid numbers were highest, all 3 push-pull treatments significantly reduced the numbers of capsid nymphs (predominantly *L. rugulipennis*) compared to the control (Marginal grandmean = 14.7 and 53.4 respectively, *P* = <.001) and *L. rugulipennis* adults compared to the control (Marginal grandmean = 0.2, and 1.05 respectively, *P* = .019) per 50 plants. Comparing capsid numbers between the different treatments, the only difference was capsid nymphs at assessment 3 where there were significantly fewer in Treatment 1 plots compared to Treatment 3 (mean = 23 and 79 respectively, *P* = <.001). However, this is considered an anomaly because numbers were similar to Treatments 1 and 2 all other assessments. Corresponding with capsid numbers, percentage mean fruit damage score was significantly lower where a treatment was applied compared to the control (Grandmean = 28.6 % and 58.8 % respectively, *P* = <.001) and mean percent of strawberries with zero capsid damage, was significantly lower in the control plot compared to treatment plots (Grandmean = 10.3 %, 55.2 % respectively, *P* = <.002). In 2019 push-pull reduced % mean fruit damage score by ≤ 31.6 % compared to 7.8 % in 2017. Concurrently, in 2019 push-pull increased mean percent of strawberries with zero capsid damage by ≤ 49 % compared to 16.14 % in 2017 - albeit overall there were fewer capsid damaged strawberries in Kent crops compared to Herefordshire. These results demonstrate push-pull can significantly reduce numbers of capsids and damage to fruit in both conventional and organically grown strawberry, compared to standard crop husbandry practices. Further, the phytotoxicity test implied the 2 types of HB sachets tested in the 2019 push had no adverse effect on strawberry foliage development compared to plants where water sachets and no sachets were applied following approximately 1-month attachment near to the crown. The discolouration on leaf edges shown in the photos (Fig 3.2.14) was consistent in all samples and probably due to natural leaf senescence at the time of the assessment; 3 September.

In Herefordshire, push-pull treatments moderated typical population fluctuations of capsid life-stages in the crops over the trial period. In the UK, adult *L. rugulipennis* migrate from weeds (such as groundsel) into strawberry crops to lay eggs on strawberry plants, late June/early July (Easterbrook 1997). This was reflected by perimeter trap catches of *L. rugulipennis* adults, which were high at the first assessment early-July, then decreased by mid-July, probably due to a combination of traps reducing adult numbers and natural adult mortality; for example in culture at 20 °C, the average lifespan of female adult *L. rugulipennis* is 23 days (Fountain et al. 2014). Following adult infestation into the crop, nymph offspring from eggs laid cause further damage to the fruit (Xu et al. 2014). In control crops, mean numbers of capsid nymphs increased to a peak mid-July and subsequent fruit damage recorded 6 weeks later increased in line with this between late July and late August. However, in push-pull treatment crops, peaks of nymphs and fruit damage were a lot lower. In Treatment 1 crops, numbers of nymphs decreased mid-July. Between mid-July and early-August nymphs declined and adults peaked in control crops, then from mid-August, capsid nymph offspring started to increase a second time. Nymphs in all treatment crops also increased at this time though numbers were lower. This was likely due to decreased repellence of HB in treatment crops reflected by increasing numbers of adults in tap samples in all treatment crops at this period. Treatment plots would have been under high pressure from immigration of adults from control plots at this time; with peak catches of *L. rugulipennis* adults in perimeter traps around the treatments supporting this. It was advised by NRI that semiochemicals should be renewed monthly. However, due to limited resources, semiochemcials were only replaced once in mid-July. Had the HB repellent been renewed mid-August, adults may have been better repelled and the subsequent increase in numbers of capsid nymphs in treatment crops prevented. When using this method of push-pull, it is therefore recommended that all semiochemcals are replaced monthly to ensure effectiveness.

Push-pull treatments tested, had no significant effect on mean numbers of beneficials counted in both crops and perimeter traps at Kent and Herefordshire blocks. Beneficials counted in the crop with numbers suitable for statistical analysis were parasitoid Hymenoptera spp., Anthocoridae spp., Araneae spp., Hemerobiidae spp., Chrysopidae spp. and Hemerobiidae spp. nymphs, Coccinellidae spp. nymphs. The technique should therefore be advantageous to IPM.

Numbers of capsids in Kent blocks 2019 (including the WET centre at NIAB EMR) were too low to analyse. Numbers of capsid nymphs per 50 plants were much lower compared to Herefordshire blocks (Grandmean = 0.3 and 34.4 respectively), and numbers of capsid adults counted in 2019 were lower compared to 2017 when there was a treatment effect (Grandmean = 0.0006 and 0.25 respectively) (2017 AHDB report). Higher numbers of capsids in Herefordshire strawberry was likely due to greater pest pressure from weed hosts in the surrounding natural habitat (Cross et al. 2001). Although no habitat assessment was made between Kent and Herefordshire blocks, in Kent herbicide was applied to control weeds in Polytunnels, herbicide was not applied at the organic Hereford site. Another reason might be that insecticides used to control capsids are not approved in organic systems (Fountain et al. 2015). The continuation of lower numbers of capsids in Kent 2019 compared to 2017 is possibly due to slow population recovery after unfavourable climatic conditions in 2018.

Increasing the level of HB released in the push did not significantly reduce capsids in the crop and capsid damage to strawberries compared to the method used in 2017. Of the 3 push-pull treatments tested in 2019, Treatment 1 (the standard push-pull method) reduced numbers of capsid nymphs per 50 plants more, though not significantly, than the other 2 treatments (increased number of HB repellent sachets in the push and increased volume HB repellent sachets in the push) (marginal grandmean = 14.7). There was also no significant difference in numbers of *L. rugulipennis* adults caught per 12 perimeter traps between the 3 treatments (marginal grandmean = 4.9). The push-pull treatments only differed significantly on numbers of adult *L. tripustulatus* caught in perimeter traps at Herefordshire which was significantly higher in Treatment 1 than 2 and 3 (marginal mean = 2.8116, 1.1508 and 0.9264 respectively, P = <.001). This finding is most likely attributable to the position of Treatment 1 at Block 6, which was surrounded by nettle (*Urtica dioica* L, Urticaceae), a natural host of *L. tripustulatus* on which the species has been recorded almost exclusively (Southwood et al. 1959). None of the push-pull treatments significantly reduced numbers of *L. tripustulatus* nymphs and adults in the crop though. Since increasing the level of HB repellent released in the push did not significantly reduce capsids in the crop or capsid damage to strawberries and given the resources required for production and deployment of the HB sachets, the standard push-pull method is considered the most efficient of the 3 treatments tested in 2019. Findings also suggest that the 2017 HB deployment method is at/exceeds the maximum level needed to repel capsids from the crop, so further optimisations could study the effects of reducing the level of HB in the push.

The significant increase in percent of fruit with zero percent capsid damage in push-pull treated compared to control crops in 2017 and 2019 is most likely due to a significant reduction in *L. rugulipennis* adults and nymphs. Most capsids identified in Herefordshire strawberry in 2019 were *L. rugulipennis*. This species is the major cause of damage on late-season and everbearer varieties (Easterbrook 1996) and identified as the most common capsid nymph taken from UK strawberry fields during July and August (Easterbrook 1997) - the months when most push-pull trial assessments took place. Although *L. pabulinus* was the most common capsid species identified in the crop and perimeter traps in 2017, the species has previously been considered less significant as a pest to strawberry (Alford 2007). Nonetheless simultaneous control of both capsids is advantageous to protect the strawberry crop.

For best capsid control in UK strawberry using push-pull, treatment should begin in late spring at the latest and continue through autumn at least. Previous work sampling weeds surrounding strawberry crops suggest that overwintered *L. rugulipennis* adults lay eggs which develop into nymphs late spring-early summer. These nymphs mature in late June/early July, providing a source of adults which can migrate into strawberry fields at that time - although many remain on suitable weed hosts (Easterbrook 1997). Commercially, traps could be positioned around the edge of the crop (not within) to intercept the primary invasion of adults late spring, but also those seeking weed hosts to overwinter at the end of the growing season; indeed had push-pull been deployed at the end of the 2018 growing season in Herefordshire, the reduction in capsids and fruit damage during the 2019 trial may have been even greater. Repellents could be deployed in the crop throughout the growing season to deter adult invasion, but the decision to do this would ultimately be informed by capsid levels in the crop the previous year.

Management of weeds that host capsids in and around the crop is also recommended. Weed hosts include; Groundsel, Mayweed, Fat-hen, Nettles, Dock and Common mugwort. Most *L. rugulipennis* probably overwinter outside strawberry fields, and even those that stay in the crop appear to leave in the spring to feed on weeds or other crops with many adults remaining on suitable weed hosts during the growing season.

Conclusions

- Push-pull has been shown to significantly reduce numbers of capsids and damage to fruit in commercial strawberry during 2 years of trials. This is most likely due to a significant reduction in *L. rugulipennis* adults and nymphs, but there is evidence that *L. pabulinus* is reduced also
- This method has been effective in conventional (2017) and organic crops (2019)
- HB appeared to have no phytotoxic effects when applied close to the strawberry crown. During the trials HB was stapled to growbags
- The technique is compatible with standard crop husbandry practices
- There were no noticeable adverse effect on numbers of beneficials counted in the crop therefore push-pull should be advantageous to IPM
- Increasing the level of HB in the push did not significantly reduce capsids in the crop and damage to fruit compared to the 2017 method. But there may be scope to optimise the cost-effectiveness of the push by reducing the amount of HB released in the crop
- Capsid traps should be deployed outside the crop from late spring at the latest through at least autumn, possibly in combination with HB repellents in the crop dependent on previous years' capsid levels
- Management of weeds that host capsids in and around the crop is also recommended

- Future work should focus on formulation of the repellent, efficacy in other capsid affected crops, and testing reduced doses of repellent in conventional crops.

Objective 4 Improve insecticide and biological control of the potato aphid, *Macrosiphum euphorbiae*, so as to be more compatible with IPM programmes

Task 4.3. Test the efficacy of foliar-applied plant protection products for control of *Macrosiphum euphorbiae*

Introduction

Several species of aphid are regularly found infesting strawberry crops. The most frequently occurring and most damaging are strawberry aphid (*Chaetosiphon fragaefolii*), melon-cotton aphid (*Aphis gossypii*), shallot aphid (*Myzus ascalonicus*), glasshouse-potato aphid (*Aulacorthum solani*) and potato aphid (*Macrosiphum euphorbiae*). Damage is caused by direct feeding, causing distortion and contamination of fruits and foliage with honeydew and leading to the growth of sooty moulds. In addition, aphids may bring damaging viruses into the crop and transmit them from plant-to-plant (e.g. strawberry crinkle and strawberry mottle virus diseases; Cross et al. 2005). Aphid infestations of strawberry (particularly those involving potato and melon-cotton aphids) may be difficult to control using the aphicides that are currently available. In addition, the neonicotinoid thiacloprid is currently used for aphid control in strawberries but approvals for Calypso and other products containing this active are likely to be withdrawn in 2020 or shortly afterwards. Insecticide resistance further complicates management of these pests and this is a particular problem with *A. gossypii* (Marshall et al. 2012).

In this experimental work, products highlighted as showing promising aphicidal activity, during the 2018 aphid trial carried out for this project (SF 156, 2018 report on results with *A. gossypii*) and the recent SCEPTREplus trials testing targeting the polyphagous aphid pest *Myzus persicae* on brassicas, were tested for activity against the potato aphid on strawberry. An insecticidal product with recent approval for application to strawberry (Batavia: spirotetramat) was included to allow comparisons to be made.

The objectives of the trial were:

- To investigate efficacy of insecticides applied to strawberry foliage on potato aphid
- To improve control of potato aphid on strawberry

The treatments applied to strawberry plants included four products with approval for strawberry at the time of the trial: Batavia (approved for protected and unprotected crops), Spruzit (protected and unprotected), FLiPPER (protected only) and Benevia 10 OD (protected only). However, it should be noted that the approval for applications of Spruzit expired following this trial (final use date 30 September 2019). The active in Batavia (100g/L spirotetramat) is a tetramic acid derivative with systemic mobility through both phloem and xylem (Nauen et al. 2008). This compound has a novel mode of action, interfering with lipid biosynthesis, and provides effective control of several groups of sap-feeding insects including *A. gossypii* (Gong et al. 2016). FLiPPER (48% fatty acids) is a plant-derived product with a physical mode of action, suffocating the pest through blockage of spiracles. Benevia 10 OD is an oil-dispersion formulation of cyantraniliprole, which currently has an extension of authorisation for a minor use on protected and outdoor strawberry. The other four products tested are not approved for application to strawberry and are therefore reported following their HDCI codes provided by AHDB, pending permission from manufacturers to uncode.

Methods

Strawberry plants (the same everbearer variety used for the 2018 trial) growing in compost in 2L plastic pots were transferred to four 10 x 7 m tunnel compartments at NIAB EMR with gauze mesh to provide insect screening around the external edges and internally between compartments. Plants were maintained in this environment on fertigation. Runners and flowers were removed weekly to encourage continued growth of vegetation until a source of infesting potato aphids was obtained.

The trial timetable during the lead-up and experimental periods is shown in Table 4.1. Between 23 and 30 May, all plots in the tunnel compartments were inoculated with potato aphids. Aphids were a pink strain of *Macrosiphum euphorbiae* collected from glasshouse infestations at NIAB EMR and the insects quickly established colonies on both the mature, fully-expanded leaves and on the young leaves unfolding from the crown (Fig. 4.1a,b).

Table 4.1. Timetable of activities for the potato aphid spray trial.

Date (2019)	Activity
23-30 May	Plants inoculated with aphids in tunnels
7 June	Pre-assessment
10 June	First treatment application (all treatments)
11 June	First post-treatment assessment
14 June	Second post-treatment assessment
	Re-application of treatments 6, 8 & 10
17 June	Third post-treatment assessment
20 June	Re-applications: 3^{rd} spray (6, 8 & 10). 2^{nd} spray (2, 5 & 7)
21 June	Fourth post-treatment assessment
24 June	Fifth post-treatment assessment
	Re-applications (4^{th} spray) of treatments 6, 8 & 10.
27 June	Sixth post-treatment assessment

Figure 4.1. Aphid-infested plants, a) colony on a large, fully-expanded leaf, b) colony on a young, folded (expanding) leaf

Plug plants from cold store were transplanted into 2L pots on 8th April 2019 and maintained in a glasshouse compartment before the trial. Flowers were removed at weekly intervals, and the plants were watered and treated with fungicides as standard. No insecticide treatments were applied. The potted plants were transferred to the field site during May 2019 and arranged inside four protected tunnel compartments (covered with 150 µm thick translucent polythene) at NIAB EMR. Data loggers were placed within a Stevenson screen at the centre of each tunnel at this time and used to record temperature and humidity at 30-minute intervals throughout the trial period. Plants were placed in two rows of five plots (Fig. 4.2a, arranged in 10 plots, each plot comprising 6 pots, 60 plants per tunnel, 240 plants used in total). Fertigation was applied as standard for growers' practice. Spaces between neighbouring plots of plants within each tunnel were approximately 90 cm.

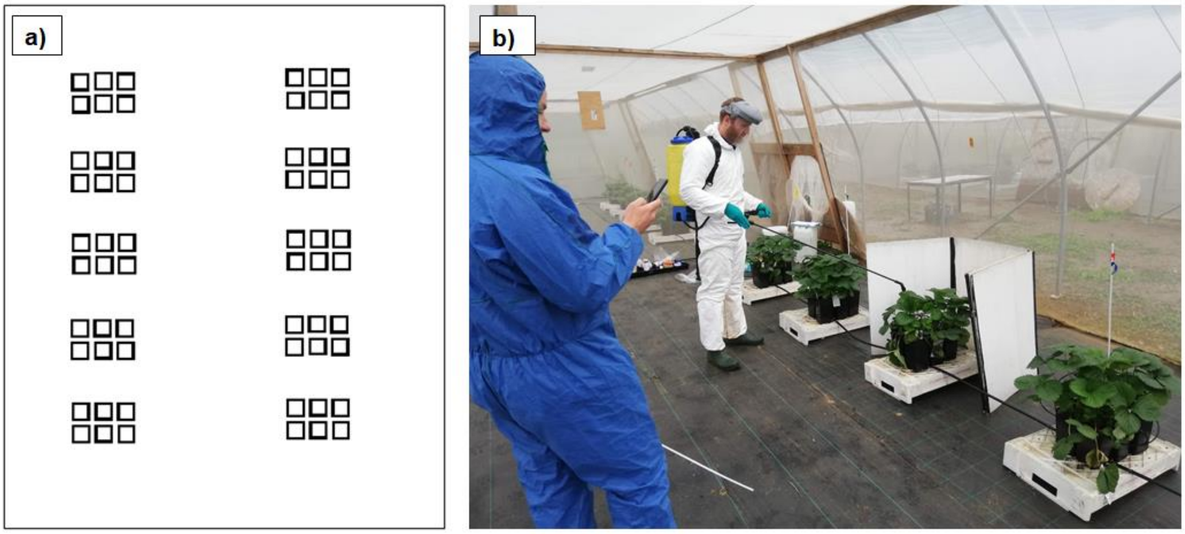


Figure 4.2. a) Arrangement of potted plants (small square = 1 plant) within one of the four tunnel compartments, b) preparation for treatment application (water controls) and screening of neighbouring plots

At the stage of pre-assessment, plants were heavily infested, with aphid colonies well established on young and mature leaves (Fig. 4.1a,b). Eight sprayed products were applied (Table 4.2). Rates of application followed manufacturers' recommended application rates when these were available, although it should be pointed out that FLiPPER was applied at a lower rate than the maximum dose permitted by the current EAMU (see footnote to Table 4.2). Treatments were allocated using a randomised block design with 4 replicates, with each treatment applied once within each tunnel (Fig. 4.2a).

Table 4.2. Treatments and dose rates for the efficacy testing to control *Macrosiphum euphorbiae* on strawberry. Two control treatments (9 and 10) were included in the trial (plants either unsprayed, or water-sprayed).

Treatment Number	Treatment	Rate applied (/ha)	Number of applications	Spray interval (days)
1	Batavia (spirotetramat)	1 L	1	N/A
2	Benevia 10 OD (cyantraniliprole)	0.75 L	2	10
3	HDCI 108	0.2 L	1	N/A
4	HDCI 109	0.5 L	1	N/A
5	HDCI 110	1 L	2	10
6	FLiPPER (carboxylic acids) [1]	4.8 L[1]	4	4-6
7	Spruzit (pyrethrins and oils)	6 L	2	10
8	HDCI 111	6.5 L	4	4-6
9	Untreated	-	-	N/A
10	Water-sprayed	-	4	4-6

1. The current EAMU (#3416, September 2019) for FLiPPER specifies a maximum dose of 10 L/Ha for protected strawberry, so this rate is lower than that permitted for the crop.

Treatments were applied using a hand pump knapsack sprayer and hand lance (Fig. 4.2b), with a size 04 Albuz red nozzle (calibrated output = 932 ml/min). Products were applied at a volume equivalent to 1000 L/ha and their rates of application are listed in Table 4.2. A hinged three-sectioned board was held around each plot during application to mask neighbouring plots and prevent spray drift (Fig. 4.2b). The nozzle was held approximately 20 cm above the top of the foliage level during application and the hand lance moved in a circular motion around the edge of the plot of 6 plants to improve coverage and canopy penetration of spray droplets. All treatments were applied on 10 June, and sub-sets of treatments (depending on their use in commercial strawberry production) were re-applied either once (total of two sprays: Treatments 2, 5 and 7) or three times (total of four sprays: Treatments 6, 8 and 10). Treatments 1, 3 and 4 were not re-applied, therefore plants received only one application of these three treatments. Total numbers of applications for each of the treatments are shown in Table 4.2.

Seven assessments of aphid numbers were carried out. An initial pre-assessment took place on 7 June. Subsequent assessments were made at regular intervals during the trial (Table 4.1; Figure 4.3). At each assessment, all six plants within each plot were initially examined carefully and the most heavily infested plant was selected for assessment. Representative mature and young leaves (supporting typical numbers of aphids) were used for the insect counts. Aphids were counted on one whole mature leaf and on one expanding (unfolding) young leaf. Adults and nymphs were not discriminated during counting, but the number of alate (winged) adults present was noted. The same aphid assessment methods were applied for all treatment groups.

Figure 4.3. Assessments of aphid numbers

Aphids within the colonies varied in colour and included a few green forms as well as the predominant pink forms of potato aphid. However, when samples were collected and checked with laboratory-based identification under the microscope, they showed features that are diagnostic of *M. euphorbiae,* including apical polygonal reticulation of the siphunculi (Blackman & Eastop, 2000). Numbers of aphidophagous natural enemies and aphid mummies were also recorded at each assessment, although these were extremely low throughout the trial.

Results

The total aphid count data (combining aphids counted on the mature leaf and younger leaf for each plant) were analysed to give an initial overview of treatment effects, using a generalised linear mixed model (GLMM), applying a Poisson distribution and log link. This enabled the numbers to be adjusted, relative to pre-assessment counts (normalised to starting mean total counts of 180 aphids) for each treatment. Figure 4.4 shows changes in these normalised aphid numbers (with the data back-transformed from the log scale) during the trial. The GLMM analysis revealed highly significant ($P<0.001$) effects of treatment (χ^2 = 39.9; df = 9), assessment date (χ^2 = 23.2; df = 5) and a treatment X date interaction (χ^2 = 233.7; df = 45). Pairwise comparisons of means were carried out to highlight statistically significant reductions in aphid numbers associated with any of the treatments at any assessment dates, compared with both water-treated and untreated controls.

The pairwise comparisons revealed that pest numbers on Batavia-treated plants were significantly ($P<0.05$) lower than on either untreated or water-sprayed control plants at the third post-treatment assessment (17 June) and all subsequent assessments. Similarly, aphid numbers on plants treated with coded products HDCI 108 and HDCI 109 were also significantly ($P<0.05$) reduced at the third post-treatment assessment and all subsequent assessments, compared with either of the two control groups. No other treatments were associated with significantly reductions in total numbers of aphids, compared with numbers on either water-treated or untreated control plants, on any of the assessment dates. At the first post-treatment assessment (11 June), mean total aphids counted on plants treated with HDCI 108 appeared to be higher than the numbers on plants from other treatments, including HDCI 109 and Batavia. However, pairwise comparisons revealed no significant differences between any of the treatment groups at this early stage of the experiment.

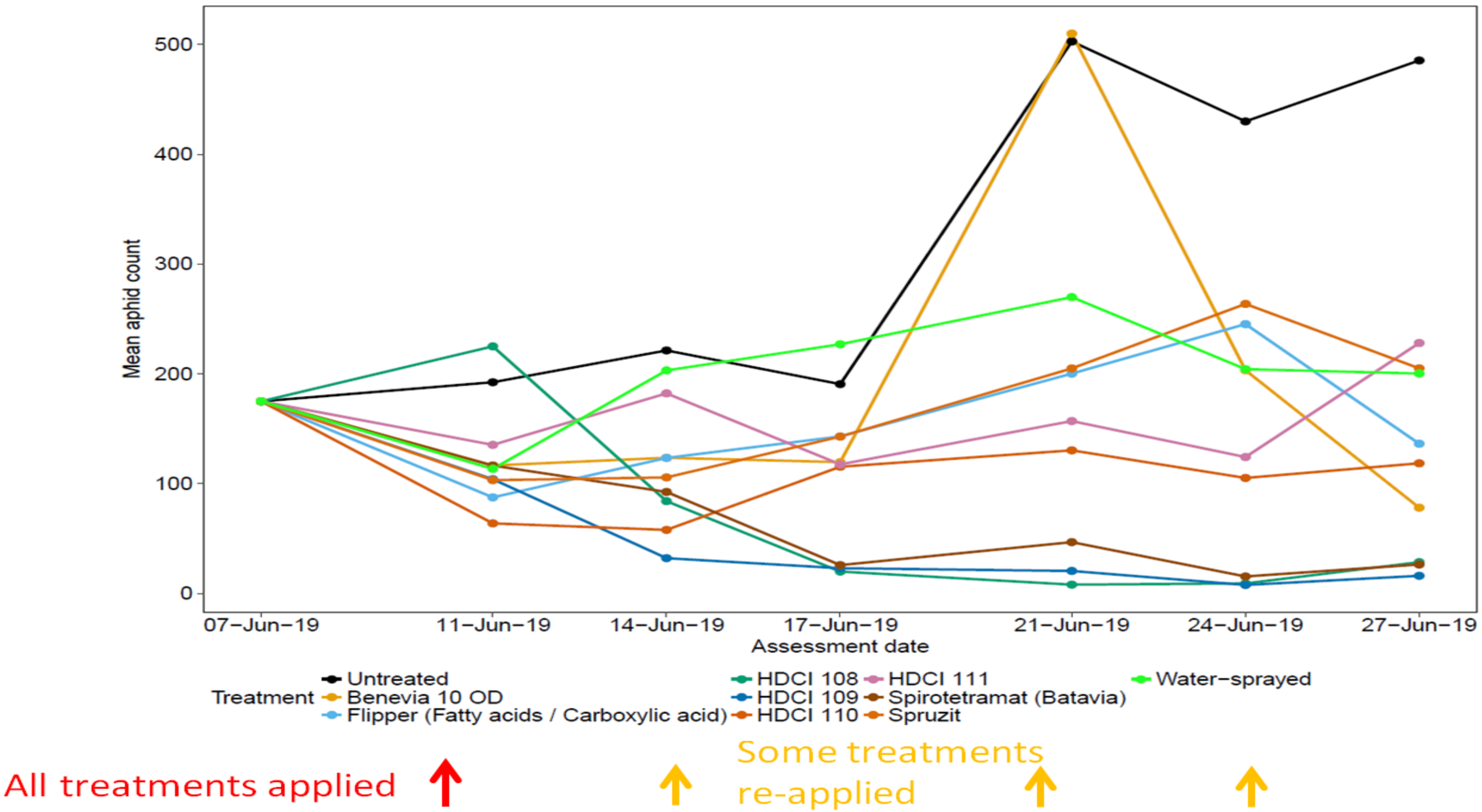


Figure 4.4. Mean total number of aphids per plant across all assessment dates, normalised to pre-assessment counts of 180 and analysed using GLMM. Treatments were all applied on 10 June and some were re-applied for a total of 2, 3 or 4 applications (see Tables 4.1 and 4.2 for details). <u>The current EAMU for FLiPPER (#3416, September 2019) specifies a maximum dose of 10 L/Ha for protected strawberry, so this rate is lower than that permitted for the crop.</u>

The total aphids per plant data presented above combines numbers from two leaves per plant: one unfolding and expanding (young) leaf, and a second larger, fully-expanded (mature) leaf. It was therefore possible to analyse aphid numbers separately, according to leaf age, and the mean aphid numbers on young leaves are presented below (Figure 4.5). When these data (normalised to starting mean counts of 25 aphids per leaf) were analysed statistically (again using GLMM with Poisson distribution and log link as above), significant ($P<0.05$) effects of treatment (χ^2 = 20.5; df = 9), assessment date (χ^2 = 12.5; df = 5) and treatment X date interaction (χ^2 = 75.9; df = 45) were highlighted by the model. However, only one of the treatments (HDCI 108) showed significant reductions in aphid numbers, compared with unsprayed or water-sprayed control plots (pair-wise comparisons with both control groups showed significant differences on 21st and 24th June, i.e. from 11 days after spraying). The graph of mean aphid numbers on young leaves (Figure 4.5) suggests a trend towards decreased numbers of aphids on HDCI 108-treated plants in an earlier phase of the experiment, very soon after spraying, but differences with other treatments were not significant at this stage.

The above approach was also repeated for the aphid numbers on the mature leaves only, to determine whether the trends in the data were affected by leaf age, in comparison with the aphid counts from young leaves. In this case, there were highly significant ($P<0.001$) effects of treatment (χ^2 = 43.0; df = 9), assessment date (χ^2 = 36.4; df = 5) and a treatment X date interaction (χ^2 = 389.3; df = 45). Pairwise comparisons of means revealed that, as for the total aphid data (numbers on young plus older leaves), the three treatments with significant reductions in aphid numbers, compared with untreated or water-sprayed controls, were HDCI 108, HDCI 109 and Batavia. However, in the separate analysis on mature leaves, HDCI 109 was associated with significantly fewer aphids from an earlier assessment date (14 June, just 4 days after spraying). Significant reductions in aphid numbers on plots treated with HDCI 108 and Batavia were seen from 17 June (Figure 4.6) and on all subsequent assessment dates.

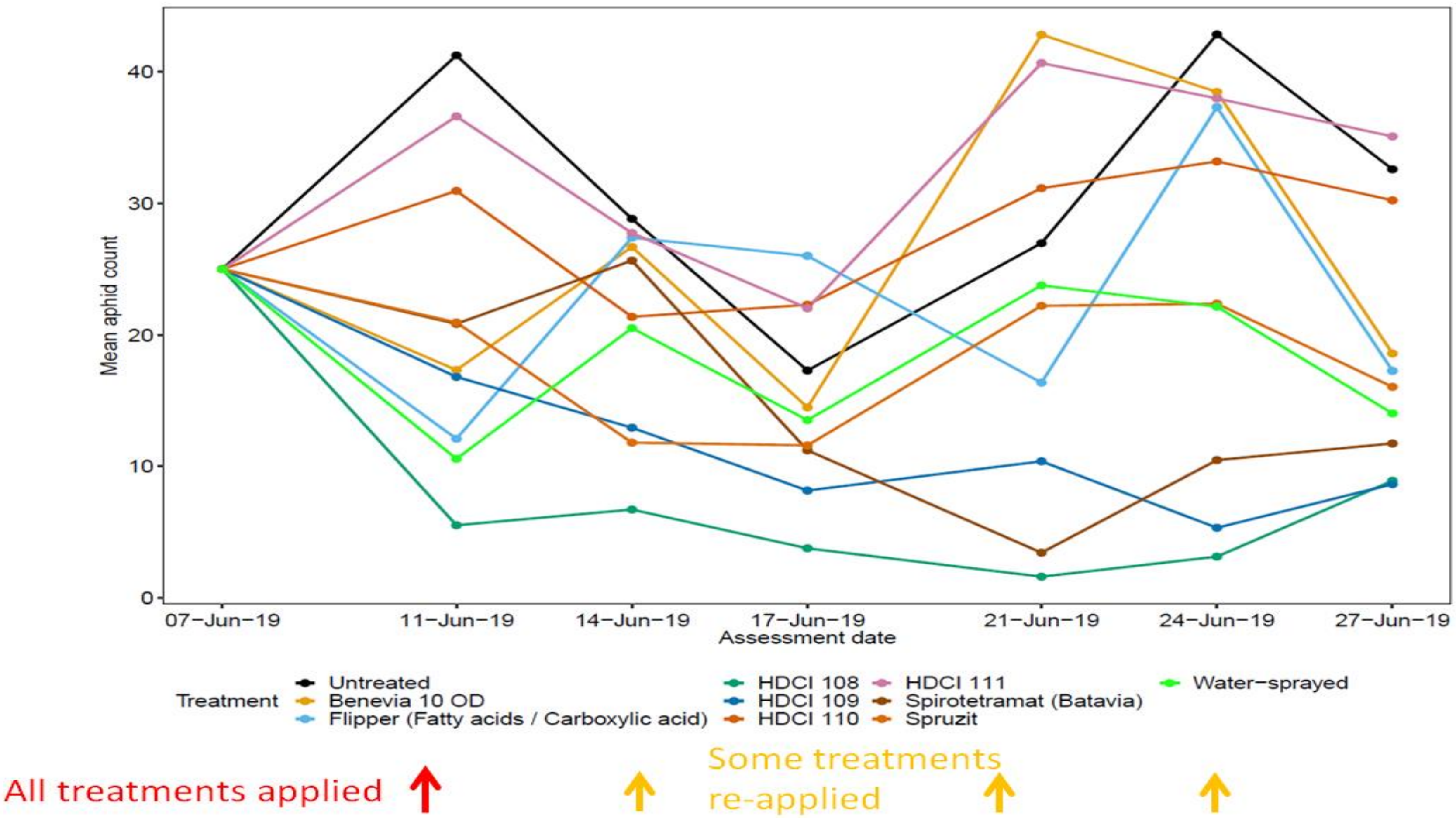


Figure 4.5. Mean number of aphids counted on young, expanding leaves across all assessment dates, normalised to pre-assessment counts of 25 and analysed using GLMM. Treatments were all applied on 10 June and some were re-applied for a total of 2, 3 or 4 applications (see Tables 4.1 and 4.2 for details). The current EAMU for FLiPPER (#3416, September 2019) specifies a maximum dose of 10 L/Ha for protected strawberry, so this rate is lower than that permitted for the crop.

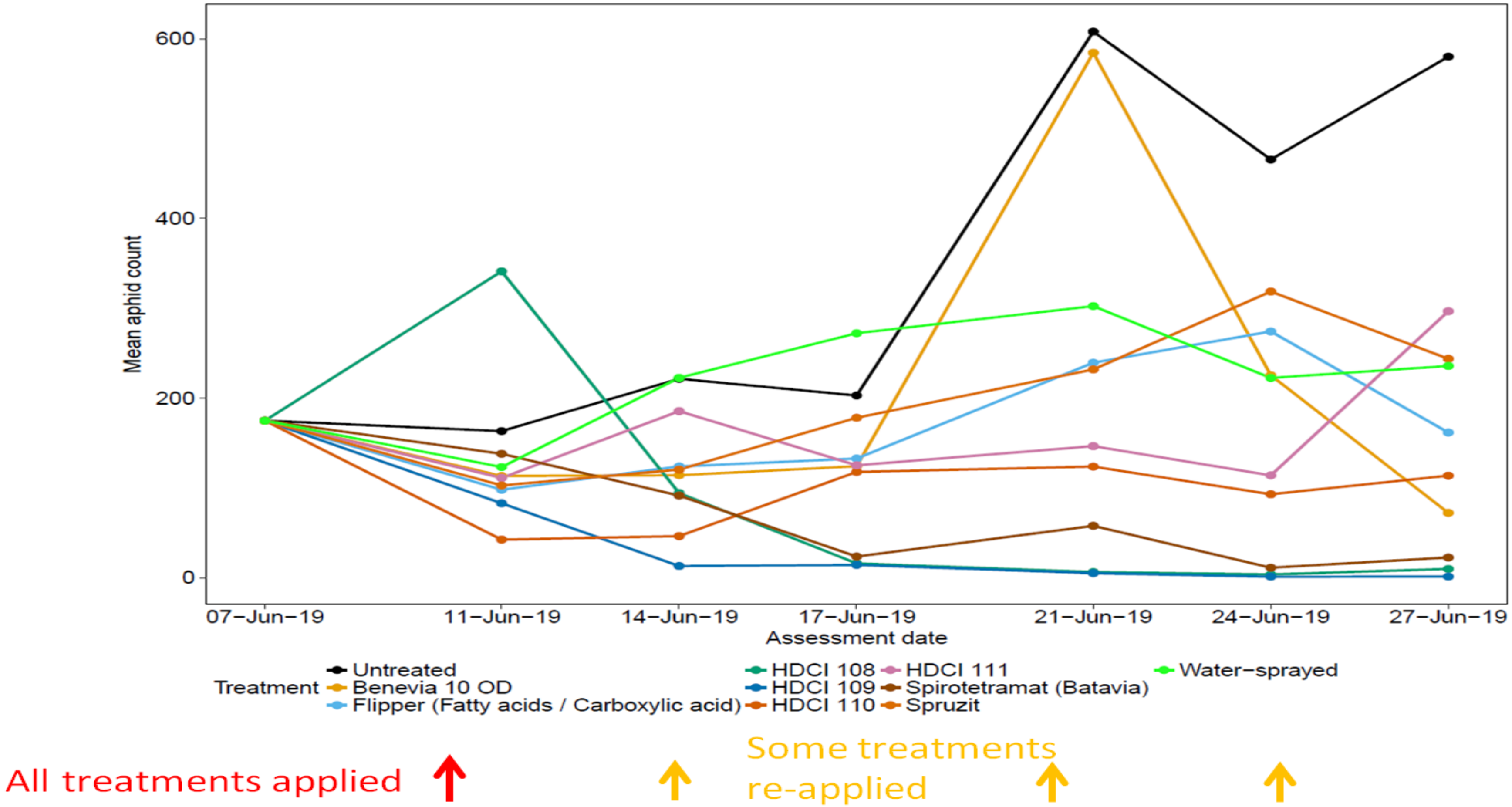


Figure 4.6. Mean number of aphids counted on mature, fully-expanded leaves across all assessment dates, normalised to pre-assessment counts of 175 and analysed using GLMM. Treatments were all applied on 10 June and some were re-applied for a total of 2, 3 or 4 applications (see Tables 4.1 and 4.2 for details). <u>The current EAMU for FLiPPER (#3416, September 2019) specifies a maximum dose of 10 L/Ha for protected strawberry, so this rate is lower than that permitted for the crop.</u>

Discussion

Of the eight products tested, three caused clear reductions in aphid numbers with protective effects persisting until the end of the trial: Batavia, HDCI 108 and HDCI 109. The two effective coded treatments were also tested in the 2018 SF 156 trial for efficacy against melon-cotton aphid, *A. gossypii* and were found to be very effective. These two treatments are both novel synthetic insecticides with potential for strawberry crop protection. The coded products that were tested in both trials (using different coding notation as required by AHDB but applied at the same rates in both years) are shown in Table 4.3 to allow direct comparison. Two of the coded treatments tested in 2019 (HDCI 108 and 109) were very effective aphicides against both target pest species on strawberry.

Table 4.3. Coded treatments that were tested in both 2018 (against *A. gossypii*) and 2019 (against *M. euphorbiae*).

Code in 2018 trial (*A. gossypii*)	Code in 2019 trial (*M. euphorbiae*)	Significant reductions in aphid numbers?
AHDB 9966	HDCI 108	Yes (both years)
AHDB 9951	HDCI 109	Yes (both years)
AHDB 9946	HDCI 110	No (neither year)
AHDB9964	HDCI 111	No (neither year)

The product coded HDCI 108 shows promising activity against *M. euphorbiae*, with treated plants supporting fewer live aphids from 1-week after application. Numbers of aphids on HDCI 108-treated plants remained low throughout the remaining trial period, despite the single application of this product. These effects are consistent with the manufacturer's information that is available for this active, which combines rapid knock-down action with longer-term systemic suppression of sap feeding pests. Results with this product are particularly encouraging when considered alongside the results from the 2018 SF 156 trial with *A. gossypii*, as the same treatment (coded AHDB 9966) was associated with a very rapid and sustained clean-up of aphids from plants. Comparisons between results on older and younger leaves in the present study suggest that this insecticide may be particularly effective at reducing aphid numbers on young, actively-growing and expanding leaves. This effect, and the systemic mode of action, would likely help control aphids in the crown of strawberry plants, where it is very difficult to achieve good spray coverage and kill aphids through direct contact with insecticides. Indeed, none of the other treatments tested in this trial achieved significant reductions in aphid numbers on the young, expanding leaves.

A second coded product (HDCI 109) also showed very good efficacy against *M. eurphorbiae* in the trial. This treatment appeared to be particularly effective at controlling the aphid on mature leaves, with significant reductions in pest numbers from just 4 days after application. Like HDCI 108, only one application was required for persistent plant protection: numbers of aphids on treated plants remained low for the rest of the trial period (final assessment took place 17 days after treatment). This product was previously shown to be very effective at protecting strawberry from another polyphagous aphid pest, *A. gossypii*, when tested (coded as AHDB 9951) during the 2018 trial.

The approved product Batavia induced a slow but steady decline in numbers of *M. euphorbiae* on the plants. This effect is consistent with Batavia's reported mode of action against target insects, with the active insecticide spirotetramat acting to block lipid synthesis and having a larger impact on growing aphid nymphs than on adults. This leads to age-specific effects and a slow but progressive decline of the whole aphid colony. Batavia also showed very good efficacy against *A. gossypii* in the 2018 trial, although it is important to note that its application to strawberry crops (both protected and unprotected) is restricted to the pre-flowering period. In commercial production, applications can only be made until plants start to show elongation of inflorescences. Two applications of the product are allowed each year, but it cannot be applied after 14 days before flowering, or during the flowering / cropping period. Despite these restrictions, the results of both recent trials suggest that Batavia offers long-lasting protection against aphids, with populations of *A. gossypii* and *M. euphorbiae* remaining low on treated plants for at least 17 days after a single application of the product. This is consistent with the systemic mobility of the active compound (spirotetramat) within the plant's xylem and phloem systems, allowing it to be translocated to growing plant parts (Nauen et al. 2008), ensuring that even newly-emerging leaves and buds remain protected from aphids.

The highly effective protection observed with Batavia, HDCI 108 and HDCI 109 occurred despite pressure of re-infestation from surrounding plants within the trial tunnels. The randomised block design means that control plots with plants harbouring large colonies of aphids at high density were in close proximity to plots treated with effective insecticides. By the end of the trial, winged forms of aphids had started to appear in the more crowded colonies in control plots and in plots treated with the less effective treatments, and non-winged aphids were seen wandering over and away from such infested plants. Despite these sources of potential re-infestation in close proximity, plants treated just once with Batavia, HDCI 108 or HDCI 109 remained relatively free of aphids until the end of the trial (over a 17-day period). Residue levels of these three effective products were not measured on/in the crop plants during this trial.

The three products that were effective in this investigation are all synthetic insecticides. Three other insecticide treatments were included in the experiment (Benevia 10 OD, Spruzit and HDCI 110) but had no significant impact on aphid numbers. Other products tested in the trial included "softer" bioprotectant products, particularly FLiPPER and HDCI 111. Neither of these biopesticides were associated with significant reductions in the numbers of aphids. Future trials should include FLiPPER applied at higher rates than were tested here, since the current EAMU allows a maximum dose that is more than double (10 L/Ha) that used in the present experiment (4.8 L/Ha). A previous report (Convertini et al. 2018) indicated that applications of FLiPPER diluted to just 1% gave effective field control of the aphid pests *Myzus persicae* and *A. gossypii*, but it is not possible to calculate the volume applied per hectare from the information given in this publication.

The study was designed to incorporate different numbers of applications for the various treatments, so that the synthetic insecticides were applied once or twice, but the biopesticides could be re-applied up to a total of four times, at spray intervals that would reflect those used by growers when applying these products in commercial strawberry production. However, despite re-application, these treatments were not associated with reduced numbers of aphids at any stage of the trial.

Conclusions and future work

- Single applications of the coded products HDCI 108 and HDCI 109 and the approved insecticide product Batavia gave effective control of potato aphid on strawberries, all reducing numbers of live aphids on mature leaves and therefore the total aphids per plant.
- Product HDCI 108 was additionally effective at reducing numbers of live aphids infesting the young, expanding leaves in the crowns of plants.
- The other products tested included bioprotectant products such as FLiPPER and HDCI 111. These treatments were applied at the short spray intervals that are typically used by growers when applying such "softer" treatments. However, these products still gave no effective control of the pest. Future studies could incorporate applications

of such products as part of a spray rotation programme, to investigate whether they are able to contribute to effective aphid control on strawberries when multiple biopesticides are applied to the crop and the use of these products at the full field rate.

- Potato aphid (*Macrosiphum euphorbiae*) and melon-cotton aphid (*A. gossypii*) remain of primary interest as targets for aphicide sprays on strawberries. Although the two recent trials have highlighted two new products with potential to control both aphid species, an analysis of their impact on beneficial insects has not been possible. Numbers of natural enemies on plants were very low in the 2018 and 2019 trials, and it was not possible to include an assessment of impact on beneficial insects in the experiments. Future studies could include combining insecticide treatments with released biocontrols, to assess to what extent the most effective aphicides (HDCI 108, HDCI 109 and Batavia) are compatible with aphidophagous natural enemies.

Objective 6. Fill key gaps in knowledge on *Thrips fuscipennis* biology in strawberry crops so that IPM strategies can be developed

Introduction

For many years, the western flower thrips (WFT, *Frankliniella occidentalis*) has been a serious pest of strawberry, feeding on flowers and developing fruits leading to damaged bronzed fruits which are unmarketable. Similar damage to that caused by WFT has occasionally also been caused by onion thrips, *Thrips tabaci* but ADAS has recently identified the presence of rose thrips (*Thrips fuscipennis*) in strawberry flowers where fruit bronzing is occurring (Brown & Bennison 2018).

Rose thrips adult females are darker than those of WFT but microscopic examination is needed for species confirmation. At a few sites where fruit bronzing has occurred prior to this project, rose thrips has been the only thrips species present in the flowers but usually it has been present in species mixes with other thrips species such as the rubus thrips (*Thrips major*). However, where fruit damage has occurred and thrips species mixes have been present prior to work in this project, numbers of rose thrips have been much higher than those of other species suggesting that rose thrips have been mainly responsible for the damage (Brown & Bennison 2018).

At sites where fruit damage attributed to rose thrips has occurred, some growers have been using Integrated Pest Management (IPM) programmes based on the predatory mite *Neoseiulus cucumeris* and good control of WFT has been achieved. However, at the same sites, rose thrips have not been controlled and growers have needed to apply plant protection products to prevent further fruit damage. Growers have often used spinosad (Tracer) for control of rose thrips which is currently effective. However, there is concern that, like WFT, rose thrips could develop resistance to Tracer and other insecticide products. In addition, the number of Tracer applications permitted on each crop is limited and growers may prefer to reserve these for control of spotted wing drosophila (SWD).

So why do rose thrips and possibly other species not seem to be controlled on crops where *N. cucumeris* is providing good control of WFT? Fruit damage often seems to occur soon after 'dark' thrips adults are noticed in the flowers, so it is possible that adults are migrating into the crop and damaging the fruit before they start reproducing and thus they are not controlled by *N. cucumeris* which only feeds on first instar WFT larvae. It is unknown whether *N. cucumeris* can successfully predate *T. fuscipennis* larvae. ADAS work in AHDB Project

CP 89 indicated that the predatory bug *Orius laevigatus* provided similar reduction in numbers of rose thrips to Tracer on an outdoor commercial strawberry crop in 2014 (Bennison & Hough 2015). This predator was observed feeding on adult rose thrips in the field. However, *O. laevigatus* needs high temperatures to breed and not all years are warm enough for good establishment. In addition, fruit damage can occur before the predator establishes in sufficient numbers to provide control.

During 2018, adults of five species of thrips known or considered to damage strawberry fruit were recorded on four commercial everbearer strawberry crops. These were rose thrips (*T. fuscipennis*), rubus thrips (*T. major*), onion thrips (*T. tabaci*), flower thrips (*Frankliniella intonsa*) and WFT (*F. occidentalis*). The activity periods and times of peak numbers were identified. At sites where species other than WFT were predominant, few larvae were found compared with the site where WFT was the main species. Larvae from all four sites are currently being identified to species. Numbers of adult thrips at three of the sites were low during 2018 and fruit damage was only slight. This is likely to have been due to a combination of released (including *Orius*) and naturally-occurring predators (including the banded wing predatory thrips, *Aeolothrips intermedius*) and to plant protection products applied for SWD control. At the fourth site where numbers of thrips adults were higher and where a mix of species occurred but WFT was predominant, more severe fruit damage occurred.

The work in this Objective aimed to fill key gaps in knowledge on *T. fuscipennis* biology in strawberry crops so that IPM strategies can be developed:

1. Determine when adult activity starts and identify peaks in numbers between April and August inclusive.
2. Determine which larvae develop in strawberry flowers.
3. Record fruit damage associated with rose thrips (*Thrips fuscipennis*) and other thrips species in flowers.
4. Determine colour attraction (using coloured water traps) of thrips species for potential development of a mass monitoring system.

Materials and methods

During 2019, four sites were selected for monitoring where *Thrips fuscipennis* was confirmed as either the only or predominant thrips species in 2017 and confirmed during monitoring during 2018. Two of these sites were monitored and the thrips identified by ADAS (Site 1 and Site 2 which were the same as Sites 1 and 2 in 2018) and two sites were monitored and identified by NIAB EMR (Site 3 and Site 5, Site 4 being a different site monitored by NIAB EMR in 2018).

Locations

Site 1 (Essex) – unprotected outdoor 'pick your own' strawberry crops (Fig 6.1), Variety 1 Sonata (June bearer), Variety 2 Murano (new planting, everbearer). At this site releases of *Neoseiulus cucumeris* and applications of spinosad (Tracer) were used for thrips control within an IPM programme.

Site 2 (Bucks) – 'pick your own' strawberry crops (Fig 6.2), Variety 1 (Vibrant, tunnelled June bearer, new planting), Variety 2 (Finesse, unprotected outdoor everbearer new planting). At this site releases of both *Neoseiulus cucumeris* and *Orius laevigatus* and applications of Tracer were used for thrips control.

	
Figure 6.1: Site 1, unprotected everbearer crop	**Figure 6.2**: Site 2, unprotected everbearer strawberry crop

Site 3 (Kent) – protected (Fig. 6.3), first planting of cv. Katrina (everbearer, new planting). At this site releases of *Neoseiulus cucumeris* were made for thrips control within an IPM programme. Applications of spinosad (Tracer), thiacloprid (Calypso) and cyantraniliprole (Benevia 10OD) were made, probably for capsid and SWD control.

Site 4 (Kent) – This site was not continued from 2018 and was replaced by monitoring at site 5.

Site 5 (Kent) – protected (Fig 6.4), first planting of cv. Favori (everbearer, new planting). At this site no applications of Tracer or bioprotectants were made during the trial period.

	
Figure 6.3: Site 3, protected everbearer crop	**Figure 6.4**: Site 5, protected everbearer crop

<u>Assessments</u>

As in 2018 a total of 80 flower samples were collected from each site on each assessment date, once every two weeks from 8 May to 22 August 2018 (Site 1), 24 April to 22 August (Site 2) and 29 April to 20 August (Sites 3 and 5). Four rows (or replicate blocks) of strawberry plants were used for sampling, with each of these blocks containing four equally spaced monitoring plots two metres in length. Five flowers were sampled from each monitoring plot. Only upward facing mid-aged flowers (all petals present, anthers brown rather than yellow) at the top of each plant were sampled. All thrips were collected into lidded specimen tubes (one tube per plot) and returned to the laboratory for thrips extraction and identification using the procedures detailed below (Extraction and Identification).

In one monitoring plot in each block, five plants were sampled in the field and numbers of flowers, green fruit, white fruit and ripe fruit on each plant recorded. This was carried out as often thrips damage to fruit is more severe when there are few flowers available as thrips adults congregate in the few available flowers, leading to more intensive feeding on the young developing fruit. When ripe fruit were available percentage fruit area with thrips bronzing damage was assessed on 80 fruit per site on each sampling date.

<u>Coloured water traps</u>

In order to identify thrips spp. attraction to colour, lidded plastic bowls (plasticboxshop.co.uk) were selected by dimension and lip size (15 cm x 5 cm, 5 mm lip) and were painted one of three colours; green (control), blue and yellow. The blue and yellow were colour-matched by spectral analysis to commercially available sticky traps and the green was matched by eye to mimic a strawberry leaf. Three coats of coloured paint plus a gloss varnish were applied using brushes over a black sprayed undercoat.

The traps were used twice during the estimated peak of rose thrips abundance during the season at both sites, each trap was anchored with a ground cover fixing peg in a space on the table top with little crop coverage (Figure 6.5). The traps were set out in a randomised block design and equally spaced down a single row close to the field boundary. The traps were filled with water and a few drops of washing up liquid, left for 72 hours, then lidded, collected and sieved in the laboratory. The thrips in each trap were then removed and identified (see below). An extra trap of each colour was sent to Keel University, where absolute irradiance spectra from 300-700 nm were measured. This was with a FLAME-S-UV-VIS spectrometer calibrated for absolute irradiance (Ocean Optics, Duiven, the Netherlands), with sunlight from an overcast sky and the sensor positioned perpendicular to the horizontal trap surface at a distance of 50 mm.

Figure 6.5. Blue water trap attached by pins to the grow bags

Extraction

In the laboratory, thrips, any *Orius* sp. (natural or released) and any other thrips predators (except for *N. cucumeris*) were extracted from the water traps and flowers from each of the 16 plots using the following procedure:

1) A square piece of thrips proof mesh (120 microns) was secured onto the top of a beaker using an elastic band. A depression was made in the mesh to prevent spillage of alcohol and thrips.
2) The contents of the water traps, or flowers and alcohol were gently agitated in the sampling tube.

3) The contents of the water traps, or alcohol and flowers were emptied from the tube into the beaker through the thrips-proof mesh using a sieve (mesh of suitable size to retain the flowers) held over the mesh-covered beaker.
4) The flowers were removed from the sieve using forceps and placed back in the tube and alcohol added to the tube.
5) Steps 2-5 were repeated twice more (a total of three flower rinses)
6) The flowers were discarded. The alcohol in the beaker was kept for washing further flower samples.
7) The mesh was removed and placed on top of a laminated sheet of white paper and examined under a dissecting microscope.

Identification

A minimum of one thrips adult and one thrips larva (if present) per monitoring plot was identified, i.e. a minimum total of 16 thrips adults and 16 larvae (if present) per site per sampling date. Identification was done after mounting adult thrips females or larvae in a clearing medium on glass slides, viewing them under a high power microscope once the specimens had cleared sufficiently to see the diagnostic features and using morphological keys (Mound et al. 1976 for adults; Vierbergen *et al*. 2010 for larvae). The following procedure was used:

a) Numbers of thrips adults were recorded (males and females recorded separately) and numbers of larvae.
b) Numbers of *Orius* sp. adults and nymphs were recorded.
c) Numbers of *Aeolothrips* adults were recorded.
d) A minimum of one adult female per plot was identified (minimum of 16 per site per assessment date if available). Additional thrips adults were mounted on slides to ensure enough females could be identified (only females should be used when keying out the species) as some may lie in an awkward angle on the slide to enable species confirmation. Numbers of each species were recorded.
e) Total numbers and proportion of each species was estimated e.g. if a total of 100 thrips adults were found and 16 are identified and if eight of these were *T. tabaci* and eight were WFT it was assumed that 50 of the total were *T. tabaci* and the remaining 50 were WFT.
f) Where found a minimum of one larvae per plot was identified, if low numbers of larvae were found then all were identified if in a suitable condition.

g) All remaining thrips adults and larvae on the mesh were kept by picking them off into a tube of 70% alcohol under a dissecting microscope using a fine paintbrush. These thrips were kept in the laboratory to be used for further identifications if needed. All tubes were labelled with the date, site, tunnel or row and plot number.

Statistics

Water trap data from two sampling dates at Sites 1 and 2 and one sampling date at Sites 3 and 5 were tested using Analysis of Variance in GenStat 16. Sites were examined separately in order to look at trends of the species at each location. The water in some of the traps dried out due to high temperatures, these were noted and excluded from the analyses.

Results

June-bearer crops

Site 1 - June bearer cv. Sonata

Monitoring began on 8 May and continued until 4 June. No adults were seen until 22 May and were in low numbers both on this date and on 4 June (Table 6.1). After 4 June either very few or no flowers were present but fruit damage assessments continued (Tables 6.2). Only *Thrips tabaci* was present on 22 of May. Two species were present on 4 June, *Thrips fuscipennis* and *Thrips major,* reaching a maximum of 0.06 *T. major* per flower on 4 June. No thrips larvae and no thrips predators were recorded on any date. Only slight fruit damage was recorded, reaching a maximum of 0.05% fruit area bronzed on 4 June (Table 6.2).

Table 6.1. Site 1 June-bearer crop cv. Sonata: Mean numbers of adult thrips species and mean numbers of larvae per flower.

Date	Mean *T. fuscipennis* adults/flower	Mean *T. major* adults/flower	Mean *T. tabaci* /flower	Mean thrips larvae/flower
08.5.2019	0	0	0	0
22.5.2019	0	0	0.01	0
04./6.2019	0.01	0.06	0	0

Table 6.2. Site 1 June-bearer crop cv. Sonata: Mean fruit area bronzed (%) and mean number of flowers, green, white and ripe fruit per plant

Date	Area bronzed (%)	No. Flowers per plant	No. green fruit per plant	No. white fruit per plant	No. ripe fruit per plant
8.5.2019	0*	2.05	0	0	0
22.5.2019	0*	5.4	0	0	0
4.6.2019	0.05*	1.95	3.2	14.5	0
26.6.2019	0	0	12.75	17.95	8.65
11.07.2019	0	0	1.88	5.63	15.13

*Bronzing assessed on white fruit as no ripe fruit available

Site 2 - June bearer cv. Vibrant.

Monitoring began on 24 April and continued until 4 June. Thrips adults were recorded on all sampling occasions including 4 June, after this date there were no or few flowers present (Tables 6.3 and 6.4). Five species of thrips adults were seen in the sampling period, *T. fuscipennis* was the most abundant species found, recorded from 8 May, peaking at a mean of 1.19 per flower on 4 June (Table 6.3). Both *T. fuscipennis* and *T. major* were present on all three dates from 8 May to 4 June. Presence of *T. tabaci, F. intonsa and T. minutissimus* was more variable, being recorded on only one or two sampling dates. No thrips larvae and no thrips predators were recorded on any date. Only slight fruit damage was recorded, reaching a maximum of 0.6% fruit area bronzed on 22 May (Table 6.4).

Table 6.3. Site 2 June-bearer crop cv. Vibrant: Mean numbers of adult thrips species and mean numbers of larvae per flower.

Date	Mean per flower					
	T. fuscipennis	***T. major***	***T. tabaci***	***F. intonsa***	***T. minutissiumus***	**Mean thrips larvae/flower**
24.4.2019	0	0	0.03	0	0.0375	0
8.5.2019	0.08	0.01	0	0	0	0
22.5.2019	0.10	0.01	0.06	0	0	0
4.6.2019	1.19	0.05	0	0.025	0	0

Table 6.4. Site 2 June-bearer crop cv. Vibrant: Meanfruit area bronzed (%) and mean numbers of flowers, green, white and ripe fruit per plant.

Date	Area bronzed (%)	Mean no. flowers per plant	Mean no. green fruit	Mean no. white fruit	Mean no. ripe fruit
24.4.2019	0.00*	4.15	0.00	0.00	0.00
8.5.2019	0.00*	3.75	6.47	1.55	0.00
22.5.2019	0.6	2.00	6.10	6.95	4.00
4.6.2019	0.1055	0.05	0.90	2.50	1.25

*Bronzing assessed on white fruit as no ripe fruit available

Everbearer crops

Mean thrips adults and larvae per flower (all species combined)

At Site 1, thrips adults were recorded on all dates and mean numbers peaked at 2.1 per flower on 26 June (Figure 6.6). Thrips larvae were mainly recorded on 11 and 25 July and were fewer in number than the thrips adults, peaking at a mean of 0.4 per flower on 11 July. Mean numbers of flowers per plant peaked on 8 August at 8.4 per plant.

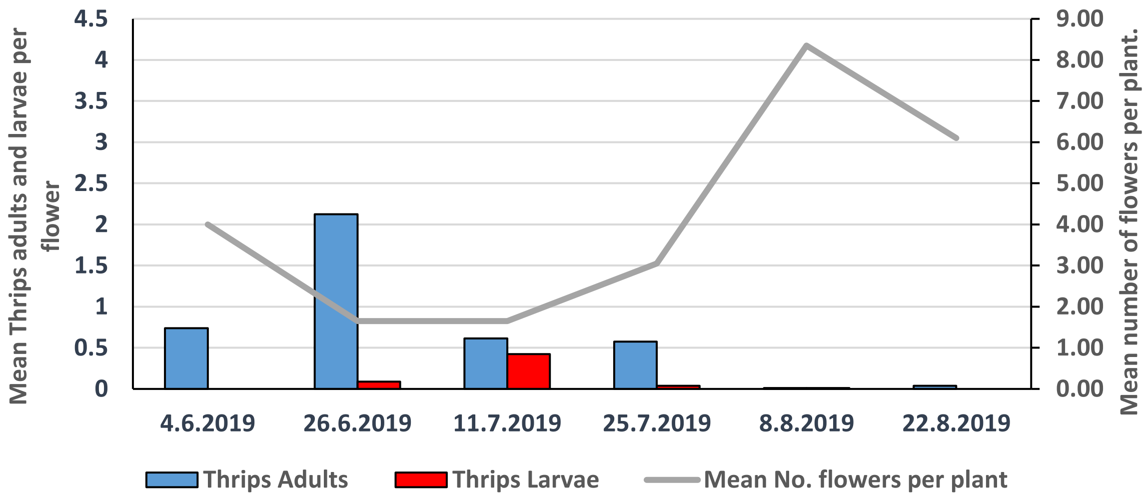


Figure 6.6. Site 1 everbearer cv. Murano: Mean numbers of thrips adults and larvae per flower (all species) and mean numbers of flowers per plant

At Site 2, thrips adults were recorded on all dates and mean numbers peaked on the same date as Site 1 at 3.6 per flower on 26 June (Figure 6.7). Thrips larvae were mainly recorded on 11 and 25 July and were fewer in number than the thrips adults, peaking at a mean of 0.7 per flower on 11 July. Mean numbers of flowers per plant peaked between 8 and 22 August at 8.4 and 8.5 per plant respectively.

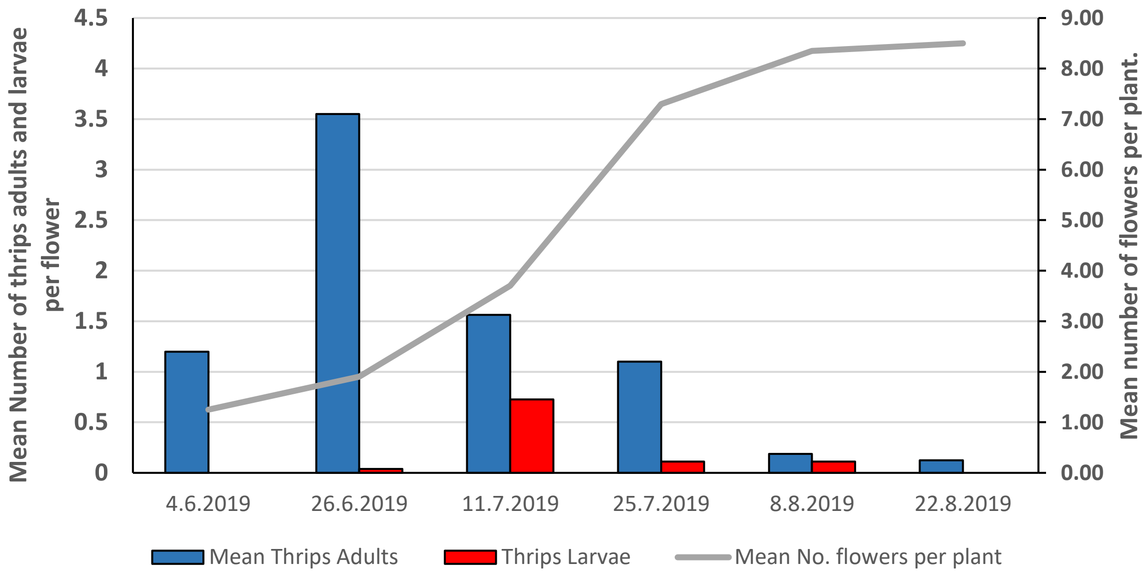


Figure 6.7. Site 2 everbearer cv. Finesse: Mean numbers of thrips adults and larvae per flower (all species) and mean numbers of flowers per plant.

At Site 3, thrips adults were recorded on all dates, peaking at a mean of 3.9 per flower on 11 June (Figure 6.8). Thrips larvae were also found on all dates except for 29 April and 13 May and there were higher numbers of adults than larvae on most dates except for 20 August when mean numbers of larvae peaked at 3.3 per flower.

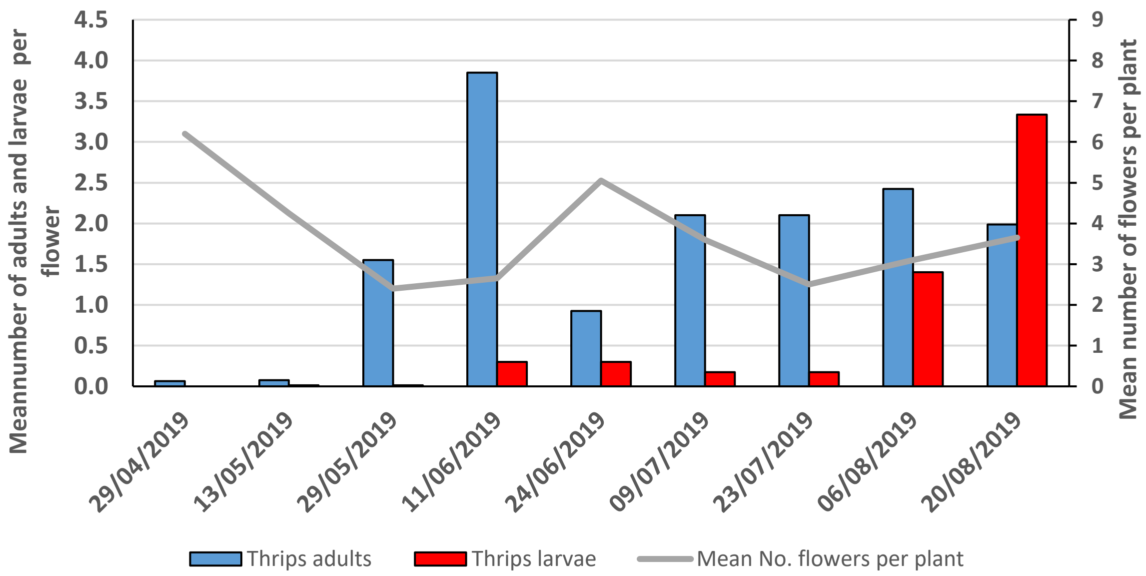


Figure 6.8. Site 3 everbearer cv. Katrina: Mean numbers of thrips adults and larvae per flower (all species) and mean numbers of flowers per plant.

At Site 5, thrips adults were recorded on all dates, peaking on 3 August at a mean of 2.3 per flower (Figure 6.9). Thrips larvae were also recorded on all dates and exceeded adult abundance on three sampling dates, peaking at a mean of 2.0 per flower on 23 July. Mean numbers of flowers per plant was high initially (mean 5.8), then dropped to 2.2 and 2.0 per plant on 29 May and 11 June respectively, then rose again on 23 July and 6 August to 4.7 and 4.5 per plant respectively.

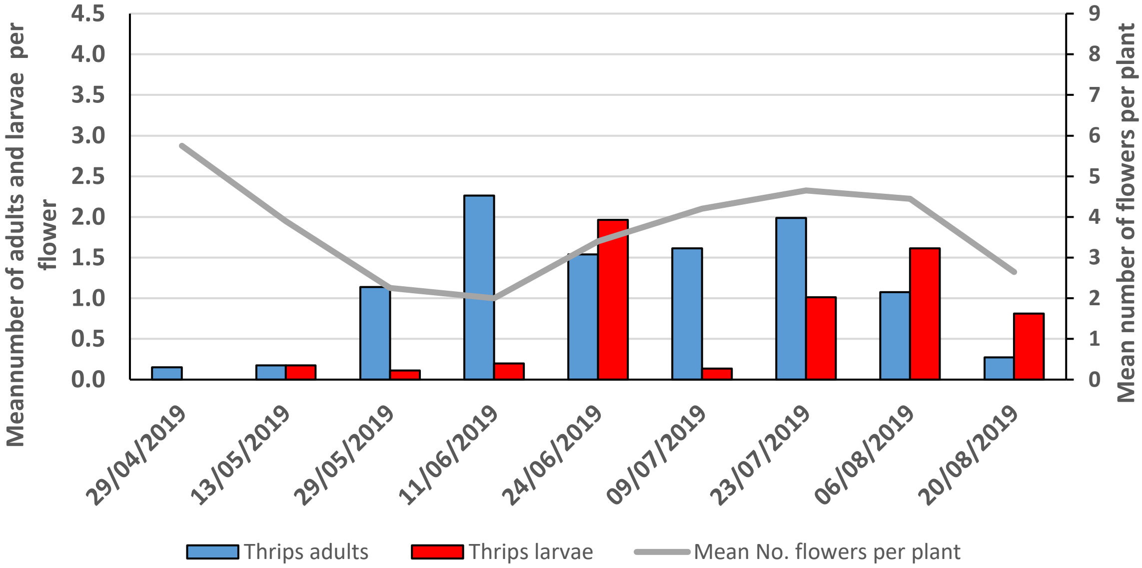


Figure 6.9. Site 5 everbearer cv. Favori: Mean numbers of thrips adults and larvae per flower (all species) and mean numbers of flowers per plant

Mean numbers of thrips species per flower

At Site 1, *T. fuscipennis* was the main species occurring in the whole sampling period (Figure 6.10). *Thrips fuscipennis* was recorded on both dates in June and July, peaking at a mean of 1.79 adults per flower on 26 June. Other species recorded in small numbers were *Thrips major*, *Thrips tabaci*, *Thrips vulgatissiumus, Thrips pillichi and Limothrips cerealium.*

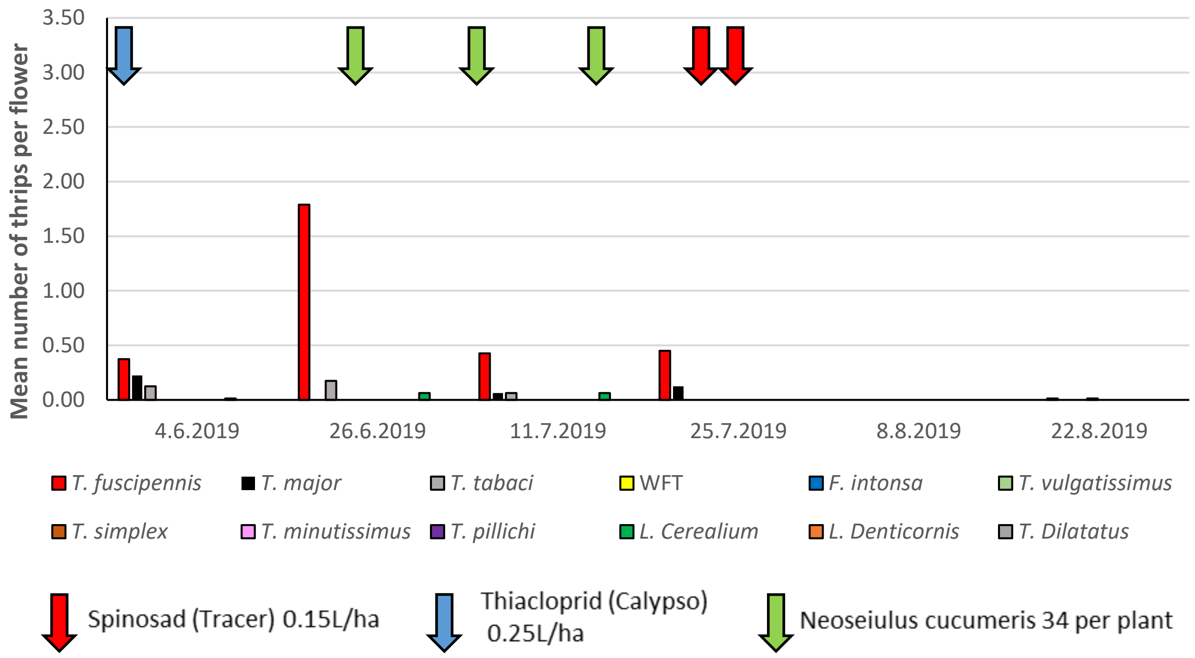


Figure 6.10. Site 1 everbearer cv. Murano: Estimated mean numbers of adult thrips species per flower

As at Site 1, *T. fuscipennis* was the main species occurring at Site 2 (Figure 6.11). *Thrips fuscipennis* was recorded in June, July and August, peaking at a mean of 3.2 adults per flower on 26 June. *Thrips major* was recorded on all sampling dates but in lower numbers, peaking at a mean of 0.2 adults per flower on 25 July. *Thrips tabaci* was recorded on all dates except for 25 July, peaking at a mean of 0.2 adults per flower on 4 June. Other species occurring in much smaller numbers were *Frankliniella intonsa, Limothrips cerealium and Thrips dilatatus*.

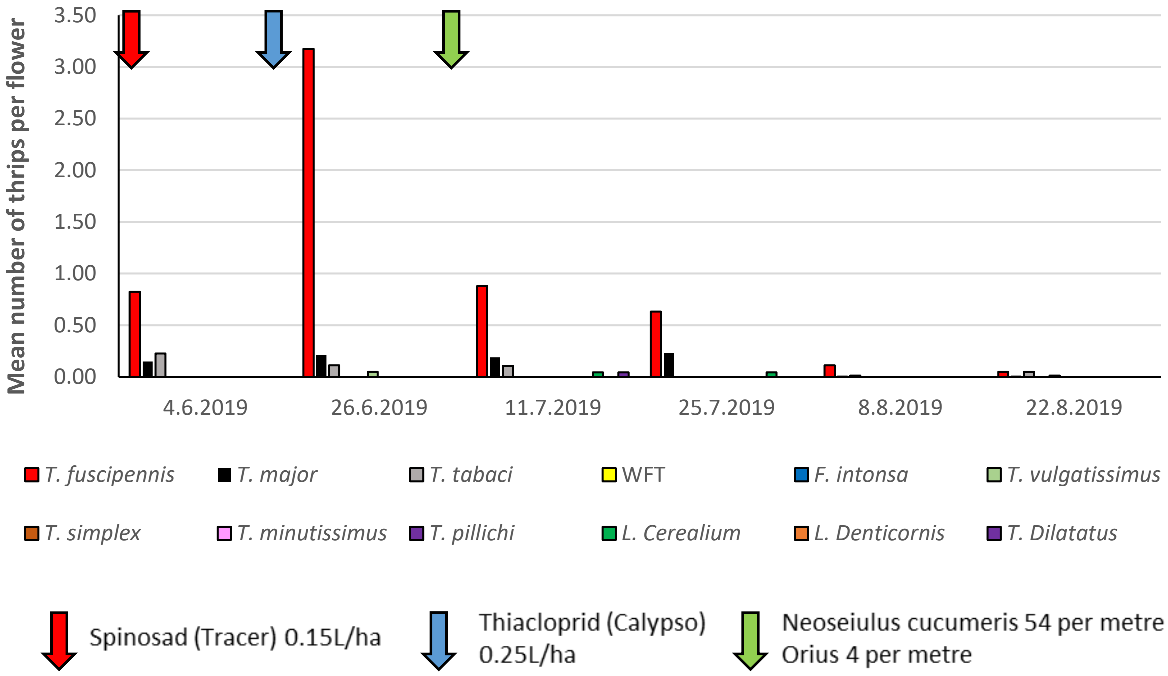


Figure 6.11. Site 2 everbearer cv. Finesse: Estimated mean numbers of adult thrips species per flower

At Site 3, the species were more mixed than at the other sites. During April, May and June the predominant thrips species was *T. fuscipennis* which was recorded on all dates, peaking at a mean of 2.1 adults per flower on 11 June (Figure 6.12). *Thrips major* was recorded on all dates apart from 29 April, peaking at a mean of 0.96 adults per flower on 11 June. *Thrips tabaci* was recorded on all dates apart from 6 August, peaking at a mean of 0.1 adults per flower on 11 June. Abundance of WFT increased as the season progressed, it was present on all sampling dates apart from 13 May and mean numbers peaked on 20 August at 1.8 per flower. Other species found in very low numbers were *Frankliniella intonsa* and *Thrips vulgatissimus.*

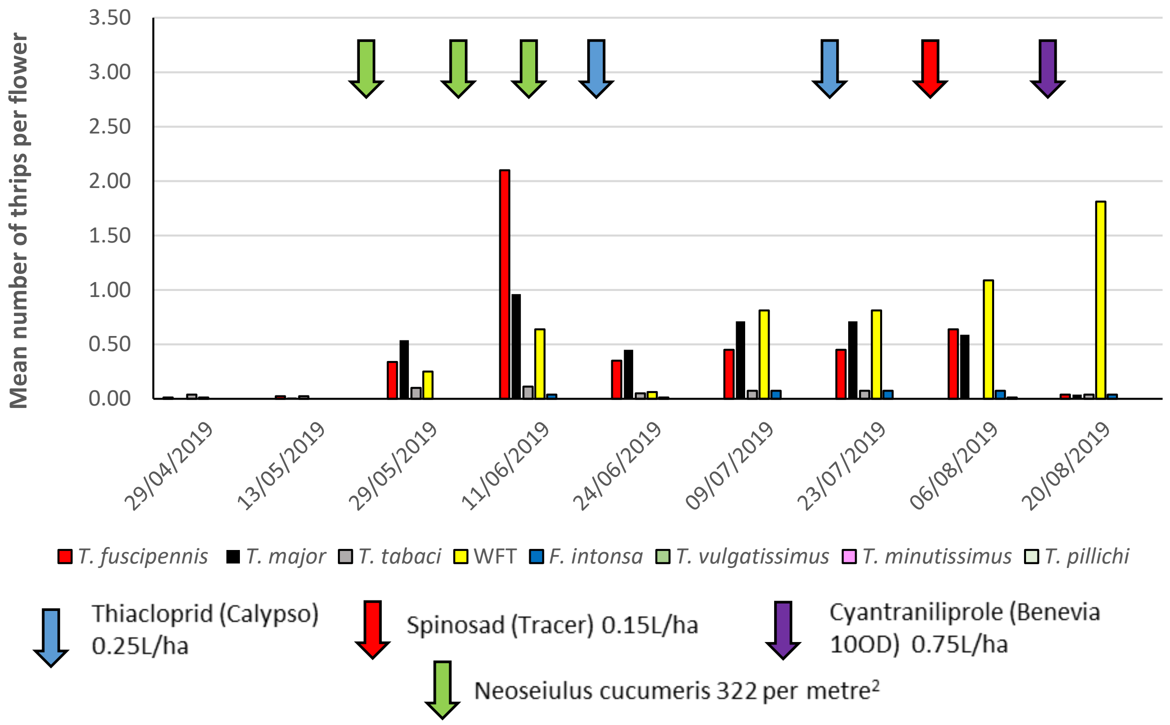


Figure 6.12. Site 3 everbearer cv. Katrina: Estimated mean numbers of adult thrips species per flower

At Site 5, the predominant species was WFT, which was recorded on all dates, peaking at a mean of 2.2 adults per flower on 11 June (Figure 6.13). Low numbers of *Thrips fuscipennis* were recorded on four sampling dates between 29 May and 23 July, peaking at a mean of 0.1 adults per flower on 11 June. *Frankliniella intonsa* was recorded on all dates from 29 May, peaking at a mean of 0.1 adults per flower on 23 July. Other species recorded in small numbers were *Thrips major* and *Thrips minutissimus.*

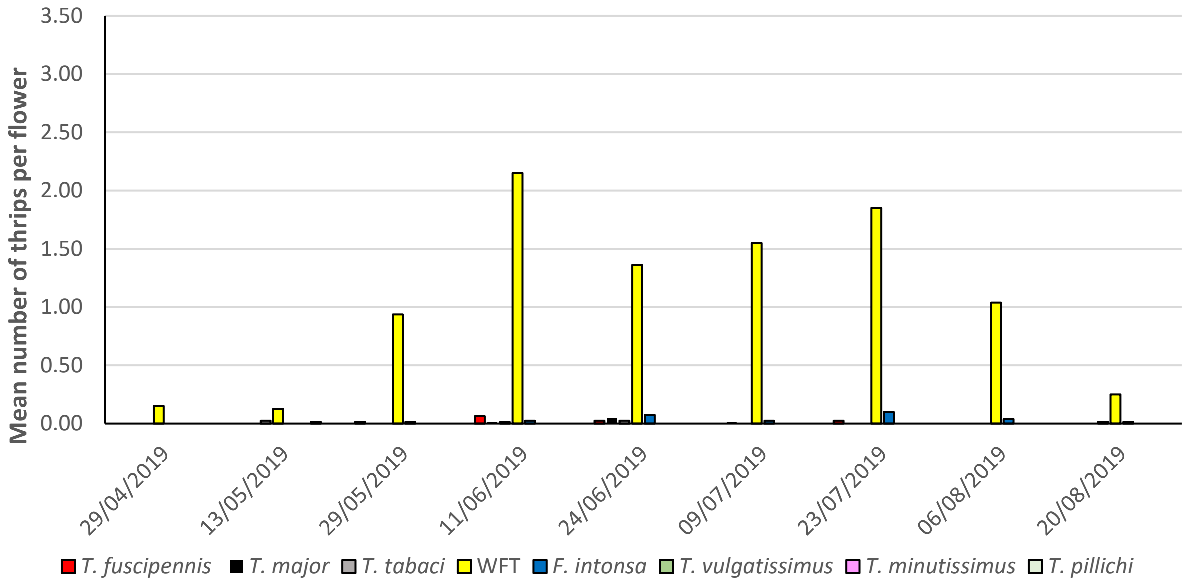


Figure 6.13. Site 5 everbearer cv. Favori: Estimated mean numbers of adult thrips species per flower. No plant protection products were applied during the trial duration.

Spectra analysis

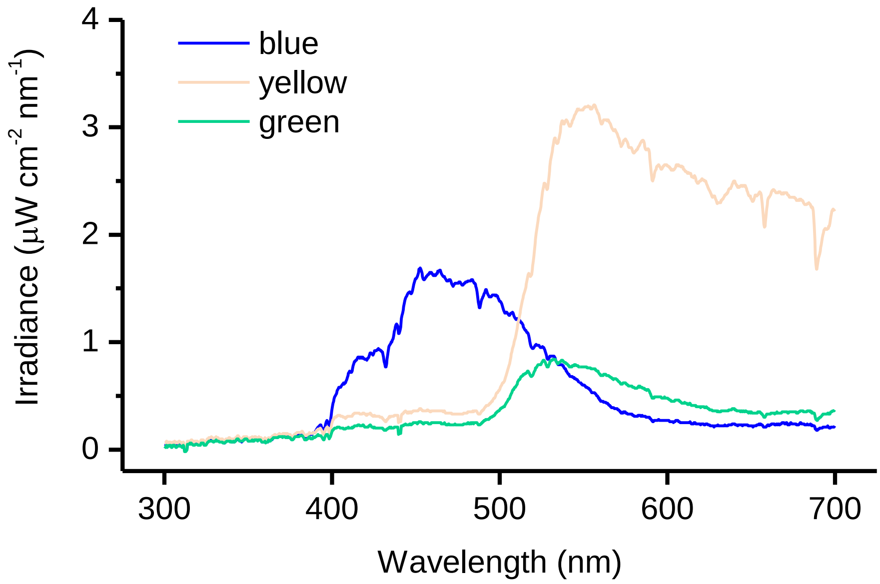


Figure 6.14: Spectral analysis of one of each colour water trap.

The analysis of the traps was as expected with wavelength of each colour being similar to those in Kirk (1984); all the traps had low UV and were predominately in the 300-700 nm range (Fig. 6.14) which is the range that thrips can see. The spectral analysis recorded the actual amounts of radiation coming off the trap (absolute irradiance spectra) rather than the diffuse reflectance spectra which is the irradiance as a percentage of the incoming radiation at each wavelength.

Mean numbers of thrips larvae per flower (Sites 1& 2, 2019 season)

At Site 1, thrips larvae were not recorded on all dates, the predominant species was the predatory banded wing thrips, *Aeolothrips* spp. peaking at a mean of 0.3 on 11 July (Fig. 6.15. Low numbers of *T. tabaci* were confirmed on 26 June and *T. major* and *F. intonsa* were confirmed on 11 July. No thrips larvae were present on 4 June, 8 August and 22 August. Some larvae present on 25 July were first instar and could not be identified with the key for second instar thrips.

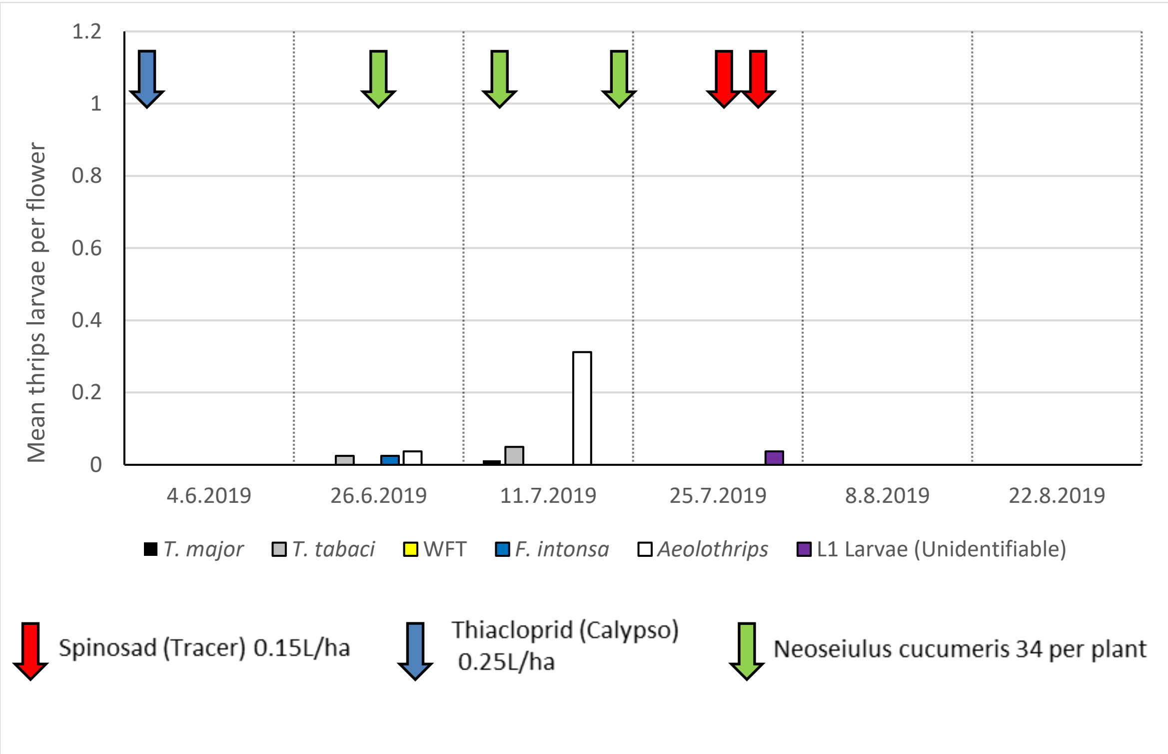


Figure 6.15. Site 1 everbearer cv. Finesse: Estimated mean numbers and species of thrips larvae per flower.

At Site 2, thrips larvae were not recorded on all dates, the predominant species was *T. major* peaking at a mean of 0.3 on 11 July (Fig. 6.16) and this species was also confirmed on three other sampling dates in lower numbers. Low numbers of *T. tabaci* were confirmed on 11 July and *Aeolothrips* spp. were confirmed on 11 July and 8 August. Some larvae present on 11 July were first instar and could not be identified with the key.

Mean numbers of thrips larvae per flower (Sites 1 & 2, 2018 season)

Larvae retained from Sites 1 & 2 in 2018 were assessed from Sites 1 & 2, no different species to 2019 were found and due to low levels of identifiable specimens were not represented graphically. Larvae from Site 1 were identified at three dates, *F. intonsa* was confirmed at 9 May (1 identified), 8 August (5 identified) and 20 August (1 identified). T. tabaci was confirmed at 20 August (1 identified).

Larvae from Site 2 were identified at two dates, *F. intonsa* was confirmed at 9 July (1 identified), and 23 July (3 identified). *T. tabaci* was confirmed at two dates 9 July (1 identified), and 23 July (1 identified). *T. major* was only confirmed at 9 July (1 identified).

Mean numbers of thrips larvae per flower (Sites 3 & 5, 2019 season)

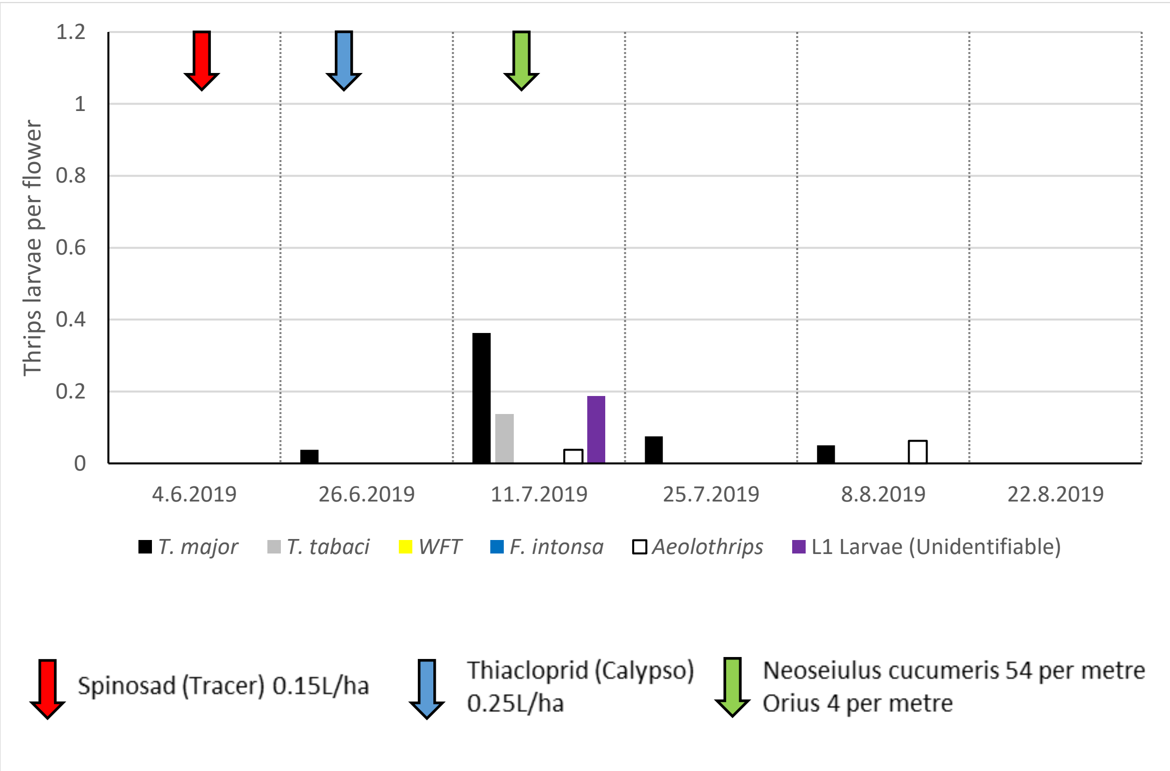


Figure 6.16. Site 2 everbearer cv. Murano: Estimated mean numbers and species of thrips larvae per flower.

At Site 3, thrips larvae were recorded at all dates after April, the predominant species were WFT and *F. intonsa*, peaking on 24 June and 6 August respectively, both at 0.8 per flower (Fig 6.17). *Aeolothrips* sp. also peaked on 6 August at 0.8 per flower. Lower numbers of first instar larvae and *T. tabaci* were present.

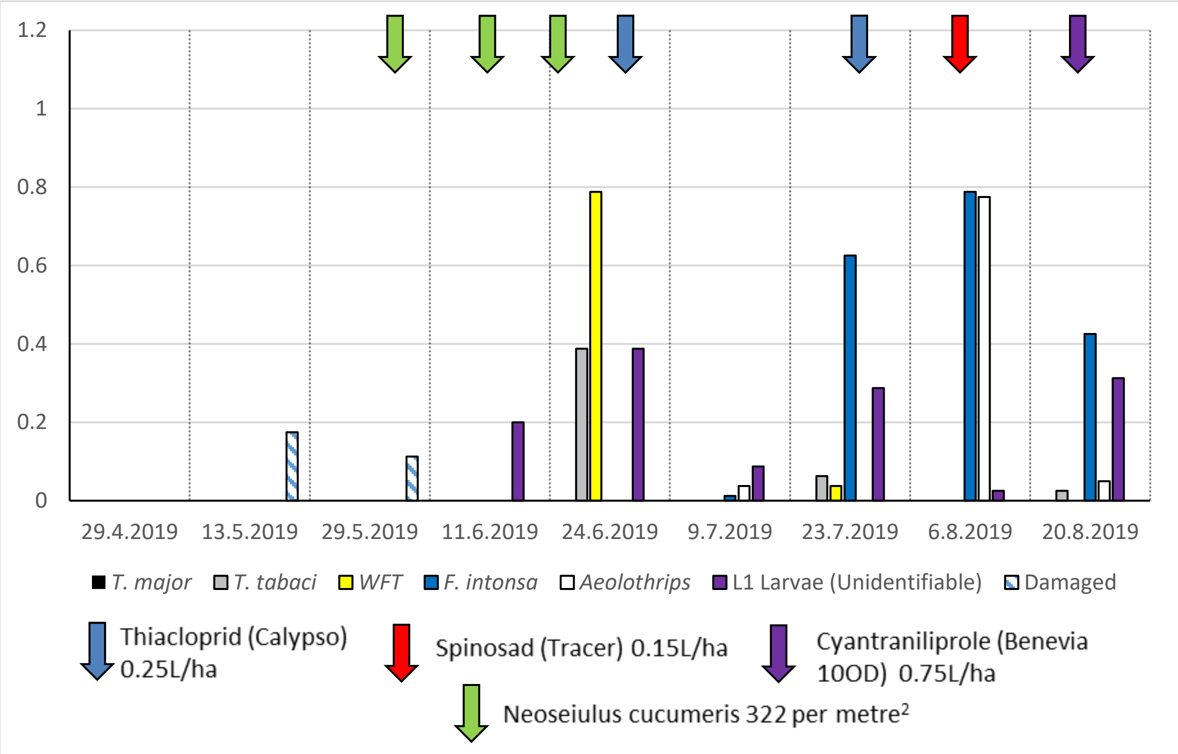


Figure 6.17. Site 3 everbearer cv. Katrina: Estimated mean numbers and species of thrips larvae per flower.

At Site 5, thrips larvae were recorded on all dates after April, the predominant species was WFT which peaked on 24 June at one per flower with large numbers of first instar larvae also present throughout the season (Fig. 6.18). Lower numbers of *T. major, Aeolothrips* and *T. tabaci* were present throughout the season. Some damaged larvae that could not be identified were also present.

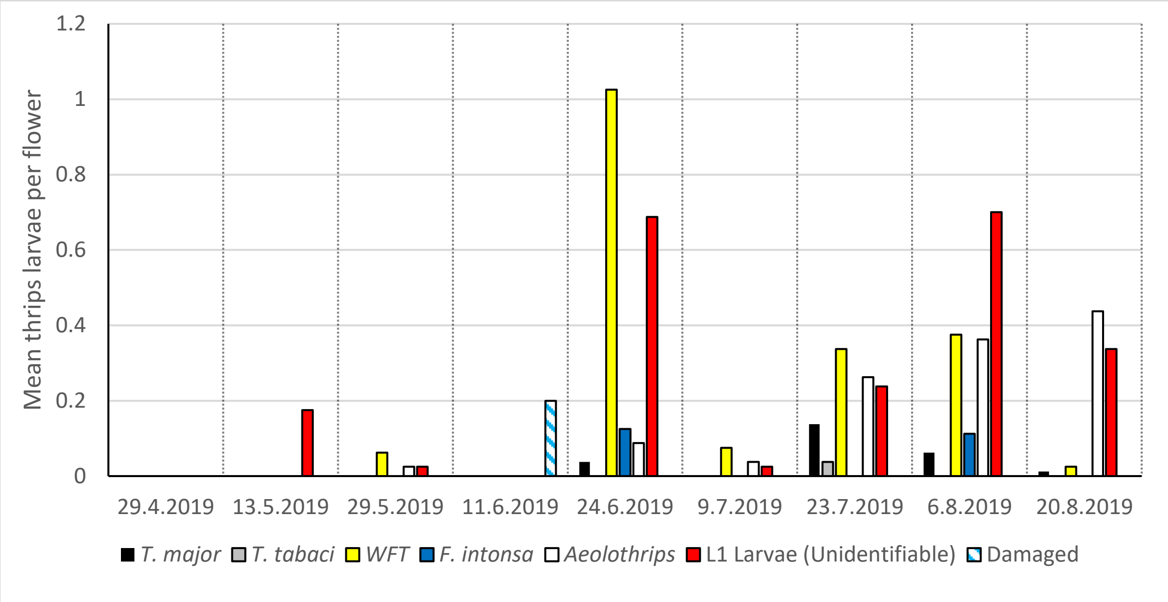


Figure 6.18. Site 5 everbearer cv. Favori: Estimated mean numbers and species of thrips larvae per flower (all species). No plant protection products were applied during the trial duration.

Fruit damage

At Site 1, fruit damage was only seen on 21 August. Damage was only slight, with an average of 0.25% fruit area bronzed (Figure 6.19). At Site 2, fruit damage was also slight and was recorded only on 21 August with a mean of 2.25% area bronzed (Figure 6.19). At Sites 3 and 5 fruit bronzing occurred more regularly. Fruit damage was more severe at Sites 3 and 5. At Site 5, fruit damage was recorded on all dates from 11 June to 20 August, with a maximum of 4.9% area bronzed on 11 June (Figure 6.20). At Site 3, fruit damage was recorded on dates from 11 June to 20 August except for the 24 June and maximum damage reached a mean of 5.08% fruit area bronzed on 9 July (Figure 6.21).

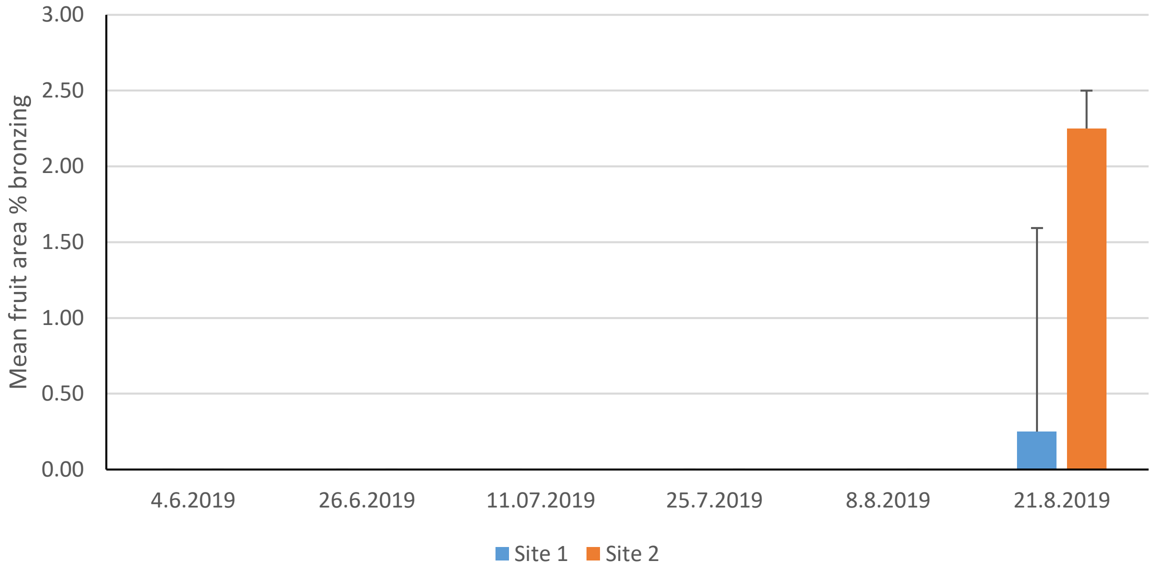


Figure 6.19. Site 1 everbearer cv. Murano and Site 2 everbearer cv. Elsanta: Mean % fruit area bronzed

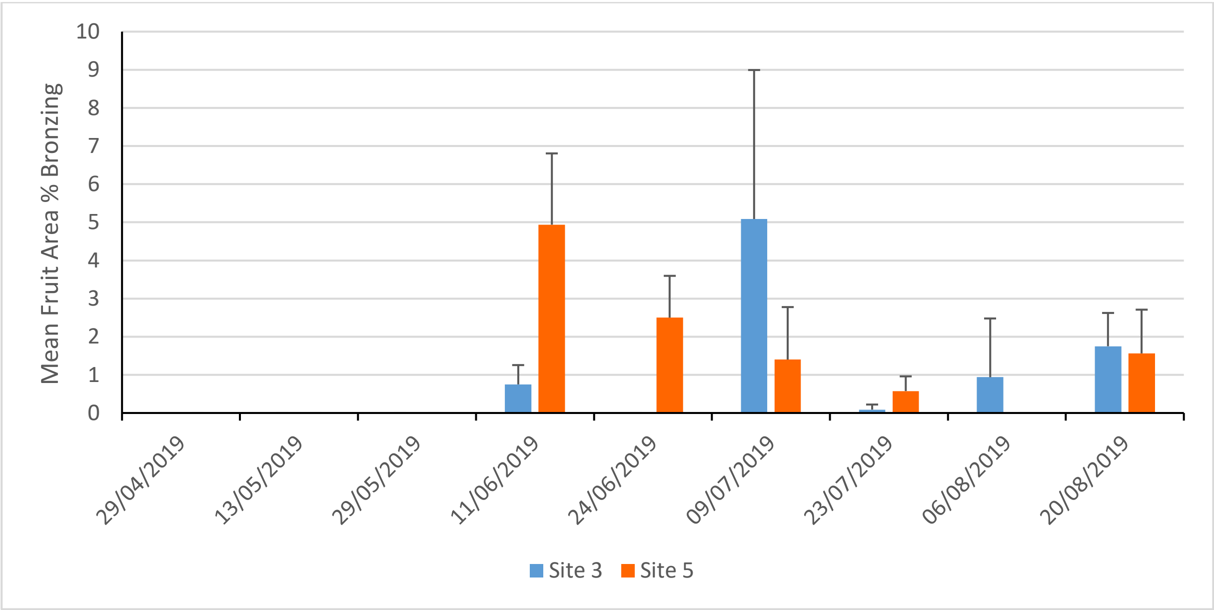


Figure 6.20. Site 3 everbearer cv. Katrina and site 5 everbearer cv. Favori: Mean % fruit area bronzed.

IPM programme used and natural thrips predators

At Site 1, *Neoseiulus cucumeris* were released at 18 per plant on 31 May and 34 per plant on 3 and 17 July (Figure 6.21). No *Orius laevigatus* were released and they were not recorded in the flowers during sampling. Naturally-occurring predatory banded wing thrips, *Aeolothrips sp.* were recorded in the flowers from 22 May to 25 July, with mean numbers peaking on 11 July at 0.3 per flower. Pyrethrins (Pyrethrum 5EC) was applied on 18 and 28 July and spinosad (Tracer) was applied for SWD control on 18 July and 7 August. Thiacloprid (Calypso) was applied on the 31st of May for the control of strawberry blossom weevil and aphids.

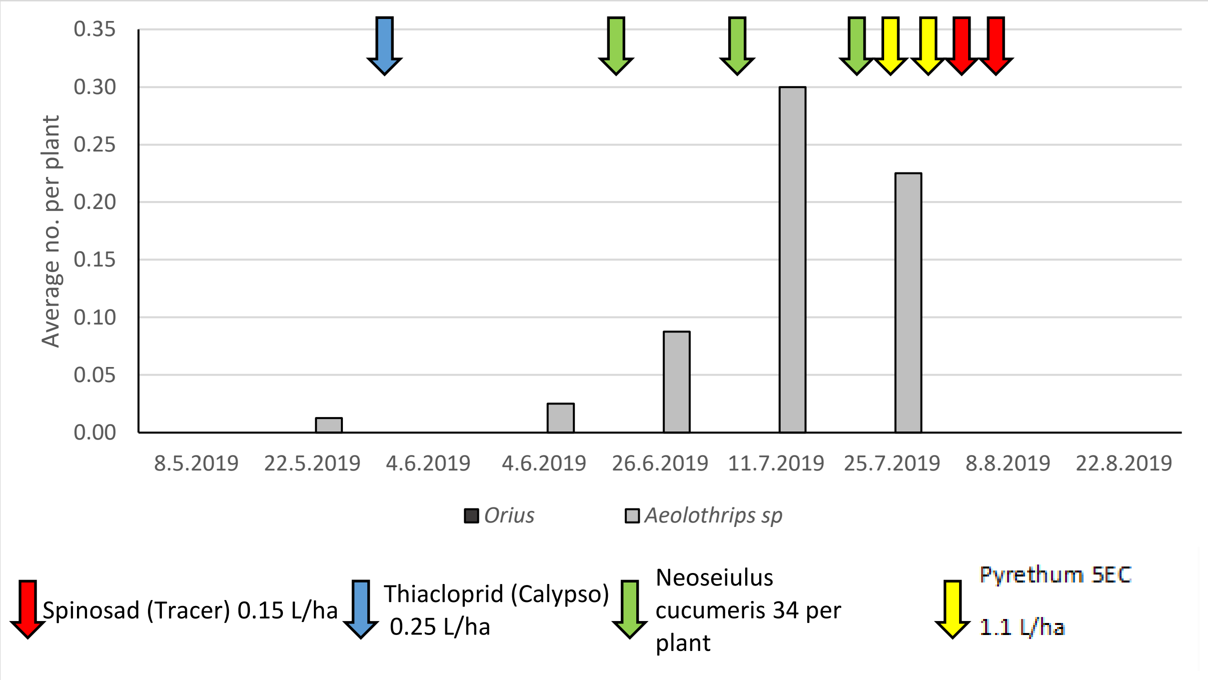


Figure 6.21 Site 1 everbearer cv. Murano: Dates of thrips predator releases, plant protection products applied and mean numbers of predatory thrips and *Orius* per flower

At Site 2, *N. cucumeris* (54 per metre) and *O. laevigatus* (4 per metre) were released to the crop on 30 June (Figure 6.13). *Orius* were recorded in flowers between 26 June and 22 August, with mean numbers reaching a maximum of 0.3 per flower on 25 July. Banded wing predatory thrips were recorded in flowers between 8 May and 25 July, with a maximum of 0.1 per flower on 11 July. Plant protection products were applied on 5 June (Tracer, for thrips control), 3 June (Calypso, for strawberry blossom weevil control).

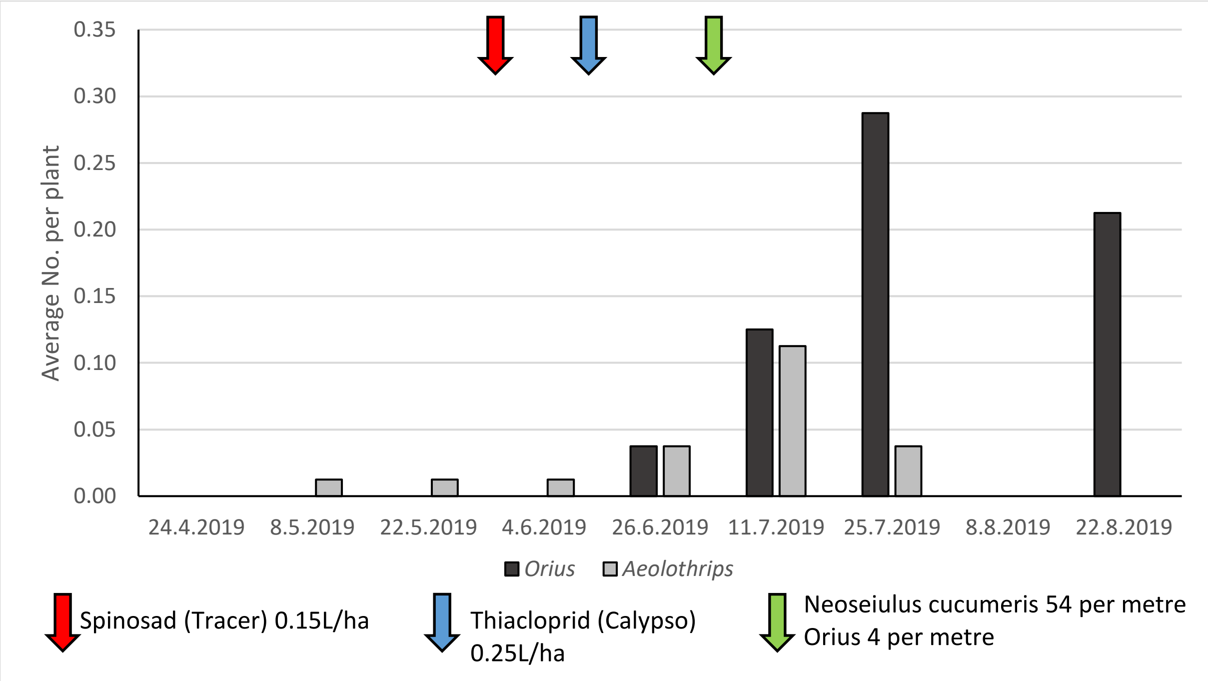


Figure 6.22. Site 2 everbearer cv. Finesse: Dates of thrips predator releases, plant protection products applied and mean numbers of predatory thrips and *Orius* per flower.

For Site 3, *Neoseiulus cucumeris were released at 322 per m*^{2} on the 22 May, 7 June and 15 June. *Orius* were recorded in flowers on 24 June and on 6 and 20 August and peaked on 24 June with a mean of 0.2 per plant. Predatory banded wing thrips were recorded in flowers on 13 May, 9 July and 20 August with a mean of 0.1 per flower on 6 August (Figure 6.14). An application of Calypso and Tracer was made on 15 June, Calypso on 12 July, Tracer on 29 July and Benevia on 19 August, probably for capsid and SWD control.

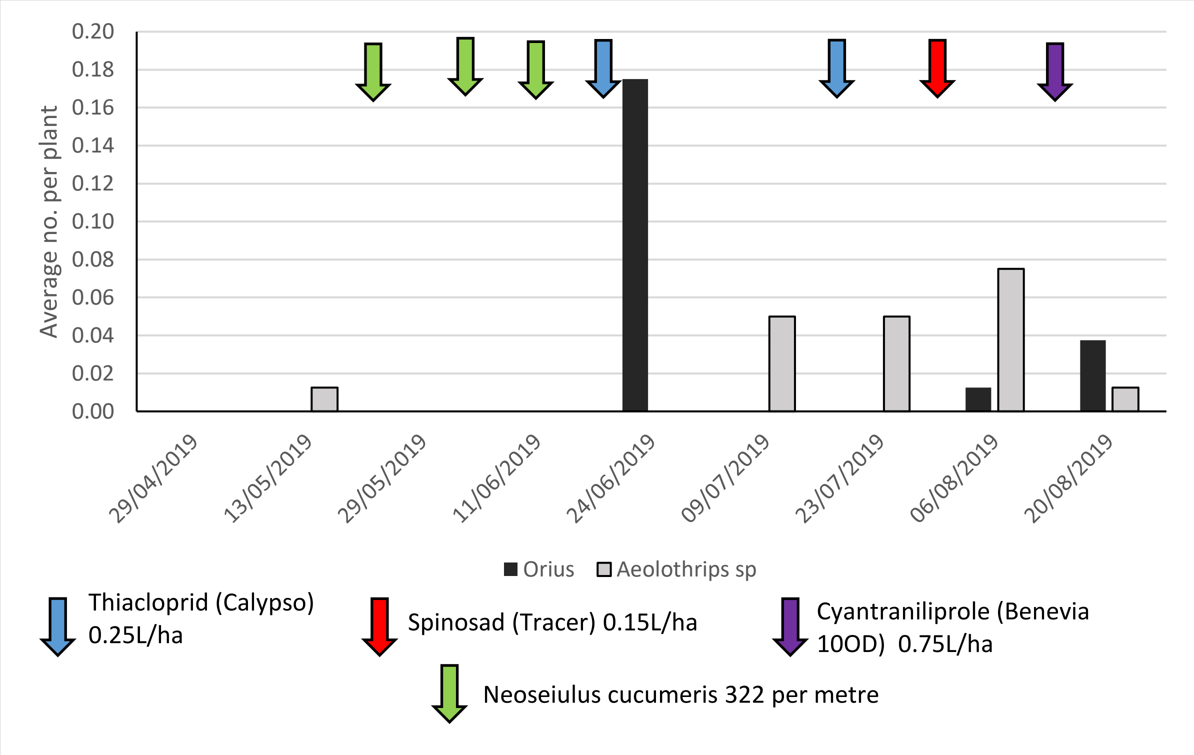


Figure 6.23. Site 3 everbearer cv. Katrina. Mean numbers of predatory thrips and *Orius* per flower

For Site 5, *Orius* were recorded in flowers on all dates between 9 July and 20 August, peaking at a mean of 1.7 per flower on 24 August (Figure 6.24). Predatory banded wing thrips were recorded in flowers on all sampling occasions peaking at a mean of 0.4 per flower on 23 July. No insecticides or biological control were applied by the grower during the sampling period.

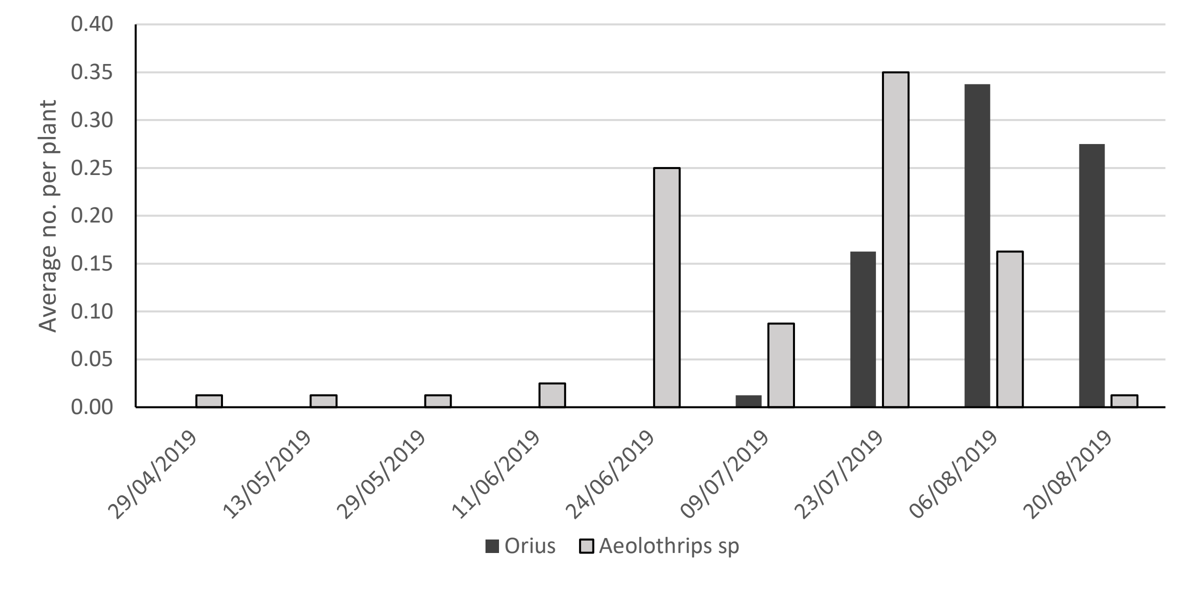


Figure 6.24. Site 5 everbearer: Favori Mean numbers of predatory thrips and *Orius* per flower

Mean numbers of thrips adults per water trap

At Site 1, *T. fuscipennis*, *T. major*, *T. tabaci, Limothrips denticornis and L. cerealium* were caught (Figure 6.25) at two sample dates. All the species were found in all three trap colours. However, total mean numbers of thrips per trap of all three colours were low, ranging from 2 to 2.9 per trap and although more *L. cerealium* were recorded than other species there were no significant differences between any species in any colour of trap.

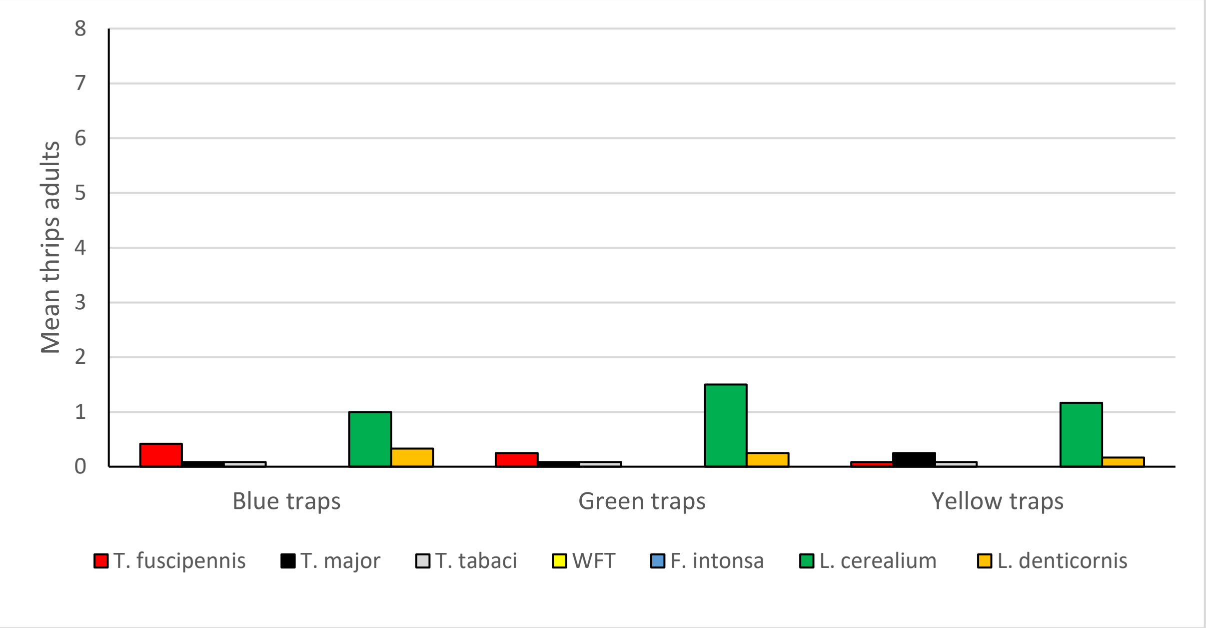


Figure 6.25. Site 1 water traps: mean numbers of adult thrips per trap.

Table 6.5. ANOVA results for water trap colour attraction at site 1.

	Trap colour (average per trap)			**Statistics**			
Species	**Blue**	**Green**	**Yellow**	**d.f**	**s.e.d.**	**L.s.d**	**P**
T. fuscipennis	0.42	0.25	0.08	**28**	**0.197**	**0.403**	**0.255**
T. major	0.08	0.08	0.25	**28**	**0.177**	**0.363**	**0.561**
T. tabaci	0.08	0.08	0.08	**28**	**0.122**	**0.250**	**1.000**
L. denticornis	0.33	0.25	0.17	**28**	**0.214**	**0.438**	**0.740**
L. cerealium	1.00	1.50	1.17	**28**	**0.503**	**1.030**	**0.604**

At Site 2, *T. fuscipennis*, *T. major*, *T. tabaci, L. denticornis, L. cerealium, Chirothrips manicatus and Thrips fulvipes* were caught (Figure 6.26). As at Site 1, only low numbers of thrips were caught, with total mean numbers of thrips ranging from 1.3 to 1.8 per trap of the three colours. Although more *T. fuscipennis* were caught than other species in all three colours of trap, there were no significant differences between any species in any colour of trap (Table 6.6). *Thrips major* was caught in blue and green traps but not yellow and *T. tabaci* was only caught in blue traps. *L. cerealium* was caught in traps of all three colours and *L. denticornis* were only caught in green and yellow traps. *Chirothrips manicatus* and *T. fulvipes* were caught in very low numbers and were not statistically analysed.

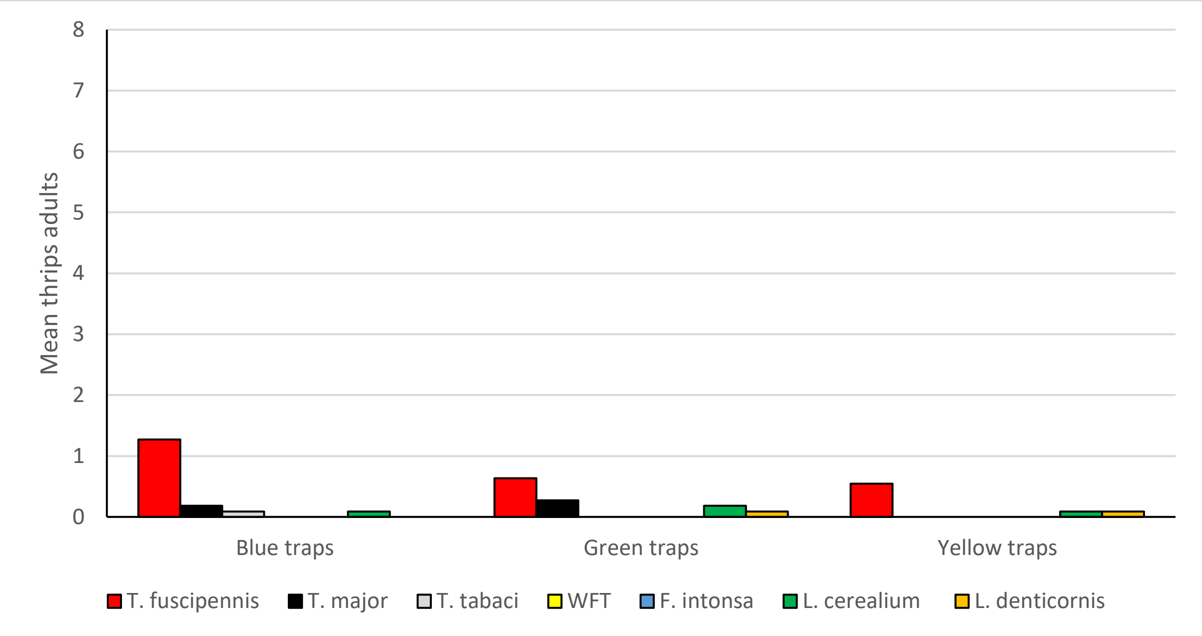


Figure 6.26. Site 2 water traps: mean numbers of adult thrips per trap

Table 6.6. ANOVA results for water trap colour attraction at site 2.

	Trap colour (average per trap)			Statistics			
Species	**Blue**	**Green**	**Yellow**	**d.f**	**s.e.d.**	**L.s.d**	**P**
T. fuscipennis	1.26	0.62	0.53	**25**	**0.445**	**0.917**	**0.225**
T. major	0.17	0.26	0	**25**	**0.158**	**0.325**	**0.233**
T. tabaci	0.08	0	0	**25**	**0.072**	**0.148**	**0.358**
L. denticornis	0.02	0.11	0.11	**25**	**0.098**	**0.201**	**0.570**
L. cerealium	0.11	0.11	0.20	**25**	**0.136**	**0.280**	**0.745**

At Site 3, *T. fuscipennis*, *T. major*, *T. tabaci, F. occidentalis*, *F. intonsa, T. vulgatissimus, T. minutissimus, L. denticornis and L. cerealium* were caught (Figure 6.27). Total mean numbers of thrips per trap of the three colours ranged from 2 to 7.8. Significantly more *T. fuscipennis* were caught in blue traps (mean 2.5) than yellow (mean 0.33) or green (mean 0.33) ($P < 0.05$). Also, significantly more *L. cerealium* were caught in yellow traps (mean 1.67) than blue (mean 0) ($P < 0.05$). There were no significant differences between any of the other individual species caught in any coloured trap (Table 6.7).

Western flower thrips and *F. intonsa* were caught in traps of all three colours. *Thrips major* and *T. tabaci* were only found in blue and yellow traps and *L. denticornis* were only found in blue and yellow traps. *T. vulgatissimus* and *T. minutissimus* were only caught in very small numbers and were not statistically analysed.

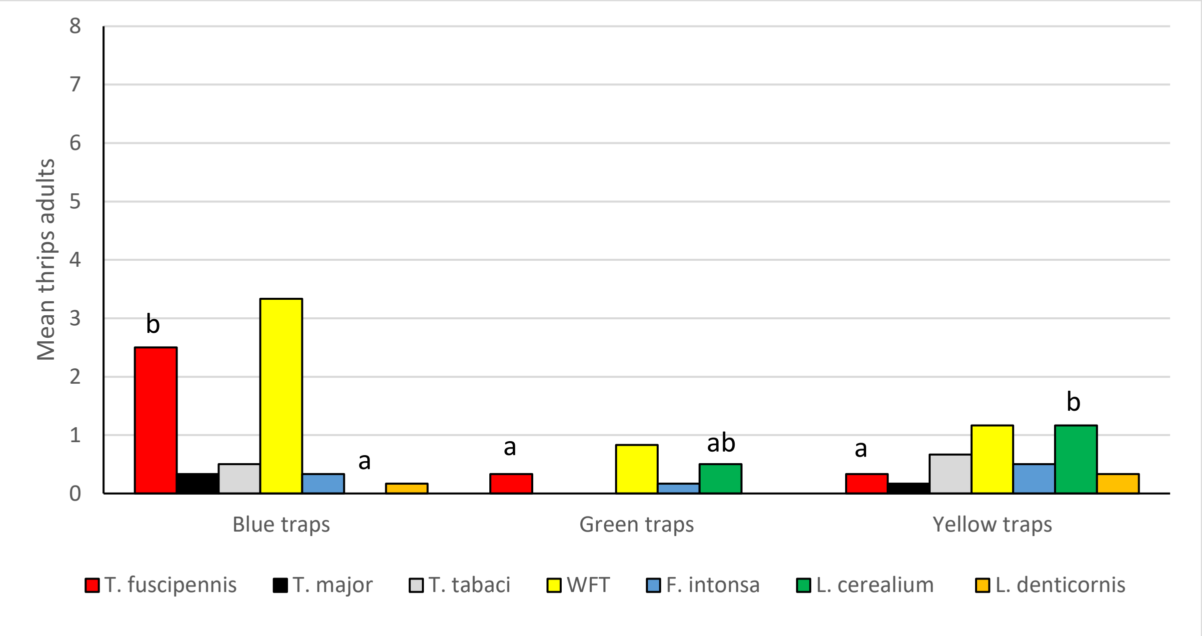


Figure 6.27. Site 3 water traps: mean numbers of adult thrips per trap. Values sharing any of the same letters above the bars are not significantly different

Table 6.7. ANOVA results for water trap colour attraction at site 3 (Results in blue were significantly different (P<0.05)).

	Trap colour (average per trap)			Statistics			
Species	**Blue**	**Green**	**Yellow**	**d.f**	**s.e.d**	**L.s.d**	**P**
T. fuscipennis	2.50 b	0.33 a	0.33 a	**10**	**0.513**	**1.143**	**0.002**
T. major	0.33	0.00	1.67	**10**	**0.236**	**0.525**	**0.402**
T. tabaci	0.50	0	0.67	**10**	**0.612**	**1.363**	**0.546**
L. denticornis	0.17	0	0.33	**10**	**0.236**	**0.525**	**0.402**
L. cerealium	0 a	0.50 ab	1.67 b	**10**	**0.390**	**0.868**	**0.040**
F. occidentalis	3.33	1.17	0.83	**10**	**0.987**	**2.199**	**0.060**
F. intonsa	0.33	0.17	0.50	**10**	**0.316**	**0.705**	**0.590**

At Site 5, *F. occidentalis*, *F. intonsa*, *T. tabaci, L. denticornis, L. cerealium,* were caught (Figure 6.28). Total mean numbers of thrips per trap of the three colours ranged from 2.3 to 5.8. There were no significant differences between individual species caught in any coloured trap. Western flower thrips and *F. intonsa* were caught in traps of all three colours (Table 6.8), *T. tabaci* was only caught in yellow, *L. cerealium* was only caught in yellow and green and *L. denticornis* was only caught in blue. *T. tabaci, L. denticornis* and *L. cerealium* were caught in very low numbers and were not statistically analysed.

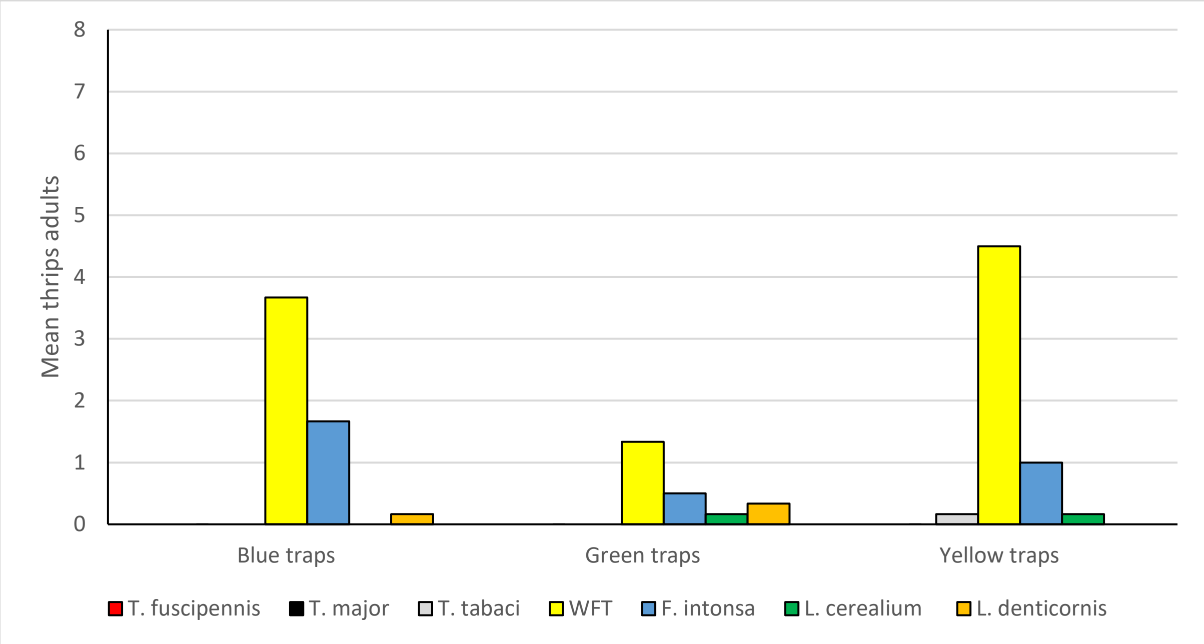


Figure 6.28. Site 5 water traps: mean numbers of adult thrips per trap.

Table 6.8. ANOVA results for water trap colour attraction at site 5.

	Trap colour (average per trap)			Statistics			
Species	**Blue**	**Green**	**Yellow**	**d.f**	**s.e.d.**	**L.s.d**	**P**
F. occidentalis	3.67	1.33	4.50	**10**	**1.683**	**3.751**	**0.200**
F. intonsa	0.50	1.00	1.67	**10**	**0.647**	**1.441**	**0.243**

Temperatures

Mean daily maximum temperatures in the outdoor everbearer crops were frequently above 20 °C (Fig 6.29 & Fig. 6.30). Temperature data at Sites 3 and 5 are not available, however, during 2019, (April-August) mean temperatures at the NIAB EMR weather station were generally higher than the previous two years (Figure 6.31).

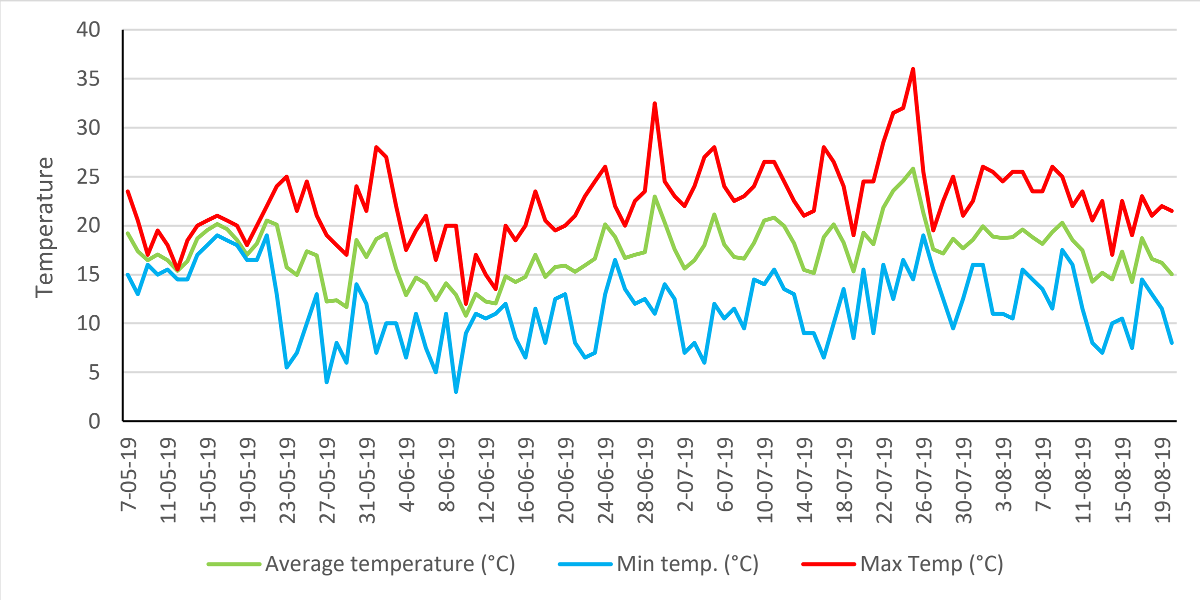


Figure 6.29. Mean daily temperatures from ADAS data logger in the crop canopy at site 1.

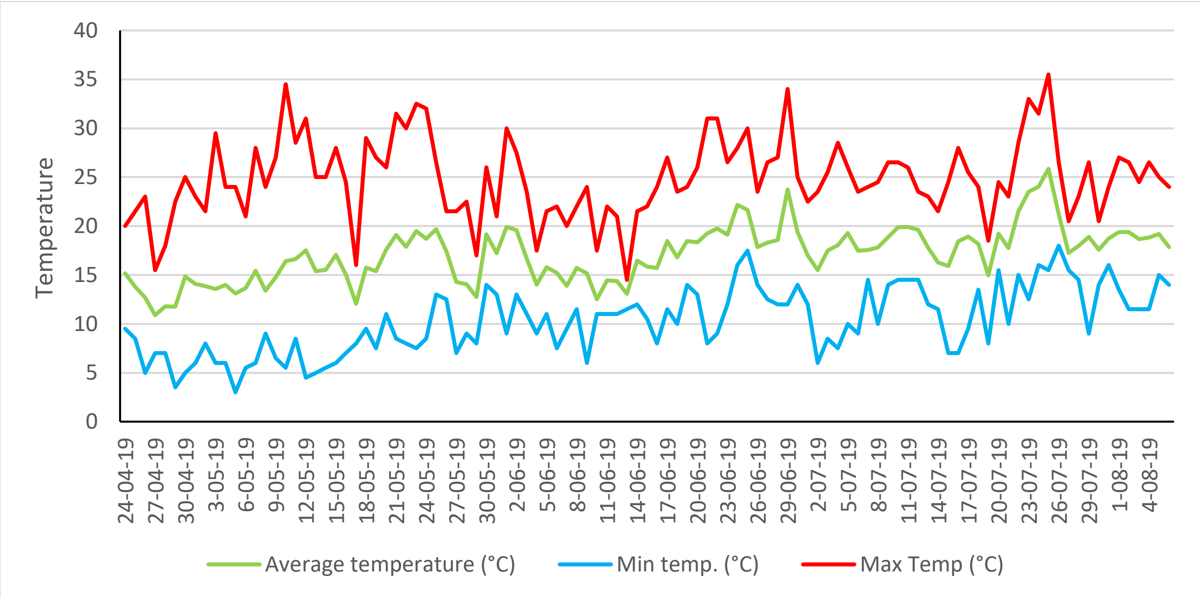


Figure 6.30. Mean daily temperatures from ADAS data logger in the crop canopy at site 2.

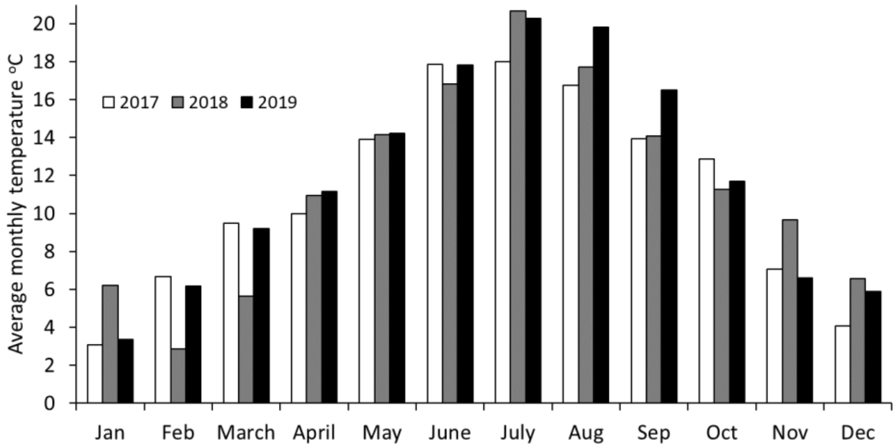


Figure 6.31. Mean monthly temperatures from NIAB EMR weather station (2017-2019)

Discussion

Start of thrips adult activity, peaks in numbers of adult thrips species and activity through the season

Rose thrips (*Thrips fuscipennis*): All four sites were selected as having a history of *T. fuscipennis* activity during 2017 and/or 2018. During 2018 this species was active from mid-June to early August. During 2019, it was first recorded in the June-bearer crop at Site 2 in early May and was the predominant species in both outdoor everbearer crops at Sites 1 and 2, with numbers per flower peaking on 26 June at both sites with means of 1.8 and 3.2 adults per flower respectively. These peak numbers were higher than those recorded at the same sites in 2018. In the tunnelled everbearer crop at Site 5 where the predominant species recorded was WFT, *T. fuscipennis* was only recorded in early June, in very low numbers. In the tunnelled everbearer crop at Site 3, *T. fuscipennis* was recorded between May and August, peaking on 11 June when it was the predominant species recorded with a mean of 2.1 per flower. *Thrips fuscipennis* is known to have caused fruit damage at Site 1 in 2017 where it was the only species recorded (Brown & Bennison, 2018) and is also reported to damage strawberry fruit in Italy (Gremo et al. 1997).

Onion thrips (*Thrips tabaci*)*:* During the monitoring period in 2019, the overall pattern of *T. tabaci* activity was similar to that in 2018 with a long period of activity between April and August but occurring in lower numbers than *T. fuscipennis* and, at Sites 3 and 5, than WFT. This species is known to damage strawberry fruit (Bennison 2015; Steiner date not published).

Rubus thrips (*Thrips major*)*:* During 2019, the activity of this species was similar to that in 2018, being recorded between May and July in the two outdoor crops at Sites 1 and 2 but in lower numbers than *Thrips fuscipennis*. In the tunnelled crop at Site 5, *T. major* was active during June and early July in much lower numbers than WFT. *Thrips major* was more active in the tunnelled crop at Site 3, recorded between late May and early August and during July, mean numbers per flower were slightly higher than those of *Thrips fuscipennis* and almost as high as those of WFT. *Thrips major* has been implicated in fruit losses in strawberry (Lewis, 1997), although no further published records of this could be found (Seymour, Bennison & Kirk, in press). However, slight fruit damage occurred in the June-bearer crop at Site 2 in 2018 where *T. major* was the only species recorded in flowers, which indicates that it can cause damage.

Western flower thrips (WFT, *Frankliniella occidentalis*): As in 2018, WFT was not recorded at all in the outdoor crop at Site 1 during 2019. Although WFT was recorded in low numbers during June and July in the outdoor crop at Site 2 in 2018, it was not recorded during 2019 at this site. In the tunnelled crop at Site 5, WFT was the predominant species during the entire monitoring period in 2019, with mean numbers of adults per flower peaking at 2.2 on 11 June. In the tunnelled crop at Site 3, WFT was recorded between May and August and was the predominant species in July and August, with mean adults per flower peaking at 1.8 on 20 August. WFT is well known to cause strawberry fruit bronzing caused by its feeding damage to young developing fruit.

Flower thrips (*Frankliniella intonsa*): During 2018, *F. intonsa* was recorded in higher numbers than usually seen in UK strawberry flowers (Brown & Bennison, 2017) at all four sites and was the predominant species at Sites 1 and 2. This was considered to be due to the unusually high temperatures between July and August, as this species is thought to be more adapted to the extreme climate of central Europe (Morison, 1957), although during the hot summer of 2019, this species was recorded in very low numbers at all four sites. However, *F. intonsa* was the only species of thrips occurring in tunnelled strawberry in early June 2019 in the West Midlands where it occurred in higher numbers than the four monitored sites in this project (Jasper Hubert, personal communication). *Frankliniella intonsa* is reported to cause strawberry fruit damage in Italy (Gremo et al. 1997). In addition, *F. intonsa* was the only species recorded in a tunnel-grown everbearer crop cv. Murano in Denmark during 2018 when numbers of adults exceeded 20 per flower and where severe fruit damage occurred (Stubsgaard, Bennison & Brown, unpublished).

Other species: Very low numbers of *Thrips vulgatissimus* were found at sites 1, 2 and 3 in the everbearer flowers. This species is often found in strawberry flowers in low numbers and it is not known whether it causes any fruit damage.

Very low numbers of *Thrips minutissimus, Thrips pillichi*, *Thrips dilatatus, Limothrips cerealium* and *Limothrips denticornis* occurred at some sites. None of these species are known to damage strawberry fruit, although these species cannot be distinguished from the others without high power microscopic examination and expertise in thrips identification.

Relationship between numbers of thrips adults per flower and numbers of flowers per plant

With WFT infestations, mean numbers of adults per flower often increase on strawberry crops when mean numbers of flowers per plant decrease, typically in between flower flushes on everbearers. This is due to the WFT adults congregating on the few available flowers when flowers are scarce, and this leads to fruit damage due to the more intensive feeding on young developing fruit (Raffle et al. 2015). At Site 1, mean numbers of thrips adults per flower (all species combined) peaked on 26 June which was the time when numbers of flowers were lowest (mean 1.7 per plant). A similar pattern was seen at Site 2 where peak numbers of thrips adults per flower was on the same date (26 June) as when flower numbers were low (mean 1.9 per plant). The declining number of thrips after this point at both sites could partly be due to thrips adults dispersing between the increased availability of flowers but also to other factors such as fewer adults flying into the crops and predation from increased numbers of either *Orius* (at Site 2) and/or *Aeolothrips* (both Sites 1 and 2). A similar relationship between numbers of thrips adults per flower and numbers of flowers per plant was seen at both Sites 3 and 5. At both Site 3 and 5 numbers of thrips adults were highest when the mean number of flowers (2 and 2.7 per plant respectively) was lowest on 11 June.

Development of larvae in flowers

Identification of larvae retained from flowers collected from Sites 1 and 2 in 2018 were identified as *T. tabaci*, *F. intonsa* and *T. major.* As in 2018, thrips larvae were found in flowers in the everbearer crops at both Sites 1 and 2 during June and July in 2019, but in much lower numbers than thrips adults. Second instar larvae from the four sites in 2019 were identified as those of *T. major, T. tabaci, F. intonsa, WFT and Aeolothrips* sp., confirming that all these species bred in the strawberry flowers. *Thrips tabaci* and *F. intonsa* larvae have also been recorded in strawberry flowers in Denmark, where they were identified using a PCR molecular method (Nielsen, 2019). No *T. fuscipennis* larvae were identified from flowers at any of the four sites in either 2018 or 2019 despite this being the main species of adult thrips confirmed at Sites 1 and 2 during 2019.

Very little is known about the biology of thrips species other than WFT on strawberry. Strawberry is recorded as a larval host for *T. fuscipennis* (Alford 1984; Morison 1947) but these authors do not report whether larvae occurred in the flowers or elsewhere on the plants. Speyer (1938) reports finding *T. fuscipennis* larvae in young rose shoots and eggs within the tissues of bracts and stems of young shoots and in sepals of flower buds or opening blooms, but rarely in the leaves of young shoots and never in older foliage or stems. It is possible that *T. fuscipennis* larvae occur in young strawberry shoots rather than in flowers but only flowers were assessed in this project. However, adult *T. fuscipennis* can be abundant in the flowers of many wild plant species in summer without any larvae present (Ward, 1973). Massive invasions of *T. fuscipennis* adults to glasshouse crops have also been reported in Europe where they occasionally damage sweet pepper, aubergine and rose crops and are difficult to control biologically, with larvae rarely being seen under glass (Malais & Ravensberg, 2003).

As in 2018, higher numbers of larvae per flower were found at Sites 3 and 5 during 2019 where WFT was predominant. This commonly occurs with WFT infestations as this species breeds very quickly in strawberry flowers especially at high temperatures. Although it has not yet been confirmed that larvae of *T. fuscipennis* occur in strawberry flowers, they may occur elsewhere on the plants and as larvae of other species known to damage strawberry fruit have been confirmed in the flowers, IPM programmes for control of mixed thrips species on strawberry should include components for control of larvae as well as adults.

Fruit damage

Of the thrips species confirmed at the four sites, the following species can cause bronzing damage to strawberry fruit: WFT, *Frankliniella occidentalis,* rose thrips, *Thrips fuscipennis,* onion thrips, *Thrips tabaci,* rubus thrips, *Thrips major, and* flower thrips, *Frankliniella intonsa*.

As in 2018, fruit damage in the June-bearer crops at Sites 1 and 2 was very slight, with a maximum of 0.05% and 0.63% fruit area bronzed respectively. Only small numbers of thrips adults per flower of the species *T. fuscipennis, T. major* and *T. tabaci* and at Site 2, *F. intonsa* were found on these June-bearer crops and it is likely that they caused the slight damage.

Fruit bronzing at sites 1 and 2 in the everbearer crops only occurred at the end of the season, on 21 August with means of 0.3% and 2.3% fruit area bronzed respectively. Thrips numbers at the time were very low (means of 0.04 and 0.13 adults per flower respectively), thus it is possible that the damage was caused by thrips feeding on flowers or young developing fruit on earlier dates when higher numbers of thrips were recorded. However, growers and agronomists frequently report fruit damage occurring as soon as thrips species other than WFT are seen in flowers.

At Sites 3 and 5 more severe everbearer fruit damage was seen than at Sites 1 & 2, with mean % fruit area bronzed peaking at 4.9% at Site 3 on 11 June and 5.1% at Site 4 on 9 July. This damage is likely to have been caused by WFT at Site 5 where WFT was the predominant species. At Site 3, the damage may have been caused by the mix of species present including WFT, *T. fuscipennis*, *T. major* and *T. tabaci*. Fruit damage at all sites remained well below 10% fruit area bronzed which is considered to be the threshold at which fruit is downgraded.

Water traps and colour attraction

Of all the species that were caught in the water traps, significant differences in the different coloured traps were only given by *T. fuscipennis* and *L. cerealium.* The colour attraction of *T. fuscipennis* is not well understood or reported in the literature, *T. fuscipennis* was found at three of the sites in the water traps. At all three of these sites more *T. fuscipennis* were found in the blue traps than in the yellow or green traps, but this was only significant at Site 3, where mean numbers in blue water traps were eight times that of the others. This might lead to the industry being able to utilise blue sticky traps as a tool for population monitoring and trapping for this species.

Significantly more cereal thrips, *L. cerealium,* were caught in yellow water traps than the blue at Site 3, but *L. denticornis* showed no colour preference. These species infest cereal crops and are not known to cause damage to strawberry. Often, they can be found as incidental species in other crops when nearby cereal fields have been harvested and there were cereal fields located closely to Sites 1 & 2.

Frankliniella occidentalis (WFT) was seen in large numbers in traps at Site 3 and Site 5 but there was no significant difference in colour preference. Determining colour attraction of WFT was not the objective of this study as it has been widely reported in the literature (e.g. Brødsgaard, 1989; Sampson *et al.,* 2012; Sampson, 2014; Vernon & Gillespie, 1990). *Thrips Major* and *T. tabaci* were caught at all four sites but in low numbers, no statistical difference in colour preference was found and there were no trends in our data to indicate that the species had any preference.

Effects of released and naturally-occurring thrips predators and plant protection products on thrips and predator numbers

At Site 1, although *T. fuscipennis* was the predominant species, other species were also present and it is likely that the three releases of *N. cucumeris* contributed to keeping any thrips species that produced larvae in the flowers below damaging levels, together with the naturally-occurring predatory banded wing thrips, *Aeolothrips* sp. which reached a maximum of 0.3 per flower on 11 July. No *Orius* were released or recorded as naturally-occurring predators at this site. Calypso was applied for strawberry blossom weevil control in early June and Tracer was applied for control of SWD in early August and these may also have contributed to thrips control.

At Site 2, where *T. fuscipennis* was also the predominant species in a mix of species, it is likely that both the *N. cucumeris* and *Orius laevigatus* released in late June contributed to keeping the thrips below damaging levels, together with naturally-occurring *Aeolothrips* sp. which reached a maximum of 0.1 per flower on 11 July. *Orius* were recorded in flowers during June, July and August, with maximum mean numbers occurring on 25 July (0.3 per flower). As at Site 1, Calypso applied for strawberry blossom weevil control on 3 June and Tracer applied for SWD control on 5 June are also likely to have impacted numbers of thrips.

As in 2018, the naturally-occurring predatory banded wing thrips, *Aeolothrips intermedius* was recorded in flowers at both Sites 1 and 2 during June and July, with maximum numbers recorded on 11 July at both sites with means of 0.3 and 0.1 per flower respectively.

At Site 3 early in the season *T. fuscipennis* was the predominant adult species in the mix before WFT increased at the end of the sampling period. The applications of *Neoseiulus cucumeris* applied to the crop in May and June probably contributed to the lower levels of thrips larvae of the species that bred in the flowers earlier in the season. Later in the season applications of Calypso, Tracer and Benevia 10OD will have contributed to the reduction in numbers of Thrips other than WFT towards the end of the sampling period. The use of chemical plant protection products mid-season is likely to have assisted the shift in species dominance from *T. fuscipennis* to WFT. Low numbers of naturally occurring *Orius* and *Aeolothrips* are likely to have helped reduce thrips numbers but are unlikely to have been sufficient on their own.

At Site 5, no *Neoseiulus cucumeris* were applied for thrips control and no chemical plant protection products were applied during the monitoring period. Numbers of *Aeolothrips* and *Orius* increased in late June and during July, peaking at means of 0.3 and 0.4 per flower respectively, which coincided with a peak of both WFT adults and larvae (species of larvae still to be confirmed). It is known that *Orius* and *Aeolothrips* compete with each other for thrips prey when prey is at low densities (Fathi et al. 2008). The lack of *N. cucumeris* release at this site may have led to high numbers of WFT larvae during August despite the *Orius* presence.

Summary

- As in 2018, adults of five species of thrips known to damage strawberry fruit were recorded at four sites during 2019.
- Numbers of the combined species peaked on 26 June in the two outdoor everbearer crops in Essex and Bucks at 2.2 and 3.5 adults per flower respectively and these were mainly rose thrips, *Thrips fuscipennis*. This differed from in 2018 when peak numbers of thrips adults peaked on 11 July at both sites and the predominant species was the flower thrips, *Frankliniella intonsa*.
- In the two tunnelled everbearer crops in Kent, numbers of thrips adults peaked on 11 June in similar numbers to those in the two outdoor crops at around two and four adults per flower respectively and when numbers these were mainly WFT at Site 5 and rose thrips at Site 3. This differed from in 2018 in two tunnelled crops in Kent when peak numbers occurred in August and September and were mainly WFT. However, as in 2018, WFT was the predominant species at both sites in July and August.
- Adults of the onion thrips, *Thrips tabaci* and the rubus thrips, *Thrips major* had similar patterns of activity to those in 2018 with a long period of activity between April/May and July/August. These species usually occurred in lower numbers than *T. fuscipennis* and, at Sites 3 and 5, than WFT, although at Site 3 in Kent numbers of *T. major* were higher than those of *T. fuscipennis* and WFT in late May and late June
- Adults of the flower thrips, *Frankliniella intonsa* were found in higher numbers than usual in 2018. Very low numbers were found at the four monitoring sites in 2019. This species is native to the UK but is thought to be more adapted to the more extreme climate in central Europe, so with climate change it could become a more common pest of UK strawberry crops.
- As in 2018, thrips larvae were found in the everbearer flowers at all sites and as in 2018, were recorded in lower numbers per flower than thrips adults in the two outdoor crops at Sites 1 and 2, mainly during July. Thrips species larvae confirmed at sites 1 and 2 were *Aeolothrips* sp., *T. tabaci, T. major* and *F. intonsa.* In the two tunnelled

crops at Sites 3 and 5, greater numbers of larvae than adults per flower were recorded during August, when the species confirmed were mainly *F. intonsa* and WFT.

- No larvae of *T. fuscipennis* were identified in strawberry flowers from any of the sites in either 2018 or 2019 and it is possible that this species does not breed in strawberry flowers and thus *N. cucumeris* would not contribute to control as it feeds only on first instar thrips larvae.
- As in 2018, fruit damage was only slight in the two outdoor everbearer crops in Essex and Bucks. Damage was more severe at the two tunnelled sites in Kent, but was well below a mean of 10% fruit area damaged which is usually considered as the 'threshold' above which fruit is downgraded. Fruit damage may have been caused by a mixture of *T. fuscipennis*, *T. tabaci, T. major* and *F. intonsa* adults in the two outdoor everbearer crops although *T. fuscipennis* was the predominant species. Fruit damage is likely to have been caused mainly by WFT in the tunnelled crop at Site 5 in Kent where it was the predominant species. In the tunnelled crop at Site 3 in Kent, damage may have been caused by a mixture of WFT, *T. fuscipennis*, *T. major*, *T. tabaci* and *F. intonsa*. Peak numbers of thrips adults (all species combined) per flower did not exceed four per flower at any site during 2019 so it can be concluded that on the everbearer varieties monitored (Favori, Finesse, Katrina and Murano), mean numbers of thrips adults per flower would need to be higher than this to cause severe fruit damage.
- As in 2018, numbers of thrips are likely to have been kept below damaging levels by a combination of released and naturally-occurring predators and by plant protection products applied for the control of strawberry blossom weevil and SWD.
- An effective IPM programme needs to be developed for control of a range of thrips species other than WFT that are known to cause fruit damage. *Orius* is likely to feed on both adults and larvae of all thrips species but it needs warm temperatures to establish and these do not occur every year. In addition, *Orius* is very susceptible to some of the pesticides applied for control of other pests such as SWD. *Aeolothrips* sp. is known to feed on thrips larvae but it is not known whether they also predate thrips adults. Although most thrips species other than WFT still seem to be susceptible to pesticides, there is a risk of pesticide resistance developing so reliance on control with chemical plant protection products is not sustainable.
- Significantly more *T. fuscipennis* adults were caught in blue water traps than in yellow or green in the tunnelled crop at Site 3 in Kent. This might lead to the opportunity to

develop an IPM strategy incorporating blue sticky traps for mass monitoring. No significant differences between the different coloured water traps were given in numbers of any of the other thrips species known to damage strawberry.

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We would like to thank the funders of the research AHDB Horticulture for their support. We would also like to thank all growers for the use of their plants and crops. We also thank the temporary technicians at NIAB EMR for help with treatment application and Greg Deakin for his advice on the statistics used.

Knowledge and Technology Transfer

2017

18-20 Apr 2017. Fountain. 2017 International Heteroptera Symposium, Pests for the Next Decade: Lygus, Plant and Stink Bug, Monterey Bay, CA. *Controlling Lygus in strawberry with semiochemical traps*

4-5 September 2017 Charlotte Rowley and Tom Pope – AAB – *Advances in IPM*.

21 November 2017 EMR Association/AHDB Soft Fruit Day *New predators of WFT* (Chantelle Jay, NIAB EMR)

21 November 2017 EMR Association/AHDB Soft Fruit Day *The latest research into WFT control and a device to extract pest and predators* (Jean Fitzgerald and Adrian Harris, NIAB EMR)

21 November 2017 EMR Association/AHDB Soft Fruit Day *the benefits of hoverflies in strawberry crops* (Dylan Hodgkiss, NIAB EMR)

21 November 2017 EMR Association/AHDB Soft Fruit Day *The latest research into SWD control* (Madeleine Cannon and Michelle Fountain, NIAB EMR)

2018

31 Jan 18 Rothamsted Research BCPC Pests and Beneficials Review - Successful application of biocontrols in outdoor horticultural crops. Fountain

22 Feb 18 AHDB/EMR Association Tree Fruit Day. Pear bud weevil – recent findings and new information, Pear sucker and natural enemy monitoring, Wildflower strips and solitary bees. Fountain

10 Jun 18 LEAF Open Farm Sunday, Tuesley Farm, Surrey. Bumblebees in horticultural crops – on behalf of BBSRC. Attended by Michael Gove. Fountain

Jul 18 Fruit Focus, East Malling. Pollination within strawberry crops. Fountain

5-7 Sep 18 IOBC Working Group "Integrated Plant Protection in Fruit Crops" Sub Group "Soft Fruits", 9th International IOBC/WPRS Workshop on Integrated Plant Protection of soft fruits. Rīga, Latvia. Push-Pull with synthetic attractants and repellents for control of fruit pests. Fountain

21 Nov 2018 – Jude Bennison presented a summary of Thrips results at the AHDB Soft Fruit Day

Dec 18 AAB Advances in IPM 2018: Making it work for the farmer. Push-Pull with synthetic semiochemicals for control of fruit pests. Fountain

2019

20-25 Jan 19 Joint meeting of the IOBC-WPRS Working Groups "Pheromones and other semiochemicals in integrated production" and "Integrated Protection of Fruit Crops", Lisboa, Portugal. Pull with Synthetic Semiochemicals for Control of Fruit Pests. **Fountain**

21 Nov 2018 EMR Association/AHDB Soft Fruit Day Technical Up-Date on Soft Fruit Research.

- Understanding the influence of Thrips fuscipennis in strawberry (Sam **Brown**, ADAS)
- The potential of garlic for pest control in strawberry (Adam **Walker**, NIAB EMR)
- The effect of aphicide use on N. cucumeris establishment in strawberry (Francesco Maria **Rogai**, NIAB EMR)
- The push/pull effect on control of capsid in strawberry (Adam **Walker**, NIAB EMR)

27 Feb 19, 2020AHDB/NIAB EMR Tree Fruit Day

- Protecting natural enemies (Michelle **Fountain,** NIAB EMR)

17 Apr 19 Talk to Lord Selborne on entomology work at NIAB EMR, Pollinators and entomology **Fountain**

15-16 May 19LEAF Network Summer Event LEAF, Hainey Farm, Barway, Ely, Cambridgeshire, CB7 5TZ IPM in fruit at NIAB EMR **Fountain**

21 Jun 19 Innovation in Horticulture event, NIAB EMR, WET Centre: Fruit Quality attributes – research in to the role of beneficials and pollinators **Fountain**

Jul 19 Fruit Focus tour, Enhancing pest control by planting floral resources in and around strawberry crops **Fountain**

01 Oct 19 Canterbury Christ Church University 'Integrated Pest Management of Fruit Crops' **Fountain**

08 Oct 19 Agrii Fruit team, Throws Farm Essex. SWD, aphid control and forest bug **Fountain**

09 Oct 19 HWH Workshop, NIAB EMR. Capsid push-pull **Fountain**

10 Oct 19 H L Hutchinson Ltd., WET Centre, Capsid Push Pull **Fountain**

14 Nov 19 Berry Gardens Growers Conference 'Improved control of capsids' **Fountain**

20 Nov 19 AHDB/EMR Association Soft Fruit Day Orchards Events Centre at East Malling. **Fountain**

13 Jan 20 Agrovista Grower Day, Black Horse Inn, Pilgrims Way, Thurnham, Maidstone, SWD, aphid control and forest bug **Fountain**

28 Jan 20 Agrovista Grower Day, White Lion, The Street, Selling, Faversham, SWD, aphid control and forest bug **Fountain**

2020

23 Mar 20 Frank Parkinson room of the School of Agriculture, Policy and Development, University of Reading, The use of semiochemicals to monitor and control insect pests **Fountain**

23 Apr 20 Canterbury Christ Church University, Agroecology MSc students field visit **Fountain**

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APPENDIX 3.2.1. Husbandry capsid push-pull 2019

BERRY GARDENS LIMITED
HARVEST INTERVAL CHECK FORM

Field name / planting	Product	Application		Harvest Interval	First available harvest		Actual harvest		Picking authorised by
		Date	Time		Date	Time	Date	Time	
Hop GARDEN									
	Fortress Batalia SPO 58	~~1/4~~	18:00	14	15/4	18:00			
	TALIUS Maxicrop	5/4	14:30	3	8/4	14:30			
	Kimolineal Dynomec Apollo SPO58	9/4	16:15	35	14/4	16:15			
								P.L	
	Fortress Calypso SPO58	27/4	10:00	14	11/4	10:00			
	Topaz Hortiphyte	7/5	08:15	3	10/5	08:15			
	AMISTAR Hortiphyte	13/5	07:30	3 ~~16/5~~	16/5	07:30			

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Berry Gardens

BERRY GARDENS LIMITED
HARVEST INTERVAL CHECK FORM

Field name / planting	Product	Application		Harvest Interval	First available harvest		Actual harvest		Picking authorised by
		Date	Time		Date	Time	Date	Time	
HOP GARDEN	Stroby Colmax	16/5	12:30	3	19/5	12:30			
	FRUPICA TOPAZ HORTIPHYTE	20/5	06:30	3	23/5	06:30			
	Signum Maxicrop	23/5	08:00	3	26/5	08:00			
	Maxicrop CHARM	26/5	07:00	1	27/5	07:00			
	Topaz Colmax	30/5	20:00	3	2/6	20:00		P.K	
	TAKUMI SC Maxicrop	3/6	06:30	3	6/6	06:30			
	LUNA Tracer Maxicrop	7/6	07:00	1	8/6	07:00	12/6	6:00	P.K
	Maxicrop NITRON	25/6	23:00	1	26/6	23:00	27/6	6:00	P.K.

Doc no: QA107 | Issue No: 18 | Issue date: 31/01/19 | Authorised by: L Nuttall

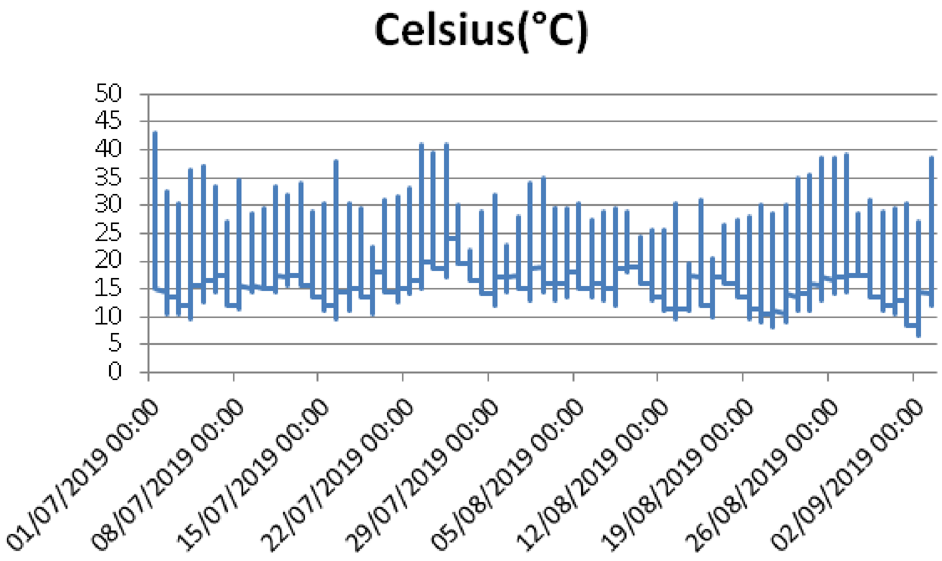
Berry Gardens

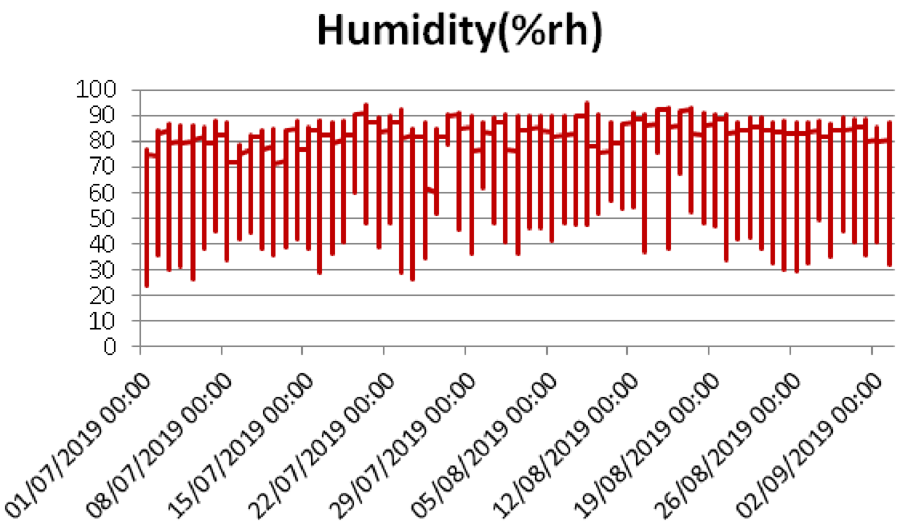
BERRY GARDENS LIMITED
HARVEST INTERVAL CHECK FORM

Field name / planting	Product	Application		Harvest Interval	First available harvest		Actual harvest		Picking authorised by
		Date	Time		Date	Time	Date	Time	
Hop GARDEN									
	CHARM Colmax	22/7	20:00	1	23/7	20:00	24/7	6:00	P.K
	LUNA	12/8	18:45	1	13/8	18:45	14/8	6:00	P.K
	Benevia	5/9	22:00	1	6/9	22:00	7/9	6:00	P.K
	K50 Teldor Teracov	23/9	20:00	1	24/9	20:00	25/9	6:00	P.K

APPENDIX 3.2.2. Temperature and Humidity data capsid push-pull trial 2019

Block 1





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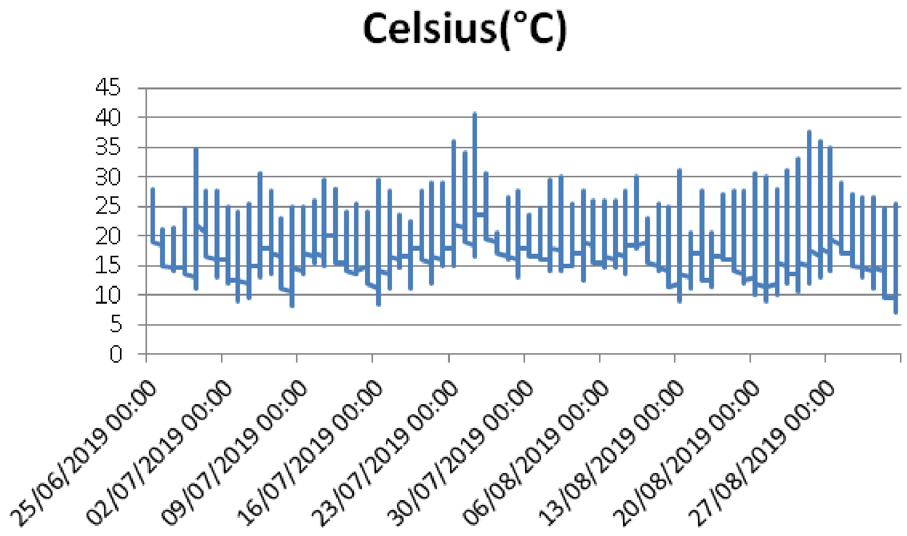
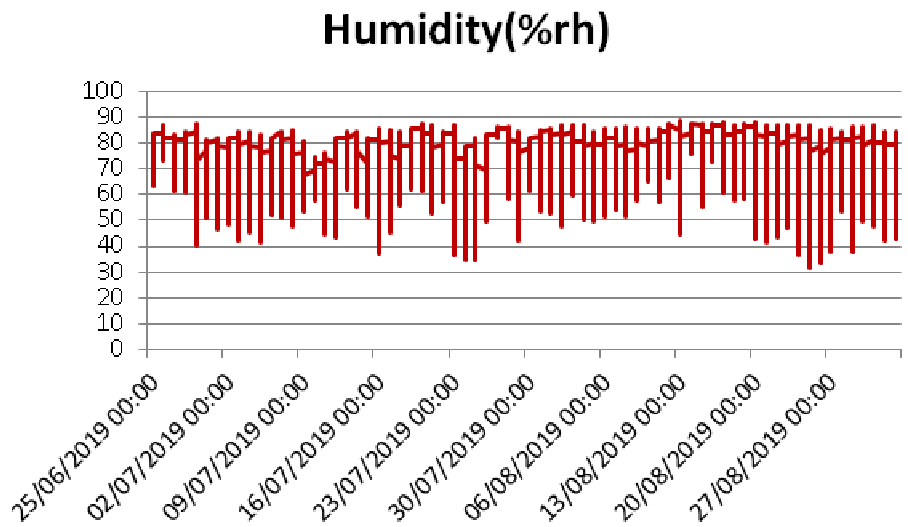


Celsius(°C)
45
40
35
30
25
20
15
10
5
0
25/06/2019 00:00
02/07/2019 00:00
09/07/2019 00:00
16/07/2019 00:00
23/07/2019 00:00
30/07/2019 00:00
06/08/2019 00:00
13/08/2019 00:00
20/08/2019 00:00
27/08/2019 00:00



Humidity(%rh)
100
90
80
70
60
50
40
30
20
10
0
25/06/2019 00:00
02/07/2019 00:00
09/07/2019 00:00
16/07/2019 00:00
23/07/2019 00:00
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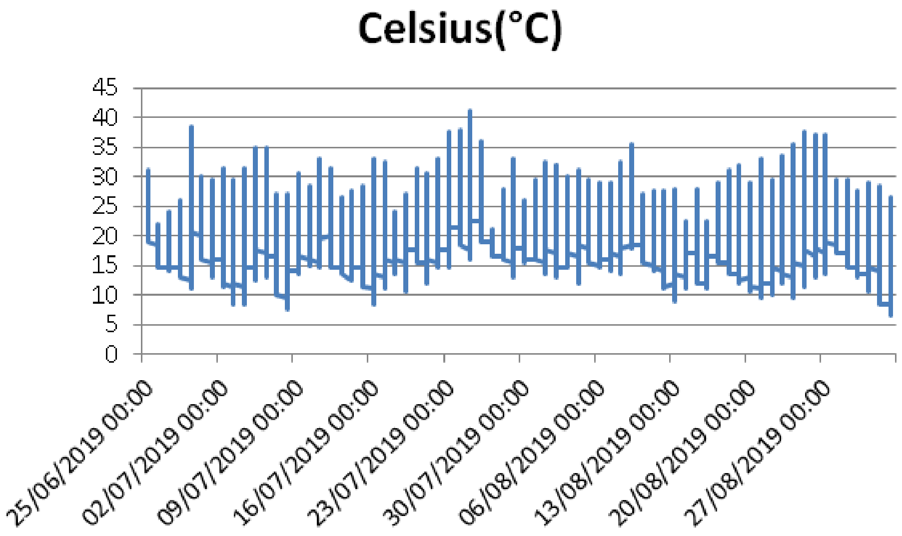
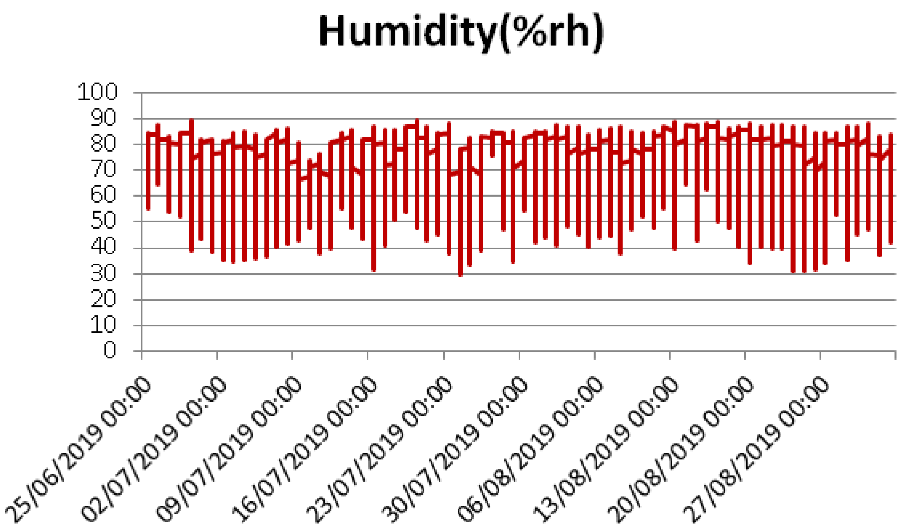
06/08/2019 00:00
13/08/2019 00:00
20/08/2019 00:00
27/08/2019 00:00

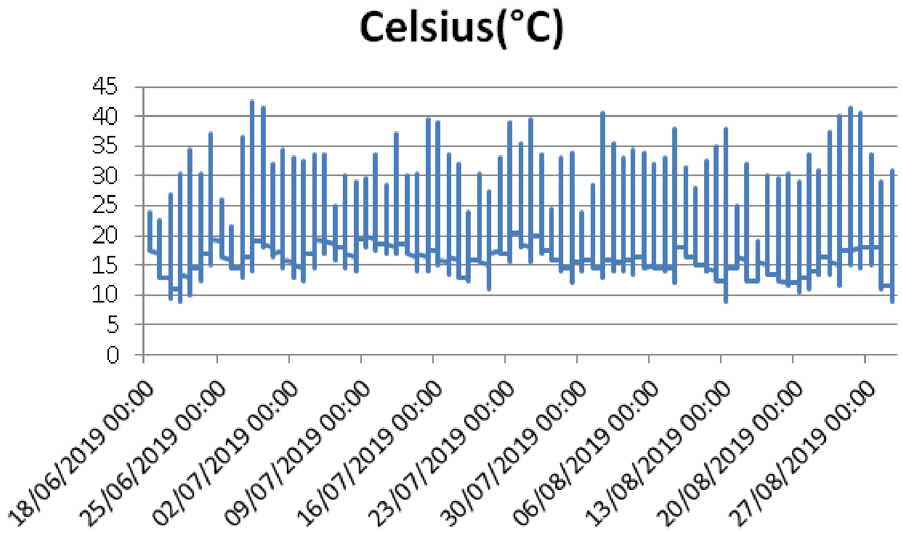
Block 3

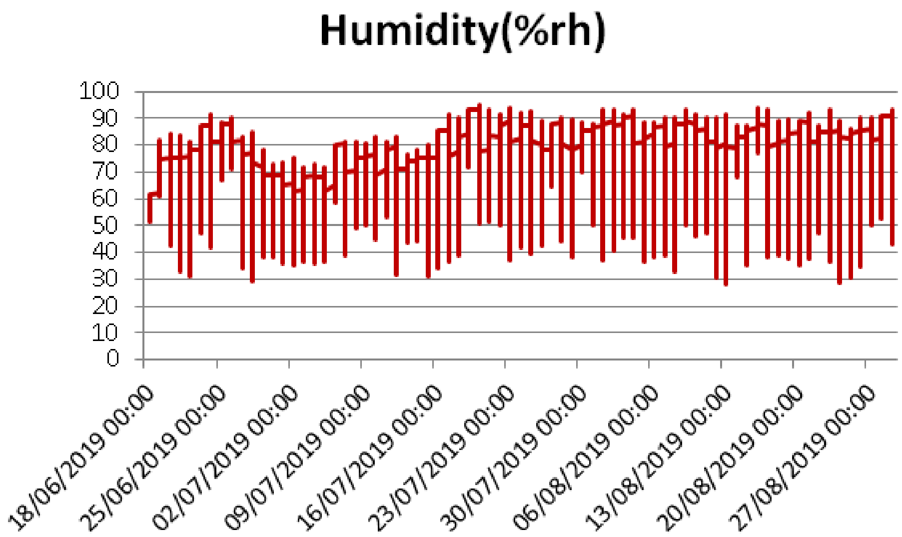




Block 4 (data requested from WET CENTRE)

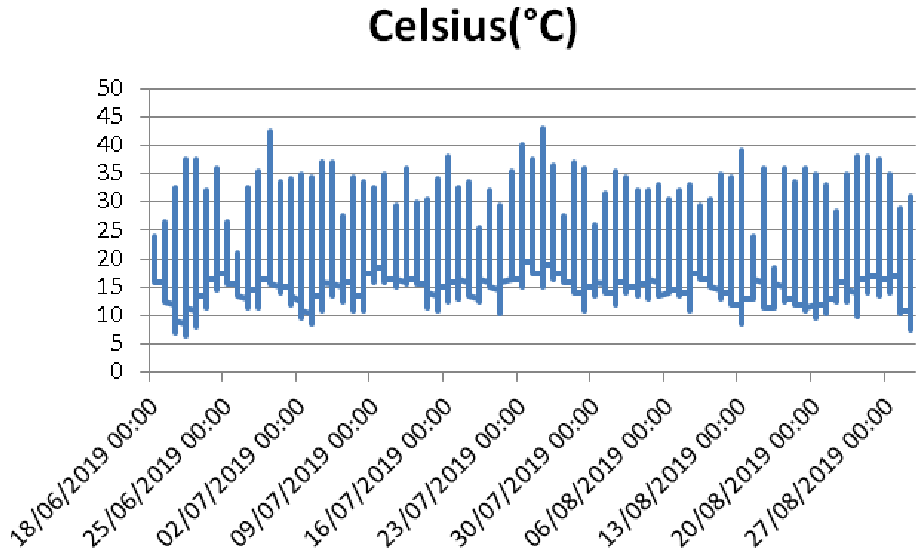
Block 5

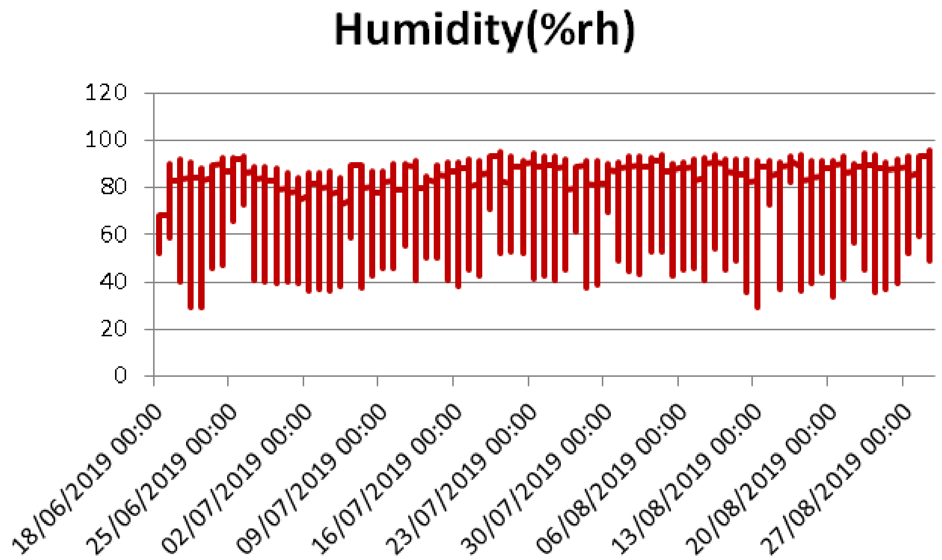




Block 6 Data loggers broken

Block 7


Celsius(°C)
50
45
40
35
30
25
20
15
10
5
0
18/06/2019 00:00
25/06/2019 00:00
02/07/2019 00:00
09/07/2019 00:00
16/07/2019 00:00
23/07/2019 00:00
30/07/2019 00:00
06/08/2019 00:00
13/08/2019 00:00
20/08/2019 00:00
27/08/2019 00:00


Humidity(%rh)
120
100
80
60
40
20
0
18/06/2019 00:00
25/06/2019 00:00
02/07/2019 00:00
09/07/2019 00:00
16/07/2019 00:00
23/07/2019 00:00
30/07/2019 00:00
06/08/2019 00:00
13/08/2019 00:00
20/08/2019 00:00
27/08/2019 00:00

APPENDIX 3.2.3. Leaf phytotoxicity key

- Discolouration of the whole leaf lamina:
- chlorosis
- whitening
- other abnormal coloration

Local leaf discolouration or abnormal coloration of:

- veins
- areas between veins
- edges of leaves
- tip of leaves
- along the veins
- the whole leaf lamina
- stunting, dwarfing, curling, etc.
- deformation of the leaf lamina (wilt, swelling, curling, etc.)
- modification of venation (position and form of veins)
- sticking together of organs (petioles, peduncles, leaf lamina)