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Project leader:	Michelle Fountain, NIAB-EMR, New Road, East Malling, Kent ME19 6BJ
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Key staff:	Glen Powell, Adam Walker, Francesco Maria Rogai, Rosa Blanco Fernandez, Gabriele Antoniella, Alastair Gibbons, Molly Perry-Clark, Chris Coyne, Phil Brain (NIAB EMR); Bryony Taylor, Belinda Luke, Rhian Whelan (CABI); Jude Bennison, Sam Brown (ADAS), William Kirk, (Keele University); Clare Sampson (Russell IPM); David Hall, Dudley Farman (NRI); Tom Pope (Harper Adams University); Robert Irving (ADAS), Neil Audsley (Fera)
Location of project:	NIAB EMR
Industry Representative:	Louise Sutherland, Freiston Associates Ltd.
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[The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.]

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.

Michelle Fountain

Deputy Head of Pest and Pathogen Ecology

NIAB EMR, New Road, East Malling, Kent ME19 6BJ

Signature ..... Date .22 March 2019..

Report authorised by:

Louise Sutherland,

Industry Representative

Freiston Associates Ltd.

Signature ..... Date .....

[Name]

[Position]

[Organisation]

Signature ..... Date .....

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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 is planned there will be work on five objectives over the five year duration:

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.

For ease of reading, this Grower Summary report is split into sections for each of the objectives being worked upon. In Year 4 of the project, Objectives 1, 2, 3 and 4 were worked on and are reported here.

Objective 1. Develop effective biological methods for managing western flower thrips, *Frankliniella occidentalis* (WFT), compatible with pesticide use for control of spotted wing drosophila, *Drosophila suzukii* (SWD)

Task 1.1 Develop and determine the efficacy and ease of use of the prototype extraction device for WFT and the predatory mite *N. cucumeris* in commercial strawberry crops, by agronomists and growers

Headline

- An extraction device has been developed for detecting *N. cucumeris,* thrips, *Orius,* and predatory thrips in strawberry button fruit samples and could be produced ready for growers and agronomists to use.

Background and expected deliverables

In 2015, the fumigant methyl isobutyl ketone (MIK), was shown to be effective as a fumigant to extract arthropods from button fruit, with higher numbers recorded by extraction compared to 'by eye' assessments of flowers or fruits (see 2016 Annual Report). Three prototype monitoring devices, making use of this fumigant extraction method, were constructed. Following grower/advisor feedback on the different designs and prototypes, a 'Tupperware' type device was chosen for further development based on its robustness, ease of use, and transparency.

Following initial laboratory studies in 2016 to assess the efficacy of the device in extracting thrips and mites from flowers and fruit, further laboratory and field experiments were carried out in the summer and autumn of 2017 to achieve a more thorough calibration of the device with *N. cucumeris*. Laboratory findings indicated that around 57% of the mites that were present on the button fruit were recovered. However, under field operation with more variable conditions and using a hand lens rather than a microscope, the recovery of mites from button fruit using the extraction device represented a much lower proportion (27%). In 2018, the objective was to finalise calibration of this device using the following four trials:

1. Improve MIK dispenser release
2. Determine the minimum time for maximum *N. cucumeris* extraction
3. Determine the maximum number of uses from the MIK dispenser
4. Confirm temperature effects on *N. cucumeris* extraction

Summary of the project and main conclusions

To improve release of MIK and improve operator handling, three different MIK dispensers were tested in the labroratory. After 10 minutes, the best dispenser for field testing from an operator perspective contained two ‘size 2’ dental rolls saturated in the fumigant. These fitted securely into the dispenser, preventing escape and lowering user contact exposure. They produced a higher MIK release than the dispenser used in 2017 (25 mg in 10 minutes as opposed to 14 mg). As a result, this dispenser was selected for field tests.

To determine the minimum time for maximum arthropod extraction, the extraction device was tested in the field at five different exposure times (1, 3, 5, 10 and 20 minutes) on samples of 20 strawberry button fruits. Subsequently, the percentage of arthropods extracted was compared for each exposure. Overall, for *N. cucumeris*, pale thrips and dark thrips, as duration of exposure to MIK increased, the percentage of extraction increased in the device up to 10 minutes. After this time there was no significant increase. The mean percentage of *N. cucumeris* extraction levelled off at 57% which is similar to laboratory findings in 2017 after 20 minutes of exposure (57.8% and 58.4%), although the percentage of *N. cucumeris* extraction in the field in 2017 was lower (27%). Mean numbers of *Orius* and aphids were too low for statistical analysis. As a result of these findings a 10 minute exposure period was selected for the remaining two field trials.

To determine the maximum number of uses from the MIK dispenser, arthropod extraction was assessed in the field using 30 dispensers, prepared with previous uses ranging from 0 to 57. The number of MIK uses, up to 57 times, resulted in no significant difference in the percentage of *N. cucumeris,* pale thrips or *Orius* extracted from strawberry button fruit. For predatory thrips, there was also no significant difference, but mean numbers were very low. For dark thrips there was a significant difference, but again mean numbers were low. Overall mean percentage of *N. cucumeris* extracted was 21.8%, less than half that found in the second trial (57%), but numbers in the crop were also low. Correspondence with the grower confirmed *N. cucumeris* had stopped being released nearly two weeks prior to this trial. Mean percentage *N. cucumeris* extraction appears more variable when the mean number of mites on button fruit samples is below ten, although this requires further testing for confirmation. Findings here indicate that the MIK dispenser developed in Trial 1 is suitable for at least 57 uses, though given the low numbers of *N. cucumeris* upon which this assumption is based, a repeated test would be advised.

To confirm the temperature effects on *N. cucumeris* extraction, 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 exposed to MIK at each time point in the field. Subsequently, the percentage of arthropods extracted from the button fruits at each time point and corresponding temperature were analysed. Findings showed that the mean percentage of *N. cucumeris* extracted was not significantly linked to time of day, or average temperature, however mean percentage 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. During this experiment, the effect of temperature was not fully explored. Average temperatures ranged from 13.9 °C at 20:00 to 20.7 °C at 15:00. It may be that the percentage of extraction is significantly affected by temperature, but outside this range. To assess this possibility, further studies at more extreme temperatures are recommended. The highest mean percentage of *N. cucumeris* extracted was 44.5% at 15:00. Of the other arthropods extracted, mean numbers were low.

If using the device to estimate numbers of *N. cucumeris* in the crop, temperature should be taken into consideration. In 2017, it was found that a 1 °C increase in mean temperature could result in an approximate 2.5% reduction of numbers of *N. cucumeris* counted in sample units (e.g. strawberry button fruits).

Financial benefits

Western flower thrips (*F. 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 is testing 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

- Test the practicality of the extraction device for detecting *N. cucumeris* and thrips compared to existing methods.
- Sample button fruit to determine establishment of *N. cucumeris* in the crop.
- Sample mid-aged flowers to determine thrips numbers in the crop.
- Consider reducing the number of repeated applications of tank mixes of plant protection products as these may be harmful to introduced *N. cucumeris*.

- Careful thought needs to be given to the tank mixes used, ensuring that thrips and tarsonemid control is achieved early before *D. suzukii* enters the crop and requires treatment.
- Reduce use of crop protection products where possible to ensure that *N. cucumeris* gains control of WFT before *D. suzukii* control is needed.

Task 1.2. Testing *Metahzium brunneum* (strain F52) against biological control insects used in strawberry production

Headline

- Met52 is a commercially available biopesticide to control thrips, among other insects. Contact experiments concluded that Met52 has minimal effect on the viability of beneficial insects, even under ideal conditions for Met52 and hence Met52 EC is recommended for growers to use on their strawberries.

Background and expected deliverables

The Monsanto marketed product Met 52 EC, containing the active ingredient *Metarhizium brunneum* strain F52 in an emulsifiable oil for suspending in water, is sold through Fargro in the UK. It is anticipated that it will become available to UK growers in 2019 for the control of pests such as thrips, whitefly and mites on commercially grown crops including strawberries. At present, the label does not show natural enemy compatibility. However, Fargro say that under the IOBC Classification system for non-target effects on augmentative and native biological control insects (Hassan, 1992), Met52 is classified as harmless against *Amblyseius swirskii*, *Macrolophus caliginosus* and *Nesidiocoris tenuis*. It is compatible (EPA tox) with *Chrysopa* spp. and *Nasonia vitripennis* and it is anecdotally okay against *Orius* spp. and *Hypoaspsis miles*. Testing is underway for *Encarsia formosa*, *Eretmocerus eremicus* and *Phytoseiulus persimilis*. Its status is unknown for *Feltiella acarisuga* and *Aphidius* spp. Therefore, bioassays were carried out, testing Met52 (as product Met52 EC or the spores only F52) against three commercially produced natural enemy products (Chrysopa, Aphidalia and Ervipar), to fill a knowledge gap so that growers may best know how to utilise it within their growing systems.

To determine the effect of Met52 on beneficial insects regularly purchased and used in the UK strawberry growing system, two tasks were conducted:

1. A literature review on effects of *M. brunneum* strain F52 (the active ingredient of Met52) against western flower thrips and natural enemies.

2. The effect of *M. brunneum* strain F52 spores and Met52 EC was investigated on natural enemies used in UK strawberry growing systems.

Summary of the project and main conclusions

To establish which natural enemies had already been tested for effects of F52, a literature review was conducted prior to the commencement of work.

In the literature review, two abstracts referred to the effects of F52 on non-target organisms directly (Saito & Brownbridge, 2016 and EFSA, 2012). Saito and Brownbridge (2016) exposed soil-dwelling predators (a rove beetle, *Dalotia coriaria* (Kraatz); predatory mites, *Stratiolaelaps scimitus* (Womersley) and *Gaeolaelaps gillespiei* (Beaulieu) to filter papers treated with Met52 EC. They found only *D. coriaria* was significantly affected by exposure to the high dose of Met52. EFSA (2012) Annex IIM 8; HIM 10 shows that there is evidence that direct application of Met52 to *Orius majusculus* (insidious flower bug) (dripping onto the insect at a rate of 5.1 x 108 CFU /mL) causes 70% mortality after seven days. In addition, 37% mortality after 12 days has been noted for *Chrysoperla carnea* (common green lacewing), through dietary exposure of Met52 at 4.2 x 105 CFU/mL, and 31% mortality was observed after 22 days for *Hippodamia convergens* (convergent lady beetle) (Coccinellidae).

The literature review showed that some work on the effects of Met52 EC on beneficial insects has already been studied. However, there is little information available about the main natural enemies which are used in cropping systems in the UK. The experimental work in this study will therefore be focused on the main beneficials used in the UK strawberry system.

The experimental work was divided into two parts: firstly, the active ingredient of Met52 EC, *Metarhizium brunneum*, was tested on five natural enemy products: Aphiscout (*Aphidius colemani, Aphidius ervi, Aphelinus abdominalis, Praon volucre* and *Ephedrus cerasicola*), Chrysopa (*Chrysoperla carnea*), Thripor-L (*Orius laevigatus*), Aphidalia (*Adalia bipunctata*) and Ervipar (*Aphidius ervi*). First a 'dipping assay' method was employed and secondly 'spray contact assays' were performed on the three products which showed the highest mortality levels in the dipping assay (Chrysopa, Aphidalia and Ervipar). All experiments were carried out at the recommended field rate for Met52 EC.

The results for the dipping assay, where the insects were submerged in the recommended dose of *M. brunneum* spore suspension showed that Aphiscout and Chrysopa had mortality levels around 50%. For Thripor-L and Aphidalia there was around 65% mortality and 70% mortality in Ervipar three days after treatment. This was a worse-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 concluded that Met52 EC is likely to have little significant effect on survival of Thripor-L, Ervipar, Aphiscout, Aphidalia and Chrysopa products when applied to UK strawberry system.

Financial benefits

Western flower thrips (*F. 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 is testing 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

- Use of Met52 EC is recommended for use by UK strawberry growers and is likely to have minimal impact on beneficial organisms.

Task 1.3. 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 aphids in the crop.

Background and expected deliverables

In 2017, a strawberry grower reported that intercropping garlic and periodically breaking garlic leaves within the strawberry crop, could reduce the prevalence of thrips. This effect had not been quantified alongside an untreated crop. However, 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 the summer of 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 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 the 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.
- Tap sampling 20 strawberry plants for capsids and natural enemies.

Throughout the assessments the main aphid species recorded was the strawberry aphid (*Chaetosiphon fragaefolii*). Of the key findings, fewer *C. fragaefolii* occured in first year strawberry plantings than second year plantings. More mummified aphids, parasitoids and predatory spiders were also present in the older crop.

During most full assessments, the garlic treatment significantly reduced *C. fragaefolii* in strawberry compared to untreated strawberry. It is hypothesised that breaking garlic leaves may release compounds which repel aphids and is sustained by the continuous presence of garlic plants in the crop. However, this is yet to be confirmed. Also it is unclear whether the reduction in numbers of *C. fragaefolii* is significant enough to reduce 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 also remains to be confirmed.

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

Financial benefits

The estimated cost of applying this garlic treatment was £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. However, this may also need to be taken into consideration.

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 these proposed action points do so with caution. For growers wishing to trial the use of garlic, follow these action points:

- 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 garlic every 1 metre along the crop row.
- When the garlic plants are established, snap leaves at least fortnightly and lay these 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.

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

Headline

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

Background and expected deliverables

This field study looked at the effect that aphicides, commonly used to target spring aphids, have on the establishment of *N. cucumeris* and other predators. In order to make rational decisions on the release of this predator, during the spring time, it is important to determine whether *N. cucumeris* is affected by plant protection products applied for aphid control.

Summary of the project and main conclusions

The experiment was set up on a commercial table top of 2nd year June bearer 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 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 followed by three post-spray assessments. 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 over the duration of the trial, 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 the time in control and treated plots.

The newly emerging folded leaves and flowers where *N. cucumeris* was detected had very little or no target product residue, potentially enabling the predatory mites to establish and reproduce (evidenced by the presence of eggs and nymphs). Hallmark, which is suggested to have a persistence of activity against *N. cucumeris* of between 8 and 12 weeks, did not appear to have an adverse effect on mite releases in the field, in this trial.

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 proliferate.

Action points for growers

- Release *Neoseiulus cucumeris* early in strawberry crops to control western flower thrips and tarsonemid mite.
- It is better to use products that are not sympathetic to IPM programmes early in the season to control aphid if needed, than to rely on introduced biological controls and wild natural enemies as the temperature increases.
- *N. cucumeris* should be introduced into the crop frequently through the growing season. Added to parasitoids for aphids and Orius for thrips control, these can mitigate the need for later insecticide applications which disrupt thrips control.
- Growers need to couple this with control of SWD and control of non western flower thrips 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*.

Headline

- Although the push-pull of capsid bugs was successful in 2017, the low numbers of capsid in 2018 resulted in levels of strawberry damage which were too low to draw any conclusions this year.

Background and expected deliverables

Push-pull is a strategy with the potential to control capsidsi n strawberry. The strategy uses a stimulus to repel the capsids away from the crop (push), in combination with another stimulus (pull) which attracts them to a trap surrounding the crop where they are concentrated and eliminated. Besides pest control, additional benefits of the technique are likely to include a reduced need for chemical plant protection products (PPP) and an elevation of natural enemies in the crop.

In UK strawberry, the European tarnished plant bug (*Lygus rugulipennis*) and the common green capsid (*Lygocoris pabulinus*) are two potential targets for push-pull. *L. rugulipennis* can cause up to 80% crop loss due to misshapen fruits. In everbearers, it requires routine treatment with plant protection products, usually from June onwards. *L. pabulinus* may also be a damaging pest. Products currently used for control can disrupt biological control agents and increase residue levels in fruits.

In summer 2017, NIAB EMR generated promising data after trialing a push-pull strategy for capsids in four commercial everbearer strawberry crops in Kent. Findings 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, the objective was to continue the development of this push-pull strategy. Field trials were performed in four everbearer strawberry plantations in Kent, to test: 1) whether a significantly improved push could be achieved when using the 2017 push in combination with a second one, 2) capsid damage (cat-facing of the fruit) could be reduced where treatments were applied and 3) if the additional push also attracts natural enemies into the crop.

Summary of the project and main conclusions

The experiment was conducted between July and September in four tunnel grown commercial strawberry plantations in Kent. To compare the different push-pull variations, each plantation was divided into the following four equal sized plots;

1) A push-pull plot, where the push was the same as 2017.
2) A push-pull plot, testing a new push.
3) A push-pull plot, testing the 2017 push with the new push and.
4) A control plot with no push or pull.

The pull was the same as 2017, consisting of traps holding a lure and a killing agent, positioned at regular intervals around the perimeter of the push-pull plots.

Fortnightly assessments were made in all four plots at each of the four plantations. Assessments consisted of tap samples of 50 strawberry plants for capsids and natural enemies within the plots, counts of capsids in traps around the perimeter of push-pull plots and damage assessments of approximately 100 strawberries within the plots, at each visit.

In 2018 results were inconclusive. Capsid numbers from both tap samples and trap counts were low (lower than 2017) and therefore unsuitable for statistical analysis. The same applied to natural enemy numbers. Results from the fruit damage assessment showed no significant difference between any of the push-pull variants and the control, unlike in 2017. Climatic conditions in 2018 were unusual in being very warm and dry. This is believed to have contributed to the low capsid counts.

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. The development of improved trap and monitoring systems for capsids will help growers to identify the exact time of their appearance in the crop, allowing control measures to be implemented at the optimum time.

Should traditional spray control products be employed, the numbers required can be reduced by applying at the optimum time, saving money on unnecessary sprays. Novel control methods such as the 'push-pull system' will help to reduce reliance on traditional control products, which will further reduce crop protection costs for growers. Such a system will also enhance biological control methods employed for other pests, increasing their efficacy and reducing the need to introduce additional numbers of predatory mites, further reducing costs.

Action points for growers

- There are no grower actions points for growers at this stage of the research.

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

Headlines

- A single application of the approved product Batavia or the coded product AHDB9966 gave durable (up to three weeks) and effective control of the melon-cotton aphid.
- Applications of two other coded experimental spray treatments (AHDB9934 and AHDB9951) were also very effective at killing aphids and protecting strawberry plants.

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-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 aphicides. The remaining 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 making 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, and like the potato aphid, it causes feeding damage and contaminates fruit with honeydew and cast skins. In addition, melon-cotton aphids are known to be resistant to multiple classes of plant protection products, 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 melon-cotton aphid. Comparisons were made with untreated control plants and with plants treated with four approved products (Batavia, Flipper, Met52 OD and Majestik).

Summary of the project and main conclusions

- Single applications of the coded product AHDB9966 and the approved insecticide product Batavia gave effective control of melon-cotton aphid on strawberries.
- Effective aphid control was also achieved using two applications of two further coded products: AHDB9934 and AHDB9951.
- 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, in practice, growers are likely to apply these treatments using shorter spray intervals than used in this experimental trial.

Financial benefits

Potentially, if not controlled, aphid infestations can lead to complete crop loss. No quantitative data on industry average losses from aphids is available but conservatively, assuming that 1% of the crop is lost, this is equivalent to 1,316 tonnes of strawberries; worth £2.7 million per annum (Defra Horticultural Statistics 2018). Improved control as a result of this work would reduce the scale of these losses considerably.

Action points for growers

- Batavia provides effective control of melon-cotton aphid and other aphid species which damage strawberries. However, application of this product to strawberry crops (both protected and unprotected) is restricted to the pre-flowering period. Two applications of Batavia are permitted each year, but it can only be applied up to 14 days before flowering and not during the flowering / cropping period.
- Carefully consider early season control sprays and wherever possible, choose benign products which are sympathetic to aphid parasitoids and any biocontrol agents being employed to control other pests.
- To help inform product selection, visit website: https://www.koppert.com/side-effects/ or http://www.biobestgroup.com/en/side-effect-manual

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

Headline

- Adults of five thrips species that can damage strawberry fruit were confirmed at four sites during 2018 where rose thrips had been the predominant species in 2017.

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. ADAS has recently 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 of species 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 have 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 control 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).

Adult female rose thrips and other *Thrips* species are darker than WFT and 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 a number of crop protection products.

The aims of the project are to:

1. Determine when adult thrips species activity starts in strawberry crops and identify peaks in numbers between March and August inclusive.
2. Determine if larvae of species other than WFT develop in strawberry flowers.
3. Record fruit damage associated with *T. fuscipennis* and other thrips species in flowers.

Summary of the project and main conclusions

- Adults of five thrips species that can damage strawberry fruit were recorded at four sites in 2018 where fruit damage attributed to rose thrips had occurred during 2017.
- 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.
- The rose thrips (*Thrips fuscipennis*) was recorded at all four sites and was the predominant species during June in the two outdoor everbearer crops in Essex and Buckinghamshire, with mean numbers peaking in late June and early July at 0.8 and 1.5 per flower. Rose thrips numbers peaked in early August in the tunnelled crops in Kent with means of three and 0.6 per flower.
- Numbers of the combined species peaked on 11 July in the two outdoor everbearer crops at around four adults per flower and these were mainly the flower thrips (*Frankliniella intonsa*), with means of 3.1 and 1.9 per flower. This species occurred in much higher numbers than usual in strawberry flowers in 2018, possibly due to the unusually hot summer. Severe fruit damage due to *F. intonsa* occurred in Denmark in 2018 where mean numbers exceeded 20 per flower.
- In the two tunnelled everbearer crops, numbers of thrips adults peaked on 3 August and 20 September at 46 and 13 adults per flower respectively and these were mainly western flower thrips (WFT).
- Low numbers of thrips larvae were found in flowers in the outdoor everbearer crops during July and August and these are likely to be species other than WFT. Thrips larvae were found in higher numbers in the two tunnelled everbearer crops between July and early October and these are likely to be mainly WFT. Thrips larvae at all sites will be identified during 2019.
- Fruit damage was only slight in the two outdoor and one of the tunnelled everbearer crops. The damage may have been caused by a mixture of *F. intonsa*, *T. fuscipennis*, *T. tabaci* and *T. major* adults in the two outdoor everbearer crops and is likely to have been caused by WFT in the tunnelled crop. More severe damage occurred in the second tunnelled everbearer crop where high numbers of WFT led to a mean of 7.3% fruit area bronzed. However, this is below the 10% fruit area bronzed that is considered to be the threshold at which fruit is downgraded.
- However, *F. intonsa*, *T. fuscipennis*, *T. tabaci* and *T. major* adults may also have contributed to the damage. More severe damage occurred in the second tunnelled everbearer crop where a maximum mean of 7.3% fruit area was bronzed. However, this

is below the 10% fruit area bronzed that is considered to be the threshold at which fruit is downgraded. WFT was the dominant species in this crop but *F. intonsa*, *T. fuscipennis*, *T. tabaci* and *T. major* adults may also have contributed to the damage.

- Numbers of thrips in the two outdoor everbearer crops are likely to have been kept below damaging levels by a combination of released predators (*N. cucumeris* and *Orius*) and naturally-occurring predators including the banded wing thrips and by plant protection products applied for the control of SWD.
- An effective IPM programme needs to be developed for control of a range of thrips species that can cause fruit damage, including components for control of both adults and larvae. The biology and behaviour of thrips species other than WFT on strawberry is currently largely unknown. *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. Although most thrips species other than WFT still seem to be susceptible to plant protection products, there is a risk of resistance developing so reliance on control with such products is not sustainable.

Financial benefits

Western flower thrips can cause financial annual losses to the UK strawberry industry in excess of £15m if IPM techniques are not deployed. Financial loss due to other thrips species is still not known, but these species have the potential to cause severe losses if effective IPM strategies are not developed in future.

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. Useful guidance is set ou in AHDB Factsheet 14/15. The salient points are summarised below:

- Release the predatory mite *Neoseiulus cucumeris* regularly throughout the season from first flower. 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.
- 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 this species is 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* are 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 adults of other thrips species. Colour preference in other thrips species is being investigated in this project during 2019.
- 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. Consult your agronomist to seek help in getting the thrips species identified and for choosing a plant protection product if required.

SCIENCE SECTION

Objective 1. Develop effective biological methods for managing western flower thrips, *Frankliniella occidentalis* (WFT), compatible with pesticide use for control of spotted wing drosophila, *Drosophila suzukii* (SWD)

Task 1.1 Develop and determine the efficacy and ease of use of the prototype extraction device for WFT and the predatory mite *N. cucumeris* in commercial strawberry crops, by agronomist and growers

Introduction

In 2015, methyl isobutyl ketone (MIK) was shown to be effective as a fumigant to extract arthropods from button fruit, with higher numbers recorded by extraction compared to 'by eye' assessments of flowers or fruits (see 2016 Annual Report). After testing three prototype monitoring devices – each making use of the MIK fumigant extraction method - a "Tupperware" type device (Figure 2.1.) was selected for further development based on its robustness, ease of use, and transparency.

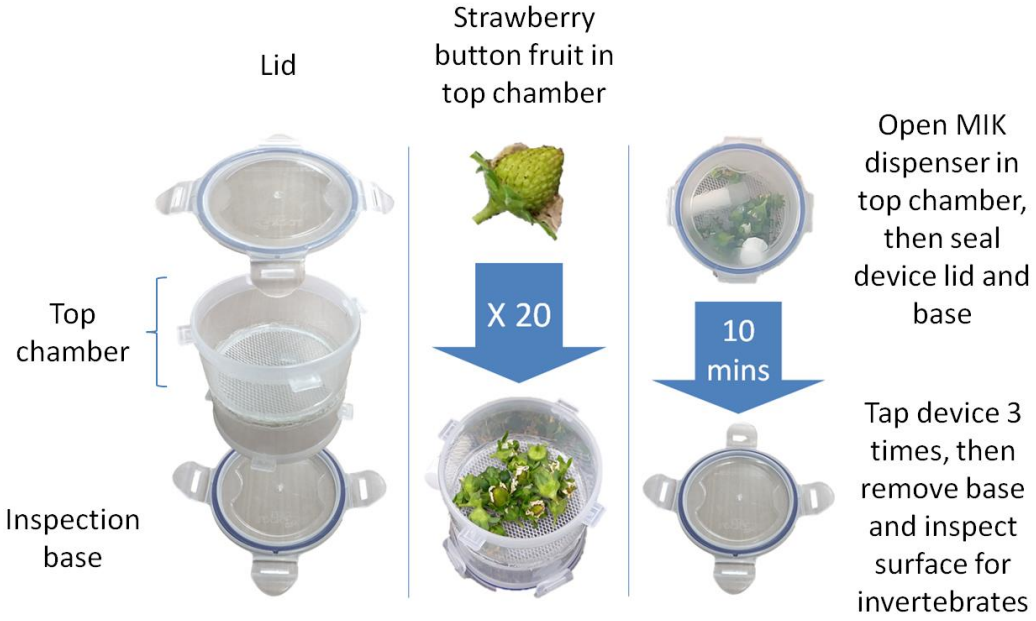


Figure 2.1. Diagram of extraction device (10 x 10 cm) with instructions for use

Following initial laboratory studies to assess the efficacy of this device in extracting thrips and mites from flowers and fruits (see 2017 Annual Report), further laboratory trials were carried out in the summer and autumn of 2017 to achieve a more thorough calibration. Laboratory findings showed that from individual fruits placed in the extraction device, there was a close correlation between the numbers of *N. cucumeris* released and the numbers recovered (R^2=0.987), which indicated that around 57% of the mites that were present on the button fruit

were recovered, however, under field operation with more variable conditions and using a hand lens rather than a microscope, the recovery of mites from button fruit using the extraction device represented a much lower proportion (27%). In 2018, the objective was to finalise calibration of this device using the following four trials:

Trial 1 and 2. Improve MIK dispenser release (NRI):
To improve the MIK release rate whilst minimising user exposure, a laboratory study was conducted at NRI to optimise the MIK dispenser. Firstly a study was performed to improve MIK release from the dispenser into the device chamber. To investigate this, three modifications were made to the MIK dispenser. Subsequently, a laboratory experiment was conducted, comparing these modified dispensers for levels of MIK release over time. Secondly, the dispensers were assessed for potential user exposure to MIK to determine the most suitable dispenser to proceed with. Two examples of Safety Data Sheets for use by growers were downloaded by NRI, and instructions for safe use of the extraction device provided (see Appendix 1.1 and 1.1.2 respectively) which will be included in any future availability of the device.

Trial 2. Determine the minimum time for maximum *N. cucumeris* extraction:
In parallel to Trial 1, a field experiment was conducted to investigate whether the time taken to extract the maximum number of arthropods from button fruits could be reduced below 20 minutes – the time period used for testing the device in 2017. Five replicates of twenty button fruits were sampled from a commercial strawberry crop and exposed to MIK from the dispenser for 1, 3, 5, 10 and 20 minute intervals. Subsequently, relative percentages of arthropods extracted at each of these time intervals were compared.

Trial 3. Determine the maximum number of uses from the MIK dispenser:
Previously, MIK loading into the release device was calculated to give approximately 20 MIK dispenser uses. To investigate the possibility of increasing this number of uses, work was conducted at NRI to increase MIK loading in the dispenser (Trial 1). Subsequently, a field trial was conducted to indicate the maximum number of times this modified MIK dispenser could be used to extract arthropods on samples of 20 button fruits.

Trial 4. Confirm temperature effects on *N. cucumeris* extraction:
Previous findings showed that *N. cucumeris* extraction using the MIK device was affected by temperature. To confirm this finding, *N. cucumeris* extraction was evalutated in the field at

different temperatures. To achieve different temperatures extraction was performed at different times throughout the day (09.00; 12.00; 15.00; 18.00; 20.00). At each time point samples of 20 button fruits were exposed to MIK and the temperature was recorded. Subsequently, the percentage of arthropods extracted from the button fruits at each temperature were analysed.

Materials and methods

Locations:

- *Trial 1*: Laboratory at NRI
- *Trials 2 & 3*: a commercial everbearer strawberry crop in Kent, where *N. cucumeris* had been deployed five times between 16 May and 25 July at a rate of approximately 200 m^{-1} to control thrips and pest mites during the summer (Appendix 1.3.1).
- *Trial 4*: another commercial everbearer strawberry crop in Kent, same variety as Trials 2 and 3. At the time of the trial, *N. cucumeris* had not been released for over a month so the day before the trial start, NIAB EMR deployed 200,000 *N. cucumeris* evenly along four 50 metre rows (a rate of approximately 1000/metre to increase the chance of *N. cucumeris* detection), following approval from the grower.

Dates:

- *Trial 2:* 16 July 2018
- *Trial 3:* 6 August 2018
- *Trial 4:* 7 - 12 of September 2018

Sampling:

Trials 2, 3 and *4*: Twenty button fruits were sampled for each replicate. Button fruits were sampled from the crop by walking along four 50 metre rows and picking at regular intervals from various positions on the plant. Button fruits were alternately placed in the top chamber of replicate extraction devices until a total of 20 were reached in each.

Treatments:

Trial 1: To improve MIK release into the extraction device chamber and reduce user exposer to MIK, three MIK dispenser modifications were tested:

1. A larger (‘size 2’) dental roll carrying more MIK (3 ml) than the variety of dental roll previously tested (1.25 ml), inserted into the dispenser. Besides a higher MIK load and anticipated release rate than previously used, this dispenser had the added advantage of being activated by unscrewing and removing the lid.

2. A ‘size 2’ dental roll carrying 3 ml MIK, with complete removal of the dental roll from the dispenser. Although this modification was anticipated to give a higher MIK release, complete removal of the dental roll was likely to increase the possibility of user exposure to MIK, principally through physical contact.
3. Two ‘size 2’ dental rolls each carrying 3 ml MIK, packed into the device to increase MIK loading and prevent the dental rolls from falling out. Again the dispenser could be activated by removing the lid to minimise user exposure.

Trial 2: Five MIK exposure time intervals (1, 3, 5, 10 and 20 minutes) were selected for *N. cucumeris* extraction. For each exposure time interval, five extraction devices were used, representing five replicates. Extractions were conducted on the same farm the same day

Trial 3: Thirty MIK dispensers were used to test the maximum number of uses of the MIK dispenser. Each consecutive dispenser was prepared to have more uses than the last. The MIK dispensers were prepared outdoors at NIAB EMR to have 0, 1, rising in steps of 2 up to 57 uses, predicted to be sufficient to confirm previous laboratory calculations from NRI that the device could be effective for at least 20 uses. Extractions were conducted on the same farm the same day.

Trial 4: Five daily time points (09.00; 12.00; 15.00; 18.00 and 20.00) were selected for *N. cucumeris* extraction. For each daily time point, similar to those used in 2017, five extraction devices were used, representing five replicates. Extractions were conducted on the same farm and repeated on three separate days.

For Trials 2, 3 and 4, local temperature and humidity was recorded using data loggers (Lascar, EL-USB-2) (Appendix 3.2.3). All dispensers were made at NRI.

Assessments:

Trial 1: To test the MIK release efficacy of the modified dispensers, MIK release was measured over time. Tests were conducted at ~ 20 °C. Dental rolls were weighed before and after testing to determine MIK release (mg).

Trials 2, 3 and *4*: Field extractions of arthropods (Figure 2.2) were conducted on the same day and involved two people, one recording time and arthropod counts, the other viewing the inspection lid using a hand lens (X20 magnification) and counting extracted arthropods, then relaying counts for recording. For each extraction and replicate (Trials 2 and 4), lids were unscrewed from the MIK dispensers and dispensers were placed into the top chamber of the device on top of the 20 button fruits. The extraction device was then sealed immediately. At the end of the extraction, each replicate device was tapped three times on the side and the lid removed. The MIK dispenser was also removed and re-sealed. Button fruits from the

device were transferred to pots of 70% ethanol (labelled with date and replicate number) and returned to the laboratory at NIAB EMR for washing and counting following SOP 780. Arthropods on the inspection lid were then counted and recorded for each replicate. This process was repeated for each extraction.

Numbers of arthropods observed in each sample of 20 button fruits were used to calculate percentage detection, as a proportion of the total numbers present (total present = numbers extracted using the device plus numbers recovered using the ethanol wash technique).

Statistical analysis:
Trials 2, *3 and 4*: GLM with a binomial distribution & a logit link.

Figure 2.2. Top row: five replicate extraction devices, each containing 20 button fruits and an open MIK dispenser in the top chamber. Bottom row: five corresponding pots of 70% ethanol for button fruits to be transferred to after MIK fumigation

Results

Trial 1. Improve MIK dispenser release (NRI):

Three modifications of the MIK dispenser were compared by measuring the release of MIK (mg) over time:

1. The MIK dispenser containing a single dental roll released 14 mg of MIK after 10 minutes which was higher than the dispenser used in 2017. After 20 minutes, the dispenser released 25 mg of MIK.
2. The MIK dispenser with removable dental roll released 67 mg after 10 minutes which was the highest rate of MIK release of all three dispensers.
3. The dispenser containing two ‘size 2’ dental rolls secured inside the dispenser, released 25 mg of MIK after 10 minutes. This was a higher release than the first dispenser tested

and the dispenser used in 2017, but lower than the second dispenser. However, the dental rolls remained securely inside the dispenser as apose to the second dispenser where the dental roll needed to be completely removed, thus reducing the chance of user exposure. For these reasons, the third dispenser was selected for Trials 2, 3 and 4.

Trial 2. Determine the minimum time for maximum N. cucumeris extraction:

For *N. cucumeris*, pale thrips and dark thrips, the mean percent extracted from 20 strawberry button fruit using the device was significantly different depending on length of exposure to MIK (P = <.001), the exceptions were *Orius* and aphids, but mean numbers were low (grand mean = 1.3 and 1.9 respectively). For *N.* cucumeris, pale thrips and dark thrips (not identified to species), mean percent extracted was positively correlated with length of exposure to the MIK fumigant (Figure 2.3). However, following multiple pair-wise comparisons, mean percent extracted did not significantly increase after 10 minutes exposure. Mean percent *N. cucumeris* extracted plateaued at 57%. The 10 minute exposure period was selected for Trials 3 and 4. The average temperature in the tunnel during the assessment period (approximately 11:00 to 15:00) was 40.9 °C; though possibly attributable to the logger being placed on the ground of the tunnel during the assessment.

Trial 3. Determine the maximum number of uses from the MIK dispenser (Figure 2.4):

For *N. cucumeris,* pale thrips and *Orius* extracted, there was no significant difference in percentage extracted from strawberry button fruit and number of MIK uses (grand mean = 5.1, 25.1 and 27.3 respectively). The exception was dark thrips, however mean numbers per 20 button fruits were low (grand mean = 2.6). Overall mean percent of *N. cucumeris* extracted was 21.8%. The average temperature in the tunnel during the assessment period (approximately 11:00 to 16:00) was 34.2 °C.

Trial 4. Confirm temperature effects on N. cucumeris extraction:

Following statistical analysis, mean percent of *N. cucumeris* extracted was not significantly linked to temperature or time of day (grand mean = 22.6 %). However, though not significant, mean percent extraction and temperature did appear to be positively correlated (Figure 2.5), whereby extraction was lowest at 09:00 and 20:00 (22.1% and 21.6% respectively) when average temperatures were coolest (16.9 °C and 13.9 °C respectively) and highest at 15:00 (44.5%) when average temperature was warmest (20.6 °C).

Mean *N. cucumeris* extraction levels after 10 minutes for Trials 2, 3 and 4 were 57%, 21.8% and 44.5% respectively.

Of the other arthropods extracted, time of day had a significant effect on mean percent of aphids and dark thrips extracted (P = <.001 and 0.029 respectively). Mean percent aphid

extraction was highest at 15:00 (56.5%) and lowest at 20:00 (15.3%). Mean percent dark thrips extraction was highest at 9:00 and 12:00 (both 71.4%) and lowest at 20:00 (0%). However mean numbers of both groups of arthropods in samples of 20 button fruits was low (grand mean = 1.2 and ~ 0.2 respectively). Temperature and time of day did not have a significant effect on mean percent of *Orius* and pale thrips (adults and nymphs) extracted, though mean numbers per 20 button fruits were also low (grand mean = 1 and ~ 0.7).

Thrips (pale and dark) remaining in button fruit samples were also identified (Table 1.1). Following ethanol extraction and slide mounting, life stage and species composition was determined. The most abundant were thrips larvae (total = 59), these were not identified to species. Of the adults, *Thrips tabaci* (total = 15) was the most common. The least common was *Thrips funeb*ris (total = 1).

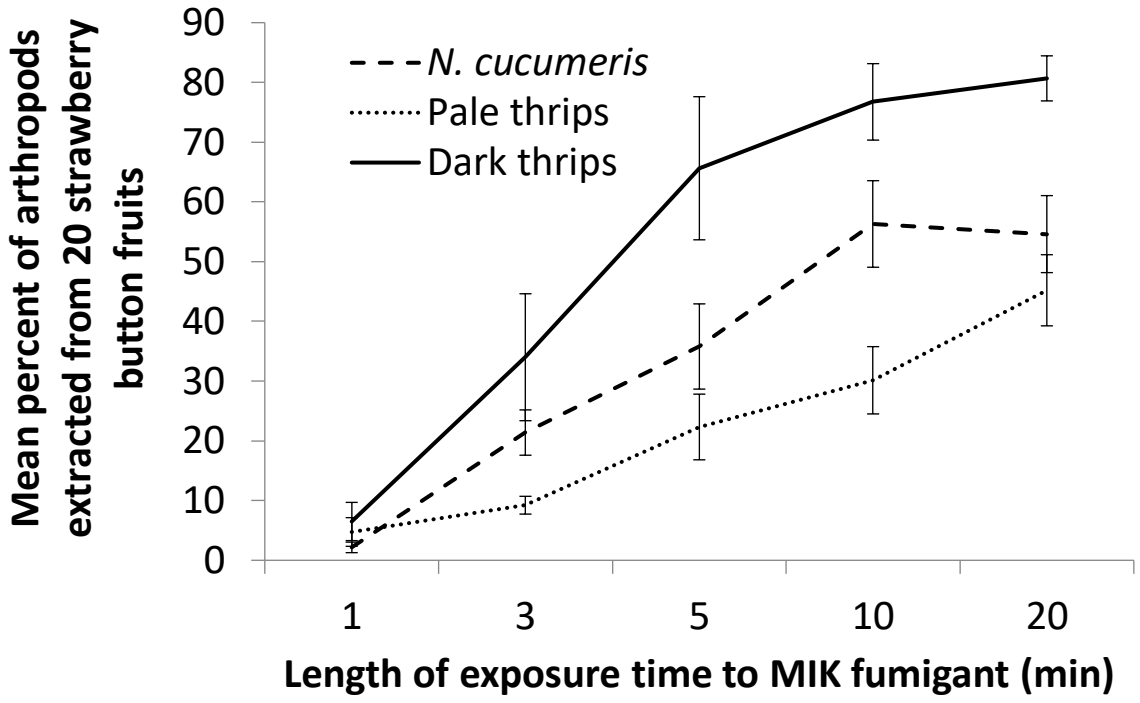


Figure 2.3. Trial 2: Effect of MIK exposure on mean number of arthropods extracted from 20 strawberry button fruit

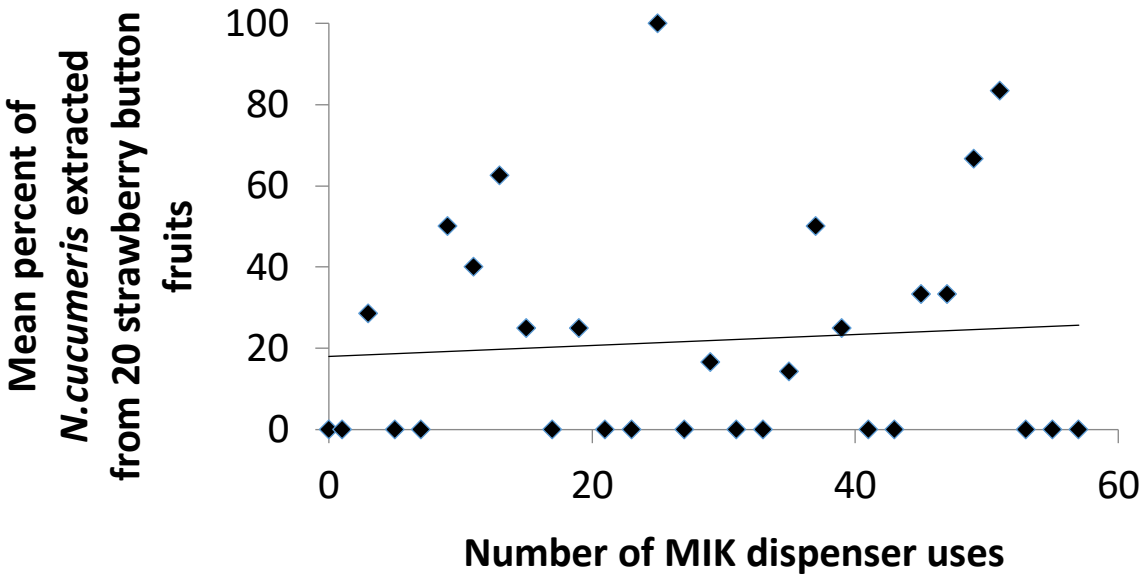


Figure 2.4. Trial 3: Effect of number of MIK dispenser uses on mean number of *N. cucumeris* extracted from 20 strawberry button fruit

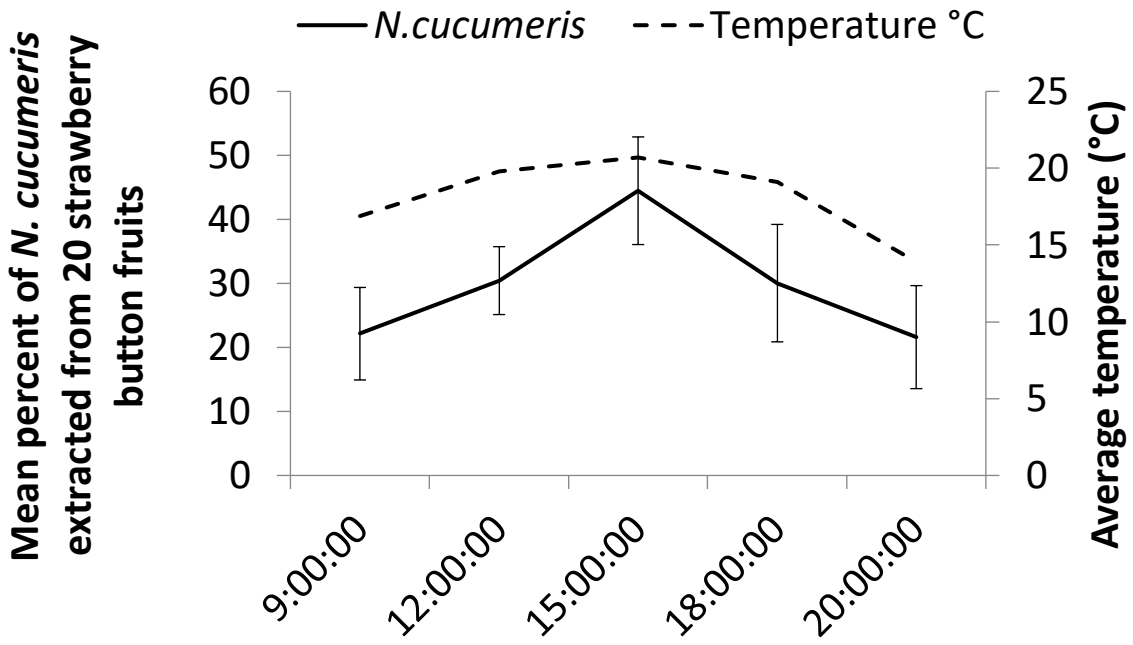


Figure 2.5. Trial 4: Effect of temperature (right axis) and time-of-day on mean number of *N. cucumeris* (left axis) extracted from 20 strawberry button fruit using the *N. cucumeris* extraction device

Table 1.1. Trial 4: total numbers of thrips (larvae and adults) extracted using EtOH from button fruits at different time points

Time	Average temp. °C	No. of button fruit	Thrips larvae	*Frankliniella occidentalis*	*Thrips major*	*Thrips funebris*	*Thrips tabaci*	Unidenti-fiable
09:00	16.9	300	22	0	1	0	3	0
12:00	19.8	300	7	0	1	1	3	2
15:00	20.7	300	9	0	0	0	1	0
18:00	19.1	300	11	1	0	0	4	0
20:00	13.9	300	10	1	3	0	4	0
	Total	1500	59	2	5	1	15	2

Discussion

To improve release of MIK and reduce user exposure, three different MIK dispensers were tested at NRI. After 10 minutes, dispenser two with removable dental roll produced the highest release of MIK (67 mg at room temperature). However this modification posed a higher risk of user exposure to MIK because the dental roll had to be completely removed from the dispenser by hand as it was difficult to fasten securely to the lid; MIK rendered glues ineffective. Also, 67 mg might have been a wasteful release amount of MIK if *N. cucumeris* and other arthropods require less to be extracted, though this was not confirmed. The better alternative from an operator perspective for field testing was determined to be dispenser three containing two ‘size 2’ dental rolls saturated in MIK. These fitted securely into the device chamber, preventing escape and lowering user contact exposure, and produced a higher MIK release than the dispenser used in 2017 (25 mg in 10 minutes as opposed to 14 mg). As a result, this dispenser was selected for field tests in Trials 2, 3, and 4.

To determine the minimum time for maximum arthropod extraction, the extraction device was tested at five different MIK exposure times (1, 3, 5, 10 and 20 minutes) on samples of 20 strawberry button fruits on the same day. Subsequently, the mean percent of arthropods extracted was compared for each exposure. Overall, the mean percent of *N. cucumeris*, pale thrips and dark thrips extracted was significantly different depending on exposure time (Figure 2.3). *Orius* and aphids were not significantly effected, but mean numbers were too low for statistical analysis (grand mean = 1.3 and 1.9 respectively). There was a positive correlation between the length of exposure to the MIK fumigant and the mean number of *N.* cucumeris, pale thrips and dark thrips extracted up to 10 minutes exposure, after which mean percent extracted did not significantly increase. Mean percent *N. cucumeris* extraction plateued at 57%. This result was similar to Trial 2 laboratory findings in 2017 after 20 minutes exposure

(57.8% and 58.4%). Of note: after 10 minutes exposure, arthropods on the inspection lid remobilised slightly after a minute. This feature enabled counting of the small arthropods without the assistance of a hand lens. As a result of these findings, the 10 minute exposure period was selected for Trials 3 and 4.

To determine the maximum number of uses from the MIK dispenser, arthropod extraction was assessed using 30 dispensers prepared with uses ranging from 0 to 57. For *N. cucumeris,* pale thrips and *Orius*, there was no significant difference in percentage extracted from strawberry button fruit and number of MIK uses (Figure 2.4). For predatory thrips there was no significant difference either, but mean numbers were very low (grand mean = 0.2). For dark thrips there was a significant difference, but mean number per 20 button fruit was low (grand mean = 2.6). Overall mean percent of *N. cucumeris* extracted was 21.8%, less than half that found in Trial 2 (57%). This may be due to the low and variable number of *N. cucumeris* recovered per 20 button fruits (grand mean = 5.1). Correspondence with the grower confirmed *N. cucumeris* had stopped being released nearly two weeks prior to this trial. Mean percent *N. cucumeris* extraction appears more variable when mean number of mites on button fruit samples is below 10. During 2018 Trials 3 and 4, and 2017 Trial 2, mean percent *N. cucumeris* extraction was 21.8%, 44.5% and 39.6% when mean numbers were 5.1, 7.6 and 6.4 respectively. Whereas during 2018 Trial 1 and 2017 Trial 2, mean percent *N. cucumeris* extraction was 57%, 57.8% and 58.4% when mean numbers were 28.1, 11.5 and 25.7 respectively, however further testing is needed to confirm this. Findings here indicate that the MIK dispenser developed in Trial 1 is suitable for at least 57 uses; however, given the low numbers of *N. cucumeris* upon which this assumption is based, a repeated test would be advised.

To confirm the temperature effects on *N. cucumeris* extraction, 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 exposed to MIK at each time point. Subsequently, the percentage of arthropods extracted from the button fruits at each time point and corresponding temperature were analysed. Findings showed that the mean percent of *N. cucumeris* extracted was not significantly 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. During Trial 4 the effect of temperature was not fully explored. Average temperatures ranged from 13.9 °C at 20:00 to 20.7 °C at 15:00 (Figure 2.5). It may be that percent extraction is significantly effected by temperature, but outside this range. To assess this possibility, further studies at more extreme temperatures are recommended. The

highest mean percent of *N. cucumeris* extracted was 44.5% at 15:00. This percent extraction was lower than that of Trial 1 (57%), however a significant proportion of the mites were still extracted.

Of the other arthropods extracted, time of day had a significant effect on mean percent of aphids and dark thrips extracted. However mean numbers of both groups of arthropods was low (grand mean = 1.2 and ~ 0.2 respectively). Temperature and time of day did not have a significant effect on mean percent of *Orius* and pale thrips (adults and larvae) extracted, though numbers were also low (grand mean = 1 and ~ 0.7). Further investigation of percent extraction of other arthropods according to temperature and time of day is recommended.

Thrips (pale and dark) from Trial 4, remaining in button fruit samples after MIK extraction, were also identified (Table 1.1). The most abundant were thrips larvae (total = 59, not identified to species). Of the adults, *Thrips tabaci* was most common (total = 15) and *Thrips funeb*ris was least common (total = 1). *Frankliniella occidentalis* and *Thrips major* were also identified, but in very low numbers (total = 2 and 5 respectively). Thrips identified are those commonly found in UK strawberry; however mean numbers were too low for statistical analysis.

Other factors should also be taken into consideration if using this device to estimate numbers of *N. cucumeris*. In 2017, it was found that a 1 °C increase in mean temperature could result in an approximate 2.5% reduction of numbers of *N. cucumeris* counted in sample units (e.g. strawberry button fruits). Also button fruit density in the crop is expected to influence arthropod density, i.e. a higher button fruit density will dilute arthropod density.

Conclusions

- A *N. cucumeris* extraction device has been developed and could be produced ready for grower and agronomists to use.
- MIK is an effective extraction fumigant and the new design reduced exposure to the skin of the user.
- The device should be closed for a minimum of 10 minutes to be effective.
- The device can be used to detect other arthropods including *Orius*, predatory thrips and aphids within 10 minutes exposure; however mean numbers were too low during this trial to calibrate the device for their extraction.
- When mean numbers present on the button fruits exceed 10, the extraction efficacy of *N. cucumeris* is around 57%, but below this, extraction efficacy can vary to as low as 22%. However, as the crops are inspected regularly a pattern of numbers in the crop can be recorded and plotted to enable decision making for biocontrol releases and the need for plant protection product application.

- Our findings suggest the MIK release tube extracts for at least 57 uses, although this is based on low mean numbers of *N. cucumeris* in button fruit samples. However, laboratory tests suggest they should last for 101 uses.
- Performance is not affected by time of day or temperature within the range of 13.9 °C and 20.7 °C.

Future Work

- The device should now be manufactured and made available.
- A factsheet and instructions should be developed.

Task 1.2. Testing *Metarhizium brunneum* (strain F52) against biological control insects used in strawberry production

Introduction

The Monsanto marketed product Met52 EC, containing the active ingredient *Metarhizium brunneum* strain F52 in an emulsifiable oil for suspending in water, is sold through Fargro in the UK. It is anticipated to become available to UK growers within 2019 for the control of pests such as thrips, whitefly and mites on commercially grown crops e.g. strawberries. The label does not, presently, show natural enemy compatibility. However, Fargro say that under the IOBC Classification system for non-target effects on augmentative and native biological control insects (Hassan, 1992), Met52 is classified as harmless against *Amblyseius swirskii, Macrolophus caliginosus* and *Nesidiocoris tenuis,* compatible (EPA tox) with *Chrysopa* spp. and *Nasonia vitripennis* and anecdotally not harmful to *Orius* spp. and *Hypoaspsis miles*. Testing is underway for *Encarsia formosa, Eretmocerus eremicus* and *Phytoseiulus persimilis*; and status is unknown for *Feltiella acarisuga* and *Aphidius* spp. Therefore, CABI was tasked with carrying out bioassays, testing Met52 (as product Met52 EC or the spores only F52) against three commercially produced natural enemy products, to fill a knowledge gap so that growers may best know how to utilise it within their growing systems.

Aims:

- Carry out a literature review on effects of *M. brunneum* strain F52 against Western Flower Thrips and natural enemies.
- The effect of *M. brunneum* strain F52 spores and Met52 EC on natural enemies used in UK strawberry growing systems

Systematic literature review of effects of *M. brunneum* strain F52 against Western Flower Thrips and natural enemies.

To establish which natural enemies had already been tested for effects of F52, a literature review was conducted prior to the commencement of work. A search using all synonyms for F52 were entered into CAB Direct (www.cabdirect.org).

There were 233 papers returned, of those, 142 were not applicable to the search criteria which left 91 papers of relevance. Of these seven were studies specifically on the use of Met 52 EC, but only one of these studies related to the control of Western Flower Thrips. Four papers were specifically targeted at strawberry growing systems.

From the returned search, two abstracts referred to the effects of F52 on non-target organisms directly (Saito & Brownbridge, 2016 and EFSA, 2012). Saito and Brownbridge (2016) tested the compatibility of soil-dwelling predators (a rove beetle, *Dalotia coriaria* (Kraatz); predatory mites, *Stratiolaelaps scimitus* (Womersley) and *Gaeolaelaps gillespiei* (Beaulieu) exposed to filter papers treated with Met52 EC. Their results showed corrected mortalities of 41.33%, 18.42% and 30.59% respectively when exposed to a high dose (containing 1 x 10^7 conidia/ml) and 19.07%, 21.04% and 36.37% when exposed to a low dose (containing 1 x 10^5 conidia/ml). Only *D. coriaria* was significantly different from the control when exposed to the high dose.

The effects on non-target organisms was summarised in EFSA (2012) Annex IIM 8; HIM 10 (https://www.efsa.europa.eu/en/efsajournal/pub/2498). The document shows there is evidence that direct application to *Orius majusculus* (dripping onto the insect at a rate of 5.1 x 10^8 CFU /mL) causes 70% mortality after seven days. In addition, mortality has been noted for *Chrysoperla carnea*, through dietary exposure at 4.2 x 10^5 CFU/mL, as 37% after 12 days and *Hippodamia convergens* (Coccinellidae) as 31% after 22 days. Laboratory assay mortality rates are shown in Table 1.2.1.

A further search was made in Google Scholar to ensure all papers were captured during the literature review. An additional paper by Fischoff et al. (2017) tested the effects of F52 on non-target organisms when the formulation was sprayed to control ticks; however, orders such as Coleoptera, Hymenoptera, Hemiptera and Diptera, which may contain predatory species, saw no negative effects.

Table 1.2.1. Laboratory mortality rates for non-target organisms from EFSA (2012).

Order	Predator/Parasitoid	Application method	Application strength	Mortality (%)	Time (days)
Hemiptera	*Orius majusculus* (Heteroptera: Anthocoridae)	Dripping onto insect	10^9 CFU/mL	70	7
Coleoptera	*Hippodamia convergens* (Coccinellidae)	Dietary	4.2x10^7 CFU/g feed	31	22
Hymenoptera	*Nasonia vitripennis* (Pteromalidae)	Dietary	4.2x10^7 CFU/g feed	20	26

Effect of *M. brunneum* strain F52 on natural enemies used in UK strawberry growing systems

Materials and methods

Natural enemies

The species tested in this trial were selected based on those used within strawberry growing systems in the UK and where gaps in the literature existed (Table 1.2.2). Originally, *Neoseiulus cucumeris* was listed to be tested, however a paper published by Saito and Brownbridge (2018) gave informative results for this species using Met52 EC, therefore this species was removed from the test list. All species sourced for testing were obtained from Koppert UK Ltd. Initial assays exposed insects to a high dose of *M. brunneum* F52 conidia (see Appendix 1.2) by using a dipping protocol. Those showing susceptibility were then taken forward for contact bioassays where insects were exposed to strawberry leaves sprayed with Met52 EC.

Dipping and contact bioassay treatments

Dipping: Using harvested F52 spores a suspension was prepared and adjusted to the recommended label rate for Met52 EC (1×10^7 conidia/ml). The insects were immersed in the suspension for 10 seconds and, once all the excess had been removed using a Buchner filter, they were transferred to a glass tube or bottle either in 10's or in individuals depending on the species. Two further treatments were included; a blank formulation control (sterile 0.05% Tween 80) and a no-treatment control (no dipping). The insects were checked for mortality only and not for mycosis. For further detail see Appendix 1.2

Contact: Using the Met52 EC a suspension in water was prepared to the tank mix concentration and applied to strawberry leaves, using a Burkard Computer Sprayer. The leaves were then air dried in a flow cabinet to remove excess moisture. Once dried, insects were exposed for three days and the leaves removed. Two further treatments were included; a blank control (codacide only) and a no spray control. All insects had a food source available to them for the duration of the assessments. The insects were checked for mortality only and not for mycosis. For further details see Appendix 1.2

Table 1.2.1. List of natural enemies used in dipping assays with *M. brunneum* F52 isolate suspended in sterile 0.05% Tween 80 at recommended label rate

Product	Latin name	Dose-dipping protocol	Lifestage	No. Reps
Thripor-L	*Orius laevigatus*	1 x 10^7 conidia/ml	Adult	5 per treatment, on 2 occasions*
Ervipar	*Aphidius ervi*	1 x 10^7 conidia/ml	Adult	5 per treatment, on 5 occasions
Aphiscout	*Aphidius colemani, Aphidius ervi, Aphelinus abdominalis, Praon volucre,* and *Ephedrus cerasicola.*	1 x 10^7 conidia/ml	Adult	5 per treatment, on 4 occasions
Aphidalia	*Adalia bipunctata*	1 x 10^7 conidia/ml	Larvae	5 per treatment, on 1 occasion**
Chrysopa	*Chrysoperla carnea*	1 x 10^7 conidia/ml	Larvae	5 per treatment, on 3 occasions

*denotes that assay was run six times but only two reps were useable due to high control mortality. ** denotes only one rep conducted as there was a supply issue with Aphidalia

Analysis:

Corrected mortality was calculated using Abbott's formula (Abbott, 1925). Differences in mortality between treatments were assessed using a generalised linear mixed effect model (GLMM) using binomial errors. A vector was created using the numbers dead and alive in each replicate at each time point, and a GLMM was applied to these data. A Chi-squared test was used to test to see whether the treatment effect was significant compared to a null model. Treatment contrasts were applied using Tukey post hoc test (using the 'lsmeans' function in

the emmeans package). All analyses were undertaken using R statistical software version 3.4.2. Structure of analysis in R is shown in Annex 1.2.

Results

Dipping Assays; Quantification of formulation. The F52 spore suspensions concentrations were quantified, prior to use, by using a Bright-Line™ Haemocytometer. In addition, a colony forming unit (CFU) test was prepared so that the concentration of living spores could be quantified (Appendix 1.2). Both results are recorded in Table 1.2.2.

Table 1.2.2. Mean concentration of F52 spore suspension used in dipping assay, quantified as both conidia/ml and CFU/ml concentrations. Figures given are ±1SE. Concentrations are equivalent to recommended label rate of Met52.

Product	Latin name	Mean conidia/ml (±1SE)	Mean CFU/ml (±1SE)	No. reps	Notes
Thripor-L	*Orius laevigatus*	1.11 x 10^7 (±1.43 x10^6)	8.46 x 10^6 (±5.81 x10^5)	2	6 completed, but high control mortality in 4 reps
Ervipar	*Aphidius ervi*	9.55 x 10^6 (±9.52 x10^5)	7.91 x 10^6 (±6.89x10^5)	5	Reps 1 and 2 only 7 days data, reps 3-5= 14 days data
Aphiscout	*Aphidius colemani, Aphidius ervi, Aphelinus abdominalis, Praon volucre,* and *Ephedrus cerasicola.*	1.13 x 10^7 (±1.07 x10^5)	1.02 x 10^7 (±1.84 x10^6)	4	Reps 1 and 2 no filter paper in no treatment control, high mortality. No treatment control discounted from these reps, but blank and formulation treatments kept for analysis.
Aphidalia	*Adalia bipunctata*	6.73 x 10^6 *	5.33 x 10^6	1	Supply issue with Aphidalia from Koppert
Chrysopa	*Chrysoperla carnea*	1.11 x 10^7 (±9.52 x10^5)	9.76 x 10^6 (±3.15 x10^6)	3	

* Denotes that only one replicate was achieved due to supply issues so there were no ± values

Mortality

Ervipar (*Aphidius ervi*)

Three days after exposure to *M. brunneum* F52 spores, using the dipping method, there was a significant difference in mortality of parasitoids between treatments ($\chi^2 = 64.0$, d.f. = 2, $P < 0.001$) with mortality significantly higher in the treatment exposed to F52 spores than in the formulation control (z ratio = 6.15, $P < 0.0001$), and the no treatment control (z ratio = -7.3, $P < 0.0001$) (Figure 1). There was no significant difference between the no treatment and formulation control (z ratio = -1.2, $P = 0.44$). On day seven, there was also a significant difference between treatments ($\chi^2 = 31.9$, d.f. = 2, $P < 0.001$), with significantly higher mortality in the F52 treatments compared to the no treatment and formulation control (z ratio = 5.0, $P < 0.0001$; z ratio = 4.6, $P < 0.0001$ respectively). On days 11 and 14, there were no significant differences between treatments ($\chi^2 = 5.3$, d.f. = 2, $P = 0.07$; $\chi^2 = 1.4$, d.f. = 2, $P = 0.49$ respectively) (Figure 1.2.1).

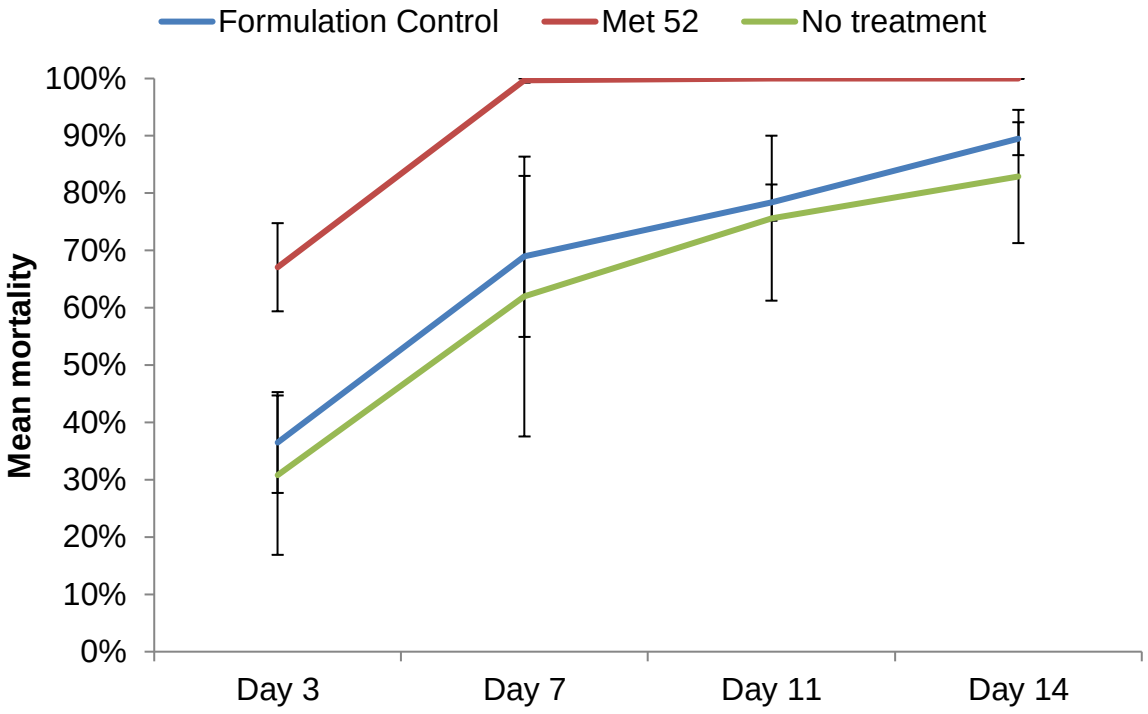


Figure 1.2.1. Dip Assay: Mean mortality over time of adult *Aphidius ervi* parasitoids in the Ervipar product (Koppert LTD) exposed to F52 *Metarhizium brunneum* spores suspended in 0.05% Tween 80, a blank formulation control (0.05% Tween 80) and no treatment (insects were not dipped). Data is from five separate experiments over time (±1SE)

Aphiscout (*Aphidius colemani, Aphidius ervi, Aphelinus abdominalis, Praon volucre,* and *Ephedrus cerasicola*)

On all assessment days, there was a significantly higher mortality recorded for parasitoids exposed to *M. brunneum* F52 spores, using the dipping method, than those exposed to the blank formulation and no dipping controls (day 3: $\chi^2 = 41.7$, d.f. = 2, $P < 0.001$ with z ratio = -5.6, $P < 0.001$ and z ratio = -2.4, $P = 0.04$ for the formulation and no treatment control respectively; day 7 $\chi^2 = 50.1$, d.f. = 2, $P < 0.001$ with z ratio = 5.4, $P < 0.0001$ and z ratio = -6.1, $P < 0.0001$ for the formulation and no treatment control respectively; day 11: $\chi^2 = 21.0$, d.f. = 2, $P < 0.001$ with z ratio = 3.9, $P < 0.001$ and z ratio = 3.7, $P < 0.001$ for formulation and no treatment controls respectively; day 14: $\chi^2 = 8.3$, d.f. = 2, $P = 0.02$ with z ratio = 2.1, $P = 0.04$ and z ratio = 2.73, $P = 0.01$ for formulation and no treatment controls respectively; Figure 1.2.2).

There was no significant difference between the no treatment and formulation controls on any of the assessment days apart from Day 3 (z ratio = 3.4, $P = 0.002$; z ratio = 1.0, $P = 0.56$; z ratio = -0.17, $P = 0.98$; z ratio = 0.72, $P = 0.75$, for days 3, 7, 11 and 14 respectively).

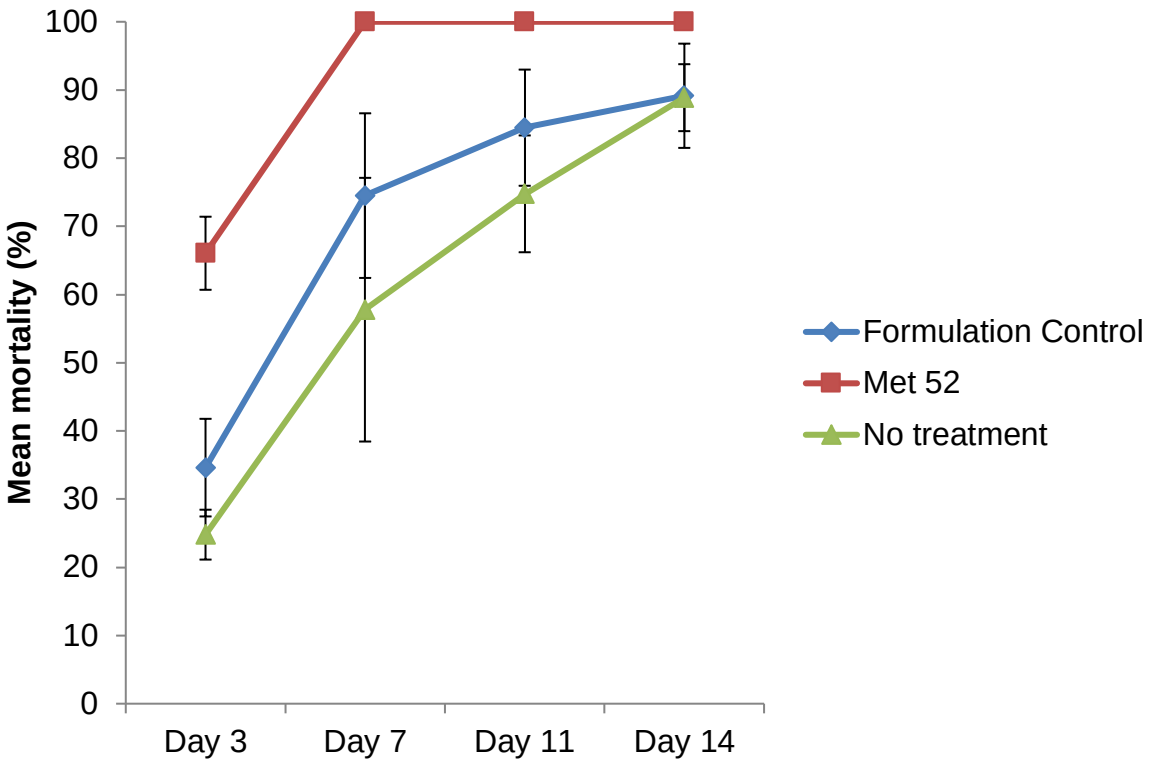


Figure 1.2.2. Dipping Method: Mean mortality over time of adult parasitoids in the Aphiscout product (Koppert LTD) exposed to F52 spores suspended in 0.05% Tween 80, a blank formulation control (0.05% Tween 80) and no treatment (insects were not dipped). Data is from four separate experiments over time except the controls which were from two experiments (±1SE)

Chrysopa (*Chrysoperla carnea*)

There was a significant difference between treatments on Days 3, 7 and 10 (χ^2 = 63.7, d.f. = 2, P < 0.0001; χ^2 = 43.5, d.f. = 2, P < 0.0001 and χ^2 = 25.0, d.f. = 2, P < 0.0001 respectively; Figure 1.2.3). On all days, mortality was significantly higher in the F52 treatment when compared to the no treatment control and formulation control (Day 3: No treatment: z ratio = -7.15, P < 0.0001, formulation control: z ratio = 5.45, P < 0.0001, Day 7: No treatment: z ratio = 6.19, P < 0.0001, formulation control: z ratio = 4.29, P = 0.0001, Day 10: No treatment z ratio = -4.71, P < 0.0001, Formulation control: z ratio = 2.62, P = 0.02 respectively). On all days there was no significant difference between the blank control and formulation control (Day 3: z ratio = - 2.05, P = 0.1, Day 7: z ratio = 2.13, P = 0.08, Day 10: z ratio = 2.3, P = 0.05 respectively).

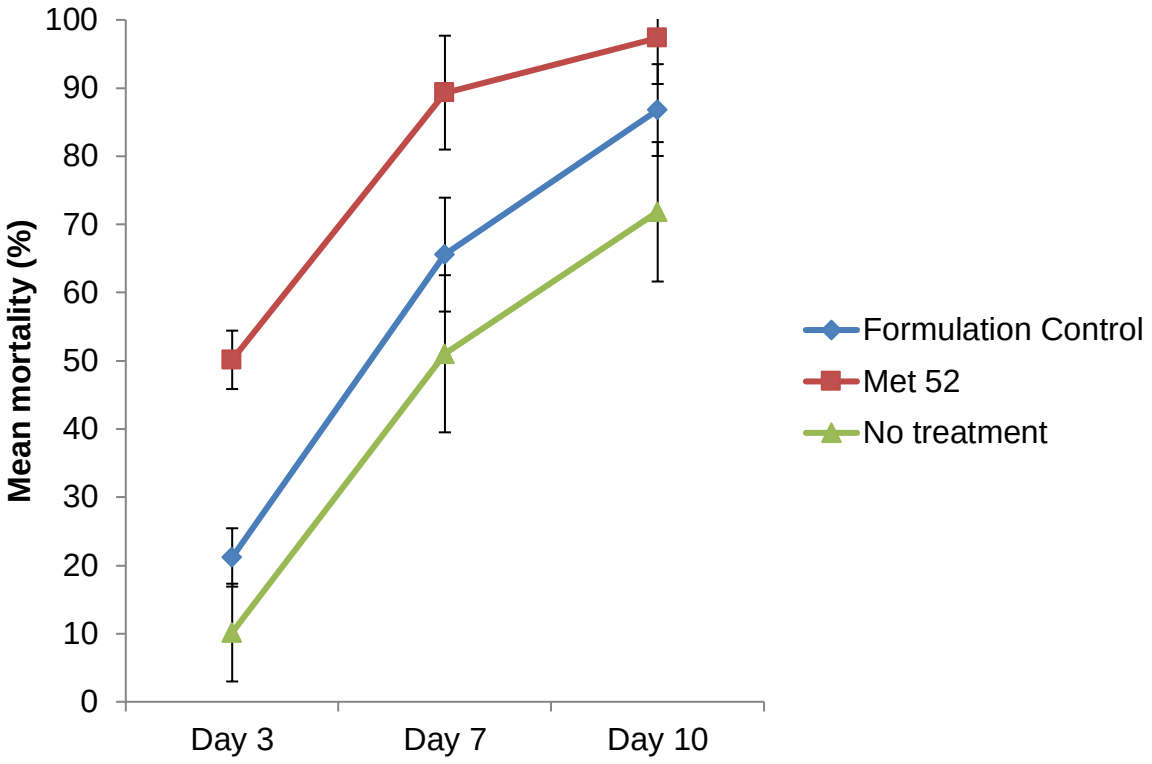


Figure 1.2.3. Dipping Method: Mean mortality over time of *Chrysoperla carnea* larvae exposed to F52 *Metarhizium brunneum* spores suspended in 0.05% Tween 80, a blank formulation control (0.05% Tween 80) and no treatment (insects were not dipped). Data is from 3 separate experiments over time (±1SE)

Thripor-L (*Orius laevigatus*)

There was a significant difference between treatments on Day 3 (χ^2 = 7.64, d.f. = 2, P = 0.02) but not on Days 7 and 10 (χ^2 = 1.70, d.f. = 2, P = 0.43 and χ^2 = 0.74, d.f. = 2, P = 0.69 respectively; Figure 1.2.4). On Day 3, mortality was significantly higher in the F52 treatment when compared to the no treatment control (z ratio = -2.52, P = 0.03) but not to the no formulation control (z ratio = 2.22, P = 0.06).

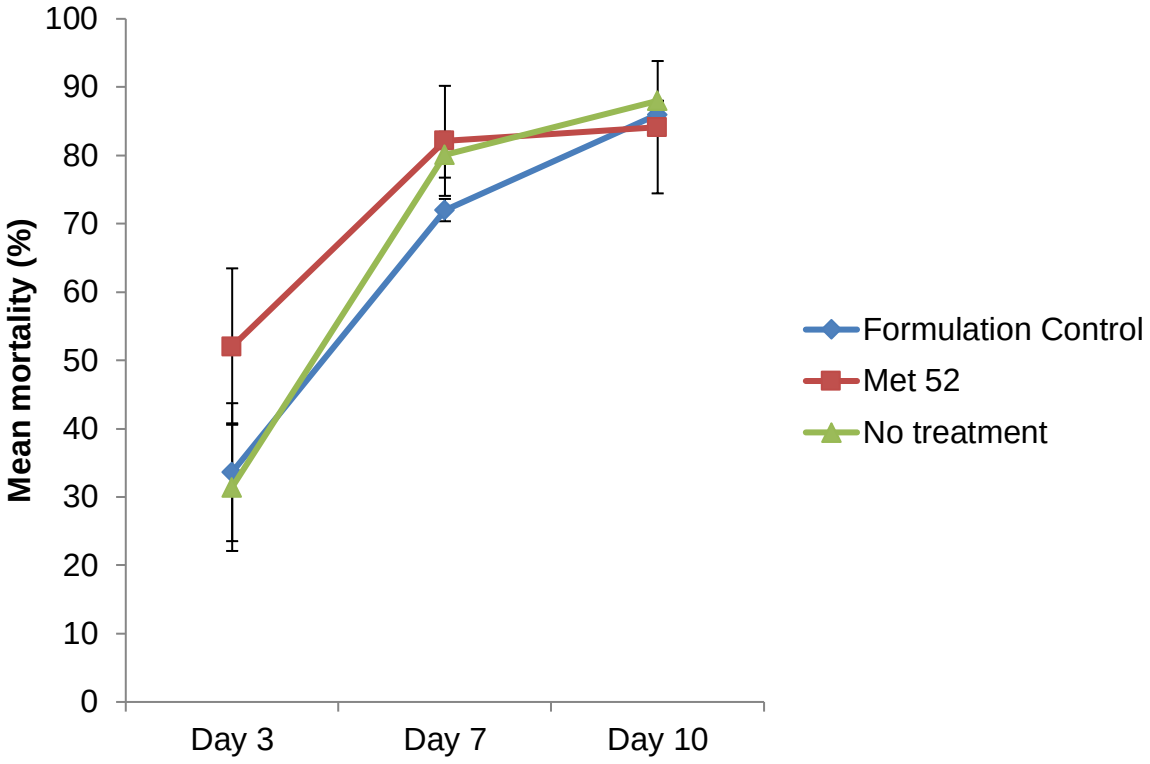


Figure 1.2.4. Dip Method: Mean mortality over time of *Orius laevigatus* exposed to F52 *Metarhizium brunneum* spores suspended in 0.05% Tween 80, a blank formulation control (0.05% Tween 80) and no treatment (insects were not dipped). Data is from two separate experiments over time (±1SE)

Aphidalia (*Adalia bipunctata*)

There was a significant difference between treatments on Days 3, 7 and 10 (difference in deviance = -28.0, d.f. = 14, P < 0.0001; difference in deviance = -10.65, d.f. = 14, P = 0.007 and difference in deviance = -7.47, d.f. = 14, P = 0.007 respectively; Figure 1.2.5). On all days, mortality was significantly higher in the F52 treatment when compared to the formulation control (Day 3: z ratio = 4.23, P = 0.0001, Day 7: z ratio = 2.95, P = 0.009, Day 10: z ratio = 2.89, P = 0.01 respectively). However, the difference in mortality was only significant between the no treatment and F52 treatments on Day 3 (z ratio = -3.77, P = 0.0005) and not on Days 7 and 10 (z ratio = -1.78, P = 0.18; z ratio = -1.29, P = 0.40 respectively). On all days there was no significant difference between the no dip control and formulation control (Day 3: z ratio = 0.56, P = 0.84, day 7: z ratio = 1.32, P = 0.38, Day 10: z ratio = 1.79, P = 0.17).

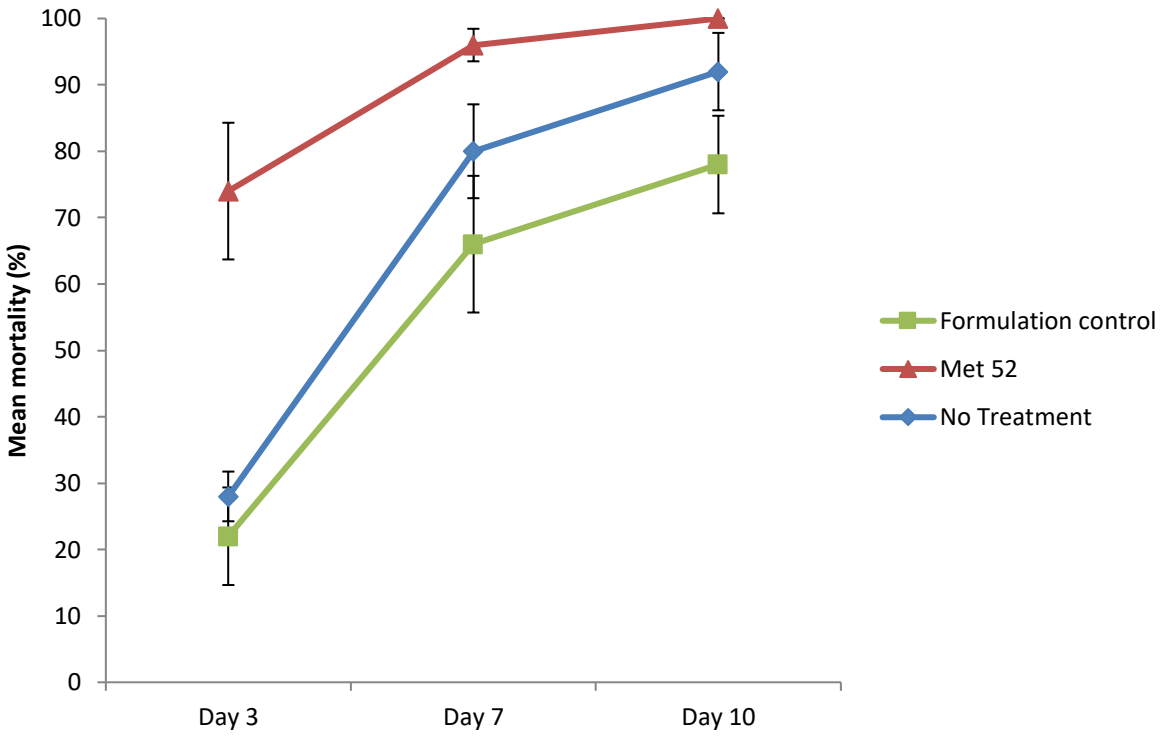


Figure 1.2.5. Dip Method: Mean mortality over time of *Adalia bipunctata* exposed to F52 *Metarhizium brunneum* spores suspended in 0.05% Tween 80, a blank formulation control (0.05% Tween 80) and no treatment (insects were not dipped). Results are shown as ±1SE based on the five replicates run-on one-time point.

Spray Contact Assays; Quantification of formulation using Met52 EC

Two treatments, a tank mix concentration of Met52 EC and a 'blank control' of codacide, were mixed in water and sprayed onto strawberry leaves using a Burkard Computer sprayer, and left to dry. Insects were then exposed to these for three days prior to removing the leaf. Concentrations were quantified using a colony forming unit (CFU) test before and after spraying (Table 1.2.3.). A no treatment control was also set up. For further details see Appendix 1.2. Due to issues with the Burkard sprayer, some insect treatments required the leaves to be dipped and dried.

Table 1.2.3. Contact assay overview using Met52 EC, including CFU/ml of tank mix used, CFU/ml of tank mix post spray (collected from spray nozzle) and CFU/cm^2 (collected from deposition plates). Figures given are ±1SE.

		Mean CFU/ml (±1SE)			
Product	**Latin name**	**Pre-spray tank mix**	**Post-spray tank mix**	**CFU/cm^2**	**No. reps**
Chrysopa	*Chrysoperla carnea*	1.37x10^6 (±4.12x10^5)	2.19x10^6 (±3.04x10^5)	1.3x10^4 (±6.6x10^3)	3
Aphidalia	*Adalia bipunctata*	2.7x10^5	NA*	NA*	1*
Ervipar	*Aphidius ervi*	2.08x10^6 (±4.9 x10^5)	2.11x10^6 (±6.41x10^5)	2.36x10^4 (±7.03x10^3)	3**

* Prior to the *A. bipunctata* assay the sprayer developed a fault therefore the leaves were dipping in formulation as opposed to sprayed, therefore there are no post spray CFU/ml results or CFU/cm^2 results.

**In rep 1 of Ervipar contact assay, 2 x no treatment, 2 x blank formulation and 1 x blank formulation replicates, insects were found 'wet' and stuck to the bottom/walls of the tube. It is suspected the mortality was caused by oversaturation of the cotton wool with honey solution, therefore these replicates were removed from analysis. This left n = 3, 3 and 4 for the treatment replicates. For the other two replicates over time, n = 5 for each treatment.

Chrysopa (*Chrysoperla carnea*)

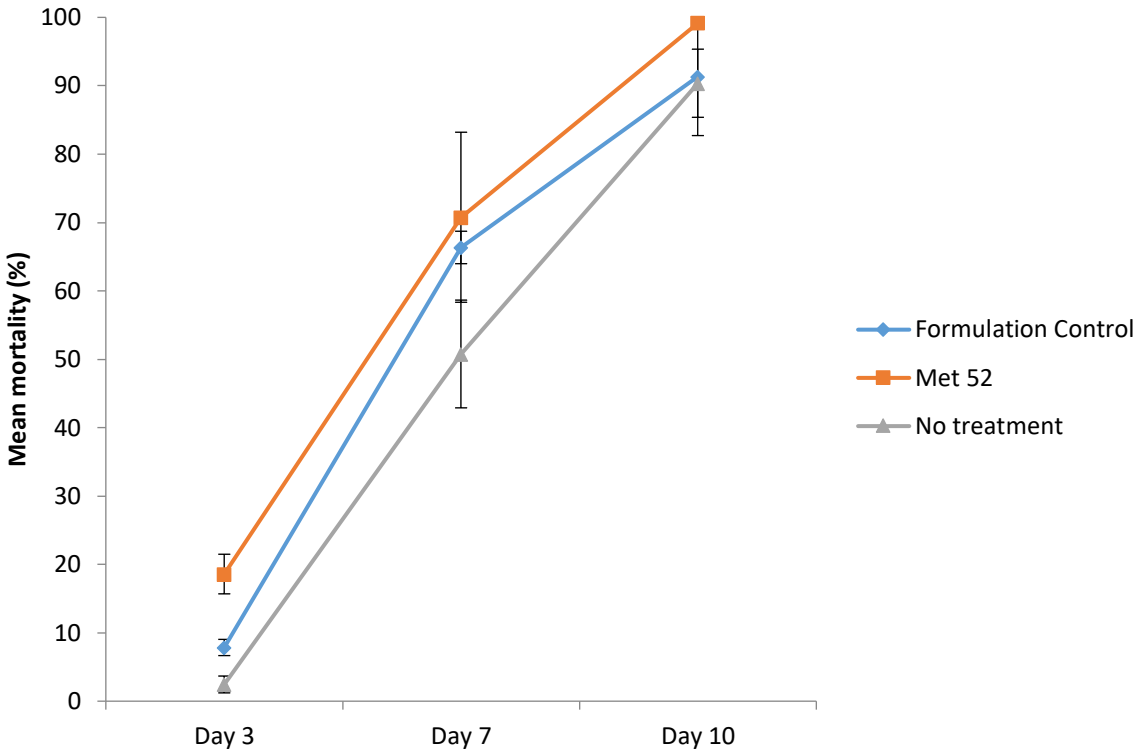


Figure 1.2.6. Mean mortality over time of *Chrysoperla carnea* larvae exposed to strawberry leaves sprayed with Met52 EC formulation, a blank formulation control (codacide oil in water) and no treatment (leaves were not sprayed). Data shown is a result of 3 separate experiments over time (±1SE)

There was a significant difference between treatments on days 3 and 7 (χ^2 = 8.25, d.f. = 2, P = 0.016; Day 7: χ^2 = 7.83, d.f. = 2, P = 0.02) but not on day 10 (χ^2 = 3.28, d.f. = 2, P = 0.19; Figure 1.2.6). A post hoc analysis showed that mortality was significantly higher in the Met52 treatment when compared to the no treatment control on Day 3 and day 7 (z ratio = -2.75, P = 0.02; z ratio = -2.70, P = 0.02 respectively). However, there were no significant differences between the Met 52 treatment and the formulation control on these days (Day 3: z ratio = 1.72, P = 0.20; Day 7: z ratio = 0.76, P = 0.73). On all days there was no significant difference between the blank control and formulation control (Day 3: z ratio = -1.09, P = 0.52, Day 7: z ratio = -1.94, P = 0.13, Day 10: z ratio = -1.79, P = 0.17).

Aphidalia (*Adalia bipunctata*)

There was an indication that mortality was proportionally higher in the Met52 EC treatment by Day 7 than for the formulation control and no treatment control (Figure 1.2.7), however the results of the survival analysis showed that there was no significant difference in survival of *A. bipunctata* over time ($\chi^2 = 0.58$, d.f. = 2, P = 0.75; Figure 1.2.8).

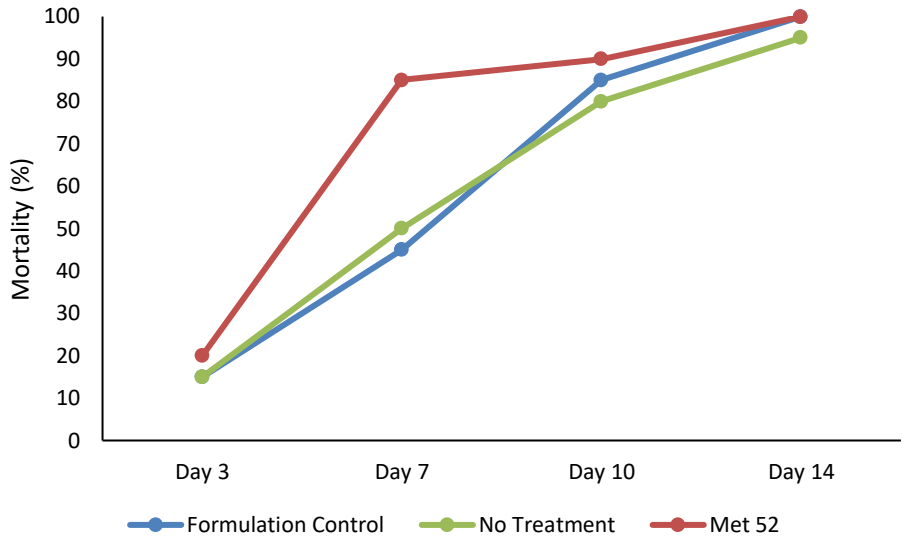


Figure 1.2.7. Accumulated percentage mortality of *Adalia bipunctata* individuals exposed to leaves which had not been treated with formulation (no treatment), leaves which had been dipped in a formulation control (Codacide oil plus water) and leaves which had been dipped in Met52 EC tank mix. For each treatment n = 20 individuals and mortality was assessed on Days 3, 7, 10 and 14

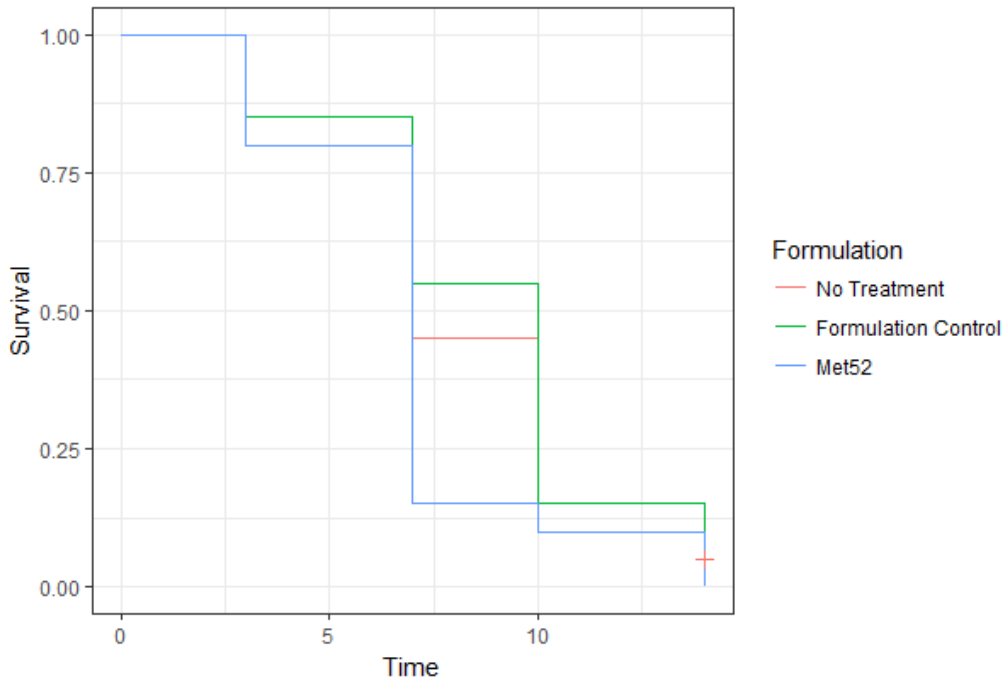


Figure 1.2.8. Survival analysis of *Adalia bipunctata* exposed to leaves, which had not been treated with formulation (no treatment), leaves which had been dipped in a formulation control (Codacide oil plus water) and leaves which had been dipped in Met52 EC tank mix. For each treatment n = 20 individuals and mortality was assessed on Days 3, 7, 10 and 14

Ervipar (*Aphidius ervi*)

During the first replicate of the contact assays, two vials from the no treatment, two vials from the blank formulation and one vial from the Met52 EC treatments were removed from the analysis as a high mortality was observed at Day 3 due to overfeeding of tubes. Thus, for this time point n = 3 for the no treatment, n = 3 for the blank formulation and n = 4 for the Met52 EC treatments. For the third replicate, there was not enough emergence of *A. ervi* to complete 5 replicates of each treatment, therefore n = 4 for each treatment. For the second replicate, n = 5 for each treatment.

Analysis showed that there was no significant difference in mortality between treatments on Day 3 ($\chi^2 = 1.43$, d.f. = 2, P = 0.49; Figure 1.2.9). However, there were significant differences on Days 7 ($\chi^2 = 7.65$, d.f. = 2, P = 0.02) and 10 ($\chi^2 = 14.7$, d.f. = 2, P < 0.001) with a significant difference in mortality between the formulation control and the Met52 EC treatments (z ratio = 2.70, P = 0.02 and z ratio = 3.19, P = 0.004 on Days 7 and 10 respectively). No significant difference was observed between Met52 EC and the no treatment control on any

day (Day 3: z ratio = -0.54, P = 0.85, Day 7: z ratio = -1.75, P = 0.19, Day 10: z ratio = 0.20, P = 0.99). On Day 10, there was a significant difference between the formulation control and no treatment (z ratio = 3.31, P = 0.003) whereas there was no significant difference observed on Days 3 and 7 between these treatments (z ratio = -1.19, P = 0.46, z ratio = 0.96 P = 0.60 respectively).

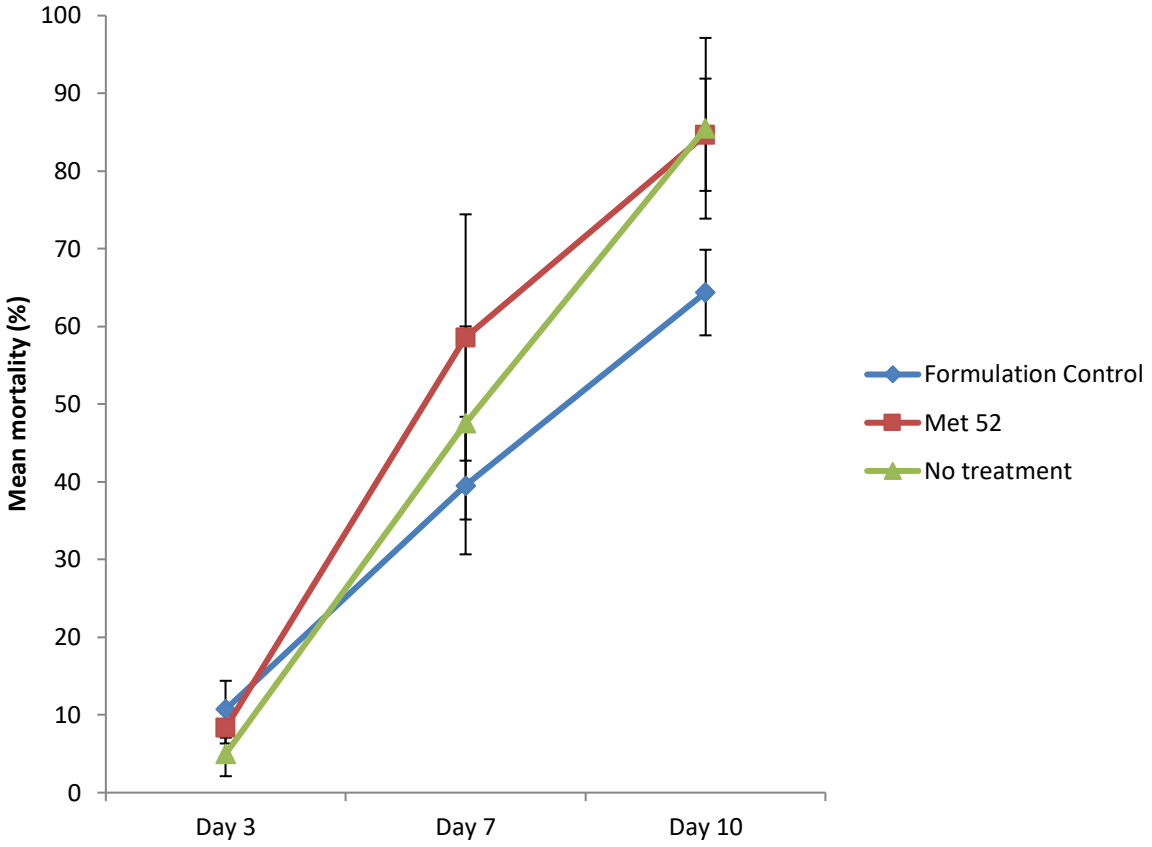


Figure 1.2.9. Mean percentage mortality of *Aphidius ervi* individuals exposed to leaves which had not been treated with formulation (no treatment), leaves which had been dipped in a formulation control (Codacide oil plus water) and leaves which had been dipped in Met52 EC tank mix. Data shown is a result of three separate experiments over time (±1SE)

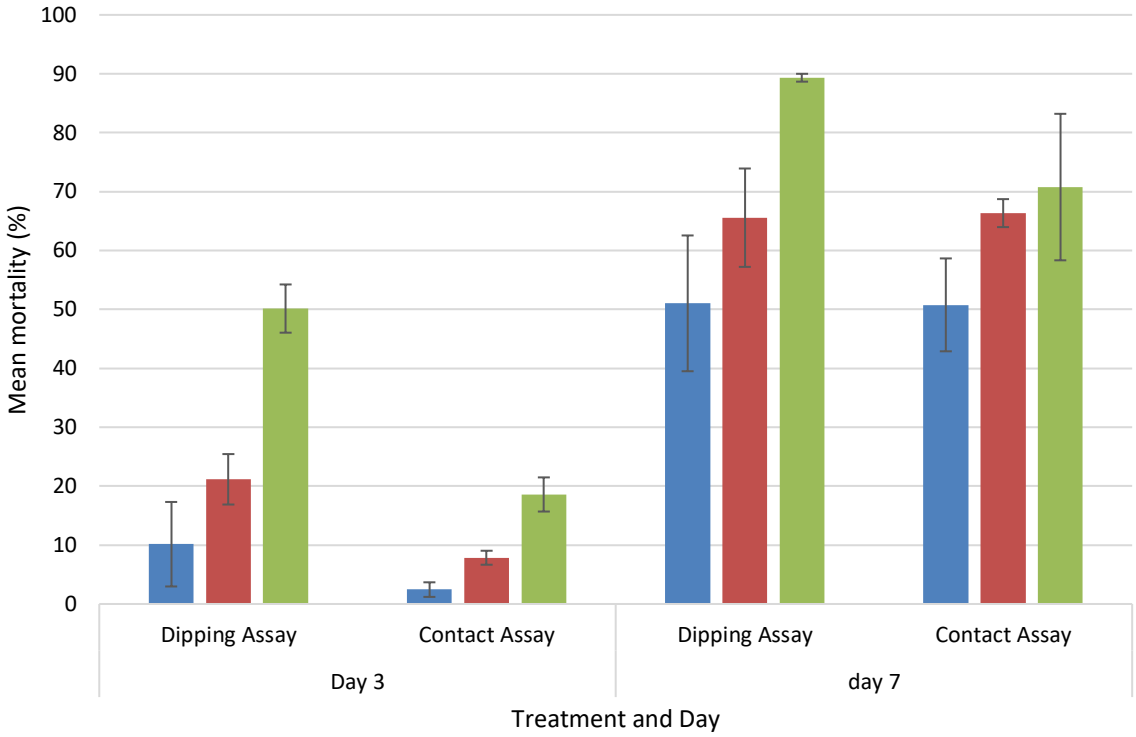


Figure 1.2.10. Comparison of mean mortalities (±1SE) between dipping assay, using F52 spore suspension and contact bioassay results, using Met52 EC tank mix on Day 3 and Day 7 for *Chrysoperla carnea*. Blue = no treatment, red = blank formulation control and green = F52 spore suspension/Met52 EC tank mix

Figures 1.2.10 and 1.2.11 show the difference in effect of the dipping method and the contact method on Day 3 an 7 for *Chrysoperla carnea* (Figure 1.2.10) and *Aphidius ervi* (Figure 1.2.11). Generally speaking the dipping method was harsher than the contact method.

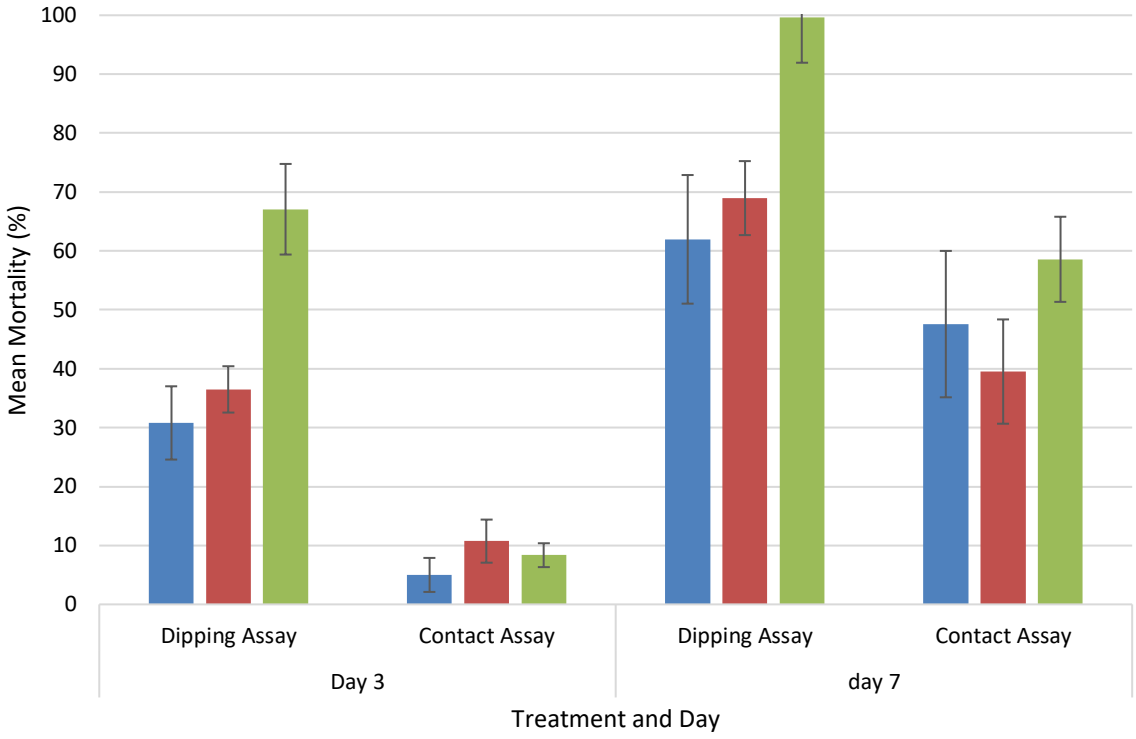


Figure 1.2.11. Comparison of mean mortalities (±1SE) between dipping assay, using F52 spore suspension, and contact bioassay, using Met52 EC tank mix, results on Day 3 and Day 7 for *Aphidius ervi.* Blue = no treatment, red = blank formulation control and green = F52 spore suspension/Met52 EC tank mix

Discussion

Results from the dipping treatments on *Aphidius ervi,* Aphiscout, and *Chrysoperla carnea* showed that *M. brunneum* F52 spores had a significant effect on Day 3 and Day 7 insect mortality compared to both controls. The *Adalia bipunctata* assay showed a significant effect on Day 3.

Bioassays using *Orius laevigatus* were conducted on several occasions but high control mortality was observed after three days in several assays therefore these results were discounted. This was mainly due to difficulty finding a suitable bioassay chamber setup despite trialling several methods. The assays giving useable results showed no significant difference between the blank formulation and the spore suspension, however further replication is required for this species to give conclusive results.

Chrysoperla carnea, *A. ervi* and *A. bipunctata* were taken forward for assessment using the contact assay method with Met52 EC as they showed significant responses to Met52 in the

dipping (i.e. maximum exposure) assays. Results showed a lesser effect of the product on insect mortality in these contact assays (see Figures 10 and 11). After three days, the only significant difference in mortality observed was between the Met52 EC treatment and the no treatment control in the *C. carnea* assay. This may indicate that the lower dose received by the insects is causing a slower mortality rate compared to the higher dose dipping treatments, however it must be noted these assays were run under ideal conditions for fungal growth thus tests in the field may yield lower mortalities. This is because of the effect that UV degradation may have on spore viability, and the effect of variable temperatures.

There was a significant difference in mortality after seven days between the blank formulation and Met52 EC for the *A. ervi* results but not for the no treatment results. It is not clear why this is the case.

There were supply issues with *A. bipunctata* meaning that only one replicate could be undertaken for both the dipping and contact assays. The contact assay indicated there could be an effect of the Met52 EC product on Day 7, however further replication is required to prove this statistically.

Conclusions

- The literature review showed that some work as already been completed on the effect of Met52 EC on beneficials used in strawberry production meaning that these did not need to be tested again.
- Dipping assays had high mortality for all products tested.
- Spraying contact assays had lower toxicity to the products resulting in a maximum to 20% mortality after three days (some were not significantly different from the control treatment).
- Met52 EC is unlikely to significantly reduce the effectiveness of the five products tested, when used in the UK strawberry system.
- Better systems for reducing control mortalities are required.

Further work

- Further replication of *A. bipunctata* to confirm results of the first bioassay.
- Field: Take forward *A. ervi* and *C. carnea* for field-testing to see if mortality is observed. Assays would include applying Met52 EC to strawberries at field rates and observing the numbers of predators recovered in treated and untreated plots (untreated to include a blank formulation and no treatment control as with laboratory studies)

Task 1.3. Investigate the potential of garlic grown in strawberry bags to reduce pests in the crop.

Introduction

With increasing legislative pressure to reduce the use of chemical pesticides in agriculture, there is rising interest in botanical alternatives. In the UK, botanical products excluding pyrethrins constitute a small, but growing portion of the U.K. pesticides market (Prowse *et al*., 2008).

Garlic intercropping is a botanical alternative with the potential to control horticultural pests. The method involves planting garlic within the crop and has been shown to reduce prevalence of *Bemisia tabaci*, *Hellula undalis* and *Brevicoryne brassicae* in cabbage (Katsaruware *et al*., 2014), *Lipaphis erysimi* in mustard (Sarker *et al*., 2007), and *Tetranychus urticae* in strawberry (Hata *et al*., 2016). In 2017 the pest control benefits of garlic intercropping were reported to the AHDB and NIAB EMR by a grower of a strawberry plantation. Grower observations stated that thrips were rarely a problem in everbearer strawberries when garlic was intercropped and garlic leaves were broken fortnightly into the strawberry plants. However, the pest control effects of this method have not been quantified alongside an untreated crop.

To investigate the grower's method of intercropping garlic, an experiment was conducted on a commercial strawberry farm in Kent during the summer of 2018. The effects of using the growers' garlic intercropping method were assessed using garlic treated and untreated plots, to determine if the technique could deter the main strawberry pests, without adversely effecting beneficials. Here we report findings from this experiment to determine if this method of intercropping garlic is a feasible control option for everbearer strawberry.

Materials and methods

Location: The experiment was conducted on a commercial strawberry farm in Kent. Four strawberry plantations were used (Figure 1.1), each containing an everbearer variety of table top grown strawberry. The two West fields with Blocks 1 to 4, contained 2nd year plantings, the two East fields with Blocks 5 to 8, contained 1st year plantings.

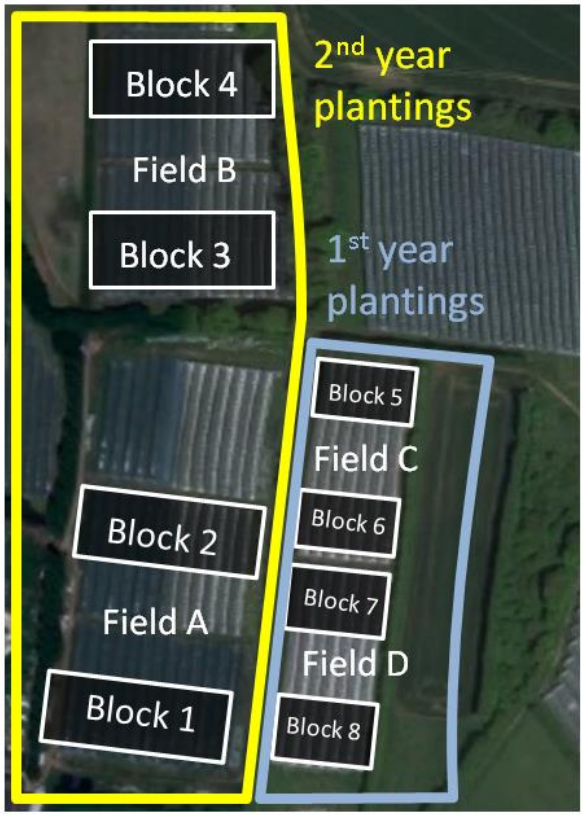


Figure 1.1. Map showing the position of the four fields (A to D) and the eight blocks. The minimum distance between blocks was 15 metres approx. (Blocks 6 and 7). The maximum distance was 120 metres approx. (Blocks 2 and 3)

Treatments:

Each field contained two blocks (Figure 1.1). Blocks contained two 16 x 16 metre plots, each 2 tunnels wide and 16 strawberry bags (1 m) long (Figure 1.2), total of eight blocks. Plots were as far apart as possible (from 15 to 80 m), to avoid interference from garlic odours, and 8 metres in from the end of the tunnels. They consisted of:

- One treatment containing garlic plants (Figure 1.2 - red).
- One control containing no garlic plants (Figure 1.2 - yellow).

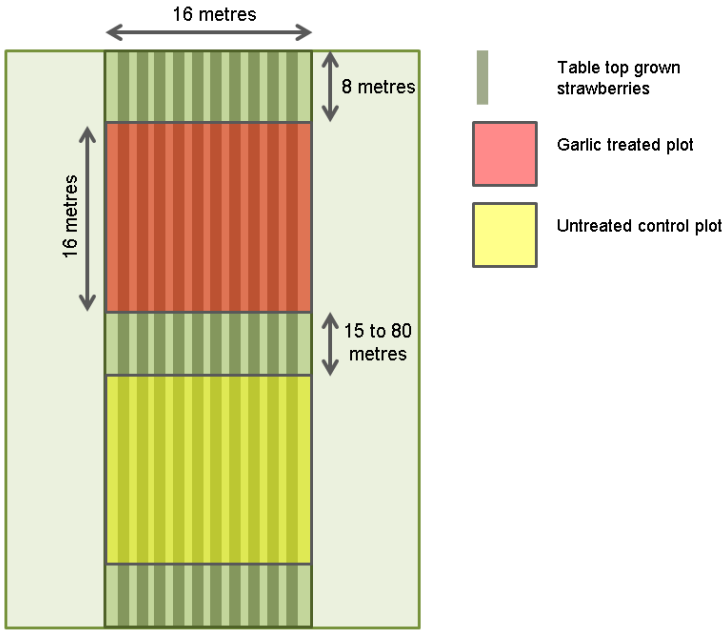


Figure 1.2. Schematic of block, containing two 16 x 16 metre plots: 1 garlic treated (red) and 1 untreated control (yellow). Each plot was situated 8 metres in from the tunnel end. The minimum distance between plots was 15 metres approx. (between blocks 6 and 7). The maximum distance was 80 metres approx. within (block 3)

The position of the plots was randomised to avoid a potential positional effect bias. Garlic cloves were planted in spring (16 May). Ordinarily seed garlic would be planted the previous autumn using a hard neck variety like Violet. However, this was not possible so we planted a soft neck leafy spring planting bulb ('Solent Wight Seed'). In preparation for the assessments, garlic cloves were individually planted, in every grow bag (Table 1.1.) within the treatment plots (Figure 1.2) (Figure 1.3 A). This amounted to 160 garlic plants per treatment plot (10 rows of 16 grow bags), 1280 cloves for the experiment. Two weeks before the first full-assessment, a garlic leaf from each bag was broken off, and dropped onto the neighbouring strawberry plants in the bag from which it derived (Figure 1.3 B). On occasions where garlic plants failed, leaves from neighbouring plants with more vigorous growth were dropped over the bags containing failed plants. This process was repeated fortnightly on five occasions (Table 1.1) until the end of the trial.

Crop husbandry involved the standard grower practices, including the grower's standard spray programme and regular release of *N. cucumeris*. The grower was advised that non-essential insecticide sprays should be avoided to prevent target pests and beneficials being affected. A copy of the spray programme was provided to NIAB EMR after the trial (Appendix

1.3.1). Data loggers recorded temperature and humidity throughout the experimental period in each crop (Appendix 3.2.4).

A. B.

Figure 1.3. A. Image of a garlic plant developing in a free strawberry growbag hole during the period of pre-assessments. B. Illustration of the garlic treatment during the period of full assessments. A garlic leaf was broken fortnightly and dropped onto strawberry plants in the same grow bag.

Table 1.1. Dates and activities performed over the duration of the garlic trial.

Date	Activity	Assessments
16 May	Garlic cloves planted	1st Pre-assessment
30 May	-	2nd pre-assessment
12 June	snap and place garlic leaves in strawberry plants	Pollinator assessment
26 June	As for 12 June	1st full assessment
12 July	As for 12 June	2nd full assessment
26 July	As for 12 June	3rd full assessment
9 August	As for 12 June	4th full assessment
23 August	-	Final assessment

Assessments:

To determine if there was a significant difference in invertebrate numbers between garlic treated plots and untreated plots, within 1st and 2nd year strawberry plantings, assessments were made fortnightly at all eight blocks. Seven assessments were made in total (Table 1.1): two pre-assessments (before garlic leaves had been broken and dropped amongst strawberry plants) and five full assessments (after garlic leaves had been broken and dropped amongst strawberry plants). Assessments were performed in the centre of each plot and involved the following:

Examination of 20 plants for the presence of aphids. Aphid species that could be identified on site were assessed for estimated population size per plant (0, 1-5, 6-20 and >20 individuals). Numbers were converted into a score (0, 1, 2 and 3 respectively) for statistical analysis. Those that could not be identified on site were taken to the laboratory at NIAB EMR for identification. Numbers of mummified aphids were also counted and the appearance of winged forms also noted.

Button fruit samples. Twenty button fruits were randomly selected then transferred to pots of 70% ethanol and returned to the laboratory for washing, following SOP 780. Afterwards, the numbers of thrips (adults and larvae) and *N. cucumeris* were counted.

Tap sampling. Twenty whole strawberry plants were indiscriminately tapped three times by hand over a white tray and the resulting numbers of capsids and natural enemies were counted.

Crop damage was not assessed during this trial.

Statistical analysis:

- Examination of 20 plants for the presence of aphids: Aphid scores per treatment were angular transformed and compared using a 2-way ANOVA
- Button fruit samples: Mean numbers of N. cucumeris, adult and larval thrips per treatment were compared using a 2-way ANOVA.
- Examination of 20 plants for the presence of aphids and tap sampling: Mean numbers of other arthropods per treatment were sqrt transformed, and then compared using a 2-way ANOVA.

Results

Examination of plants for the presence of aphids:

The majority of aphids identified in this trial were *Chaetosiphon fragaefolii*. *Aphis gossypii* were also present in the last two weeks of the trial, but not within the plots, so were not included in the results.

For all seven assessments mean *C. fragaefolii* scores were significantly lower in 1st year plantings than 2nd year plantings (Figure. 1.4), (see Table 1.2 for statistics), however grand mean *C. fragaefolii* scores for 1st and 2nd year plantings were only 0.1 and 0.6 per 20 plants, respectively. These numbers are an average from 20 plants. Aphids are normally in an aggregated or patchy distribution. Referring to total numbers (Figure 1.5), only 6 plants (0.5%) in 1st year plantings had more than 20 aphids, whereas 78 plants (7%) in 2nd year plantings had more than 20 aphids and are likely to be affected by infestations.

In most full assessments the garlic treatment was found to significantly reduce mean *C. fragaefolii* scores compared to the control (see Table 1.2 for statistics). During pre-assessments from 16 May to 30 May, planting age and treatment did not significantly affect mean *C. fragaefolii* score. However, from the first full-assessment on 26 June until the final full-assessment on 23 August, the mean *C. fragaefolii* scores were significantly lower in 2nd year garlic treated plots than 2nd year control plots in 4 out of the 5 assessments (Figure 1.6), including an interaction between planting age and treatment on 26 June and 12 July (see Table 1.2 for statistics). For both of these dates mean *C. fragaefolii* score was significantly lower in 2nd year garlic treated plots than 2nd year control plots. This was reflected in the actual numbers, whereby consistently fewer strawberry plants were observed with *C. fragaefolii* populations of each size category in 2nd year garlic treated strawberry than 2nd year untreated (control) strawberry (Figure 1.5 B). For all assessments in 1st year plantings, there was no significant difference in mean *C. fragaefolii* score between garlic treated and control plots (data not shown), because actual numbers of populations per plant were low and very similar between treatments (Figure 1.5 A).

Following a sqrt transformation of means, there was no significant difference in mummified aphids between garlic treated plots and control plots (grand mean = 3.10).

Winged aphids were first observed on 30 May in a 2nd year plot (both garlic and control), 26 June in 1st year garlic only and were absent from 1st year control plots. However the total number recorded during assessments (4) was too low for statistical analysis.

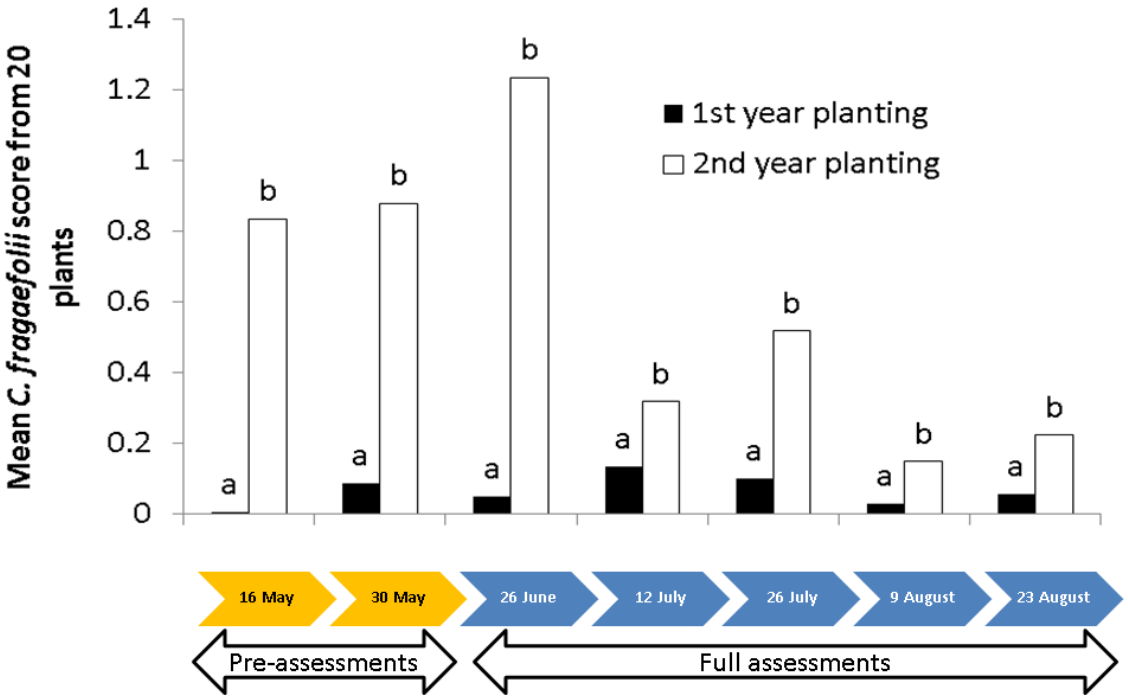


Figure 1.4. Mean *C. fragaefolii* scores (0=0, 1=1-5, 2=6-20, 3=>20 per plant) from 20 plants sampled within 1st and 2nd year strawberry plantings. Pre-garlic assessments occurred on 16 and 30 May, post-garlic assessments occurred from 26 June to 23 August

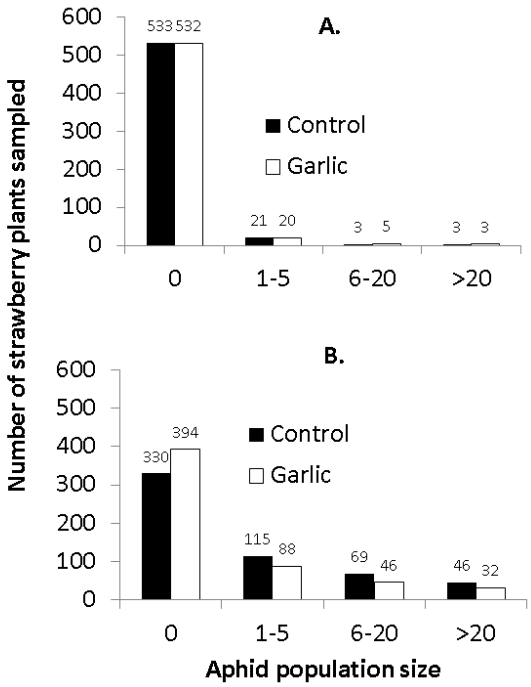


Figure 1.5. Total number and size of *C. fragaefolii* populations counted on strawberry plants in A. 1st year plantings and B. 2nd year plantings for control and garlic treatments

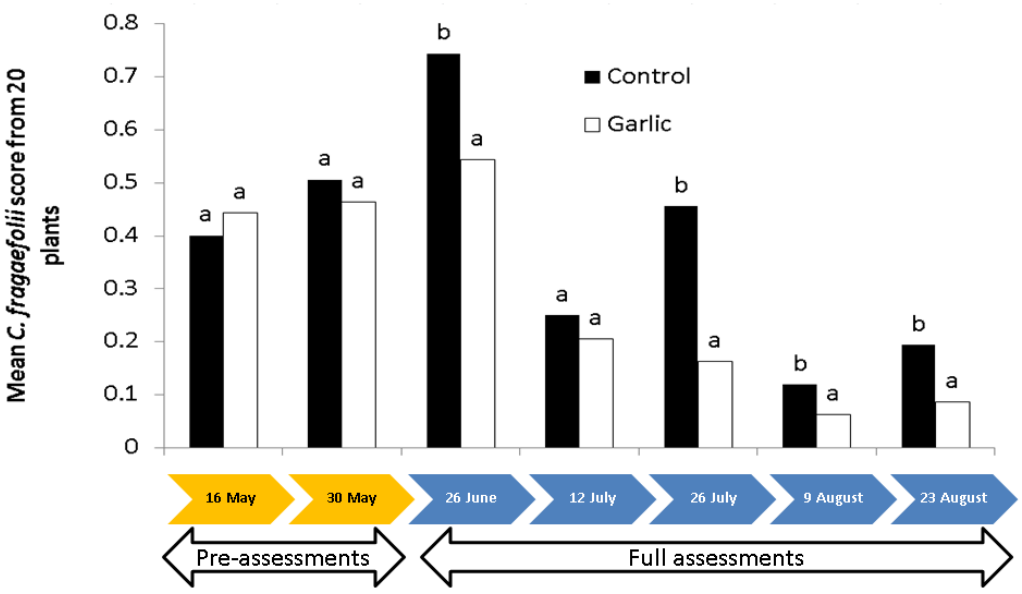


Figure 1.6. Mean *C. fragaefolii* scores (0=0, 1=1-5, 2=6-20, 3=>20 per plant) from 20 plants sampled withinin control and garlic plots. Pre-garlic assessments occurred on 16 and 30 May, post-garlic assessments occurred from 26 June to 23 August

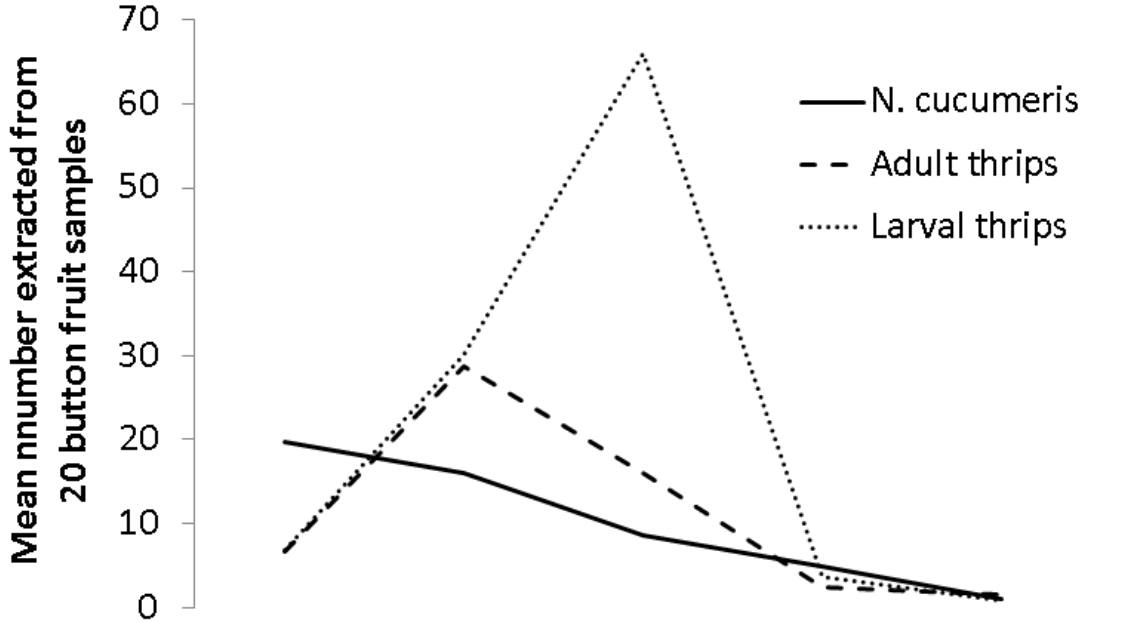
Table 1.2. Significant differences found between mean *C. fragaefolii* scores (0=0, 1=1-5, 2=6-20, 3=>20 per plant) from 20 plants sampled withinin 1st and 2nd year strawberry plantings, control and garlic plots. Pre-garlic assessments occurred on 16 and 30 May, post-garlic assessments occurred from 26 June to 23 August.

Assessment date	Treatment	Plant age	Treatment*Plant age
16-May	NS	P =<.001	NS
30-May	NS	P = <.001	NS
26-Jun	P =0.037	P = <.001	P = 0.037
12-Jul	NS	P =0.005	P = <.001
26-Jul	P = <.001	P = <.001	NS
09-Aug	NS	P = 0.002	NS
23-Aug	0.034	P = <.001	NS

Sampling of 20 button fruits for thrips (adult and larvae) and N. cucumeris:

Following statistical analysis on post-assessments, starting 26 June when more thrips appeared in the crops, treatment (garlic or control) did not have a significant effect on mean numbers of *N. cucumeris* (grand mean = 10.01), adult thrips (grand mean = 11.1) and larval

thrips (grand mean = 21.5). However, there was a significant time effect, whereby assessment date did affect mean numbers of *N. cucumeris* (P = <.001, s.e.d. = 2.722, l.s.d. = 6.082), adult thrips (P = <.001, s.e.d. = 3.39, l.s.d. = 7.58) and larval thrips (P = <.001, s.e.d. = 5.35, l.s.d. = 12.81) (Figure. 1.7). Over the course of the trial the mean number of *N. cucumeris* peaked on 30 May (mean = 19.69) and then steadily declined to the end of the trial. Adult thrips progressively increased up to 12 July (mean = 28.8) and then decreased to the end of the trial. Larval thrips peaked two weeks later on 26 July (mean = 65.9), this is consistent with the lifecycle of thrips in polytunnels.



	26-Jun	12-Jul	26-Jul	09-Aug	23-Aug
N. cucumeris	c	c	b	ab	a
Adult thrips	a	c	b	a	a
Larval thrips	a	b	c	a	a

Figure 1.7. Mean numbers and significant differences of *N. cucumeris,* adult thrips and larval thrips from samples of 20 button fruits

Tap sampling 20 strawberry plants for pests and beneficials:

Following sqrt transformation of means for all arthropods counted from tap sampling 20 strawberry plants, garlic treatment did not significantly effect mean numbers of capsids (grand mean = 0.091), earwigs (grand mean = 0.0063), hoverflies (grand mean = 0.0313), lacewings (grand mean = 0.341), ladybirds (grand mean = 0.047), mummified aphids (grand mean =

3.10), predatory beetles (grand mean = 0.0063), predatory thrips or other adult thrips (grand mean = 0.078). However, a significant difference was detected in 4 of the 12 invertebrates recorded from tap samples in response to treatment and/or plant age (see Table 1.3 for statistics). Mean numbers of mummified aphids (P = 0.020, s.e.d = 0.5307, l.s.d = 1.2986), parasitoids (P = 0.021, s.e.d = 0.1558, l.s.d = 0.3812) and predatory spiders (P = 0.013, s.e.d = 0.2863, l.s.d = 0.7004) were significantly higher in the 2nd year strawberry plantings than 1st year plantings (Figure 1.8). Mean numbers of predatory spiders were significantly higher in garlic treated strawberry compared to the untreated control (P = 0.005, s.e.d = 0.0759, l.s.d = 0.1494) (Figure 1.9). Mean numbers of *Orius* (P = 0.019, s.e.d = 0.1240, l.s.d = 0.2770) and parasitoids (P = 0.001, s.e.d = 0.1706, l.s.d = 0.3886) were significantly affected by an interaction of strawberry plant age and treatment (Figure 1.10).

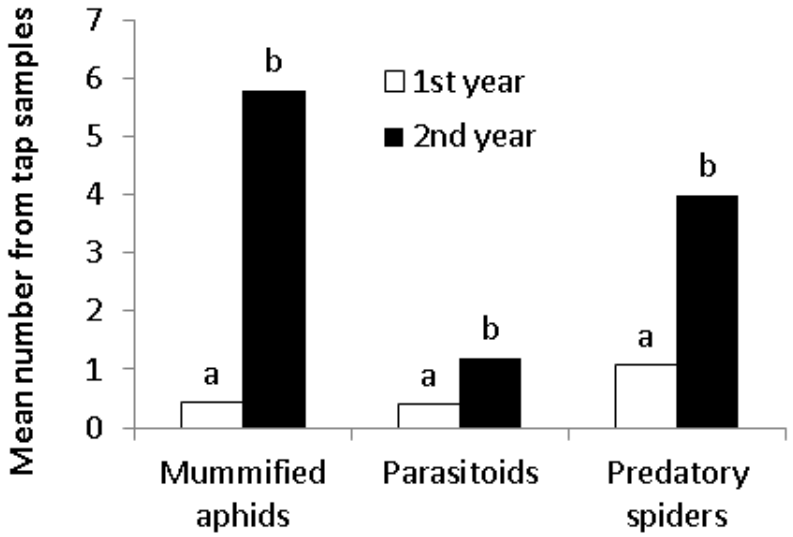


Figure 1.8. Mean numbers and significant differences of mummified aphids, parasitoids and predatory spiders between 1st and 2nd year strawberry plantings from tap samples of 20 plants

Table 1.3. Effect of treatment and strawberry planting age on invertebrate numbers from strawberry plant tap samples.

	Treatment	**Plant age**		**Interaction**
	Garlic vs Control	**1st year**	**2nd year**	**(Treatment and Plant age)**
Capsid	N/S	N/S		N/S
Earwig	N/S	N/S		N/S
Hoverfly	N/S	N/S		N/S
Lacewing	N/S	N/S		N/S
Ladybird	N/S	N/S		N/S
Mummified aphids	N/S	P = 0.02		N/S
Orius	N/S	P = 0.048		P= 0.019
Parasitoids	N/S	P = 0.021		P= 0.001
Predatory beetles	N/S	N/S		N/S
Predatory thrips	N/S	N/S		N/S
Predatory spiders	P= 0.005	P= 0.013		N/S
Adulthrips	N/S	N/S		N/S

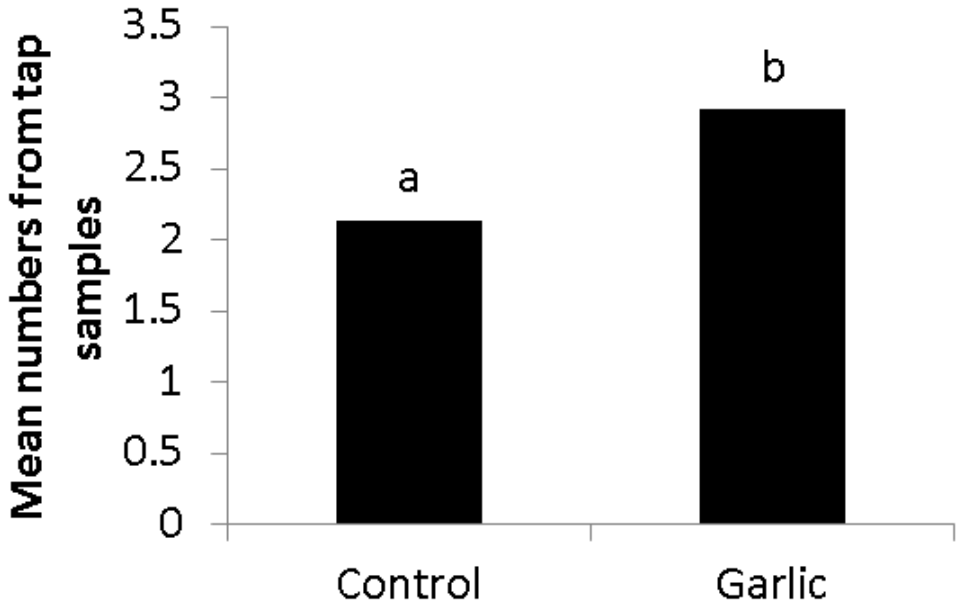


Figure 1.9. Mean number and significant difference of predatory spiders between control and garlic treated plots from tap samples of 20 plants

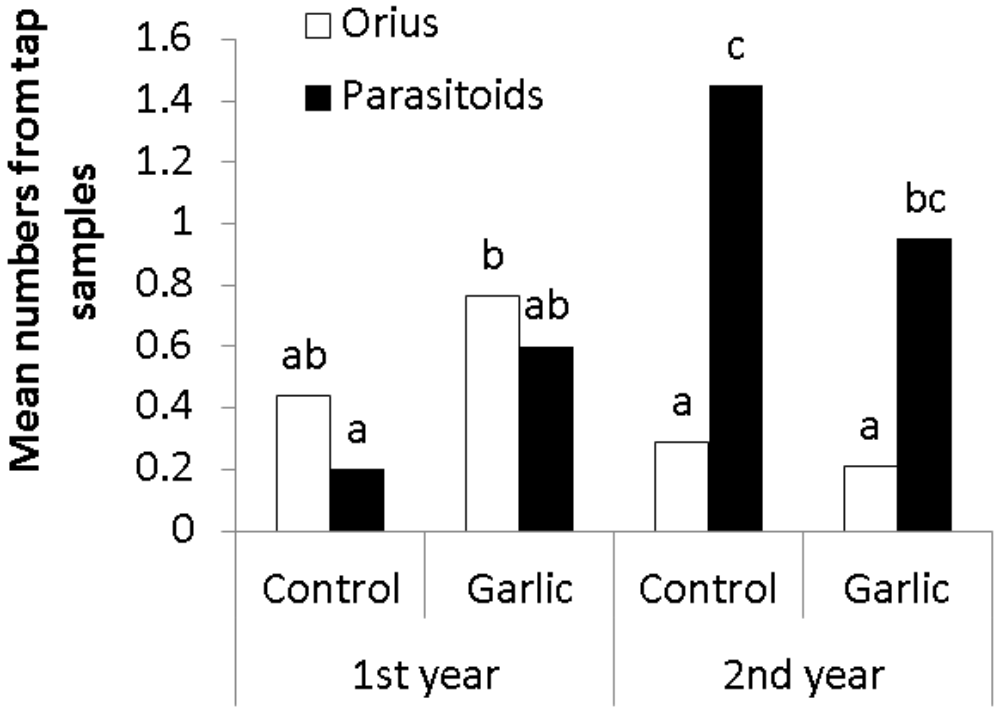


Figure 1.10. Mean numbers and significant differences of *Orius* and parasitoids between 1st and 2nd year strawberry plantings, untreated and garlic treated from tap samples of 20 plants

Discussion

All aphids found during assessments were *C. fragaefolii*. This was unexpected as *Macrosiphum euphorbiae* has been a dominant aphid pest of strawberry in recent years. The climatic conditions in 2018 were unusual in being very warm and dry and this may have changed the aphid species assemblage.

For all seven assessments, fewer *C. fragaefolii* were observed in 1st year strawberry plantings than 2nd year plantings (Figure 1.4), despite there being fewer aphicide applications in 1st year plantings. In both 1st and 2nd year plantings *C. fragaefolii* scores (grand mean = 0.1 and 0.6 respectively) were less than one, however these numbers are an average taken from 20 plants. Aphids are normally in an aggregated or patchy distribution (see Figure 1.5). In actuality only six plants (0.5%) in 1st year plantings had more than 20 aphids, whereas 78 plants (7%) in 2nd year plantings had more than 20 aphids and are likely to be affected by infestations. Referring to the spray programme (Appendix 1.3.1); two Hallmark applications were administered to 2nd year plantings at the beginning of May and mid-October and one Hallmark application to 1st year plantings, mid-October. The difference in *C. fragaefolii* numbers between plantings is likely due to an ability to overwinter in 2nd year plantings.

Plant age also significantly affected mean numbers of mummified aphids and other invertebrates detected (Table 1.3). Mean numbers of mummified aphids, parasitoids and predatory spiders were higher in 2nd year strawberry plantings than 1st year (Figure 1.8). These findings can be explained by the 2nd year plantings having a more established canopy, with places suitable for overwintering. Conversely, the mean number of *Orius* was significantly higher in 1st year strawberry plantings, than 2nd year plantings in both garlic treated and untreated plots. The reason for this difference is not known and should be explored.

In most full assessments the garlic treatment was found to significantly reduce mean *C. fragaefolii* scores compared to the untreated control. In 2nd year plantings, from the first full-assessment on 26 June until the final full-assessment on 23 August, the mean *C. fragaefolii* scores were significantly lower in garlic treated plots than control plots in four out of the five assessments (see Table 1.2 for statistics). During pre-assessments, there was no significant difference (Figure 1.6). This suggests that the garlic treatment in the strawberry bags was repellent to *C. fragaefolii*. Breaking garlic leaves releases repellent compounds e.g. essential oil of garlic, diallyl trisulfide and diallyl disulfide (Edris et al. 2002) (Plata-Rueda et al 2017) and may be more persistent in the crop than sprays of garlic. Also the continuous presence of garlic plants in the crop may have semiochemical release which could help maintain a

repellent plume. This is supported in other published literature studying *Lipaphis erysimi* in mustard (Sarker *et al*., 2007), but to our knowledge is the first time this has been recorded for *C. fragaefolii* in strawberry. Another possibility was that garlic may have attracted natural enemies into the crop. However treatment did not significantly impact mean numbers of mummified aphids or most other predatory arthropods. Overall it is still unclear how exactly garlic reduces *C. fragaefolii* numbers and whether this reduction is significant enough to reduce *C. fragaefolii* damage to the crop.

The mean number of predatory spiders was higher in garlic treated strawberry than the untreated control (Figure 1.9.). It's possible that garlic is attractive to predatory spiders or provides a structure on which to spin webbing, but as predatory spider species were not identified this remains to be confirmed.

The mean numbers of the predatory phytoseiid mite, *N. cucumeris,* extracted from button fruit samples were not significantly different between garlic-treated and untreated control plots. This indicates that garlic does not have a negative impact on this natural enemy. However, mean thrips (adults and larvae) were also not significantly affected by treatment, challenging observations made by the grower who employs this approach.

Differences between our approach and the grower's approach were the climatic condition, the variety of garlic planted and also the less regular (and possibly higher) frequency by which the grower's staff break garlic leaves.

During the course of the trial a significant difference was detected in *N. cucumeris* and adult thrips numbers over time (Figure 1.7). For thrips this can be attributed to natural fluctuations in population. The mean numbers of *N. cucumeris* peaked on 30 May and then steadily decreased to the end of the trial, despite larval thrips rising to a peak on 26 June.

Mean numbers of *Orius* and parasitoids were significantly different according to strawberry plant age and treatment (Figure 1.10). *Orius* was significantly higher in garlic treated 1st year strawberry plantings, than 2nd year plantings both garlic treated and untreated. Mean parasitoid numbers were significantly higher in 2nd year garlic treated and untreated strawberry than 1st year garlic treated and untreated. The reasons for these differences are not known and should be explored.

The estimated cost of applying this garlic treatment was £263-395/ha per year. This includes purchase, splitting, planting, breaking-leaves, harvesting and labour. However, this can be more expensive. A grower with experience interplanting garlic has informed us that it can cost

up to £1000/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.

Conclusions

- The majority of aphids identified in this trial were *Chaetosiphon fragaefolii*
- There were fewer *C. fragaefolii* in 1st year strawberry plantings than 2nd year plantings which is likely due to *C. fragaefolii* being able to overwinter in 2nd year plantings.
- Before the garlic treatment, there was no significant difference between mean *C. fragaefolii* scores in garlic treated plots than control plots.
- During the period of garlic treatment (26 June to 23 August), the mean *C. fragaefolii* scores were significantly lower in garlic treated plots than control plots in four out of the five assessments, however it is still unclear how garlic reduces *C. fragaefolii* numbers and whether this reduction is significant enough to reduce *C. fragaefolii* damage to the crop.
- The garlic treatment did not significantly effect numbers of *N. cucumeris* and thrips, both adults and larvae, but there was a significant effect of time on numbers of these arthropods.
- The mean numbers of mummified aphids, parasitoids and predatory spiders was higher in 2nd than 1st year strawberry plantings.
- The mean numbers of predatory spiders was higher in garlic treated plots than untreated plots.
- *Orius* numbers were significantly higher in garlic treated 1st year strawberry plantings, than 2nd year plantings both garlic treated and untreated. Parasitoid numbers were significantly higher in 2nd year garlic treated and untreated strawberry than 1st year garlic treated and untreated.

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

Task 2.1. In field, effect of insecticides commonly used to target spring aphids on the establishment of *Neoseiulus cucumeris*, aphids and parasitoids

Introduction

This field study looked at the effect that insecticides, commonly used to target spring aphids, have on the establishment of *N. cucumeris* and other predators.

In order to make rational decisions on release of this predator, during the spring time, it is important to determine whether *N. cucumeris* are affected by plant protection products applied for aphid control.

Materials and methods

The experiment was set up on a commercial table top strawberry crop of 2nd year everbearer. The experiment ran continuously over a 2 months period (Table 2.1).

Two fields were chosen for this experiment. At Site 1, (8,200 m²), strawberries were planted in pots with four plants per pot. There was a 50 cm gutter between pots and six table tops per tunnel (8.10 m wide, 124 m long). At Site 2, (17,600 m²), strawberries were planted in 50 cm coir bags with four plants per bag. There were four table tops per tunnel (6.5 m wide, 140 m long) (Figure 2.1).

Plots included whole sprayed tunnels and 11 m central area of the two central table top beds were used for the assessments (Figure 2.1).

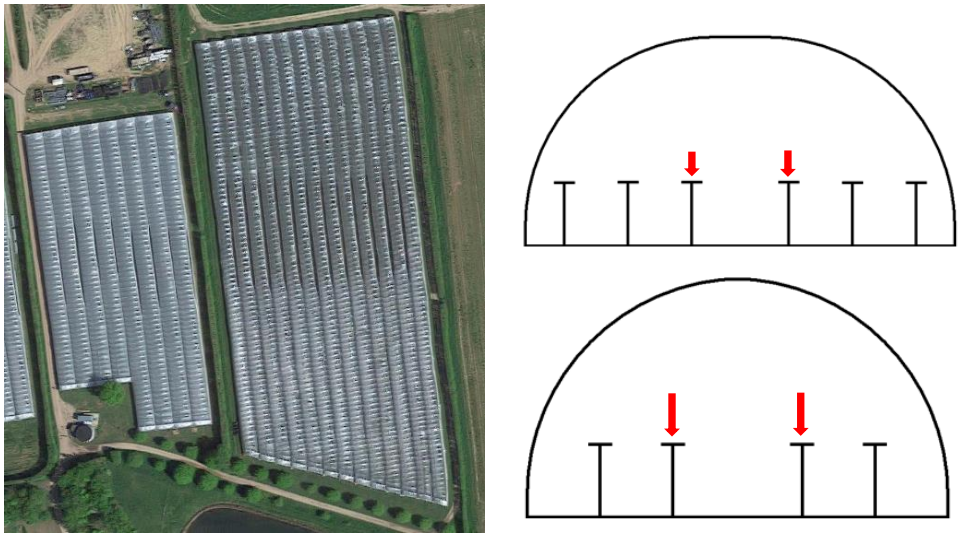


Figure 2.1. Site description: Site 1 (field on the left and top graphic), Site 2 (field on the right and bottom graphic). Red arrows show location of plants used for the assessments.

On 7 March plots were sprayed by the grower using a Bargram jet 1100 sprayer equipped with 12 red air sheer nozzles on table top strawberry at an application rate of 1000 L/ha, ensuring full plant coverage. Treatments are shown in Table 2.1. A grower standard spray programme for non-aphid pests and disease control was applied over both plantations.
The experiment was a randomised block design with six replicates of each treatment including an untreated control. Two replicates were at Site 1 and four at Site 2.
On 15 March, *N. cucumeris,* supplied by Bioline AgroSciences Ltd, were released at a rate of 200 mites per plant (Figure 2.2). Applications were made on the central 11 m of each marked row in both fields.

To achieve the required release rate of 200 *N. cucumeris* per plant, the numbers of *N. cucumeris* in ten x 1 ml replicates (of the product supplied), were counted, and the volume of the carrier to deploy on the plants calculated. The mean numbers of *N. cucumeris* per 1 ml carrier was 22 (adults + immatures). Thus 10 ml of carrier containing *N. cucumeris* were released onto each plant.

Releases were made by NIAB EMR staff, by gently sprinkling the required volume onto each plant. As the mites were difficult to detect, after the first assessment, two more releases were made to the experimental area using the same methodology. Mean numbers for these additional releases were 22 and 20 (adults + immatures) (Table 2.2).

Data loggers (2 Lascar EL-USB-2) were deployed in a Stevenson screen in the middle of the target area to collect hourly temperature and humidity levels.

Table 2.1. Treatments applied to control aphids. *A = adult, N = nymph, E = eggs of *N. cucumeris*. 1 = harmless, 2 = slightly harmful, 3 = moderately harmful, 4 = harmful (Koppert and Biobest side-effects websites). R = red, Y = yellow, G = green

Product	Harm*	Persistence (weeks)	MAPP No:	Active(s)	Target	Required dose rate product/ha
R. Hallmark	4A N4 E4	8-12	12629	Lambda-cyhalothrin	Broadspectrum	75 ml
Y. Calypso	A1	0	11257	Thiacloprid	Capsids	250 ml
G. Untreated	-	-	-	-	-	

Figure 2.2. *N. cucumeris* application.

On 23 February a pre-assessment was done; then an additional, post spray application, four assessments (Table. 2.2). 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 - randomly selected from 30 plants in every plot - into polythene bags. Counts of mites were done in the laboratory and counts of aphid in the plantations. Initially mites were counted directly under a microscope. However, after the first assessment, the ethanol extraction procedure (NIAB EMR, SOP 780) was used to maximise mite detection in samples. At the last sampling date, different plant parts were collected (young folded

leaves, middle-age leaves and flowers) to estimate the distribution of *N. cucumeris* (Table 2.3). Small samples of adults from each treatment were mounted on microscope slides, to identify species on each occasion.

Table 2.2. Timetable of the assessments and treatment applications with the sample size per plot and the sampling unit

Action	**Date**	**Sampling size and unit**
Pre-assessment *N. cucumeris* and aphids	23 Feb	30 young folded leaves
Insecticides applied	07 Mar	
N. cucumeris applied (200 mites/plant)	15 Mar	
Assessment *N. cucumeris* and aphids	22 Mar	30 young folded leaves
N. cucumeris applied (200 mites/plant)	29 Mar	
Assessment *N. cucumeris* and aphids	03 Apr	30 young folded leaves
Assessment *N. cucumeris* and aphids	10 Apr	30 flowers
N. cucumeris applied (200 mites/plant)	12 Apr	
Assessment *N. cucumeris* and aphids	16 Apr	30 young folded leaves, middle age leaves and flowers

At each assessment, aphid numbers on 30 plants in each of the 18 plots were counted. The aim was to incubate these in the laboratory to assess for potential emerging 'wild' populations of parasitoids. The occurrence of tarsonemid mites and thrips was recorded during the ethanol extraction of *N. cucumeris*.

In addition, on each assessment date, samples of leaves were collected and kept for leaf residue testing (facilitated by Jon Marcar at Berry Gardens). The residue analysis was carried out by Tentamus QTS Analytical Ltd.

Statistical analysis: Data were analysed using a repeated and generalized analysis of variance on count data in GENSTAT.

Results

Temperature records: Mean daily temperatures recorded in the two fields during the experiment are shown in Figures 2.3 and 2.4. The mean temperature was 7.3 °C and 6.8 °C at Site1 and Site 2, respectively. The mean minimum temperature, on 28 February was -1.6 °C and -2.9 °C at Site 1 and Site 2, respectively. Mean maximum temperatures were 12.9 °C and 12.2 °C.

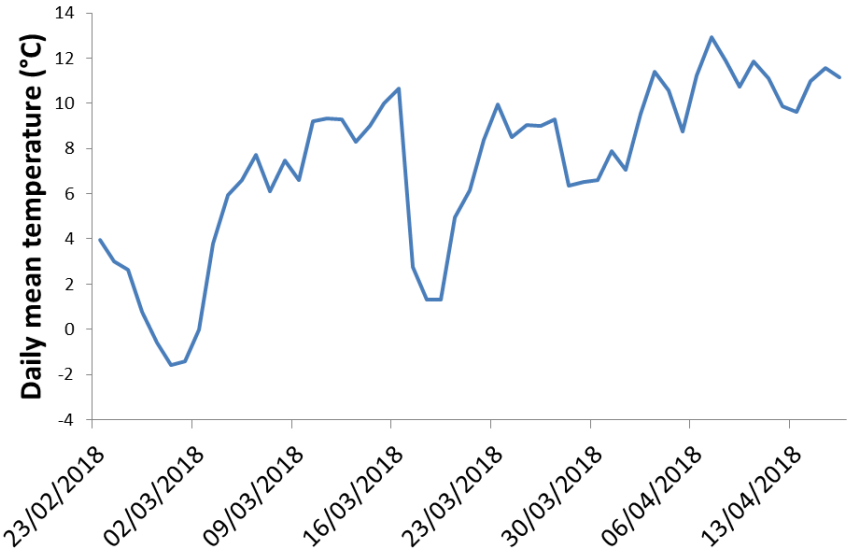


Figure 2.3. Daily mean temperatures recorded at Site 1 from 23 February to 16 April

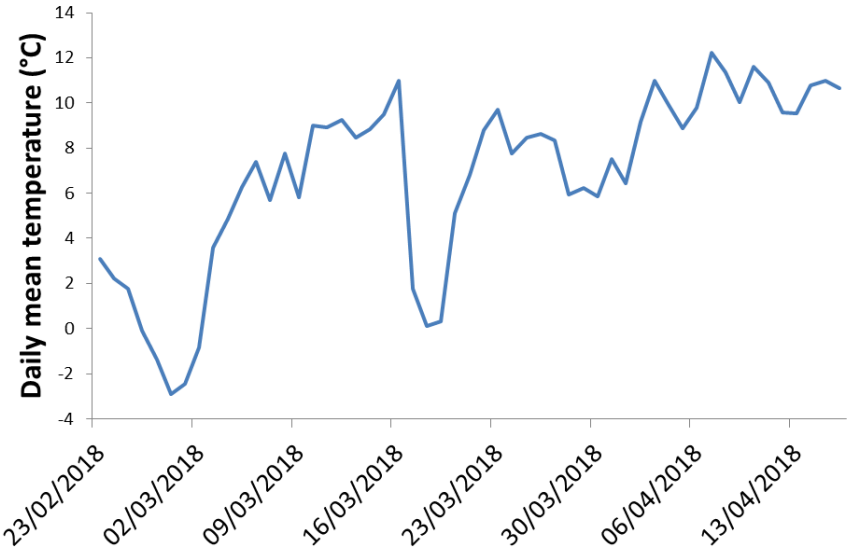


Figure 2.4. Daily mean temperatures recorded at Site 2 from 23 February to 16 April

There was no significant difference between the treatments in numbers of *N. cucumeris* adults (mean 4.50, P = 0.617). However, the numbers of adults did change over time after repeated releases. By the third assessment adults had increased to 7.67 per 30 young folded leaves

(P = 0.002, sed. 1.203, lsd. 2.681, Figure 2.5). This was after the second application of *N. cucumeris*.

Few nymphs were found during the first three assessments and there was no significant difference between the treatments (mean 0.5, P = 0.557). The numbers of nymphs showed a fluctuating trend over time, declining after the first assessment and increasing to 0.72 by the third assessment (P = 0.028, sed. 0.261, lsd. 0.55, Figure 2.5).

The mean numbers of eggs exhibited a similar pattern to adults, significantly increasing over time from 0 to 1.5, but this occurred during the second assessment, on 3 April, when the temperature was increasing (P = 0.008, sed. 0.4, lsd. 0.902, Figure 2.5). There was no significant difference in the numbers of the eggs between the treatments (mean 0.91, P = 0.573).

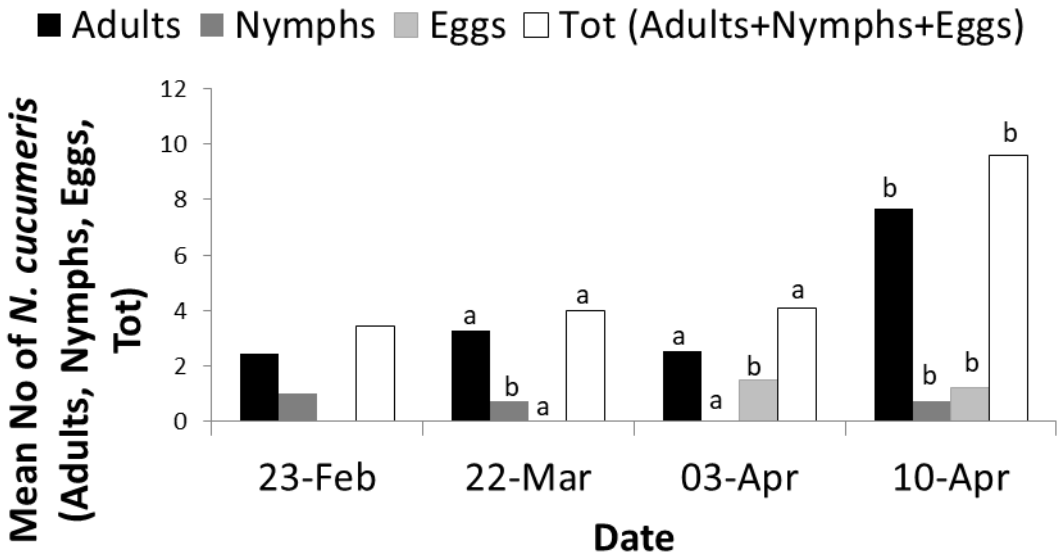


Figure 2.5. Mean numbers of *N. cucumeris* adults, nymphs and eggs at different sampling times 15 (22 March), 27 (03 April) and 34 (10 April) days after insecticide application (7 March), in all treated and untreated plots. *N. cucumeris* releases were made on 15 March, 29 March and 12 April. A pre assessment was done on 23 Feb and was a covariate in the analyses

For the final assessment, different plant parts were assessed for *N. cucumeris*. The analysis of variance showed a significant interaction between plant parts and treatments (P = 0.036), however the Tukey's test didn't exhibit any significant difference between means (mean = 5.13) in the post-hoc analysis.

There was a significant difference in the distribution *of N. cucumeris* nymphs on the different plant parts (Figure 2.6). Significantly more nymphs were found in the folded leaves than the flowers and middle-age leaves (P = 0.045, sed. 0.537, lsd. 1.086, Figure 2.7).

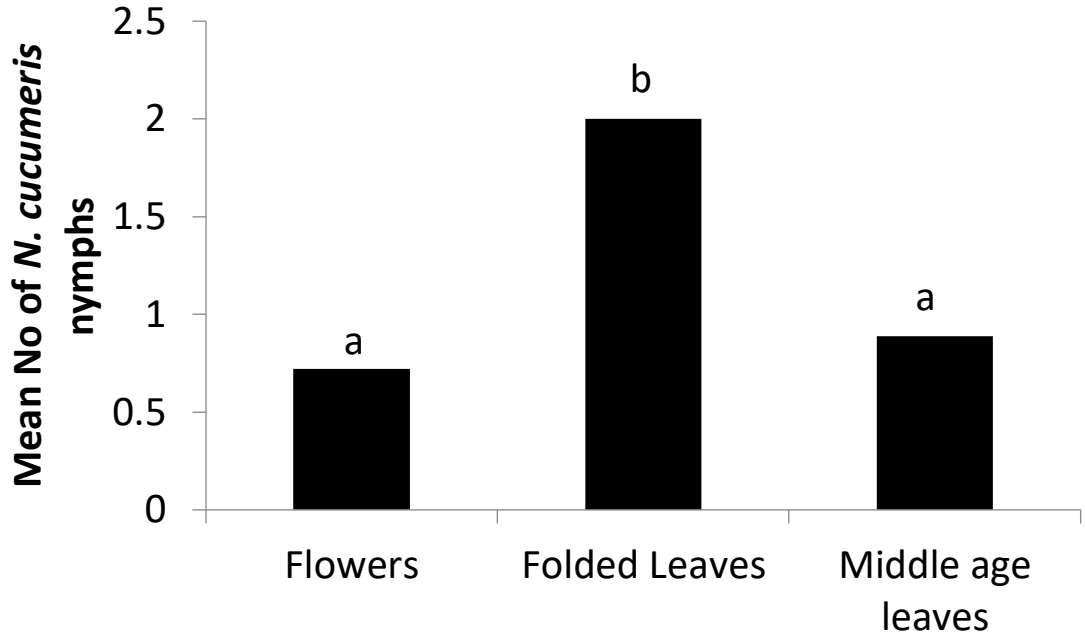


Figure 2.6. Mean numbers of *N. cucumeris* nymphs recorded on flowers, young folded leaves and middle-age leaves at the final assessment, 16 April

There was no interaction between the plant parts and treatments for either *N. cucumeris* eggs or for the sum of the different predatory mite stages (adults, nymphs and eggs) (mean 1.59, P = 0.64, 0.589, 0.778) (mean 7.93, P = 0.904, 0.25, 0.144).

Only one aphid was found over the assement period of the trial. This aphid was dissected but no parasitoids was found.

Leaf samples from each date and treatment were 'bulked' to obtain enough material to carry out the pesticide residue analyses (Table 2.3). The Hallmark active ingredient, lambda-cyhalothrin, was not detectable in any leaf samples pre- or post-spraying. Calypso active ingredient, thiacloprid, was present on some plots, including the Hallmark sprayed and unsprayed plots, pre- and post-spraying, hence did not correspond to where sprayed. It is not known if this was due to drift but levels were very low. In addition, we would still expect to find higher levels of residues on the targeted treated plots if this were the case. Samples were not replicated so no conclusions can be made. Overall, the levels detected were very low <0.093 mg/Kg of leaf sample (Table 2.3).

Table 2.3. Pesticide residue analysis of strawberry leaves from the trial plots. Each sample was a combined of leaves from all 6 replicates. Analytical reporting limit for the active ingredients is >0.01 mg/Kg. Leaf samples were taken on the assessment dates.

Sample Type	Sampling date	Treatment	Calypso mg/kg	Hallmark mg/kg
Folded leaves	23-Feb	Pre assessment	**0.093**	0
Folded leaves	22-Mar	Control	0	0
Folded leaves	22-Mar	Calypso	**0.018**	0
Folded leaves	22-Mar	Hallmark	0	0
Middle-age leaves	16-Apr	Control	**0.044**	0
Middle-age leaves	16-Apr	Calypso	0	0
Middle-age leaves	16-Apr	Hallmark	**0.038**	0

Discussion

At the beginning of this trial the weather was unusually cold for the time of year. This may have had an impact on the establishment of *N. cucumeris* in the plots.

It is also known that the presence of prey affects the distribution of *N. cucumeris* on the plants (Objective 1.2 of the Annual report 2018, AHDB Factsheet 02/18 Tarsonemid mite on strawberry). During the trial, this year, no thrips were recorded, but tarsonemid mites were constantly found in the young folded leaves over the duration of the trial, providing a source of food for *N. cucumeris*.

This experiment has shown that 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 the time in control and treated plots.

The assessment, on 16 April, gave an indication of the distribution of *N. cucumeris* on the strawberry plants at this time. More nymphs were found in the young folded leaves. One month from the pesticide application the newly formed leaves would not be expected to have Hallmark or Calypso residue. Hence these leaves offer a shelter and a source of food for *N. cucumeris* nymphs. This is supported by the pesticide residue data which recorded no or very low level of the target sprays in the leaf material. Importantly, Hallmark, which is suggested to have a persistence of activity against *N. cucumeris* of between 8 and 12 weeks, did not

appear to impact mite releases in the field, in this trial. It is likely that expanding leaves and new leaves reduced the exposure of predatory mites to Hallmark.

When mean numbers of *N. cucumeris* adults per plant part were compared between the treatments and the control there were significantly higher numbers of predatory mites on the folded leaves in the control plants at the last assessment. Again this suggests that the predatory mites were found in highest numbers at locations where their prey were present (tarsonemid mites), but this could not be statistically tested.

Presumably due to the low temperatures virtually no aphids or thrips were recorded throughout the duration of the experiment; hence it was not possible to look for emerging parasitoids or assess the relationship between predatory mites/thrips and plant protection product.

Conclusions

- In general the establishment of *N. cucumeris* was not affected by a single early application of Hallmark or Calypso used to target spring aphids.
- 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, did not appear to impact mite releases in the field, in this trial.

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 (2018).

Introduction

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. Feeding in flowers and on green fruits can cause up to 80% crop loss, rendering production uneconomic and products used can disrupt biological control agents and increase pesticide residues in fruits. *Lygocoris pabulinus* (the common green capsid), may also be a damaging pest, and its appearance within crops tends to be sporadic and locally distributed. A push-pull system could be deployed to enable medium-term control of these pests, which could be integrated into an integrated pest management (IPM) system. Push-pull strategies are designed to have an element which is unattractive to insect pests (such as repellence or masking), referred to as the push. In combination with the push, an attractant source is used to draw the pest away from the crop, referred to as the pull. The pull can be combined with a killing agent to prevent the pest re-entering the crop and to reduce population growth.

In 2017 significantly reduced numbers of capsids and damage to fruits was found in plots where a push was applied (push alone or in combination with a pull). In addition the pull seemed to reduce mirid numbers, but not significantly. In 2018, this push-pull trial was continued, to test whether:

- A significantly improved push can be achieved when using hexyl butyrate (HB) in combination with a second repellent (coded).
- Lygus damage i.e. cat-facing of the fruit, is reduced where treatments are applied.
- The additional repellent will also attract natural enemies into the crop.

Materials and methods

Locations:

The experiment was conducted in four strawberry sites (fields) on three farms in Kent:

Treatments:

Strawberries were grown in tunnels, using standard height systems, and grow-bags with staggered planting holes. A randomised block design was used, which included four strawberry sites, each acting as a replicate block. Each block was sub-divided into four plots. Plots were 25 m x 25 m (three or four tunnels wide depending on the tunnel span at each site, i.e. 8 or 6 m tunnel spans) and were set up either at the corners of the crop as in Figure 3.2.1, or along the edge of the crop, depending on pest pressure. Plots were spaced as far apart as possible to avoid interaction between the treatments:

- Push – a central block of 14.5 x 14.5 m containing polyethylene sachets of HB stapled to strawberry growbags, 1 approx. every 2 m (64 total).
- Push – a central block of 14.5 x 14.5 m with blister packs of Russell IPM compound (coded) stapled to strawberry growbags, 1 approx. every 2 m (64 total).
- Push – a central block of 14.5 x 14.5 m containing polyethylene sachets of HB and blister packs of Russell IPM compound, stapled to strawberry growbags, placed together every 2 m (128 total).
- An untreated control containing no Push or Pull.

All Push treatments were combined with a Pull treatment. The Pull consisted of 12 green cross vane “bucket traps” (Agralan UK, *Lygus rugulipennis* trap system), positioned around the perimeter of the plot at approximately 8 m intervals (12 total). Each trap contained *Lygus* sex pheromone and the female *Lygus* attractant phenylactaldehyde (PAA), along with water and a drop of detergent as a killing agent. Traps were positioned 5.5 m away from the Push treatments, to prevent interference between HB and *Lygus* sex pheromone, as HB is a component of the pheromone.

- HB was formulated in polyethylene sachets (1 ml on a dental roll in polyethylene sachet 50 mm x 50 mm x 120 µm thick) with release rate of 18 mg/d at 22 °C.
- The coded repellent was formulated by Russell IPM, formulation is confidential.
- Phenylacetaldehyde (PAA) was formulated in polyethylene sachets (0.5 ml on dental roll in polyethylene sachet 50 mm x 50 mm x 250 µm thick), release rate 6.7 mg/d at 22 °C
- *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), release rate of HB 0.93 ± 0.05 (S.E.) µg/hr at 27°C.

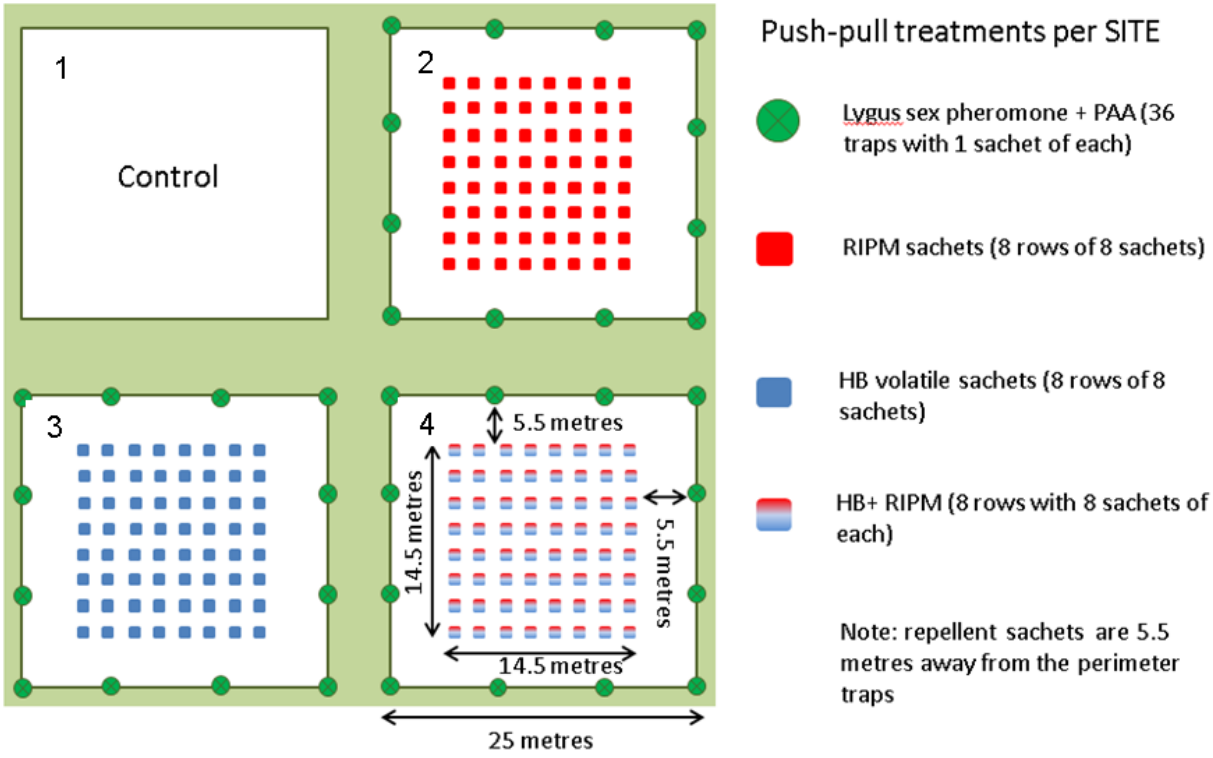


Figure 3.2.1: Diagrammatic representation of an experimental block of the push-pull experiment, showing: **1. Control plot** with no repellents or traps **2. Push-Pull** RIPM sachets within the plot and *Lygus* sex pheromone + female *Lygus* attractant (PAA) in traps every 8 m around the perimeter of the plot, **3. Push-Pull** HB sachets within the plot and *Lygus* sex pheromone + female *Lygus* attractant (PAA) in traps every 8 m around the perimeter of the plot, and **4. Push-Pull** HB sachets + RIPM within the plot and *Lygus* sex pheromone + female *Lygus* attractant (PAA) in traps every 8 m around the perimeter of the plot. 64 sachets in 210 m^2 = 1 sachet per 3 m^2

The 'pull' perimeter traps were placed in-between two grow bags or at the end of the row in between the metal support and the first grow bag (Figures 3.2.2 a & b). The 'push' HB and RIPM sachets were stapled to the grow bag (Figure 3.2.3) in a situation where they would not touch developing fruit. The semiochemical release units were renewed after 1 month, except RIPM, which did not require replacement during the period of the trial.

Figures 3.2.2. a) 'Pull' perimeter trap showing placement in the crop; **b)** positioning of the *Lygus* sex pheromone lure and female *Lygus* attractant PAA sachet within the trap.

'Push' attachment to a grow bag. In this example, a HB sachet

Figure 3.2.3. 'Push' HB sachet stapled to the grow bag

The experiment was run for two months in 2018 and was set up on 3 July at Site 1, 4 July at Site 4 and 10 July at Sites 2 & 3. Crop husbandry involved the standard grower practices, including the growers' standard spray programme which differed at each site (Appendix 3.2.2). 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 3.2.5).

The effect on capsid numbers throughout the season and resultant fruit damage was monitored. Tap samples within the assessment area of the crops were performed every two weeks on four occasions (Table 3.2.1). Fifty plants were tapped per plot. Tap sample data was analysed following a square root transformation of mean counts over four assessment

dates for *L. rugulipennis* adults and nymphs, and *L. pabulinus* adults and nymphs. The numbers of adult *L. rugulipennis* and *L. pabulinus* in the perimeter traps of the push-pull treatments were counted every two weeks following set-up (dates for the tap samples are in Table 3.2.1). Data was analysed using ANOVA after square root transformation.

Table 3.2.1. Dates for capsid assessments (tap and trap counts) at each site, 2018.

Location	Date of experiment set-up	Assessment 1	Assessment 2	Assessment 3	Assessment 4
Site 1	03-Jul	18-Jul	01-Aug	14-Aug	30-Aug
Site 2	10-Jul	23-Jul	07-Aug	22-Aug	04-Sep
Site 3	10-Jul	23-Jul	07-Aug	22-Aug	04-Sep
Site 4	04-Jul	19-Jul	31-Jul	14-Aug	30-Sep

Flowers were tagged at each visit to relate numbers of pest to subsequent damage. Crop damage was assessed for approximately 100 fruits per plot on three occasions. These were categorised as zero, slight, moderate and severe capsid damage (Figure 3.2.4). The timing of the first assessment was determined by following tagged flowers to fruit (Table 3.2.2). All fruit at the same development stage on a plant was assessed to prevent bias. Assessments were conducted in the central 14.5 x 14.5 m of each plot within a block. Damage assessments were started in August and were carried through until early-September.

Table 3.2.2. Dates for strawberry damage assessments within each crop assessment area, 2018.

Location	Date of experiment set-up	Damage assessment 1	Damage assessment 2	Damage assessment 3
Site 1	03-Jul	21-Aug	30-Aug	11-Sep
Site 2	10-Jul	15-Aug	29-Aug	04-Sep
Site 3	10-Jul	15-Aug	29-Aug	04-Sep
Site 4	04-Jul	14-Aug	30-Aug	04-Sep

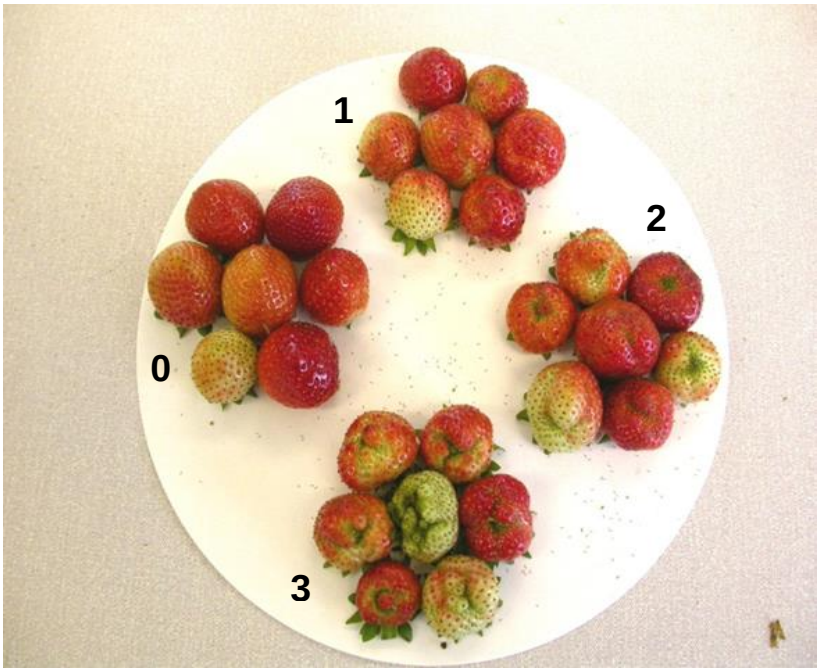


Figure 3.2.4. *Lygus* damage categories for strawberry fruits; from left working clockwise, 0 = no damage, 1 = low damage, 2 = moderate damage, 3 = high damage

As in 2017, data for 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 was used prior to ANOVA. Overall effects of the respective 'push-pull' treatments and interactions were examined.

Results

To assess whether a significantly improved push could be achieved when HB was used in combination with RIPM, tap and trap counts were performed during each assessment and the respective numbers of capsids compared between treatments using a sqrt transformation. From tap counts, the sqrt mean number of adult and nymph *L. rugulipennis* were not significantly different between treatments, however mean numbers were very low (non-transformed grand mean = 0.00313 and 0.0097 respectively).

The sqrt mean number of adult *L. pabulinus* was significantly different between treatments, Figure 2.2.5 (P = 0.013, s.e.d. = 0.00599, l.s.d. = 0.01175), with significantly fewer in control plots (non-transformed mean = 0.0062) than HB (non-transformed mean = 0.0212) and

HB+RIPM (non-transformed mean = 0.0237) plots and in RIPM (non-transformed mean = 0.0088) plots than HB+RIPM plots. However mean numbers were also low (non-transformed grand mean = 0.0150). The sqrt mean number of nymph *L. pabulinus* was not significantly different between treatments (non-transformed grand mean = 0.0219).

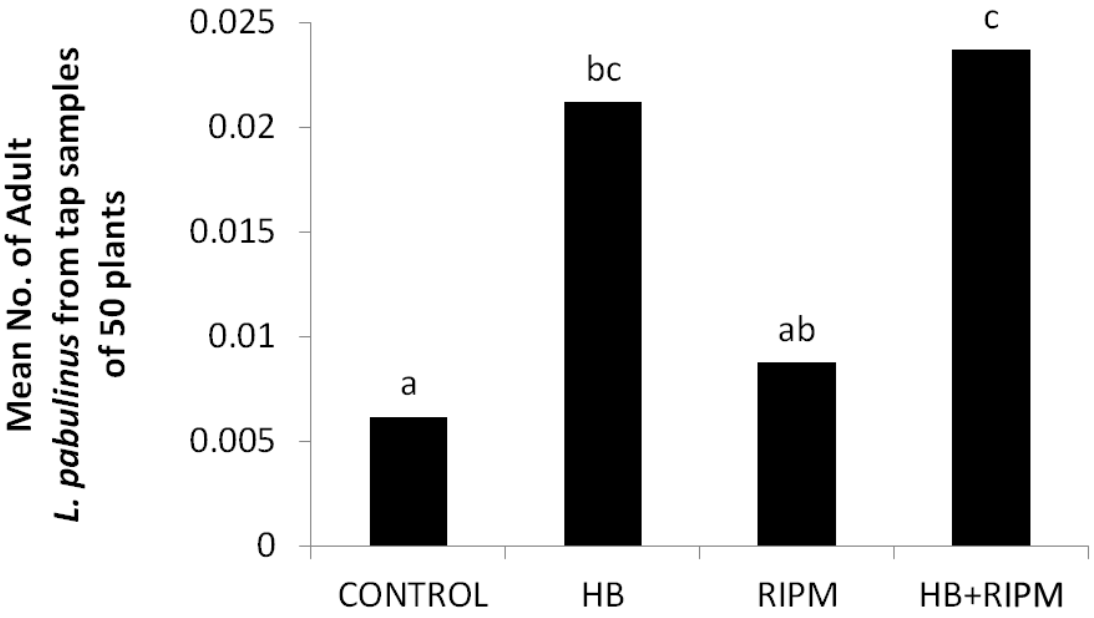
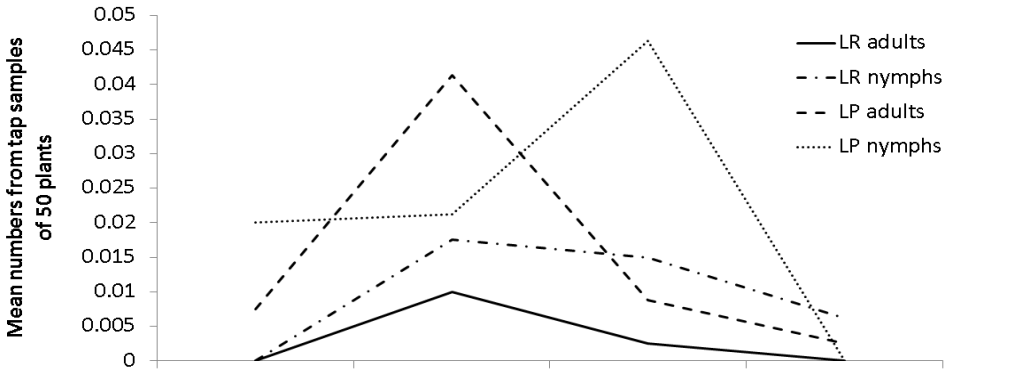


Figure 2.2.5. Effect of treatment on non-transformed mean number of adult *L. pabulinus* counted during tap samples of 50 plants within plots. Control = no push-pull, HB = hexyl butyrate push with pull, RIPM = Russell IPM push with pull, HB+RIPM = hexyl butyrate and Russell IPM push with pull

From pheromone trap counts around treatment plots, the sqrt mean numbers of adult *L. rugulipennis* and *L. pabulinus* was not significantly different between treatments (non-transformed grand mean = 0.391 and 0.0347), respectively.

The numbers of capsid bugs counted in tap samples of 50 plants (adults and nymphs of both *L. rugulipennis* and *L. pabulinus*) and from trap counts (adults of *L. rugulipennis* and *L. pabulinus*) were also analysed. Following sqrt transformation of means, for both tap and trap counts there was a significant effect of time on mean numbers of capsid bugs in the plots. From tap samples, there was a significant peak in mean numbers of *L. rugulipennis* adults (P = <.001, s.e.d. = 0.002778, l.s.d. = 0.005447) and nymphs (P = 0.002, s.e.d. = 0.00487, l.s.d. = 0.00955) and *L. pabulinus* adults (P = <.001, s.e.d. = 0.00599, l.s.d. = 0.01175) in early August (non-transformed mean = 0.01, 0.0175 and 0.0413 respectively). For *L. pabulinus*

nymphs there was a two week delay in the peak, which occured in mid-August (P = <.001, s.e.d. = 0.00728, l.s.d. = 0.01428), (non-transformed mean = 0.0463), Figure 2.2.6. Regarding counts from the 12 traps, there was a significant peak in mean numbers of *L. rugulipennis* (P = <.001, s.e.d. = 0.0610, l.s.d. = 0.1198) and *L. pabulinus* (P = 0.029, s.e.d. = 0.02111, l.s.d. = 0.04146) adults in mid-August (non-transformed mean = 0.799 and 0.0556 respectively) than mid-July when none were caught. After mid-August, there was no significant change in mean numbers of *L. rugulipennis* and *L. pabulinus* by the final assessments in early-September (non-transformed mean = 0.514 and 0.0625), Figure 2.2.7.



	mid-July	early-August	mid-August	early-September
L. rugulipennis adults	a	b	a	a
L. rugulipennis nymphs	a	b	b	ab
L. pabulinus adults	a	b	a	a
L. pabulinus nymphs	b	b	c	a

Figure 2.2.6. Non-transformed mean numbers of *L. rugulipennis* (LR) and *L. pabulinus* (LP) adults and nymphs counted during tap samples of 50 plants per plot, averaged across all treatments

To investigate whether Lygus damage i.e. cat-facing of the fruit, was reduced where treatments were applied, an angular transformation was made of the damage score, and then the level of fruit damage was compared between treatments. There was no significant difference in fruit damage between treatments (grand mean = 22.19), although a similar trend was seen to 2017 (Figure 2.2.8).

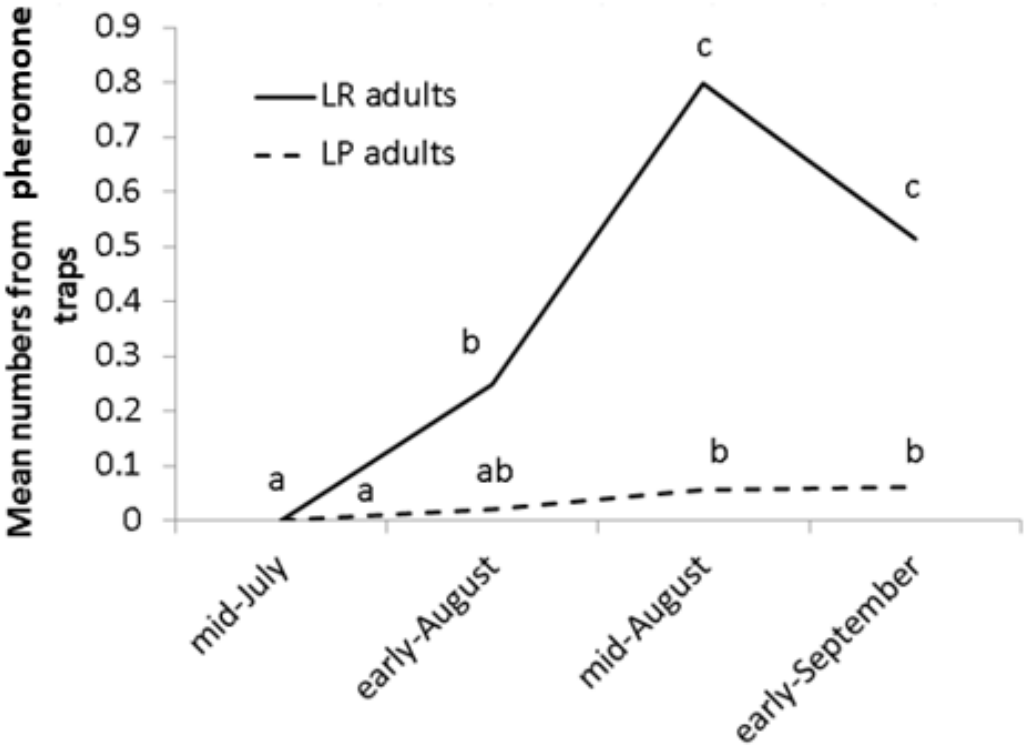


Figure 2.2.7. Non-transformed mean numbers of *L. rugulipennis* (LR) and *L. pabulinus* (LP) adults counted in the 12 pheromone traps per plot, averaged across all treatments

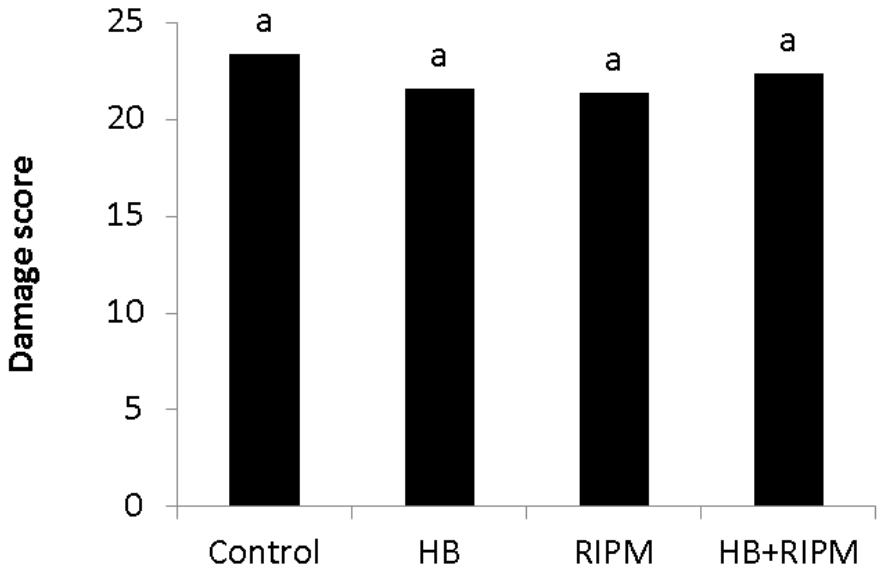


Figure 2.2.8. Effect of treatment on the strawberry fruit damage score, following angular transformation of means. Control = no push-pull, HB = hexyl butyrate push with pull, RIPM = Russell IPM push with pull, HB+RIPM = hexyl butyrate and Russell IPM push with pull

To investigate if the additional repellent could attract natural enemies into the crop, the mean numbers of natural enemies recorded during tap samples of 50 plants in each plot were compared following a square root transformation. Of all natural enemies recorded, only the sqrt mean number of adult earwigs was significantly different, however mean numbers were low (non-transformed grand mean = 0.02)

Discussion and Conclusions

- Very low numbers of capsid bugs during this year's trial meant that comparisons were not really informative about the treatment effects.
- Combining HB with RIPM, did not achieve a significantly improved push.
- The date of assessment had a significant effect on the numbers of capsid bugs recorded from tap samples and pheromone traps. *L. rugulipennis* (adults and nymphs) and *L. pabulinus* adults peaked in early-August, whereas *L. pabulinus* nymphs peaked in mid-August. In trap catches, numbers of *L. rugulipennis* adults and nymphs and *L. pabulinus* adults peaked in mid-August.
- Results showed no significant difference in fruit damage between treatments.

Future work

- Repeat the study in 2019 inside a strawberry crop, when weather conditions are not so warm and dry.
- Perform an additional study minimising the number of push treatments to HB and increasing the number of replicate blocks of control and push-pull plots, to supplement the results from 2017.
- Investigate the effect of increasing the level of HB released into the crop on capsids.

Task 3.2.1 Can the Pull be enhanced with the addition of cinnamaldehyde?

Introduction

The majority of damage caused by capsids is by the juvenile stages feeding on the strawberry flowers and young fruitlets. Females lay eggs within the crop and the resultant offspring are *in situ* ready to feed after hatching. Hence improving the 'attract and kill' strategy for female capsids could potentially reduce damage in the crop.

Currently the green cross vane bucket trap has the sex pheromone for *L. rugulipennis* males and phenylacetaldehyde which, in previous studies, shown to be attractive to female *Lygus* (EU SoftPest Project and HortLINK capsid pheromone Project, Blackmer and Byers 2009; Koczar et al. 2012). However the proportion of males captured exceeds that of females and hence there is the opportunity to improve the female capture by improving the blend of volatile attractants.

Field experiments by Koczor et al. (2012) using synthetic floral odour compounds found that phenylacetaldehyde caught more *L. rugulipennis* than unbaited traps. (E)-cinnamaldehyde was also attractive to *L. rugulipennis*, however, to a lesser extent than phenylacetaldehyde. When the two compounds were combined no synergistic or inhibitory effect was detected (Figure 3.2.1). However, the numbers captured in this study were very low.

In the EU SoftPest project there was some indication, in one of the member countries, that PV2 (1,4-dimethoxybenzene) – developed for strawberry blossom weevil attraction - was also attractive to *L. rugulipennis*.

Bait composition (mg)		Mean catch/trap/inspection ± SE		
		L. rugulipennis		
Phenylacetaldehyde	(*E*)-cinnamaldehyde	Males	Females	Total
100	0	0.57 ± 0.09c	0.41 ± 0.06b	0.98 ± 0.11c
100	10	0.42 ± 0.08bc	0.22 ± 0.06b	0.64 ± 0.11bc
100	100	0.36 ± 0.09bc	0.26 ± 0.07b	0.62 ± 0.12bc
10	100	0.35 ± 0.08bc	0.24 ± 0.05b	0.59 ± 0.09bc
0	100	0.18 ± 0.04b	0.19 ± 0.05b	0.37 ± 0.07b
0	0	0.03 ± 0.02a	0.01 ± 0.01a	0.04 ± 0.03a
Total caught		181	127	308

Figure 3.2.1. Captures of *L. rugulipennis* in VARL traps baited with phenylacetaldehyde and (E)-cinnamaldehyde at different ratios and in unbaited traps from Koczar et al. 2012.

Aims:

- To investigate whether *Lygus rugulipennis* are attracted to green cross vane bucket traps treated with certain combinations of plant volatiles more than others
- To investigate whether *L. rugulipennis* attracted more to traps where cinnamaldehyde has been added as a treatment
- To investigate which combinations are more likely to trap beneficial arthropods

Materials and methods

Six treatments, each containing the *Lygus* sex pheromone and a different combination of plant volatiles were tested (Table 3.2.1). The experiment was a randomised block design with 10 replicates of each treatment. Each trap was a plot in the experimental design. Treatments were either single or mixed floral volatiles in combination with the *Lygus* sex pheromone (Fountain et al. 2014; Innocenzi et al. 2004, 2005; Glinwood et al. 2003). Traps were green cross vane bucket traps with water and detergent, in the bucket, as a killing agent. Semiochemical sachets were suspended from the underside of the lid (Figure 3.2.2). The traps were deployed in a field containing wild and sown forbs (dock, phacelia, mayweed, fathen, ragwort, thistle, poppy, umbellifers, hawkbit, plantain, purple vetch) at 'Ditton Rough', NIAB EMR. Traps were at least 15 m from the hedgerow and at least 10 m apart. The traps were emptied every three to seven days on seven occasions (duration one month) and then moved on one place within each block. Counts were made of Lygus males and females and of beneficial species. After the first week all Lygus were dissected to determine the sex. Sample identification was completed in the laboratory.

Because there was concern that the flora was competing with the female *Lygus* the area was mown on 15 August to remove competing flowers with the aim of enhancing the trap catch.

Data was analysed using ANOVA for a complete randomised block design.

Table 3.2.1. Treatments tested for attraction of female *L. rugulipennis*. NRI supplied the PAA x40, CIN x40, PV2 x10 and SP x30 lures. Lures lasted for the duration of the trial > 4 weeks.

Treatment	PAA (phenylacetaldehyde)	CIN (cinnamaldehyde)	PV2 (1,4-dimethoxybenzene)	SP (sex pheromone)
A	x	x	x	x
B	x			x
C		x		x
D			x	x
E				x
F	x	x		x

Figure 3.2.2. Green cross vane bucket trap deployed in the field.

Results

Almost double the numbers of male *L. rugulipennis* were captured (956) compared to female *L. rugulipennis* (508). The plant volatiles appeared to have a repellent effect on male *L. rugulipennis* (ANOVA F=4.20, P=0.003, Fig.3.2.3). CIN, PAA or PV2 also had a repellent effect when in combination with sex pheromone on female *L. rugulipennis*. None of the plant volatile compounds increased the catch of female *L. rugulipennis* (ANOVA F=2.78, P=0.029).

Unfortunately, a combination of all three plant volatiles was significantly attractive to pollinating insects (Figure 3.2.3). Over the four weeks 38 bumblebees (ANOVA F=5.16, P<.001) and 29 honeybees (ANOVA F=4.99, P<.001) were captured. Numbers of solitary bees were too low to analyse. The effect of treatments was not significant for other mirids and

ladybirds. In addition mirid nymphs, nabids, and lacewing larvae were omitted from the analysis due to low sample size.

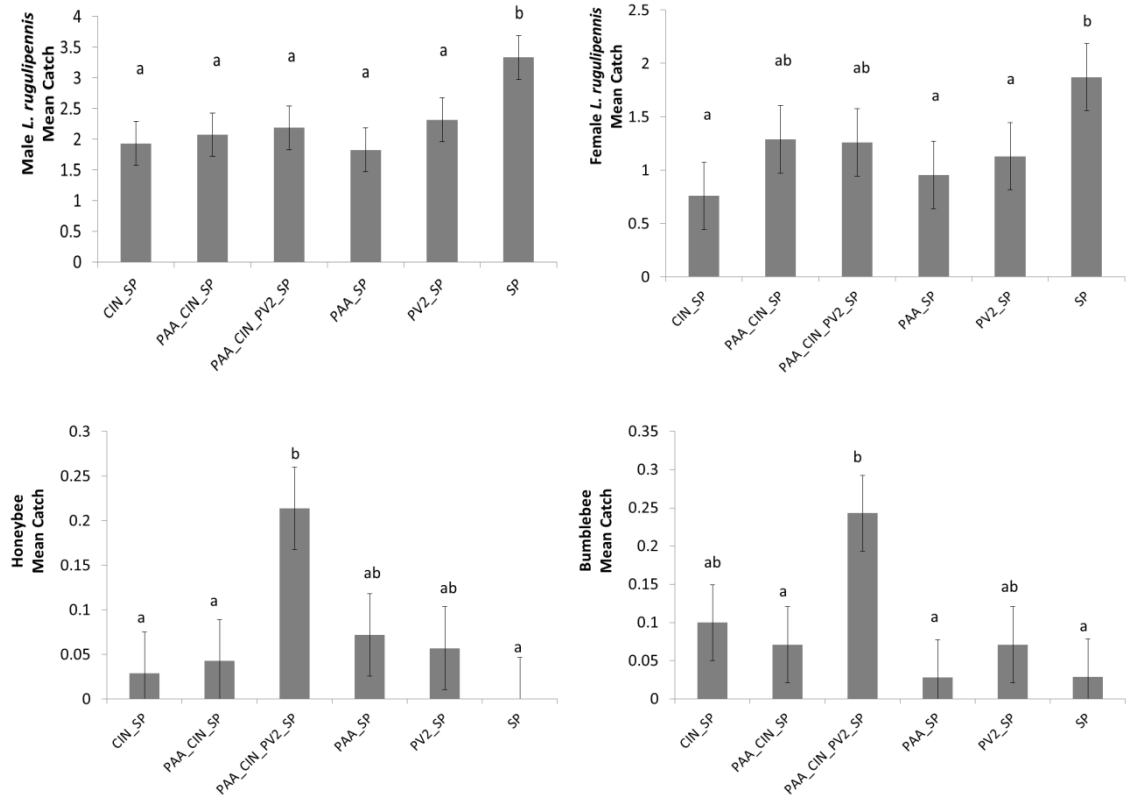


Figure 3.2.3. Mean numbers of male and female *L. rugulipennis*, other mirids, bumblebees and honeybees captured in green bucket traps baited with combinations of semiochemicals (PAA phenylacetaldehyde, CIN cinnamaldehyde, PV2 1,4-dimethoxybenzene and SP sex pheromone). ANOVA on untransformed data. Different letters denote significant differences between treatments

Numbers of *Lygus* males peaked in mid-August and females declined as the experiment progressed as did mirid nymphs and other mirid species. Bees captured in the traps peaked from the beginning to the middle of August but then declined, presumably because the flowering plants in the area were setting seed and so longer attractive. The Nabid and ladybird catch peaked after the area had been mown.

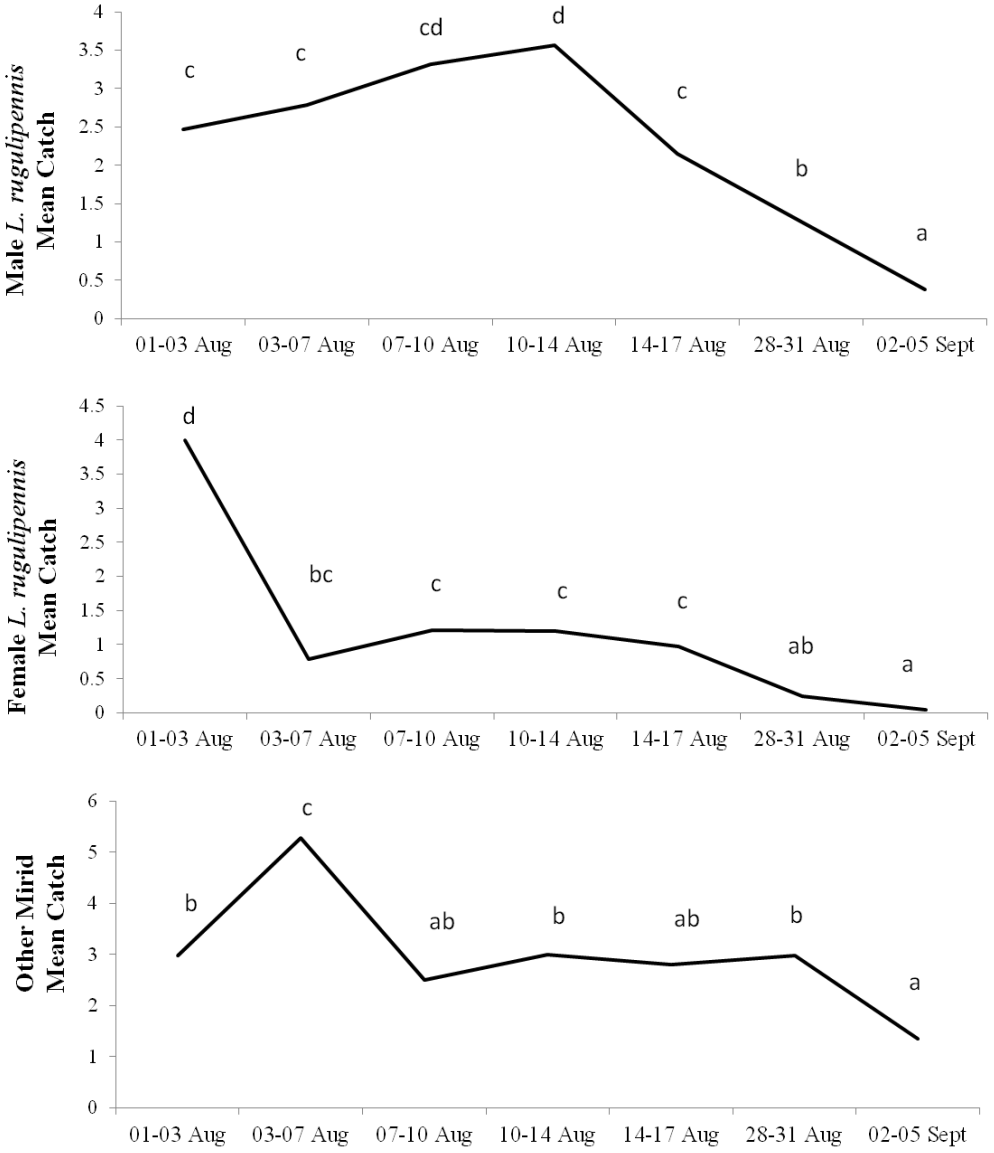


Figure 3.2.4. Mean numbers of Heteroptera captured in green bucket traps baited with combinations of semiochemicals (PAA phenylacetaldehyde, CIN cinnamaldehyde, PV2 1,4-dimethoxybenzene and SP sex pheromone) over time. ANOVA on untransformed data. Different letters denote significant differences between dates

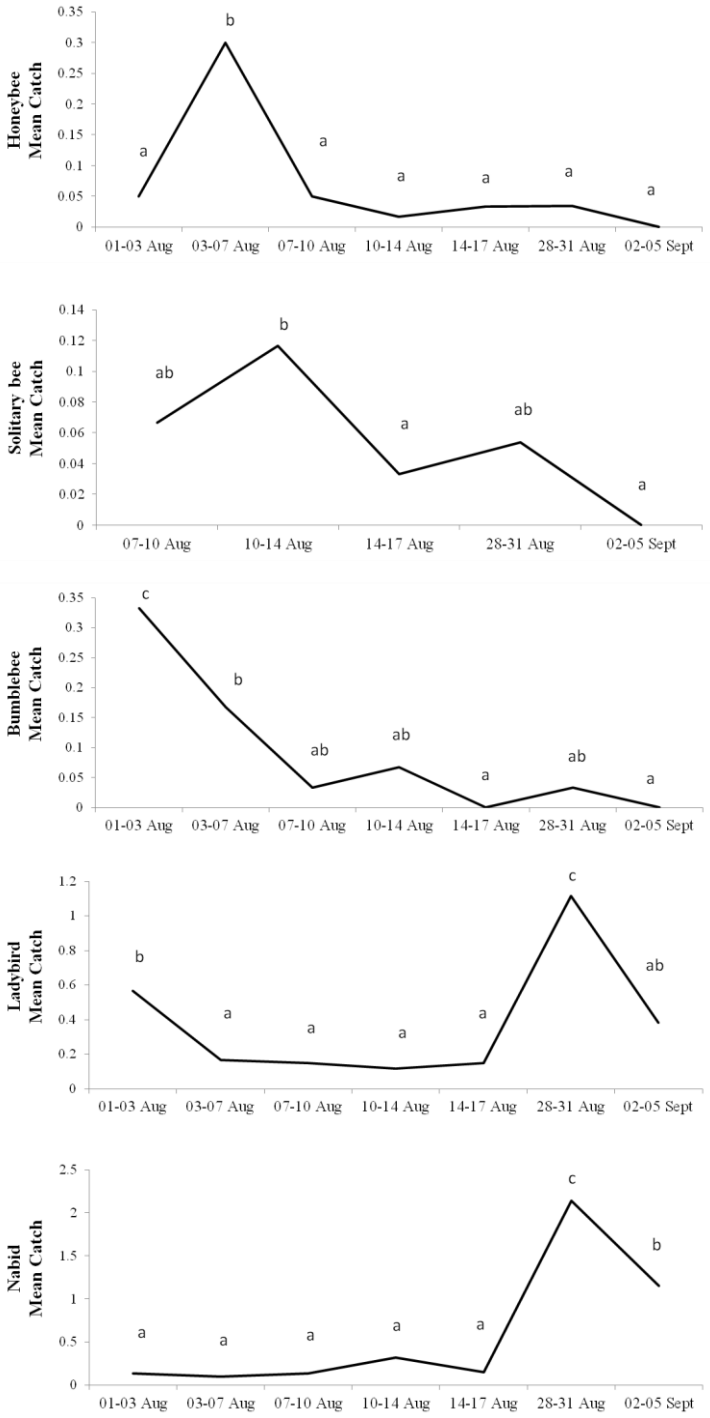


Figure 3.2.5. Mean numbers of non-target beneficial insects captured in green bucket traps baited with combinations of semiochemicals (PAA phenylacetaldehyde, CIN cinnamaldehyde, PV2 1,4-dimethoxybenzene and SP sex pheromone) over time. ANOVA on untransformed data. Different letters denote significant differences between dates

Conclusions

- *Lygus rugulipennis* female trap catches were not increased by the plant floral volatile compounds used singly or in combination in this study.
- Numbers of male Lygus were also not enhanced by these compounds including phenylacetaldehyde, cinnamaldehyde, or 1,4-dimethoxybenzene in combination with the sex pheromone.
- A significant, although low, number of bees were captured in the blend of all three compounds. This should not coincide with the provision of commercial bumblebees which are normally not in place (Jul-Aug) when *Lygus* are abundant. However, the traps may be detrimental to wild bees especially if queens are captured.
- The data suggests that the 'pull' of the push-pull system would not be improved with the use of plant volatiles from this year's data.
- It is reasonable to assume that Lygus females would be orientated to plant flower volatiles for egg laying, however this needs to be weighed against the potential attraction to beneficial species.

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

Task 4.1. Test the efficacy of foliar-applied aphicides compared to standard foliar sprays for control of *Aphis gossypii*

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., 2003). Aphid infestations of strawberry (particularly those involving potato and melon-cotton aphids) may be difficult to control using the aphicides that are currently available. Insecticide resistance further complicates management of these pests. Populations of the melon-cotton aphid are a particular concern, as they are known to be resistant to pyrethroid and carbamate insecticides (Furk & Hines, 1993; Marshall et al., 2012).

In this experimental work, products highlighted as showing promising aphicidal activity, during the recent phase of SCEPTREplus efficacy testing targeting the polyphagous aphid pest *Myzus persicae* on brassicas, were tested for activity against the melon-cotton aphid on strawberry. An insecticidal product with recent approval for application to strawberry (Batavia: spirotetramat) was included to allow comparisons to be made. The work was originally planned with potato aphid as the target, but *M. euphorbiae* populations were unusually low during 2018 and the pest was not available in sufficient numbers. Melon-cotton aphid (*A. gossypii*) was abundant during the field season and is a regular problem for strawberry growers, and was therefore agreed to be suitable as a substitute target.

Aims:

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

The treatments applied to strawberry plants included four products with current approval for strawberry: Batavia (approved for protected and unprotected crops), Majestik (protected and unprotected), Flipper (protected only) and Met52 OD (protected only). 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). Majestik (49% maltodextrin) and Flipper (48% fatty acids) are both plant-derived products with physical modes of action, suffocating the pest through blockage of spiracles. Met52 OD is an oil-based formulation containing 11% spores of the pathogenic fungus *Metarhizium brunneum* strain F52. The other eight products tested are not approved for application to strawberry and are therefore reported following AHDB codes, pending permission from manufacturers to uncode.

Materials and methods

Bare-rooted strawberry plants (an everbearer) were transplanted into compost in 2L plastic pots on 24 May and transferred to two glasshouse compartments at NIAB EMR with gauze mesh to provide insect screening. Plants were maintained in this environment with overhead watering and standard fungicide treatments applied. Runners and flowers were removed weekly to encourage continued growth of vegetation until a source of infesting aphids of an appropriate species could be obtained.

The trial timetable during the lead-up and experimental periods is shown in Table 4.1. Between 27 July and 15 August, aphids were introduced into the glasshouse compartments by transferring cut pieces of aphid-infested strawberry leaves, runners and flower stalks (from a neighbouring infested glasshouse) to the experimental plants. Aphids were a dark strain of *Aphis gossypii* and the insects quickly established ant-attended colonies on the upper plant parts (particularly the bases of flowers and nodes of the trusses; Figures 4.1a, b).

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

Date (2018)	**Activity**
27 July	Plants inoculated with aphids in glasshouse
24 August	Infested plants moved to tunnels
29 August	Pre-assessment
30 August	**First treatment application**
31 August	First post-treatment assessment
3 September	Second post-treatment assessment
6 September	Third post-treatment assessment
10 September	**Second treatment application**
11 September	Fourth post-treatment assessment
14 September	Fifth post-treatment assessment
17 September	Sixth post-treatment assessment
20 September	Assessments for mycosis (Met52 only)

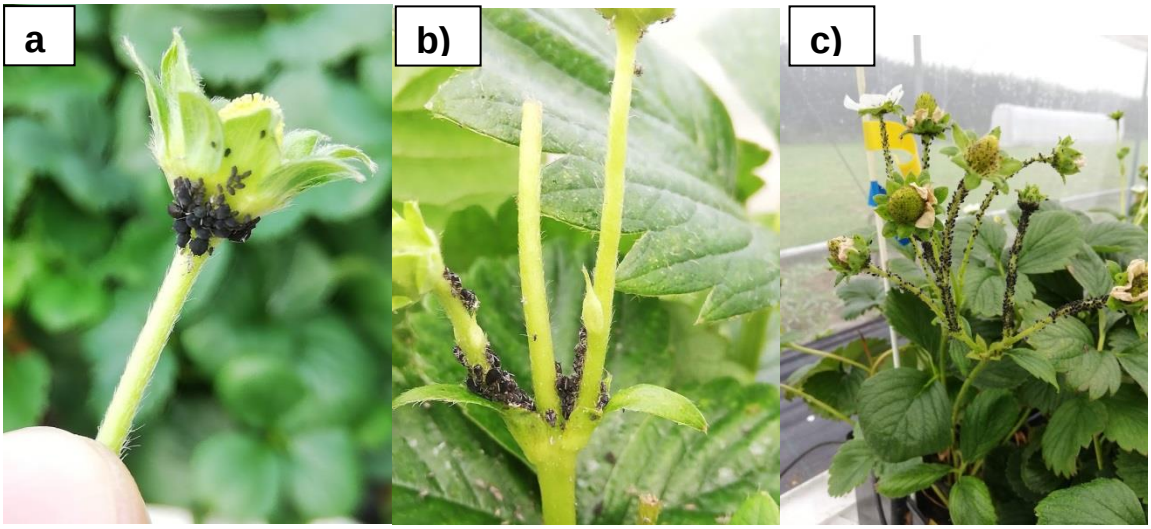


Figure 4.1. Aphid-infested plants, a) cut piece used for inoculation, b) colony on developing trusses in the tunnel, c) colonies between 2nd and 3rd post-treatment assessments.

Aphid-infested potted plants were transferred to the field site (on 24 August) and arranged inside four protected mini-polytunnels (covered with 150 µm thick translucent polythene) at NIAB EMR. Each tunnel was 12 m long and 1.5 m wide. Data loggers were placed in the tunnels at this time and used to record temperature and humidity at 30-minute intervals throughout the trial period. Plants were placed along the mid-line of each tunnel (Figure 4.2a, arranged in 13 plots, each plot comprising 6 pots, 78 plants per tunnel, 312 plants used in total). Fertigation was applied as standard for growers' practice. Spaces between neighbouring plots of plants within each tunnel were approximately 80 cm.

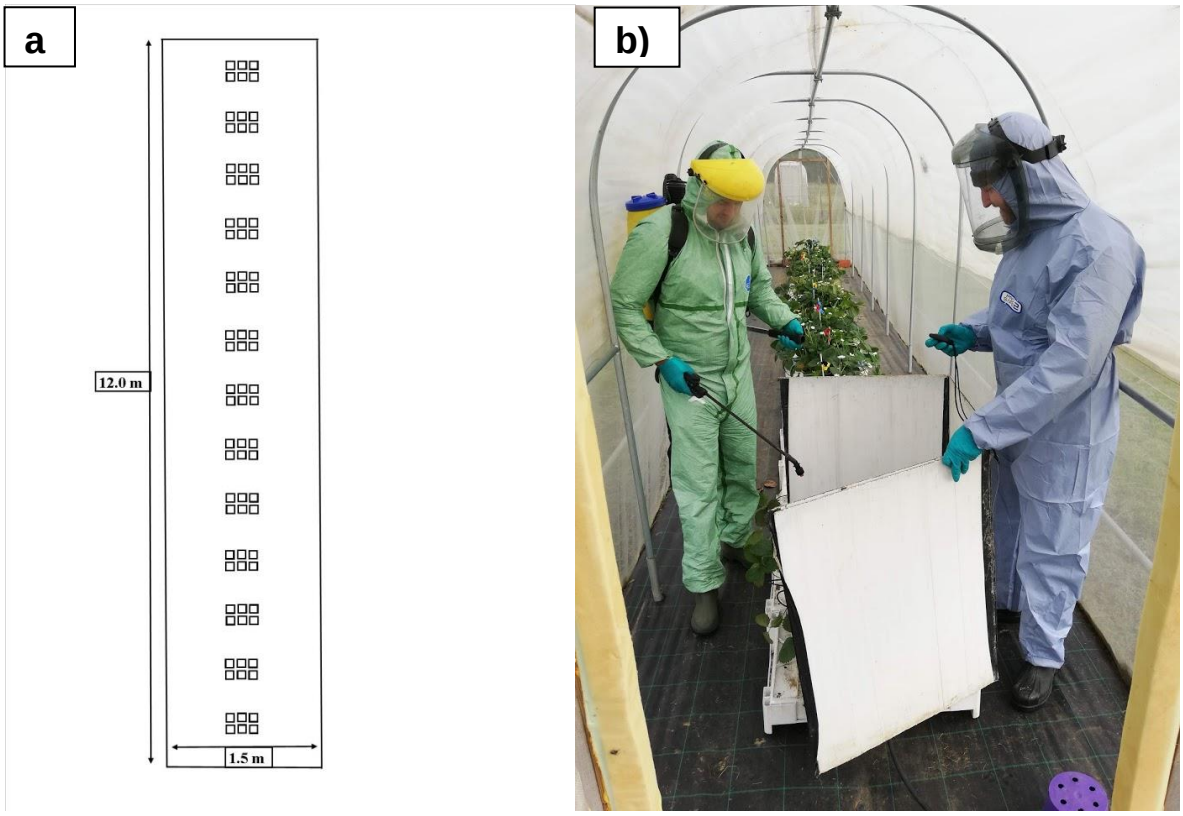


Figure 4.2. a) Arrangement of potted plants (small square = 1 plant) within one of the four tunnels, b) treatment application and screening of neighbouring plots.

At the stage of transfer from glasshouse to field, plants were heavily infested, with aphid colonies, building up on the developing trusses (Figure 4.1b), and the pest quickly (within two days) became well attended by ants at the new site. Twelve sprayed products were applied (Table 4.2). Rates of application followed manufacturers' recommended application rates when these were available, although Bavia was applied at a lower rate (0.5 L/ha) than that approved for strawberries (1L/ha). This lower rate is equivalent to 50 g/ha of active ingredient

and enables comparison of effects of the a.i. (spirotetramat) with the results of recent SCEPTREplus experiments (e.g. as part of SP 4, spirotetramat was tested at a rate of 45 g / L against *Myzus persicae* and other aphid pests of field vegetables). Treatments were allocated using a randomised block design with four replicates, with each treatment applied once within each tunnel.

Table 4.2: Treatments and dose rates for the efficacy testing to control *Aphis gossypii* on strawberry. An additional control treatment was included in the trial (these plants remained unsprayed).

Treatment	**Rate applied (/ha)**
Spirotetramat (Batavia)	0.5 L
AHDB9934	667 g *
AHDB9966	0.2 L
AHDB9943	0.75 L
AHDB9951	0.5 L
Flipper (carboxylic acids)	4.8 L
AHDB9968	0.56 L
AHDB9931	8 L
AHDB9946	1 L
Majestik (Maltodextrin)	10 L
Met52 OD (*Metarhizium brunneum*)	5 L
AHDB9964	6.5 L

*this product was obtained as a solid.

Treatments were applied using a hand pump knapsack sprayer and hand lance (Figure 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 (Figure 4.2b). All treatments were applied on 30 August, and a sub-set of treatments (depending on trends in assessed aphid numbers) were re-applied on

10 September. Ten of the twelve treatments were re-applied; the exceptions were Batavia and AHDB9966, since aphid numbers continued to show a declining trend for these two treatments at the third post-treatment assessment on 6th September. Control plants were untreated.

Seven assessments of aphid numbers were carried out. An initial pre-assessment took place on 29 August. Subsequent assessments were made 1, 4 and 7 days after each of the two spray application dates (Table 4.1). At each assessment, all six plants within each plot were initially examined carefully and the number of plants that were infested with one or more live aphids recorded. Aphids were then counted on one plant per plot. The most heavily-infested plant was selected, and marked with a flag, from each plot of six, and aphid numbers counted on one whole truss from this plant. 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.

Aphids within the colonies varied in colour from dark green to black, but when samples were taken for identification under the microscope they were confirmed as *A. gossypii* throughout the trial. Numbers of aphidophagous natural enemies and aphid mummies were also recorded, although these were extremely low throughout the trial.

Since one of the treatments (Met52 OD) is a formulation of an entomopathogenic fungus, effective action against target pests is expected to be associated with signs of fungal infection. At each assessment, aphid colonies on these plants were examined using a x10 hand lens. On 20 September (three weeks after initial application and 10 days after re-application), aphid colonies were collected from all Met52 OD-treated plants and microscopic inspection carried out in the laboratory at higher magnification as a final, more thorough assessment of mycosis.

Results

Mean numbers of aphids per treatment are plotted, with Figure 4.3 showing results at pre-assessment and the first three post-treatment assessments. Mean number of aphids following re-application of ten treatments on 10 September are shown in Figure 4.4.

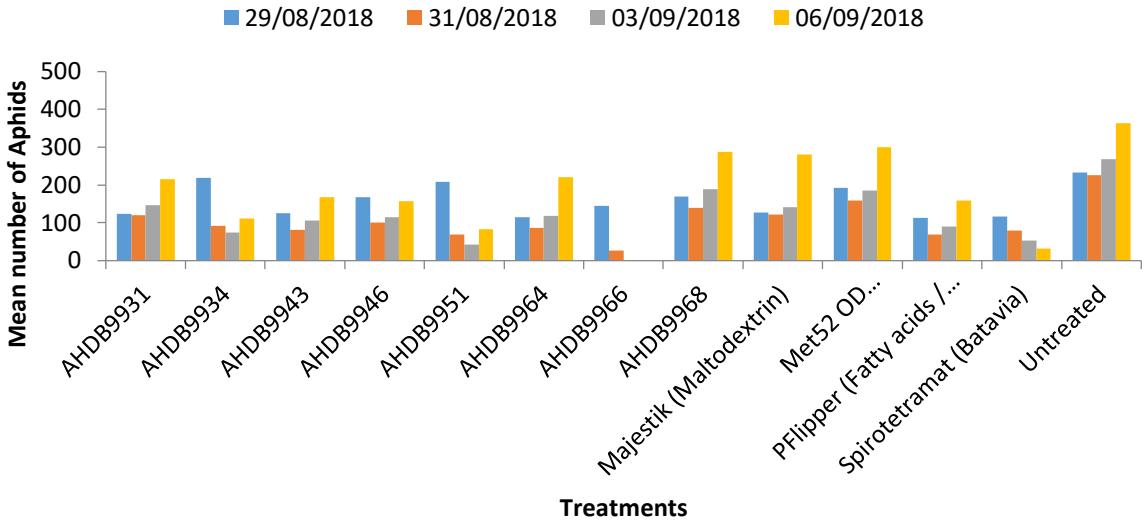


Figure 4.3: Mean number of aphids per plant at pre-assessment (29 August) and on the first three post-treatment assessment dates. All treatments were applied on 30 August. All treatments except Batavia (spirotetramat) and AHDB9966 were re-applied on 10 September. See Figure 4.5 for statistical comparisons based on these numbers

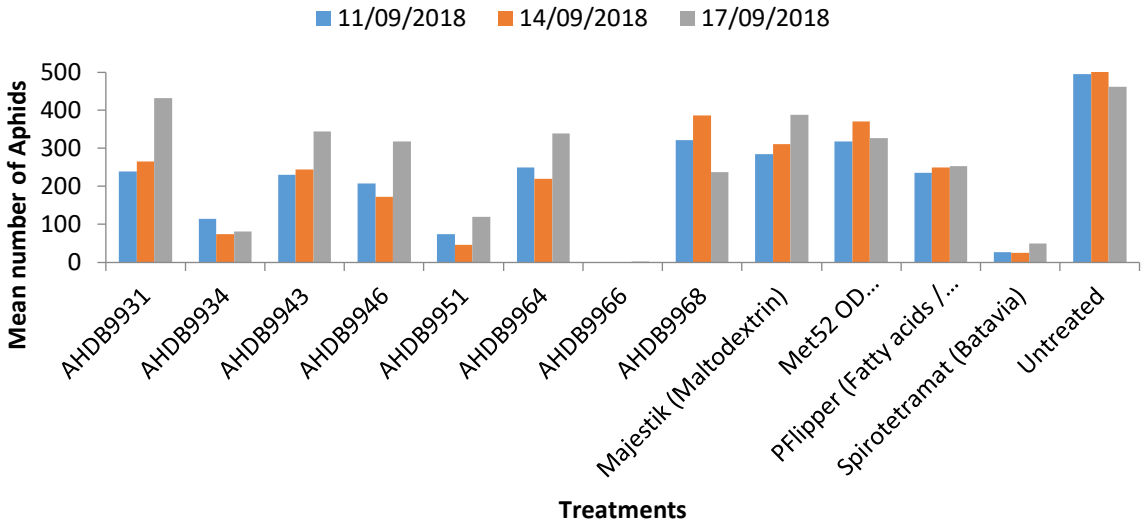


Figure 4.4: Mean number of aphids per plant at the final three post-treatment assessment dates, following re-application of all treatments (except Batavia and AHDB9966) on 10 September. See Figure 4.5 for statistical comparisons based on these numbers

At the 29 August pre-assessment (before application of treatments), the mean number of aphids per treatment was variable (Figure 4.3) The data across all sample dates were therefore analysed 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 counts of 100 aphids) for each treatment. Figure 4.5 shows changes in these normalised aphid numbers during the trial. The GLMM analysis revealed a highly significant treatment X date interaction ($F_{70,227} = 2.61$; $P<0.001$). Pairwise comparisons of means revealed that four treatments (AHDB9934, AHDB9951, AHDB9966 and Batavia) were associated with statistically significant reductions in aphid numbers.

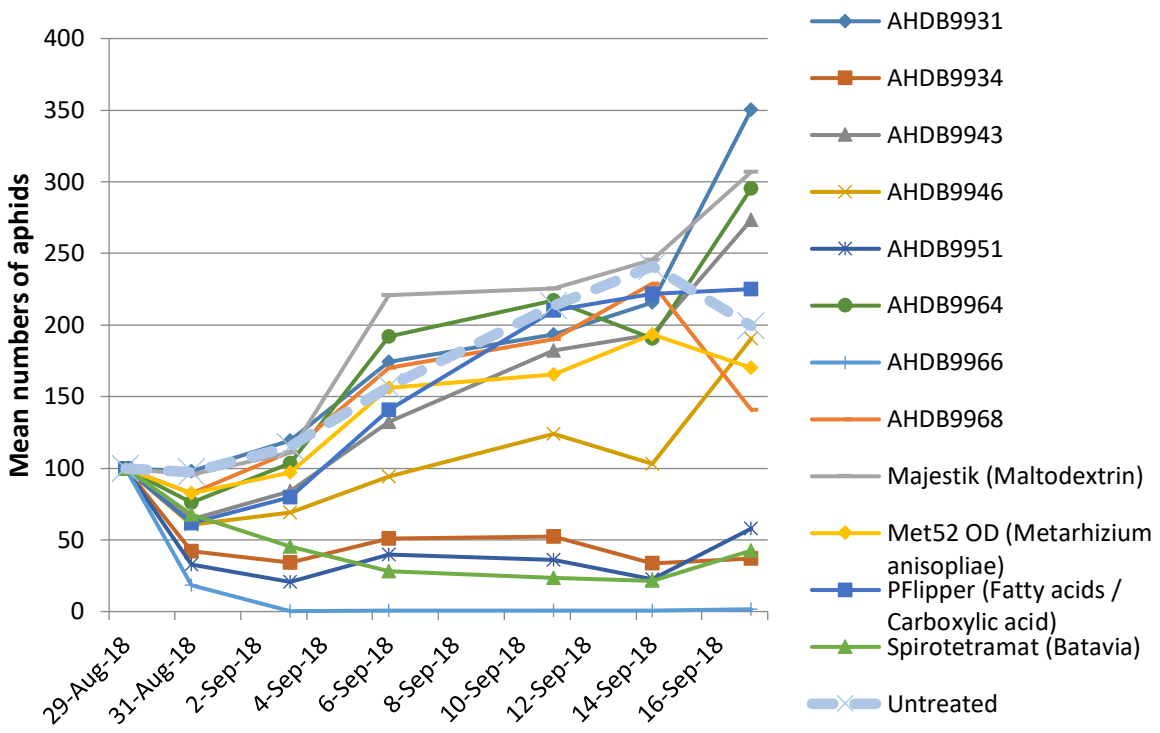


Figure 4.5: Mean number of aphids per plant across all assessment dates, normalised to pre-assessment counts of 100 and analysed using GLMM. Treatments were all applied on 30 August and re-applied (except Batavia and AHDB9966) on 10 September.

Pairwise comparisons revealed that pest numbers on Batavia-treated plants were significantly ($P<0.01$) lower than on untreated control plants at the second post-treatment assessment (3rd September) and all subsequent assessments. Aphid numbers on plants treated with AHDB9934, AHDB9951 and AHDB9966 were significantly ($P<0.001$) reduced at the first post-treatment assessment (31st August) and all subsequent assessments

The single application of AHDB9966 to plants was followed by the most rapid and sustained reduction in aphid numbers. AHDB9951 and AHDB9934 also caused reductions in aphid numbers at the first post-treatment assessment and numbers remained low following re-application of these two treatments. Batavia treatment induced a slower decline in aphid numbers, but this trend continued and numbers remained low throughout the trial despite the decision not to re-apply this product.

The data were analysed further, using pairwise comparisons at each sample date to highlight significant differences between treatments. Four days after treatments were initially applied (at the 3rd September assessment), plants sprayed with four of the products (Batavia, AHDB9934, AHDB9951 and AHDB9966) supported significantly fewer aphids than untreated

control plants. Aphid numbers on these four treatments remained low through the remaining trial period, with significantly fewer aphids counted at each subsequent date including the final assessment on 17th September.

Numbers of infested plants per plot (out of a total of six) were also analysed using a GLMM, in this case applying a binomial distribution and logit link function. However, the data were highly variable and no consistent differences between treatments emerged from this analysis. Numbers of aphidophagous predators and parasitized aphids (observed as mummies) on plants were also recorded during the trial. However, the occurrence of natural enemies in the insect mesh and ant-protected aphid colonies was extremely low, and these numbers were not informative. When the aphid colonies on Met52 OD-treated plants were examined for evidence of fungal infection, no signs of mycosis could be observed.

Discussion

Of the twelve products tested, four caused clear reductions in aphid numbers with protective effects persisting until the end of the trial: Batavia, AHDB9966, AHDB9951 and AHDB9934.

Although Batavia is approved for use on strawberry and showed very good efficacy against *A. gossypii* in this trial, 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 this trial suggest that Batavia offers long-lasting protection against aphids, with populations of *A. gossypii* still very low on treated plants even at the 6th post-treatment assessment (18 days after the single application). 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, ensuring that even newly-emerging leaves and buds remain protected from aphids. The clear reduction in numbers of *A. gossypii* following the single application of spirotetramat (this study) suggest that the active insecticide has a more dramatic impact on this pest species than was indicated in a previous study (Smith et al., 2018), where three repeated applications of spirotetramat (at 7-day intervals, applied at the same rate per hectare as the present study) were required for statistically significant reductions in aphid numbers, compared with numbers recorded on water-sprayed control plants.

The product coded AHDB9966 also showed very promising activity, leading to an even more drastic decline in aphid numbers than Batavia, despite being applied at a very low rate

(equivalent to 24 g of active ingredient / ha) relative to other products. A rapid impact on aphids was observed, with reduced numbers counted one day after application and no live aphids on plants after four days. This is consistent with the manufacturer's information that is available for this active, with rapid knock-down (in addition to longer-term systemic action against sap feeding pests) reported. By contrast, Batavia induced a slower, progressive decline in aphid numbers. This trend continued through the two-week post-treatment assessment period, with numbers of aphids on Batavia-treated plants subsequently remaining low throughout the trial. This slow but persistent action is consistent with Batavia's reported mode of action against target insects. Spirotetramat acts to block lipid synthesis and has a larger impact on growing aphid nymphs than on adults, leading to age-specific effects and a slow but progressive decline of the whole aphid colony.

The highly effective protection observed with Batavia and AHDB9966 occurred despite heavy pressure of re-infestation and indicates that both products have a persistent systemic action within the plant. At the final three assessments (following re-application of the other 10 treatments), aphid colonies had built up to very dense infestations on plants that were untreated as controls or treated with the less effective products (Figure 4.1c). A few winged forms of aphids had started to appear in the more crowded colonies at this stage (data not shown), and non-winged aphids were often seen wandering over and away from these collapsed plants. Despite these sources of potential re-infestation in close proximity, plants treated just once with AHDB9966 remained almost entirely free of aphids throughout the trial. No aphids were recorded at the first five assessments of plants treated with AHDB9966 (up to 15 days after application), and just nine nymphs were found feeding on a single button fruit at the last assessment (18 days after AHDB9966 treatment). These results therefore suggest that AHDB9966 has potential to protect strawberries from aphids if approved for use by growers. However, as a systemic aphicide, the AHDB9966 active may be subject to similar restrictions to Batavia, with its use limited to the pre-flowering period.

Two other notable products in this trial were AHDB9951 and AHDB9934. While their impact was reduced when compared with AHDB9966, both products had clear and significant effects on aphid numbers (Figure 4.5), with faster impact on the insects than Batavia. These two treatments are both novel synthetic insecticides with potential for strawberry crop protection.

The aphids in this trial were concentrated on the growing trusses, particularly at the extremities of the plant parts (Figure 4.1) and colonies were therefore in exposed positions and likely to be directly contacted by sprayed droplets. Despite this apparent exposure, the

remaining eight treatments showed minimal impact on aphid numbers in the trial, with no sustained significant differences in comparison to pest numbers on untreated control plants.

These aphids were not covered in heavy wax secretions, as occurs in some other species, and would be expected to be wettable by sprayed products. The experiment included an eleven-day interval between the first and second spray applications. Some of the products tested are approved for use with a shorter inter-treatment interval. For example, with Majestik there is no minimal time interval for re-application to aphid-infested hot spots, so growers are likely to be re-applying this product at shorter intervals than used here. Similarly, Flipper has no restrictions on the timing of applications. Met52 OD may be applied up to a maximum of eight treatments per crop, but there is no minimal time interval between applications. Growers are therefore likely to apply these treatments at shorter intervals than eleven days. However, it is surprising that these three products, with approval for targeting *A. gossypii* on strawberry and modes of action bypassing any known pest resistance issues, had no significant impacts on aphids in this trial.

Met52 OD had no observable effect on aphids in this experiment, with no reduction in pest numbers or visible signs of mycosis and very few dead aphids present. It is possible that cadavers were removed from aphid colonies by the attending ants, but if the treatment had caused mycosis then some signs of pre-lethal infection might be expected to be visible. It is possible that environmental conditions within the tunnels were not suitable for fungal infection. The *M. brunneum* strain F52 fungus has optimal activity between 25 and 30 °C, but can be reasonably active at temperatures between 15 and 32 °C. However, the mean daily temperature inside the tunnels varied between 13.8 and 20.6 °C during the trial period and there were four days when the mean temperature was below 15 °C.

Conclusions

- Single applications of the coded product AHDB9966 and the approved insecticide product Batavia gave effective control of melon-cotton aphid on strawberries.
- Effective aphid control was also achieved using two applications of AHDB9934 and AHDB9951.
- The other products tested were not associated with statistically significant reductions in aphid numbers. However, these included “softer” products such as Flipper, Majestik and Met52 OD. Growers are likely to apply these treatments at shorter spray intervals than were used in this experimental trial.

Future work

- Potato aphid (*Macrosiphum euphorbiae*) remains of primary interest as a target for aphicide sprays on strawberries. A trial will be carried out in 2019, testing effects of the synthetic insecticides that were active against *A. gossypii* in 2018 on potato aphid.
- "Softer" products such as Met52 and Flipper will also be tested against potato aphid, but applied at shorter intervals than in the *A. gossypii* study, to allow more realistic comparisons with the practices adopted by growers.

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.

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 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). Some growers have also used synthetic pyrethroid products such as deltamethrin (Decis) for control of rose thrips, but pyrethroids are incompatible with biological control agents used in IPM programmes and there is also the risk that resistance may develop.

So why does rose thrips 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 rose thrips and possibly other thrips species adults are migrating into the crop and damaging the fruit before they start reproducing. It has been suggested that as these species seem to migrate into the crop as adult thrips in large numbers, 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 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.

Aims:

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:

- Determine when adult activity starts in strawberry crops and identify peaks in numbers between March and August inclusive.
- Determine if larvae develop in strawberry flowers.
- Record fruit damage associated with *T. fuscipennis* and other thrips species in flowers.

Materials and methods

During 2018, four sites were selected for monitoring where *Thrips fuscipennis* was confirmed either the only or predominant thrips species in 2017. Two of these sites were monitored and the thrips identified by ADAS (Site 1 and Site 2) and two sites were monitored by Berry Gardens (Site 3 and site 4) and the thrips identified by NIAB EMR.

Locations:

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

Site 3 (Kent) – protected, first planting of prepriatory June bearer as 60-day Junebearer (new planting). Second planting of an everbearer variety, which had been grown on in a propagation area on the site.

Site 4 (Kent) – protected, first planting of prepriatory June bearer as 60-day Junebearer (new planting). Second planting of an everbearer variety which had been grown on in a propagation area on the site.

Assessments:

A total of 80 flower samples were collected from each site on each assessment date, i.e. once every two weeks from 3 May to 20 August 2018 (Site 1), 3 May to 20 August (Site 2) and 3 May to 4 October (Sites 3 and 4). Four rows (for 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 intense feeding on the young developing fruit. When ripe fruit were available percentage fruit area with thrips bronzing damage was assessed on five fruit in one monitoring plot in each block (total of 20 fruit per site per sampling date).

Extraction:

In the laboratory, thrips, any *Orius* sp. (natural or released) and any other thrips predators (except for *N. cucumeris*) were extracted from the 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 (Figure 6.1) to prevent spillage of alcohol and thrips.
2) The flowers and alcohol were gently agitated in the sampling tube.
3) The 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 (Figure 6.2)
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 per monitoring plot was identified, i.e. a minimum total of 16 thrips per site per sampling date. Identification was done after mounting adult thrips females 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 a morphological key (Mound *et al.*, 1976). The following procedure was used:

a) Numbers of thrips adults were recorded (males and females recorded separately) and numbers of larvae. It was possible to distinguish WFT females from *Thrips* species under the dissecting microscope.
b) Numbers of *Orius* sp. adults and nymphs were recorded.
c) 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 were 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.
d) Total numbers and proportion of each species was estimated e.g. if a total of 100 thrips 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.
e) 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.

Figure 6.1. A beaker covered with thrips proof mesh

Figure 6.2. Holding a sieve over mesh for pouring thrips and alcohol onto the mesh

Results

June-bearer crops

Site 1 - June bearer cv. Sonata

Monitoring began on 15 May and continued until 11 July. Most of the thrips adults were recorded on 29 May, after this date either very few or no flowers were present (Tables 6.1 and 6.2). The majority of the thrips species were the onion thrips, *Thrips tabaci* which reached

a maximum of 0.3 per flower on 29 May (Table 6.1). Very low numbers of the rubus thrips, *Thrips major* and *Thrips minutissimus* were also recorded on 29 May and on 15 and 29 May respectively. No thrips larvae and no thrips predators were recorded on any date.

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. major* adults/flower	Mean *T. tabaci* adults/flower	Mean *T. minutissimus*/flower	Mean thrips larvae/flower
15/05/2018	0	0	0.01	0
29/05/2018	0.02	0.3	0.02	0
13/06/2018	0	0	0	0
27/06/2018	0	0	0	0
11/07/2018	0	0	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 bronzing	No. Flowers/plant	No. green fruit/plant	No. white fruit/plant	No. ripe fruit/plant
15/05/2018	0.00	7.80	0.00	0.00	0.00
29/05/2018	0.09*	2.20	7.65	9.10	0.00
13/06/2018	0.01	0.20	2.55	25.75	3.30
27/06/2018	0.14	0.00	0.00	7.95	6.20
11/07/2018	0.38	0.00	0.00	0.15	0.80

*Bronzing assessed on white fruit as no ripe fruit available

Site 2 - June bearer cv. Vibrant

Monitoring began on 3 May and continued until 13 June. Thrips adults were only recorded on 29 May, after this date there were no flowers present (Tables 6.3 and 6.4). All the thrips identified were *T. major* which were present at 0.6 adults per flower (Table 6.3). Fruit bronzing

was recorded from 15 May and maximum fruit area bronzed (1.6%) was recorded on 29 May, the same day as *T. major* adults were recorded. No thrips larvae and no thrips predators were recorded on any date.

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 *T. major* adults/flower	Mean thrips larvae/flower
03/05/2018	0	0
15/05/2018	0	0
29/05/2018	0.6	0
13/06/2018	0	0

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

Date	% bronzing	Mean no. flowers/ plant	Mean no. green fruit	Mean no. white fruit	Mean no. ripe fruit
03/05/2018	0	16.4	0	0	0
15/05/2018	0.3*	3.4	9.9	11.6	0
29/05/2018	1.6	0.5	5.5	11.8	10.9
13/06/2018	0.1	0	2.5	2	9.2

*Bronzing assessed on white fruit as no ripe fruit available

Site 3 – Prepriority June bearer

Monitoring began on 3 May and continued until 28 June. Thrips adults were found on all assessment dates (Table 6.5). The first species to be confirmed was a single *T. tabaci* on 3 May at 0.01 adults per flower and this was the predominant species recorded, occurring on all assessment dates, with maximum numbers occurring on 28 June at 0.16 per flower. *Thrips fuscipennis* and western flower thrips (WFT), *Frankliniella occidentalis* occurred in small numbers during June. Only one thrips larva was recorded, on 3 May (0.01 per flower). No fruit bronzing and no thrips predators were recorded on any date. Data on numbers of flowers and fruit per plant are not available for this crop.

Table 6.5. Site 3 Prepriority June bearer: Mean numbers of adult thrips species and mean numbers of larvae per flower.

Date	Mean *T. fuscipennis* adults/flower	Mean *T. tabaci* adults/flower	Mean WFT adults/flower	Mean thrips larvae/flower
03/05/2018	0	0.01	0	0.01
17/05/2018	0	0.05	0	0
13/06/2018	0	0.12	0.01	0
28/06/2018	0.05	0.16	0.05	0

Site 4 - Prepriority June bearer

Monitoring began on 3 May and continued until 28 June. Thrips adults were first recorded on 17 May when single individuals of *T. major* and *T. tabaci* were confirmed, both at 0.01 per flower (Table 6.6). On 28 June, rose thrips, *T. fuscipennis* (0.01 per flower) and *T. tabaci* (0.02 per flower) were confirmed. No fruit bronzing, no thrips larvae and no thrips predators were recorded on any date. Data on mean numbers of flowers and fruit per plant are not available for this crop.

Table 6.5. Site 4 Prepriority June bearer: Mean numbers of adult thrips species per flower.

Date	Mean *T. fuscipennis* adults/flower	Mean *T. tabaci* adults/flower	Mean *T. major* adults/flower
03/05/2018	0	0	0
17/05/2018	0	0.01	0.01
13/06/2018	0	0	0
28/06/2018	0.01	0.02	0

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 4.5 per flower on 11 July (Figire 6.1). Thrips larvae were mainly recorded on 11 and 23 July and were fewer in number than the thrips adults, peaking at a mean of 0.5 per flower on 11 July. Mean numbers of flowers per plant peaked between 11 and 23 July at 3.3 and 3.5 per plant respectively.

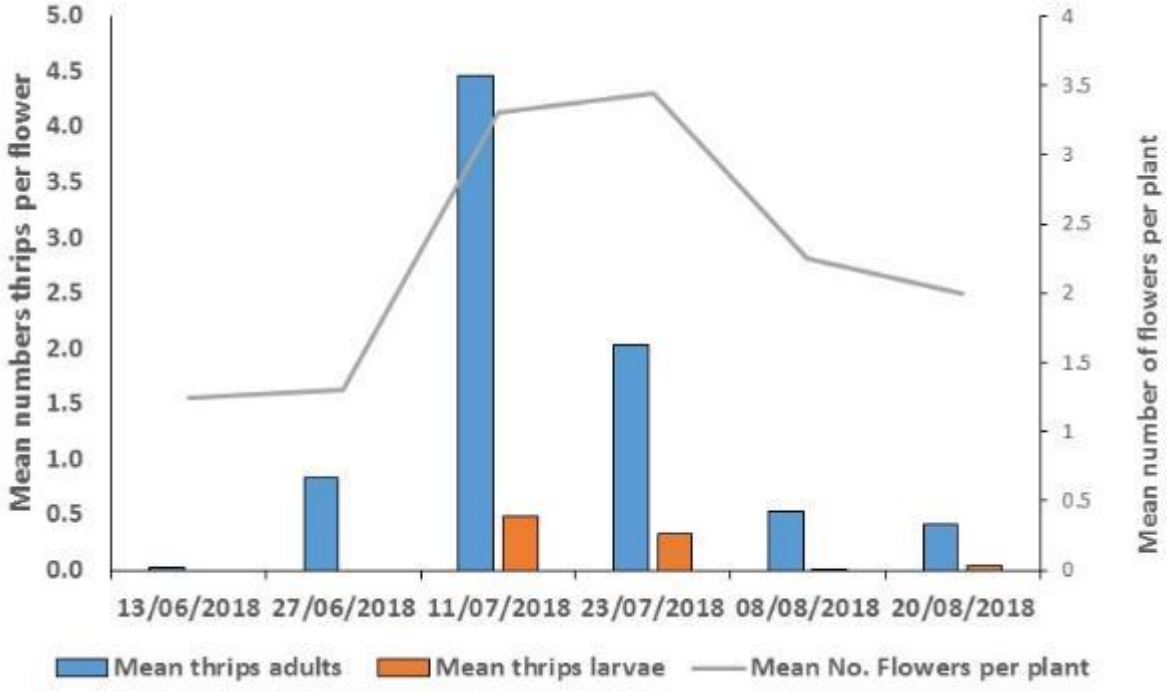


Figure 6.1. Site 1 everbearer cv. Murano: Mean numbers of thrips adults and larvae per flower (all species) and mean numbers of flowers per plant.

At Site 2, thrips adults were recorded on all dates and mean numbers peaked on the same date as at Site 1 at 3.9 per flower on 11 July (Figure 6.2). Thrips larvae were mainly recorded on 11 July and 8 August, peaking at a mean of 0.2 per flower on 8 August. Mean numbers of flowers per plant peaked on 23 July at 4.7 per plant.

At Site 3, thrips adults were recorded on all dates, peaking on 3 August at a mean of 46.4 per flower (Figure 6.3). Thrips larvae were also recorded on all dates, peaking at a mean of 2.7 per flower on 24 August. Numbers of flowers per plant are not available for this site.

At Site 4, thrips adults were recorded on all dates, peaking at a mean of 12.8 per flower on 20 August (Figure 6.4). Thrips larvae were also found on all dates and there were higher numbers of larvae than adults on most dates, peaking at a mean of 44.6 larvae per flower on 20 August. Numbers of flowers per plant are not available for this site.

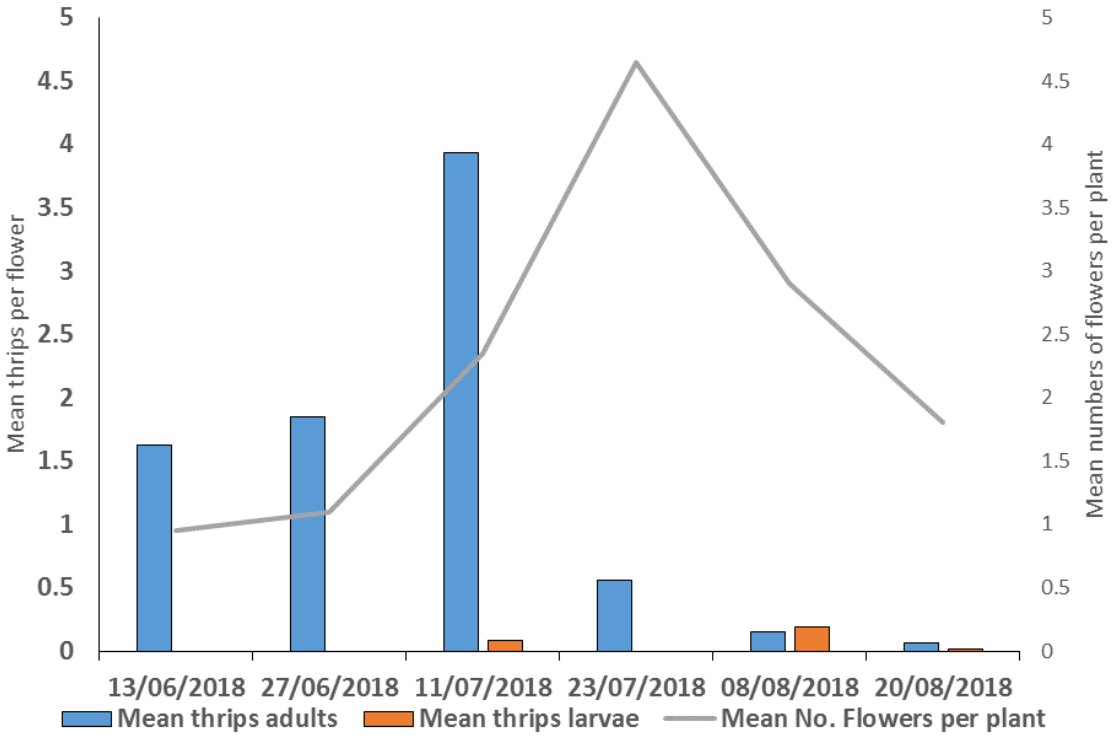


Figure 6.2 Site 2 everbearer cv. Finesse: Mean numbers of thrips adults and larvae per flower (all species) and mean numbers of flowers per plant

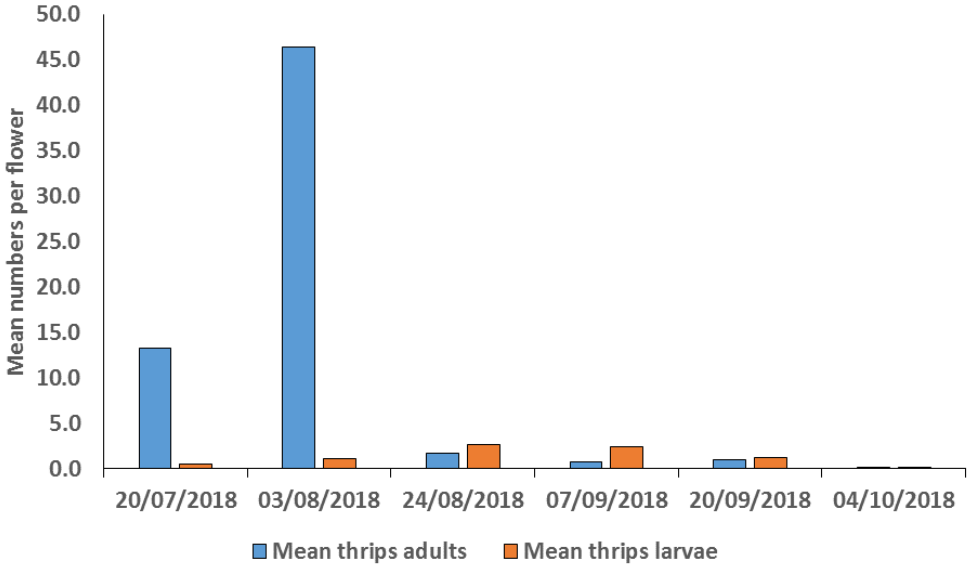


Figure 6.3 Site 3 everbearer: Mean numbers of thrips adults and larvae per flower (all species)

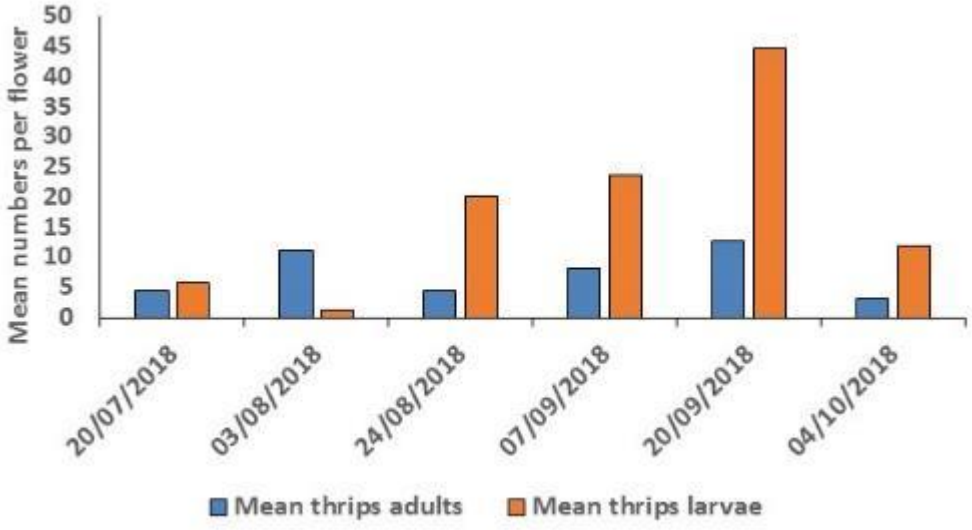


Figure 6.4 Site 4 everbearer: Mean numbers of thrips adults and larvae per flower (all species)

Mean numbers of thrips species per flower

At Site 1, *T. fuscipennis* was the main species occurring in June, *F. intonsa* the main species in July and *T. tabaci* the main species in August (Figure 6.5). *Thrips fuscipennis* was recorded on both dates in June, peaking at a mean of 0.8 adults per flower on 11 July. *Frankliniella intonsa* was recorded on all dates from 27 June, peaking at a mean of 3.1 adults per flower on 11 July. *Thrips tabaci* was recorded on all dates, peaking at a mean of 0.6 adults per flower on 11 July. Other species recorded in small numbers were *Thrips major*, *Thrips vulgatissiumus, Thrips minutissimus* and *Thrips simplex*.

At Site 2, *T. fuscipennis* was the main species occurring in June and *F. intonsa* was the main species in July and August (Figure 6.6). *Thrips fuscipennis* was recorded in both June and July, peaking at a mean of 1.5 adults per flower on 27 June. *Frankliniella intonsa* was recorded on all dates except 27 June, peaking at a mean of 1.9 adults per flower on 11 July. *Thrips tabaci* was recorded on all dates, peaking at a mean of 0.7 adults per flower on 11 July. *Thrips major* was recorded during June and on 11 July, peaking at a mean of 0.3 adults per flower on 11 July. Western flower thrips was recorded on 27 June and 11 July, peaking at a mean of 0.5 adults per flower on 11 July. Other species occurring in small numbers were *Thrips vulgatissimus*, *T. minutissimus* and *T. simplex*.

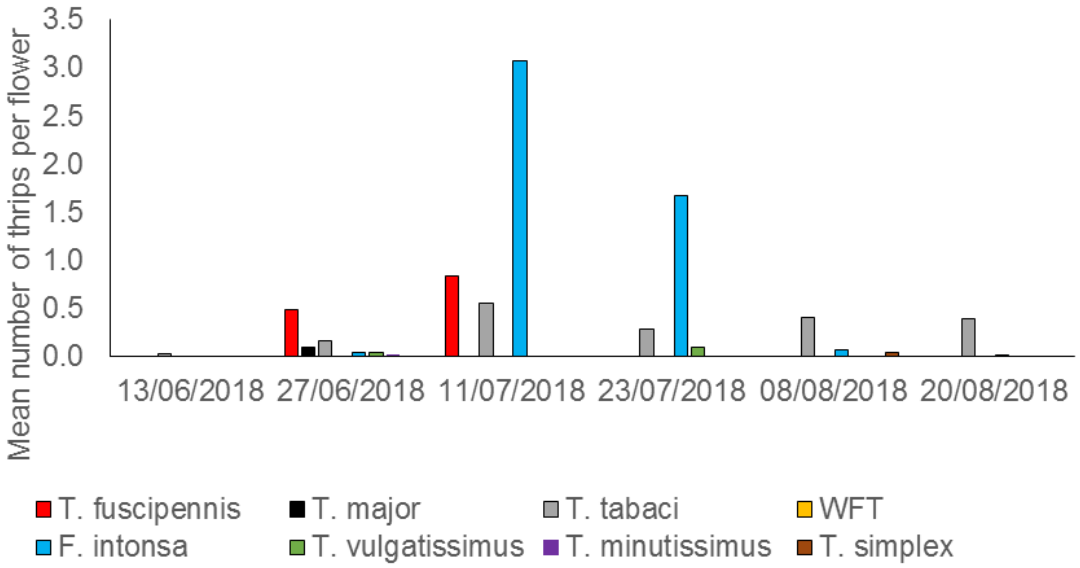


Figure 6.5. Site 1 everbearer cv. Murano: Estimated mean numbers of adult thrips species per flower

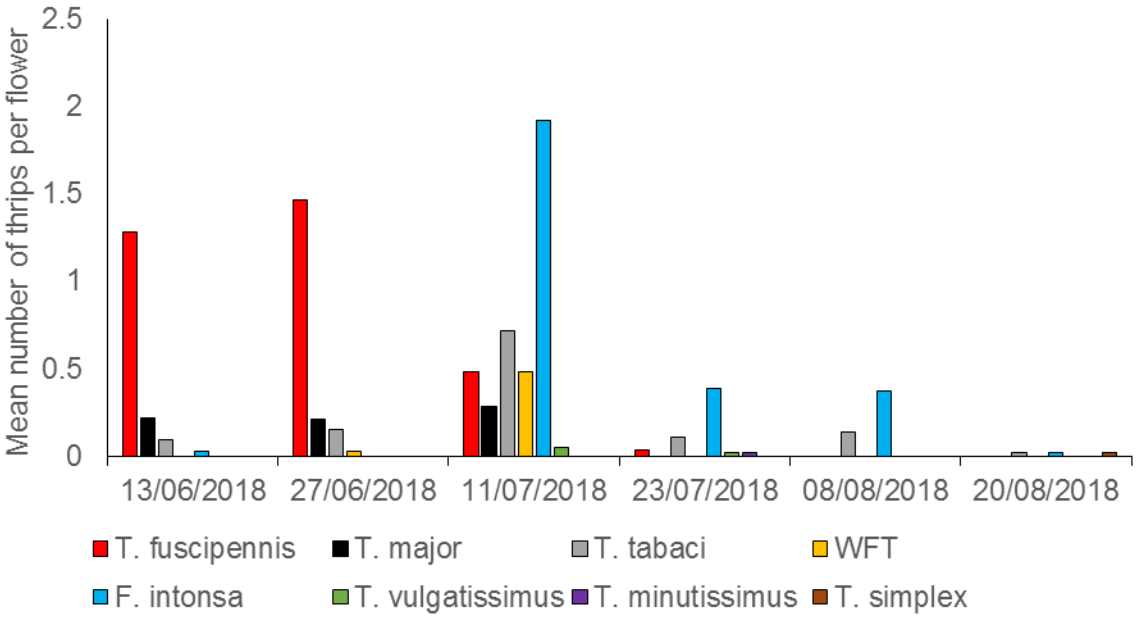


Figure 6.6. Site 2 everbearer cv. Finesse: Estimated mean numbers of adult thrips species per flower.

At Site 3, the predominant species was WFT, which was recorded on all dates except 4 October, peaking at a mean of 29.1 adults per flower on 3 August (Figure 6.7). *Thrips fuscipennis* was recorded on 20 July and 3 August, peaking at a mean of three adults per flower on 3 August. *Thrips tabaci* was recorded on all dates except for 4 October, peaking at a mean of 5.2 adults per flower on 3 August. *Thrips major* was recorded on 20 July and 3 August, peaking at a mean of 2.8 adults per flower on 3 August. *Frankliniella intonsa* was recorded on all dates except for 20 September and 4 October, peaking at a mean of 1.3 adults per flower on 3 August. At this site all these thrips species peaked in number on 3 August. Other species recorded in small numbers were *T. vulgatissimus* and *Thrips pillichi*.

At Site 4, the predominant thrips species was WFT which was recorded on all dates, peaking at a mean of 10.9 adults per flower on 20 September (Figure 6.8). *Thrips fuscipennis* was recorded on 20 July and 3 August, peaking at a mean of 0.6 adults per flower on 3 August. *Thrips tabaci* was recorded on 20 July, 3 August and 20 September, peaking at a mean of 0.4 adults per flower on 3 August. *Thrips major* was recorded on 20 July and 3 August, peaking at a mean of 0.4 adults per flower on 3 August. *Frankliniella intonsa* was recorded on all dates except for 20 September, peaking at a mean of 0.6 adults per flower on 3 August. *Thrips vulgatissimus* was recorded in small numbers on 20 July.

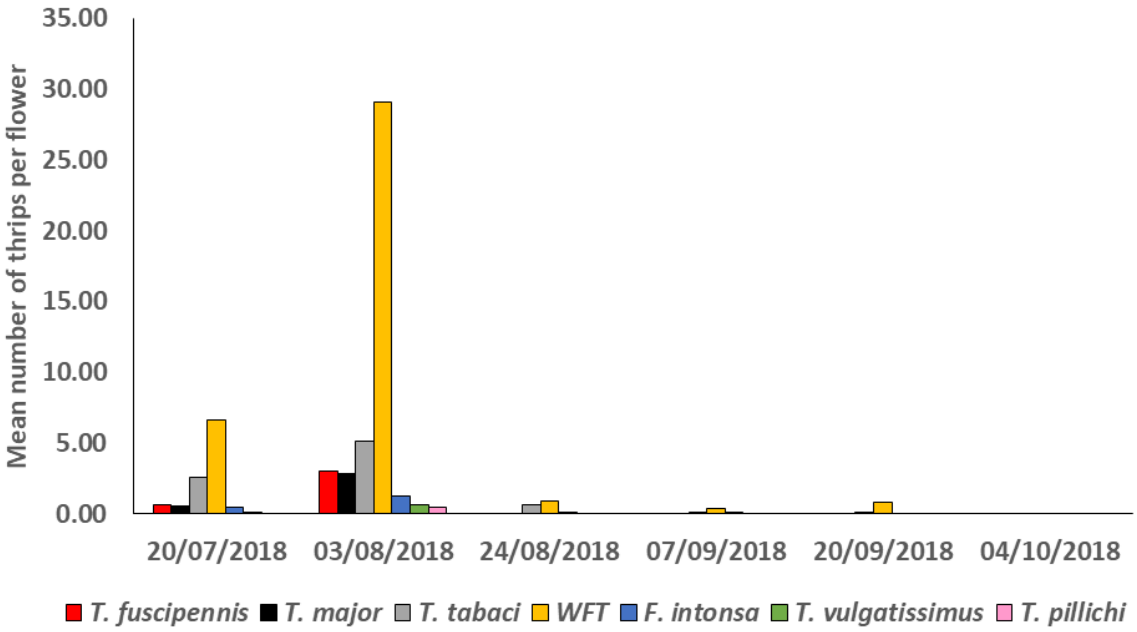


Figure 6.7. Site 3 everbearer: Estimated mean numbers of adult thrips species per flower

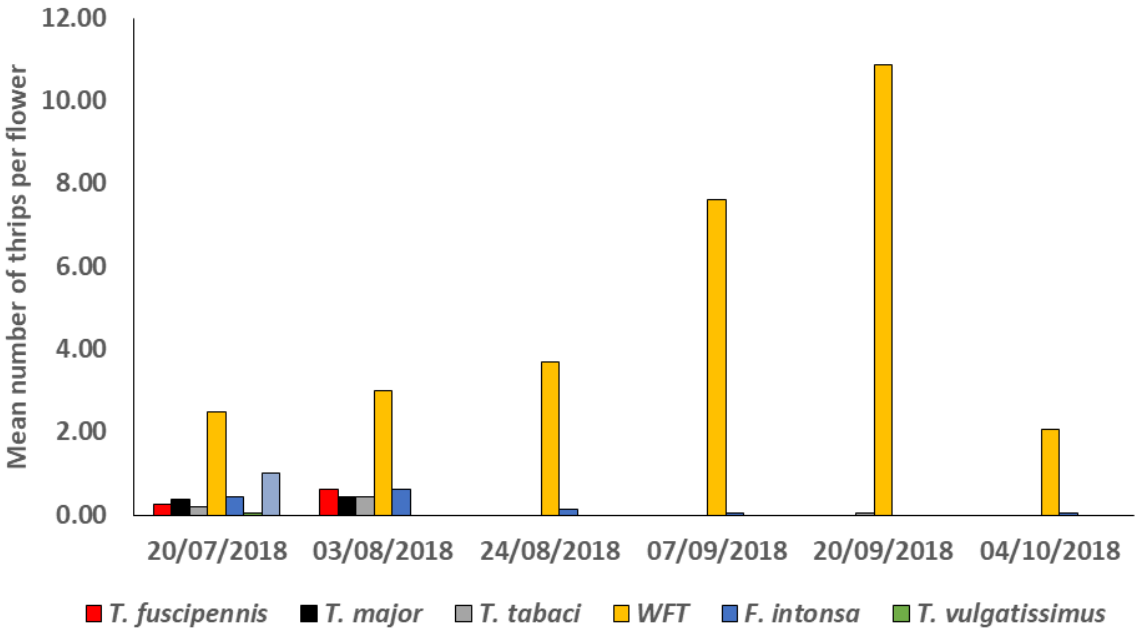


Figure 6.8. Site 4 everbearer: Estimated mean numbers of adult thrips species per flower

Fruit damage

At Site 1, fruit damage was recorded on 11 and 23 July and on 20 August. Damage was only slight, with a maximum of 1.3% fruit area bronzed on 11 July (Figure 6.9).

At Site 2, fruit damage was very slight and was recorded only on 11 July with a mean of 0.05% area bronzed (Figure 6.10).

At Site 3, fruit damage was recorded on all dates from 20 July to 20 September, but was only slight, with a maximum of 2.5% area bronzed on 24 August (Figure 6.11).

At Site 4, fruit damage was recorded on all dates from 20 July to 4 October and damage was more severe than at the other sites with a maximum of 7.3% fruit area bronzed on 3 August (Figure 6.12).

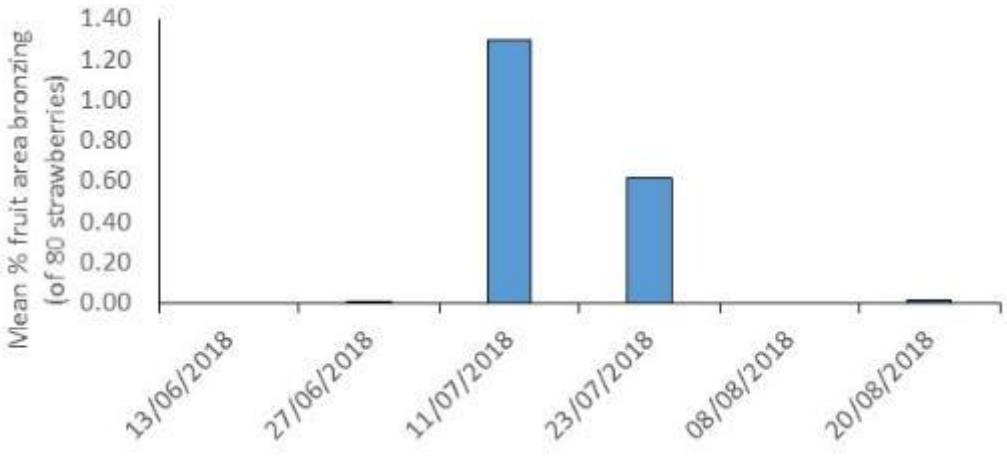


Figure 6.9. Site 1 everbearer cv. Murano: Mean % fruit area bronzed

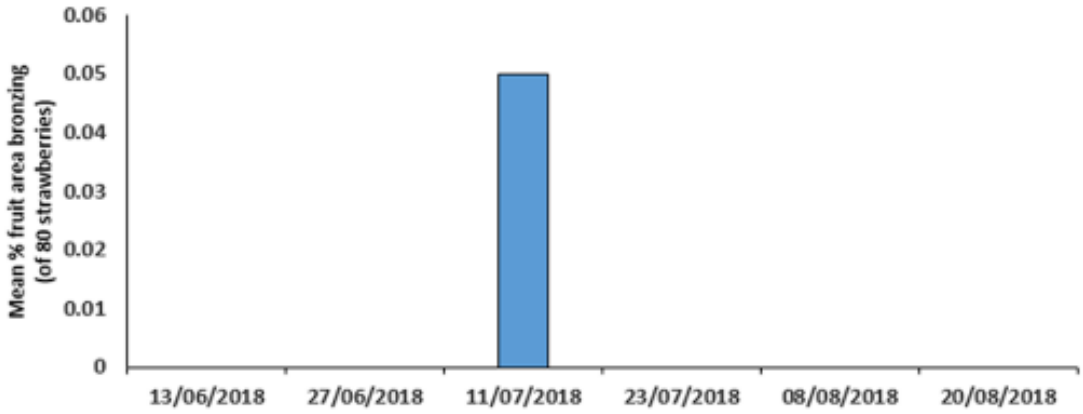


Figure 6.10. Site 2 everbearer cv. Finesse: Mean % fruit area bronzed

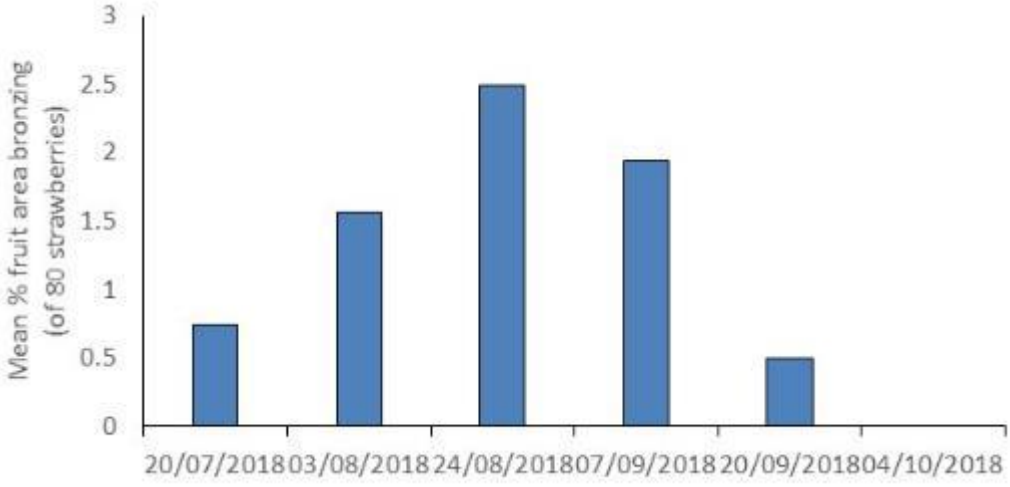


Figure 6.11. Site 3 everbearer: Mean % fruit area bronzed

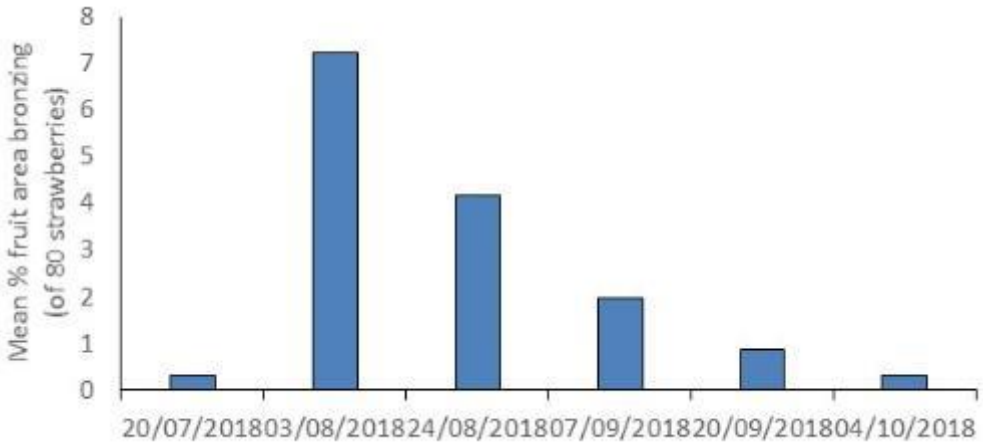


Figure 6.12. Site 4 everbearer: Mean % fruit area bronzed

IPM programme used and natural thrips predators

At Site 1, *Neoseiulus cucumeris* were released at 25 per plant on 18 May and 22 June (Figure 6.13). *Orius laevigatus* were released to an adjacent crop and were recorded in the flowers from 11 July to 20 August, with mean numbers peaking at 0.6 per flower on 23 July. Naturally-occurring predatory banded wing thrips, *Aeolothrips intermedius* were recorded in the flowers from 27 June to 8 August, with mean numbers peaking on 11 and 23 July at 0.4 and 0.5 per flower respectively. Naturally-occurring lacewing larvae were recorded in the flowers on 11 and 23 July and on 20 August. Cyantraniliprole (Benevia) was applied for control of spotted wing drosophila (SWD) on 12 and 25 July and spinosad (Tracer) was applied for SWD control on 1 and 12 August.

At Site 2, *N. cucumeris* and *O. laevigatus* were released to the crop on 14, 21 and 28 June (Figure 6.14). *Orius* were recorded in flowers between 11 July and 20 August, with mean numbers reaching a maximum of 0.2 per flower on 8 August. Banded wing predatory thrips were recorded in flowers between 13 June and 8 August, with a maximum of 0.03 per flower. Lacewing larvae were recorded in flowers on 4 August. Plant protection products for SWD control were applied on 9 July (Benevia), 16 July and 13 August (Tracer) and pyethrins (Spruzit) was applied on 30 July and 20 August.

For Site 3, details of the IPM programme and plant protection products applied are not available. *Orius* were recorded in flowers on all dates between 20 July and 4 October, peaking at a mean of 1.7 per flower on 24 August (Figure 6.15). Predatory banded wing thrips were recorded in flowers on 3 August with a mean of 0.9 per flower.

For Site 4, details of the IPM programme and plant protection products applied are not available. *Orius* and the predatory banded wing thrips were recorded in flowers on 3 August with a mean of 0.1 and 0.3 per flower respectively (Figure 6.16).

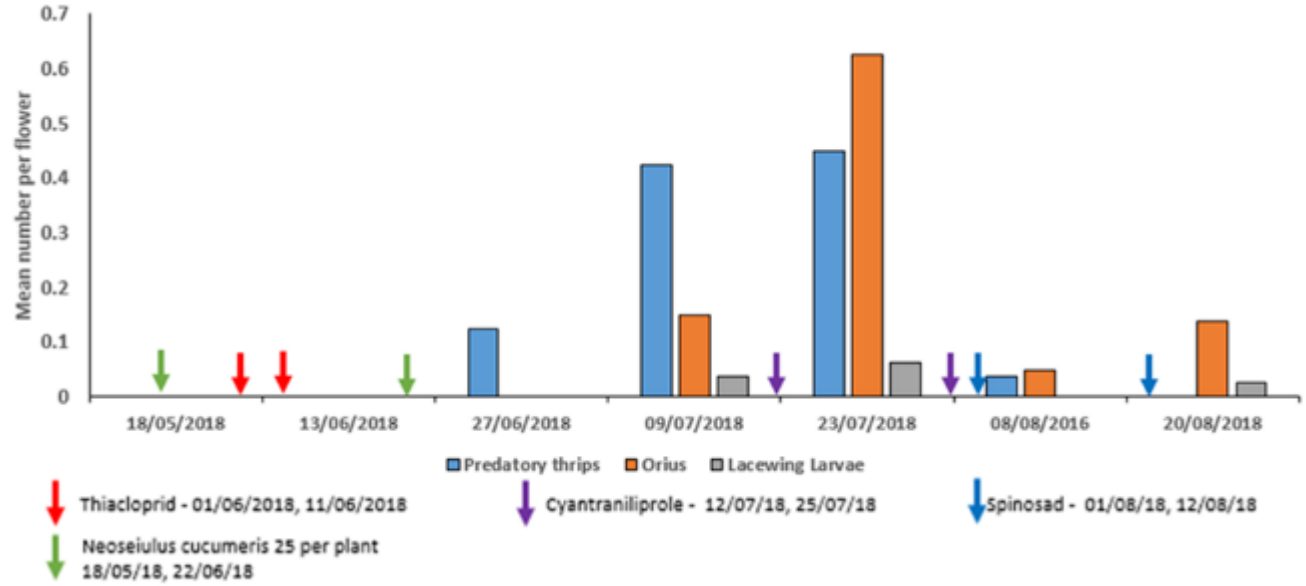


Figure 6.13. Site 1 everbearer cv. Murano: Dates of thrips predator releases, plant protection products applied and mean numbers of predatory thrips and *Orius* per flower

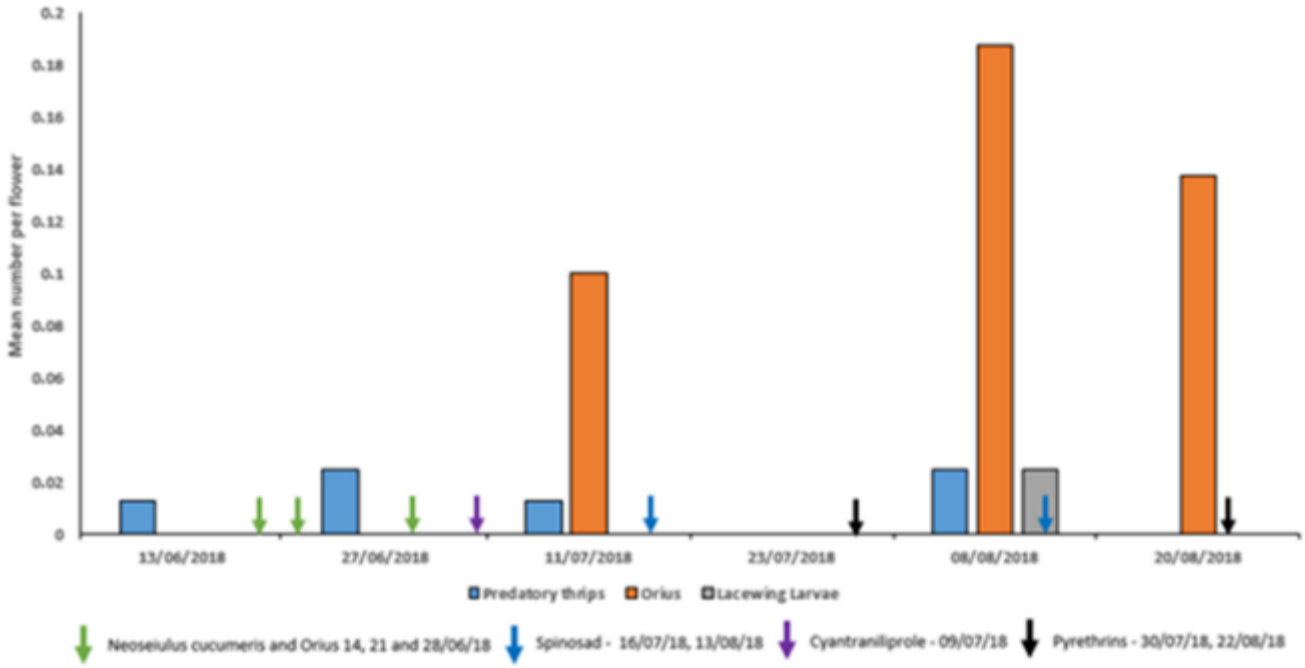


Figure 6.14. Site 2 everbearer cv. Finesse: Dates of thrips predator releases, plant protection products applied and mean numbers of predatory thrips and *Orius* per flower

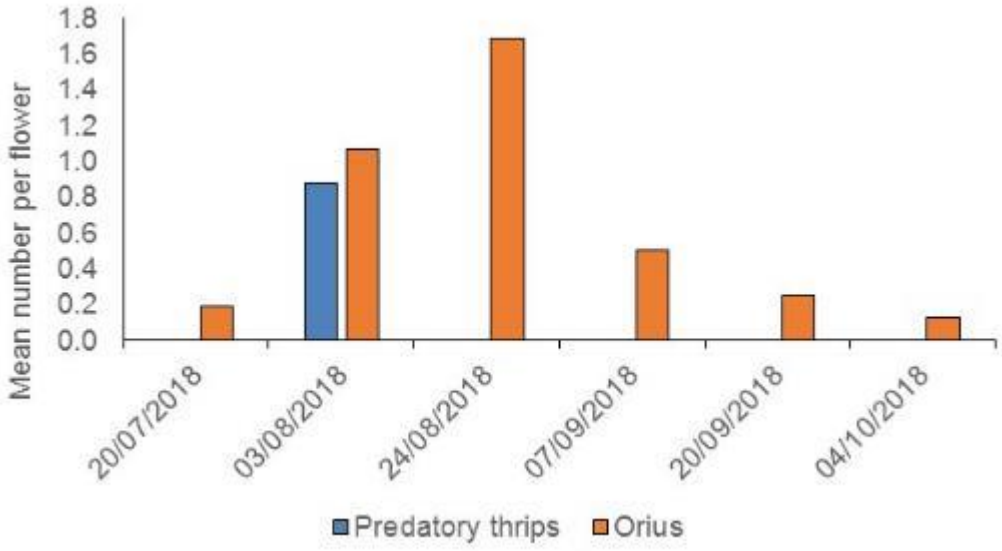


Figure 6.15. Site 3 everbearer: Mean numbers of predatory thrips and *Orius* per flower

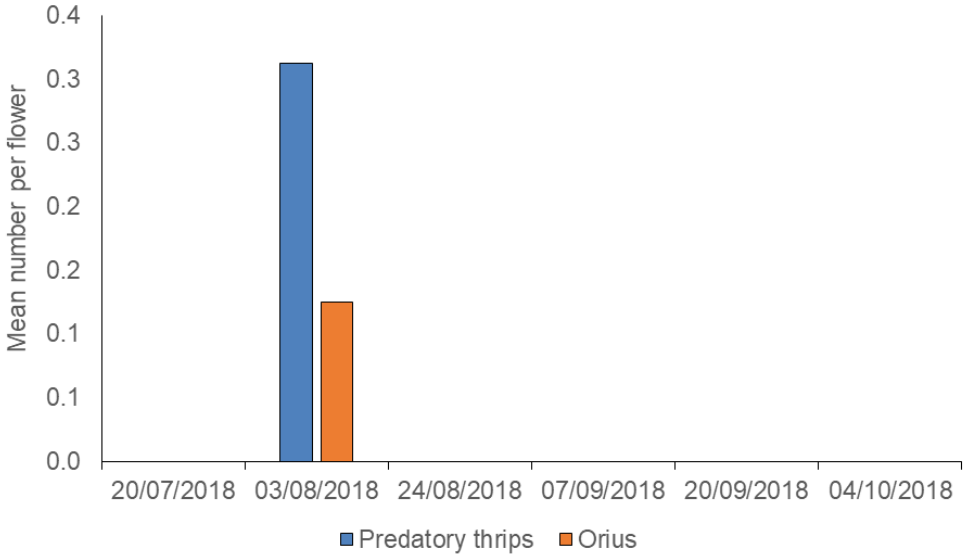


Figure 6.16. Site 4 everbearer: Mean numbers of predatory thrips and *Orius* per flower

Temperature

After a late spring, the summer of 2018 was unusually hot and sunny. Maximum temperatures in the outdoor everbearer crops at Sites 1 and 2 in Essex and Bucks regularly exceeded 25°C and 25-30°C respectively in July and August (data not shown). Temperature data are not available for the tunnelled crops at Sites 3 and 4 in Kent.

Similar temperature trends occurred in Kent with an exceptionally hot summer recorded in 2018. Mean monthly temperatures recorded at NIAB EMR in August 2017 and 2018 were 18°C and 20.7°C respectively.

Discussion

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

Thrips tabaci

Thrips tabaci and *Thrips major* were the only species recorded during May in the June-bearer crops. Both species are commonly found in strawberry flowers. *Thrips tabaci* was first recorded on 3 May in the tunnelled June-bearer crop at Site 3 in Kent, on 17 May in the tunnelled June-bearer crop at Site 4 in Kent and on 29 May in the outdoor June-bearer crop at Site 1 in Essex. *Thrips tabaci* was not recorded at all in the tunnelled June-bearer crop at Site 2 in Bucks. *Thrips tabaci* was active throughout June, July and August in the outdoor everbearer crops at both Sites 1 and 2 where numbers peaked on 11 July with means of 0.6 and 0.7 per flower respectively. In the tunnelled everbearer crop at Site 3 in Kent, *T. tabaci* was active throughout the season from July to September, with numbers peaking at 5.2 per flower on 3 August. *Thrips tabaci* was also recorded between July and September in the tunnelled everbearer crop at Site 4 in Kent with maximum numbers reaching less than one per flower on 3 August.

Thrips major

Thrips major was first recorded on 17 May in the tunnelled June-bearer crop at Site 4 in Kent with a mean of 0.01 per flower and was not recorded atall in the tunnelled June-bearer crop at Site 3. *Thrips major* was the only species recorded in the tunnelled June-bearer crop at Site 2 in Bucks with a mean of 0.6 per flower on 29 May. *Thrips major* was also recorded on 29 May in the outdoor June-bearer crop at Site 1 in Essex with a mean of 0.02 per flower. *Thrips major* was recorded at all four sites in the everbearer crops but unlike *T. tabaci* was not active throughout the season. At Site 1 *T. major* was only found on 27 June with less than 0.1 per flower and at Site 2 this species was active in June and July with maximum numbers recorded on 11 July at 0.3 per flower. In the tunnelled everbearers at Sites 3 and 4, *T. major*

was active during July and early August with peak numbers recorded on 3 August at 2.8 and 0.4 per flower respectively.

Thrips fuscipennis

All four sites were selected as having a history of *Thrips fuscipennis* in the previous year of 2017. This species was first recorded during June at all sites and was only active from June to early August. The first record of *T. fuscipennis* was on 13 June in the outdoor everbearer crop at Site 2 in Bucks where this was the predominant species during June. *T. fuscipennis* was first recorded in the outdoor everbearer crop at Site 1 in Essex on 27 June and on the tunnelled June-bearer crops at Sites 3 and 4 in Kent on 28 June. Peak numbers were recorded on 11 July at Site 1 (0.8 per flower), 27 June at Site 2 (1.5 per flower), 3 August at Sites 3 and 4 (3 and 0.6 per flower respectively).

Frankliniella intonsa

Frankliniella intonsa is occasionally found in strawberry flowers but during 2019 this was found in higher numbers than usual. This species was first recorded on 13 June at Site 2 and from 27 June at Site 1 and was active in both these outdoor everbearer crops from June to late August, with numbers peaking on 11 July at both sites with means of 3.1 and 1.9 per flower respectively. This was the predominant species during July at both Site 1 and 2. *Frankliniella intonsa* was first recorded in the tunnelled everbearer crops at Sites 3 and 4 in Kent on 20 July, where it was active until 7 September and 4 October respectively. At both Sites 3 and 4, numbers peaked on 3 August at 1.3 and 0.6 per flower respectively. This species is known to be native to the UK (Mound *et al*., 1976) and to be more common in the east and south of England than in the west and north (Morison, 1957). Morison reports finding *F. intonsa* on 81 species of flowering plants in Britain and comments that it is possibly more adapted to the more extreme climate conditions in central Europe. During July and August, recorded temperatures in the outdoor crops at both Sites 1 and 2 were very high. It is possible that with climate change, *F. intonsa* could become a more common pest of UK strawberry crops.

Western flower thrips (Frankliniella occidentalis)

Western flower thrips (WFT) was not recorded at all in the outdoor everbearer crop at Site 1 and was recorded only on 27 June and 11 July in the outdoor everbearer crop at Site 2, with maximum numbers of 0.5 per flower on 11 July. WFT was first recorded at less than 0.1 per flower on 13 June in the tunnelled June-bearer crop at Site 3 in Kent. At Sites 3 and 4, WFT was the predominant species recorded in the tunnelled everbearer crops from July to October, peaking at 29.1 per flower on 3 August at Site 3 and 10.9 per flower on 20

September at Site 4. These very high numbers of WFT are not commonly seen now that an effective IPM programme has been developed for control of this species. As no information on the IPM programme used at Sites 3 and 4 it is not known why such high numbers occurred.

Other species

Very low numbers of *Thrips vulgatissimus* were found at all sites in the everbearer flowers. This species is often found in strawberry flowers in low numbers and it is now known whether it causes any fruit damage.

Very low numbers of *Thrips minutissimus* and *Thrips simplex* (the gladiolus thrips) occurred at some sites. Neither species is known to damage strawberry fruit.

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). During 2019, numbers of flowers per plant were only recorded at Sites 1 and 2 and data is not available for Sites 3 and 4 where WFT was the predominant species. At Site 1, mean numbers of thrips adults per flower (all species combined) peaked on 11 July at the same time as numbers of flowers per plant peaked. Western flower thrips was not recorded at this site thus other factors such as immigration of other species of thrips adults may have contributed to the peak in thrips numbers at this site. At Site 2, thrips adults per flower dropped on 23 July when mean numbers of flowers per plant peaked. This could have been due to the thrips adults dispersing between the increased numbers of flowers, but could also have been due to other factors including predation as numbers of *Orius* per plant also peaked on 23 July and cyantraniliprole was applied on 12 July for SWD control which may have given some control of thrips.

Development of larvae in flowers

Thrips larvae were found in flowers in the everbearer crops at both Sites 1 and 2 during July and August, but in much lower numbers than thrips adults. This indicated that either the thrips were not breeding well on the strawberry crops, or they were being controlled by the combination of predators that were either released or naturally-occurring and by the plant protection products that were applied during July and August for SWD control. The species of larvae are still to be identified during 2019, but as no WFT adults were recorded at Site 1

and very few were recorded at Site 2, it is likely that the larvae are mainly those of the other species recorded. This indicates that an IPM programme for all thrips species breeding on strawberry should include components for control of thrips larvae as well as adults. At Sites 3 and 4, larvae were found in flowers in the everbearer crops on all dates between 20 July and 4 October and were present in higher numbers than the adults from 24 August. This commonly occurs with WFT infestations as this species breeds very quickly in strawberry flowers, especially at high temperatures, and WFT was the predominant species at both sites.

Fruit damage

Of the thrips species confirmed at the four sites, the following species are known to cause bronzing damage to strawberry fruit:

Western flower thrips, *Frankliniella occidentalis* is known to cause strawberry fruit bronzing caused by its feeding damage to young developing fruit. This species was probably responsible for the fruit damage that occurred at both Sites 3 and 4 where WFT was the predominant species.

Rose thrips, *Thrips fuscipennis* caused damage at Site 1 in 2017 where it was the only thrips species recorded (Brown & Bennison, 2018). High numbers of this species were also recorded at Sites 3 and 4 in 2017 where growers reported fruit damage. *Thrips fuscipennis* is also reported to damage strawberry fruit in Italy (Gremo *et al*, 1997).

Onion thrips, *Thrips tabaci* is known to damage strawberry fruit (Bennison, 2015; Steiner, date not published).

Rubus thrips, *Thrips major* was the only thrips species recorded on the June-bearer crop at Site 2 and where slight fruit damage occurred, indicating that this species can damage fruit. Only adult thrips were found in the flowers, indicating that fruit damage was caused by the adults.

Flower thrips, *Frankliniella intonsa* is reported to cause damage to strawberry fruit 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 severe fruit damage occurred (Stubsgaard, Brown and Bennison, personal communication).

Fruit damage in the June-bearer crops at Sites 1 and 2 was very slight, with a maximum of 0.4% and 1.6% fruit area bronzed respectively. At Site 1, only *T. tabaci* and *T. major* adults were recorded in the June-bearer flowers, with *T. tabaci* being the main species found at a mean of 0.3 per flower, so adults of this species are likely to have been responsible for the

damage. At Site 2, only *T. major* adults were recorded in the flowers at a mean of 0.6 per flower on the same date that maximum fruit damage occurred, indicating that adults of this species are likely to have caused the damage. No fruit damage was recorded in the June-bearer crops at Sites 3 and 4.

Fruit damage recorded in the everbearer crops at Sites 1, 2 and 3 was also slight. Maximum fruit damage occurred at both Sites 1 and 2 on 11 July (means of 1.3% and less than 0.1% fruit area bronzed respectively). The first thrips larvae were found at both sites on 11 July but in very small numbers compared with numbers of adults, indicating that adult thrips were mainly responsible for the fruit damage. It is not possible to confirm which species caused the damage as several species were recorded at both sites on 11 July and on the previous assessment dates in June. However, at both sites *F. intonsa* adults were the main thrips species present on 11 July at 3.1 and 1.9 adults per flower respectively and lower numbers of *T. fuscipennis* and *T. tabaci* adults were also present on this date at both sites and lower numbers of *T. major* and WFT were also present on this date at Site 2 so these species may also have contributed to the damage. In addition, during June, a mixture of adult species were recorded at both sites which may have caused damage at earlier flower and fruit stages. At Sites 1 and 2 the main adult thrips species present during June were *T. fuscipennis* but adults of *T.major*, *T. tabaci* also occurred, together with *F. intonsa* at Site 1 and WFT at Site 2.

At Site 3 maximum fruit damage was recorded on 24 August (mean of 1.9% fruit area bronzed) and this is likely to have been caused by high numbers of WFT which peaked on 3 August with a mean of 29 adults per flower. However, although WFT was also the predominant species on both 20 July and 3 August, *T. fuscipennis*, *T. major*, *T. tabaci* and *F. intonsa* adults were also present so these species may also have contributed to the damage at Site 3.

At Site 4 maximum fruit damage was higher than at the other sites, peaking at a mean of 7.3% area bronzed on 3 August. On this date and on the previous assessment date in July, all five thrips species known to cause fruit damage were simultaneously present in the flowers, with means of 11.2 and 4.4 adults of the combined species per flower on 3 August and 20 July respectively. WFT was the dominant species on both dates but adults of *T. fuscipennis*, *T. major*, *T. tabaci* and *F. intonsa* were also present so all these species may have contributed to the damage. However, fruit damage at all sites remained well below 10% fruit area bronzed which is considered to be the threshold at which fruit is downgraded.

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

Neoseiulus cucumeris and Orius

It is likely that numbers of the various thrips species were kept below damaging levels on the outdoor everbearer crops at Sites 1 and 2 by the combination of both released and naturally-occurring predators and by plant protection products applied for the control of SWD later in the season. *Neoseiulus cucumeris* was released at both sites during June and *Orius laevigatus* was released to an adjacent crop at Site 1 and to the crop at Site 2. The hot weather conditions were very suitable for *Orius* establishment during 2018. At both Sites 1 and 2, *Orius* were recorded in flowers during July and August, with maximum mean numbers occurring on 23 July at Site 1 (0.6 per flower) and on 8 August at Site 2 (0.2 per flower). At both sites, spinosad (Tracer) was used for SWD control from 1 August and 16 July and this is likely to have contributed to the subsequent reduction in numbers of *Orius* as it is known to be harmful for 1-2 weeks after application. However, *Orius* seemed to survive the application of cyantraniliprole (Benevia) applied on 12 July at Site 1 for SWD control. Benevia is reported to be safe to *Orius* (Koppert side effects list). Both Tracer and Benevia are also likely to have contributed to thrips control later in the season at at Site 1 as all the species recorded are currently susceptible to pesticides. However, as spinosad resistance is widespread in WFT and resistance has recently been reported in *T. tabaci* in salad onions in Kent, it is possible that resistance in other thrips species could develop.

At Sites 3 and 4, details of the IPM programme used are not available but *Orius* were recorded in flowers at both sites. At Site 3, *Orius* established well during August, reaching a maximum of 1.7 per flower on 24 August and were active in the crops until 4 October. *Orius* predation may have been responsible for the drop in thrips numbers at Site 3 between 3 August (mean 29.1 WFT per flower) and 24 August (mean 0.9 WFT per flower) although it is also possible that a plant protection product was applied. *Orius* numbers were lower at Site 4 and were only recorded on 3 August at a mean of 0.1 per flower. The low numbers of *Orius* at this site could explain why WFT numbers increased from 3 August, reaching a maximum of 10.9 per flower by 20 September.

Banded wing thrips

In addition to *Orius*, the predatory thrips *Aeolothrips intermedius* was recorded in the everbearer flowers at Site 1 between 27 June and 8 August, with maximum numbers recorded on 11 and 23 July (means of 0.4 and 0.5 per flower respectively). This predatory thrips is likely to have contributed to biological control of the thrips species at Site 1. Lower numbers

of banded wing predatory thrips were recorded at Site 2 between 13 June and 8 August, with a maximum of 0.03 per flower. At this site, establishment of the predatory thrips is likely to have been adversely affected by Benevia, Tracer and Spruzit applied for SWD control. At both Sites 3 and 4, banded wing thrips were only recorded on 3 August with means of 0.9 and 0.3 per flower respectively. In Tuscany, *A. intermedius* has been recorded as having 3-4 generations, with adults peaking in mid-June, mid-July and mid-August (Conti, 2009). The predator was offered both WFT and *T. tabaci* larvae and predated both species, and was often found together with *F. intonsa* and *T. tabaci* in a lucerne field. It is not known whether *A. intermedius* predates thrips adults as well as larvae.

Lacewings

Lacewing larvae are known to predate on various prey including thrips larvae. Low numbers of lacewing larvae were recorded in flowers at Sites 1 and 2 during July and August respectively.

Conclusions

- Adults of five species of thrips known to damage strawberry fruit were recorded at four sites during 2018. Numbers of the combined species peaked on 11 July in the two outdoor everbearer crops in Essex and Bucks at around four adults per flower. In the two tunnelled everbearer crops in Kent, numbers of thrips adults peaked on 3 August and 20 September at 46 and 13 adults per flower respectively and these were mainly western flower thrips (WFT).
- The onion thrips, *Thrips tabaci* and the rubus thrips, *Thrips major* were the first species to be recorded during May in the June-bearer crops.
- *Thrips tabaci* continued to be active between June and August in the outdoor everbearer crops in Essex and Bucks and between July and September in the two tunnelled everbearer crops in Kent whereas *Thrips major* was only recorded between June and early August in the everbearers.
- The rose thrips, *Thrips fuscipennis* was recorded at all four sites and was the predominant species during June in the two outdoor everbearer crops in Essex and Bucks, with numbers peaking in late June and early July. Rose thrips were only recorded until July in the outdoor crops and until early August in the tunnelled crops.
- The flower thrips, *Frankliniella intonsa* is occasionally found in strawberry flowers but during 2019 was found in higher numbers than usual, possibly due to the unusually hot summer. 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 the outdoor everbearer crops this species was recorded during June to late August and was the predominant species in both crops, with numbers peaking on 11 July. In the tunnelled everbearer crops numbers of *F. intonsa* peaked on 3 August.

- Low numbers of thrips larvae were found in flowers in both the everbearer crops during July and August. As WFT was not recorded at the Essex site and was found in only low numbers at the Bucks site, it is likely that these larvae are mainly those of the other species recorded. Thrips larvae were found in higher numbers in the two tunnelled everbearer crops in Kent between July and early October and these are likely to be WFT as this was the predominant species. Thrips larvae at all sites will be identified during 2019. It is likely that IPM programmes for all thrips species on strawberry should include components for control of thrips larvae as well as adults.
- Fruit damage was only slight in the two outdoor everbearer crops in Essex and Bucks and one of the tunnelled everbearer crops in Kent. Fruit damage may have been caused by a mixture of *F. intonsa*, *T. fuscipennis*, *T. tabaci* and *T. major* adults in the two outdoor everbearer crops and is likely to have been caused by high numbers of WFT in the tunnelled crop in Kent, although *T. fuscipennis*, *T. major*, *T. tabaci* and *F. intonsa* may also have contributed to damage. More severe damage occurred in the second tunnelled everbearer crops in Kent where maximum mean fruit area bronzed reached 7.3% fruit area bronzed. However, this is below the 10% fruit area bronzed that is considered to be the threshold at which fruit is downgraded. In this crop, WFT was the dominant species but *T. fuscipennis*, *T. major*, *T. tabaci* and *F. intonsa* may also have contributed to fruit damage.
- Numbers of thrips in the two outdoor everbearer crops 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 SWD. *Orius* established well at these sites in the hot summer but numbers fell later in the the season, probably due to the harmful effect of spinosad (Tracer) used for SWD control. However, *Orius* seemed to survive an application of cyantraniliprole (Benevia) for SWD control. The naturally-occurring predatory banded wing thrips, *Aeolothrips intermedius* occurred at all four sites but particularly in the outdoor everbearer crop in Essex where it is likely to have contributed to thrips control. This predator is known to predate thrips larvae but it is not known whether they also predate thrips adults.

- An effective IPM programme needs to be developed for control of a range of thrips species known to cause fruit damage, including components for control of both adults and larvae. The biology and behaviour of thrips species other than WFT is currently largely unknown. *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. 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.

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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)

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APPENDIX 1.1.2 Safe operation of the N. cucumeris extraction device

1. Purpose

To describe the procedure for using the *N. cucumeris* extraction device for determining the establishment of *N. cucumeris*, and detecting thrips and other arthropods in a strawberry crop.

2. Scope

Primarily, this procedure applies to extraction of *N. cucumeris*, thrips, *Orius,* predatory thrips, aphid and pollen beetle from strawberry button fruits and mid-aged flowers. Other arthropods may be extracted from other strawberry plant parts and other plant species and parts, but this is yet to be verified.

3. Health and safety

To be used by trained personnel only.

Keep MIK dispenser tightly closed when not in use. Use only outdoors or in a well-ventilated area.

Wear latex gloves when handling MIK dispenser. Use proper glove removal technique (without touching glove's outer surface). After removing gloves, wash and dry hands.

Keep MIK dispenser away from heat/sparks/open flames/hot surfaces and direct sunlight. No smoking.

If MIK gets on skin (or hair): Rinse skin with water.

In case of eye contact with MIK, rinse thoroughly with plenty of water for at least 15 minutes.

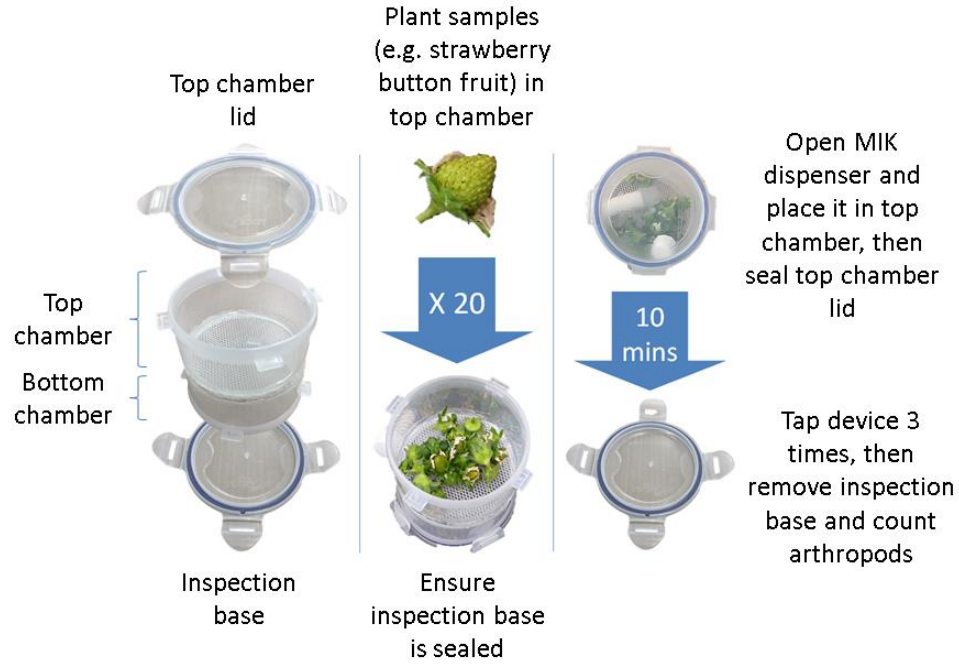


Figure 1. Diagram of extraction device (10 x 10 cm) and operating instructions for extracting arthropods from plant samples (e.g. strawberry button fruits). The same instructions also apply for extracting arthropods from mid-age flower samples.

4. Procedures

4. 1. Storage

4.1.1. Before storage, inspect MIK dispenser and extraction device and ensure all seals are intact and there are no splits, cracks or holes on any surface. If there are, do not attempt to repair. Dispose of as soon as possible in accordance with instructions specified in 4.6.

4.1.2. If undamaged, ensure MIK dispenser lid is screwed on tightly and extraction device is clean and dry. Store MIK dispenser and extraction device away from/heat/sparks/open flames/hot surfaces and direct sunlight.

4. 2. Transport

4.2.1. Before transport, inspect MIK dispenser and extraction device and ensure all seals are intact and there are no splits, cracks or holes on any surface. Ensure MIK dispenser lid is screwed on tightly.

4.2.2. Place MIK dispenser and extraction device in an impervious container, preferably in a separate compartment to the driver and passengers.

4.2.3. If the MIK dispenser is damaged when in the field, preferably dispose of before travelling, following instructions specified in 4.6, otherwise place in an impervious container and dispose of as soon as possible after travel, following instructions specified in 4.6.

4.2.4. Although unlikely, if driver or any passengers feel light headed whilst travelling, stop vehicle as soon as possible and immediately exit to fresh air. Thoroughly ventilate the vehicle. Do not drive again until the MIK leakage has been identified and dealt with.

4.2.5. After travel, store MIK dispenser and extraction device. Do not leave in vehicle.

4. 3. Extracting arthropods from strawberry button fruits (Figure 1.) or mid-aged flowers in the field

4.3.1. Ensure extraction device is clean and dry. Inspect MIK dispenser and extraction device and ensure all seals are intact and there are no splits, cracks or holes on any surface. If there are, do not use the damaged MIK dispenser and/or device. Do not attempt to repair. Dispose of as soon as possible in accordance with instructions specified in 4.6.

4.3.2. If MIK dispenser and extraction device are intact, ensure inspection base is sealed to extraction device bottom chamber.

4.3.3. Collect 20 strawberry button fruits (to extract *N.* cucumeris, thrips, *Orius,* aphids, predatory thrips and pollen beetles (other arthropods to be verified)), or 20 mid-aged flowers (to extract thrips and *Orius* (other arthropods to be verified)) from random positions on plants throughout the sample area and place samples in the top chamber of the extraction device.

4.3.4. Make a note of the estimated number of sample units in the crop per metre.

4.3.5. Unscrew MIK dispenser lid and immediately place dispenser and lid on top of samples in the extraction device top chamber and seal top chamber lid.

4.3.6. Leave standing upright for 10 minutes.

4.3.7. After 10 minutes, keep the extraction device upright and tap the side 3 times.

4.3.8. Keeping the extraction device upright, immediately remove the extraction device top chamber lid and screw MIK dispenser lid onto MIK dispenser.

4.3.9. Keeping the extraction device and inspection base upright at all times, immediately, remove inspection base and count arthropods - use a hand lens if required.

4.3.10. Record arthropod counts and number of MIK dispenser uses.

4.3.11. Empty extraction device of plant samples and arthropods. Thoroughly wipe clean extraction device inspection base and extraction device top chamber lid of arthropods and any other debris.

4.3.12. Repeat extraction procedure from step 4.3.1 in other sample areas as required.

4.3.13. Each MIK dispenser should work for 57 uses, though this has not been properly verified.

4. 4. Extracting arthropods from strawberry button fruits (Figure 1.) or mid-aged flowers in the laboratory

4.4.1. Perform extraction in a fume hood.

4.4.2. With samples in extraction device top chamber, follow steps 4.3.5. to 4.3.11.

4.5. Interpreting results from field collected plant samples and plant samples inoculated in the laboratory

4.5.1. Density of plant sample units (strawberry button fruits or mid-aged flowers) in the crop is expected to influence arthropod density. Consider this if using the device to make estimations on arthropod numbers per unit area of crop.

4.5.2. Temperature can influence the position of *N. cucumeris* in the crop so avoid sampling for *N. cucumeris* in the mid-day heat. If temperatures are high, it is likely that fewer *N. cucumeris* will be found in the button fruits and mid-aged flowers and re-sampling may be needed to ascertain establishment.

4.5.3. For *N. cucumeris* extraction: in the laboratory, when sample units are inoculated with known numbers of mites, extraction efficiency is consistently between 50 and 60% at ~20°C. In the field, extraction efficiency can vary from 57% to 22% in the temperature range of 40.9°C to 13.9 °C.

4. 6. Disposal

4.6.1. Dispose of contaminated gloves and any other disposable item after use, in accordance with applicable laws.

4.6.2. Dispose of old/damaged MIK dispensers and damaged extraction devices through a licenced disposal company.

5. Equipment

Latex gloves

Impervious container and spares to hold MIK dispenser, extraction device and MIK contaminated waste

MIK dispenser

Extraction device (including all parts)

Timer

Hand lens

Record sheet

APPENDIX 1.2. Protocols

1.1 Preparation of F52 spore suspension

Fungal culture and suspension preparation.

To obtain *M. brunneum* F52 spores for dipping assays, a formulation of Met52 was prepared to field strength and a serial dilution was carried out using 1ml of spore suspension from the stock suspension and 9ml of sterile distilled water. The serial dilution was repeated until $1x10^{-7}$. From each suspension 200µl of liquid was pipetted onto 2 x Sabouraud Dextrose Agar + Tap Water (SDA+TW) 90mm petri dishes and spread using sterile technique. Plates were incubated at 25˚C until sporulation occurred. There was some evidence of contaminant fungi within the Met52 product (*Apsergillus niger* and *Penicillium* sp.), therefore a clean sub-culture was taken and re-plated onto SDA+TW plates using the above technique. Once sporulated, these plates were kept at 5˚C prior to use within the bioassay. All bioassays were prepared from the same batch of sub-cultured plates prepared on 29/05/2018.

To prepare the F52 suspension for the dipping tests, a sterile loop or spatula was used to remove conidia from the sporulating petri dish and suspended in sterile 10ml 0.05% Tween 80. This suspension was sonicated for 3min to break up any chains of conidia, then a Bright-Line™ Hemacytometer count was undertaken on a $1x10^{-1}$ dilution of this stock suspension (prepared by removing 1ml stock and adding to 9ml Sterile Tween 80 0.05%). Once the numbers of conidia per ml had been quantified, the $1x10^{-1}$ suspension was adjusted using the stock suspension to give 1×10^7 conidia per ml. This suspension was recounted using a hemacytometer and the precise numbers of conidia per ml were noted. For each replicate (consisting of 5 pseudoreplicates) one spore suspension was prepared. A separate spore suspension was used for each replicate over time.

1.1.1 Quantification of viability of conidia used in bioassays

From the F52 suspensions prepared for each bioassay, a colony forming unit (CFU) count was prepared. This assessed the numbers of live conidia in each spore suspension. To prepare the CFU counts, the experimental stock (circa 1×10^7 conidia per ml) was used as the stock suspension and a dilution series down to $1x10^{-7}$ was prepared by making a series of dilutions of 1ml suspension in 9ml Tween 80 0.05%. From these dilutions, two SDA+TW plates were prepared by pipetting 200µl of suspension and spreading using a sterile glass spreader. Plates were incubated at 25˚C for 3 days. Plates were then removed and the numbers of colonies in each dilution were counted. From this, the number of viable conidia per ml of spore suspension was calculated.

1.1.2 Dipping protocol, using F52

Dipping experiments tested the efficacy of the fungal isolate under worst case scenario dose conditions at a concentration of 1 x 10^7 conidia/ml. This strength was chosen as it represents the maximum strength of the tank mix allowed in the UK for Met52. Additionally, in bioassays in the literature, this concentration is used to represent a 'high dose' of conidia (Saito and Brownbridge, 2016). Controls set up alongside the treatments using blank 0.05% Tween 80 alone to act as a formulation control (to test the effect of the carrier), and no treatment where there was no carrier or fungal agent (to assess mortality of insects when no treatment had been applied i.e. the "handling effect").

Insects were dipped into 3.5ml fungal suspension for a period of 10 seconds, then the suspension and insects were tipped onto a sterile filter paper on top of a Buchner Funnel. The Buchner funnel drew the liquid away from the test organisms. The insects were then transferred into experimental containers for incubation (as described below for each species). Ten individuals were dipped per replicate in each treatment (Treatment, Formulation control, Blank control) and there were 5 replicates per treatment. All replicate trials were repeated on separate occasions unless otherwise specified in the Results Section.

1.1.3 Counting of insects and bioassay set up

Product name: Thripor; Insect species: *Orius laevigatus*

Orius laevigatus were supplied in pots containing buckwheat and vermiculite and on receipt were stored at 5˚C with the addition of a vial of organic bee pollen as an interim diet. Individuals were collected into sterilised glass universals using a pooter. Five individuals were counted into a pot for all 15 replicates, then a further five to give ten per pot. For no treatment replicates, individuals were transferred directly into bioassay chambers. The assays for *O. laevigatus* were carried out on six occasions, however there was high control mortality in four of these replicates, therefore only two useable results are presented in the results section. Amendments were made to the rearing conditions to optimise survival and the useable replicates used glass push top vials with a hole cut into the lid and a small piece of gauze placed over the top. Inside the tube, a piece of concertinaed filter paper, a small amount of sterile buckwheat and a source of bee pollen were added.

Chrysopa- *Chrysoperla carnea*

Chrysoperla carnea were received in a bottle containing buckwheat and larval stages of *C. carnea.* The bottle was refrigerated prior to use at 5˚C (maximum 1 week). As *C. carnea* can display cannibalism, all individuals were kept in separate bioassay vials (approx. 2ml glass

bijoux vials with a screw top lid). Bioassay vials contained a small piece of sterile filter paper (moistened), a small amount of buckwheat (for refuge) and several pea aphids (*Aphis* sp. – original culture from Dartfrog.co.uk). Aphids were transferred into vials every 2-3 days as a food source of predators for the duration of the experiment.

To count out individuals, a small amount of buckwheat and larvae were tipped from the bottle received from Koppert into a large (20cm) glass petri dish. From here, individuals of *C. carnea* transferred using a paintbrush directly into glass bijoux vials for the no treatment controls. There were 10 vials per replicate and 5 replicates per treatment. Following treatment they were each transferred to individual bijoux vials as described previously.

Aphidalia- *Adalia bipunctata*

As *A. bipunctata* display cannibalism, assays were set up using the same protocol as *C. carnea.*

Ervipar and Aphiscout

	Ervipar (*Aphidius ervi*)
	Aphiscout (*Praon volucre, Aphidius colemani, Aphidius ervi, Aphelinus abdominalis. Ephedrus cerasicola*)

The parasitoid products (Ervipar and Aphiscout) were kept at room temperature to allow adult parasitoids to emerge from the aphid mummies in the product. Adults were used in a bioassay within 3 days of emergence and during this time were fed a 20% honey solution (Rowse Organic Honey, Tesco UK). Prior to use, five individuals were pootered into sterile glass tubes, then a further five to give ten individuals per tube. This aimed to remove selection bias

from bioassay tubes. They were then processed and afterwards each batch of 10 insects was kept together in one tube containing a concertinaed strip of filter paper. A piece of gauze covered the opening and was held in place with a push top lid, punched with a 10mm hole. During the monitoring phase this lid contained a ball of cotton wool soaked with a 20% honey solution.

1.2 Contact bioassay protocol

During contact assays, insects were either exposed to strawberry leaves (var. Elsanta) which had been sprayed with Met52 EC formulation, a blank formulation (codacide and water) or no formulation. The treated/untreated leaf sections were kept in bioassay chambers for three days before being removed. This was to ensure no effects from deterioration of leaf quality in the vial. Treated leaf discs were added to tubes following spraying, but sprayed surfaces did not cover all areas to which insects could reside, therefore this was not a no-choice trial.

1.2.1 Treatment preparation

Met52 EC tank mix

357ul of Met 52 EC formulation was removed using a 1ml wide bore pipette tip (sterile). The formulation was pipetted up and down twice before the final amount was drawn off. to ensure that the pipette tip was coated with the spores and none were lost to the plastic. The formulation was then dispensed into 25ml SDW. Care was taken to ensure the pipette tip did not meet the water as this would result in transfer of extra formulation

Blank control (codacide and water)

The blank formulation was prepared mixing 357ul of codacide (an emulsifiable oil) and 25ml sterile distilled water (SDW).

Control

Control consisted of insects being exposed to untreated strawberry leaves

After spraying, leaves either whole or cut into section, depending on the insect species, were allowed to air dry in a horizontal laminar flow cabinet switched off, prior to use.

1.2.2 Formulation calibration

The target dose for each sprayed leaf was to achieve 2×10^4 CFU/cm^2. This is equivalent to 2×10^{12} CFU per ha, the maximum dose permitted on the Met52 OD label. To achieve this, work was undertaken to quantify the CFU/ml of the Met52 formulation provided by FARGRO and to calibrate the flow rate of the Burkard Computer Sprayer to deliver the appropriate

volume per unit area. The sprayer settings and formulation strength were adjusted to achieve the target spray deposition.
The Burkard sprayer was set to click place 10 (from the tightest fitting) and 10 bar pressure for all applications

1.2.3 Formulation deposition enumeration

To check the numbers of CFU's deposited, three sterile 90mm glass Petri dishes were sprayed in addition to the leaves. These were placed in the first, penultimate and last spots on the Burkard sprayer spray template. To these dishes, after spraying, 10ml of sterile 0.05% Tween 80 was added and the bottom surface was washed to remove any sprayed spores/formulation. The Tween/spore suspension was then pipetted back into a sterile glass vial. This was used as a stock suspension for a 1 in 10 dilution series where 1ml of stock was added to 9ml of sterile 0.05% Tween 80. The dilution series was prepared down to $1x10^{-5}$. From each suspension, 200µl was pipetted onto 2 x SDA+TW plate, spread using a sterile glass rod, and incubated at 25˚C for three days. The numbers of CFU's were counted at each dilution and these figures were then converted to represent the numbers of CFU/cm^2.

In addition to the post-spray CFU check, a pre-spray and post spray (directly from the spray nozzle) sample of Met52 EC formulations were taken. This was to enumerate the numbers of CFU's before spraying and after passing through the sprayer. Colony forming unit counts were prepared as above, although sterile distilled water was used to suspend the Met52 EC formulation instead of 0.05% Tween 80. This was because it did not need to be 'washed/removed' from the surface of a petri dish and would suspend adequately in water.

Deposition renumeration was carried out for all replicates

1.2.4 Contact bioassay protocol- *Chrysoperla carnea*

Spraying of leaves.

Strawberry 'Elsanta' leaves (x 3) were removed from and placed in 3 x 90mm petri dishes per treatment. The dishes were sprayed as previously described and then allowed to air dry. Once dry, 10mm leaf disc sections were removed using a 10mm cork borer and each one was placed into the bottom of a clean glass bijoux vial.

Bioassay set up

Chrysoperla carnea were added to the vials along with at least 5-6 pea aphids and a small section of moistened filter paper. Vials were incubated at 23˚C, under a 16h:8h light:dark regime during the assessment period. Fresh aphids were added to the bioassay vials every 2-3 days. As there was a variable supply of aphids available to feed the *C. carnea* in the experimental vials, the numbers of replicates per treatment were varied during each assay, conducted over time. In the first contact assay, there were five reps (of 10 vials) per treatment, during the second contact assay there were three reps (of 10 vials) per treatment, and during the third assay there were four reps (of 10 vials) per treatment.

1.2.5 Contact bioassay protocol- *Adalia bipunctata*

The protocol for the *A. bipunctata* protocol had to be amended prior to the experiment as a fault developed with the Burkard sprayer and leaves were unable to be sprayed as previously. There was also a crash in the aphid population used to feed the predators during the assay during this time period thus only a limited number of vials could be set up per treatment. The decision was made to go ahead with the amended protocol as there had been previous supply issues with *A. bipunctata* and this was the last opportunity to test this predator thus results could be indicative of the requirement for further assays to be undertaken. The amended protocol is as follows.

Bioassay set up and analysis

Leaves were dipped into the treatments and allowed to dry. Once dry, 10mm leaf disc sections were removed using a 10mm cork borer which were then placed in the bottom of a clean glass bijoux vial

Adalia bipunctata were added to the vials along with at least 5-6 pea aphids and a small section of moistened filter paper. Vials were incubated at 23˚C, under a 16h:8h light:dark regime during the assessment period. Fresh aphids were added to the bioassay vials every 2-3 days. In total there were twenty separate vials per treatment containing one *A. bipunctata* individual. This number was not enough to use previous analysis methods; therefore these data were analysed using a survival analysis over time as a preliminary indicator of differences between treatments. To examine the differences in mortality between timepoints, further assays will need to be undertaken to give enough replication for analysis.

Dead insects were allocated the status 1 on the day mortality was recorded, and live insects at the end of the experiment were allocated the status 0. Survival analysis was then carried out using the survreg survival analysis in R statistical computing (R, 2016). A comparison between the model assuming a constant hazard and the model with Weibull errors showed

that the model using Weibull errors was significantly better ($p < 0.001$ when tested using ANOVA). Differences in survival were considered significant where $p<0.05$.

1.2.6 Contact bioassay protocol- Ervipar

Ervipar (*Aphidius ervi*) were received from Koppert LTD and parasitized aphid mummies and buckwheat from the product were transferred into a 1 litre Kilner jar with a square of muslin in the lid. Parasitoids were allowed to emerge at 23˚C over 3 days prior to the bioassay. A source of 20% honey solution (Rowse organic) was placed in the lid of the jar to ensure wasps had a food source prior to the assay.

Experimental vials

Experimental vials were glass push top tubes with plastic push top lids. The lids had 10mm diameter holes cut from them. A small square of muslin with a ball of 20% honey solution (Rowse Organic Honey) was placed in the hole and the tube was sealed with the push top lid and the muslin square. The honey solution was topped up every 2 days. Into each tube, 10 Ervipar (mixed sex) were transferred using a pooter attached to a vacuum pump. A length of concertinaed filter paper was also added to the tube.

Bioassay Set Up

Each treatment consisted of five vials of 10 parasitoids. For no treatment vials, insects had a length of untreated strawberry leaf (8sqcm) placed within the vial, in addition to a section of concertinaed filter paper. For the blank formulation and formulation treatment, 8sqcm treated sections of strawberry leaves were sprayed, allowed to dry, and then added to each vial.

APPENDIX 1.3.1 Spray records provided for each site.

Spray programme and predator introductions for trial 3 in Task 1.1 and the trial in Task 1.3:

Pesticide applications		2018									
Plot A	Ulves 1			Plot B	12 acres			Plot C,D	Ulves 2		
Date	Material			Date	Material			Date	Material		
10-Apr	Fenomenal			11-Apr	Fenomenal			02-May	Fortress		
01-May	Floramite			01-May	Fortress			03-May	Paraat	(through drippers)	
02-May	Fortress			01-May	Hallmark			09-May	Amistar		
02-May	Hallmark			08-May	Amistar			17-May	Fortress		
09-May	Amistar			16-May	Fortress			20-May	Stroby		
17-May	Fortress			23-May	Stroby			31-May	Topas		
24-May	Stroby			23-May	Floramite			06-Jun	Amistar		
24-May	Floramite			30-May	Topas			06-Jun	Switch		
31-May	Topas			06-Jun	Amistar			14-Jun	Topas		
06-Jun	Amistar			11-Jun	Floramite			14-Jun	Scala		
06-Jun	Apollo			13-Jun	Topas			22-Jun	Stroby		
14-Jun	Topas			20-Jun	Stroby			29-Jun	Amistar		
21-Jun	Stroby			28-Jun	Amistar			03-Jul	Pot bicarb		
28-Jun	Amistar			01-Jul	Pot bicarb			05-Jul	Topas		
02-Jul	Pot bicarb			05-Jul	Topas			09-Jul	Pot bicarb		
06-Jul	Topas			09-Jul	Pot bicarb			13-Jul	Luna Sensation		
08-Jul	Pot bicarb			12-Jul	Luna Sensation			17-Jul	Pot bicarb		
12-Jul	Luna sensation			17-Jul	Pot bicarb			19-Jul	Takumi		
16-Jul	Pot bicarb			20-Jul	Takumi			25-Jul	Pot bicarb		
19-Jul	Takumi			24-Jul	Pot bicarb			27-Jul	Luna Sensation		
26-Jul	Pot bicarb			27-Jul	Luna Sensation			01-Aug	Pot bicarb		
30-Jul	Luna sensation			01-Aug	Takumi			02-Aug	Takumi		
30-Jul	Teldor			01-Aug	Scala			02-Aug	Scala		
09-Aug	Scala			08-Aug	Amistar			06-Aug	Amistar		
09-Aug	Amistar			08-Aug	Benevia			06-Aug	Benevia		
09-Aug	Benevia			19-Aug	Nimrod			17-Aug	Topas		
09-Aug	Fast Copper			19-Aug	Fast Manganese			17-Aug	Signum		
15-Aug	Topas			24-Aug	Talius			17-Aug	Fast Boron		
15-Aug	Signum			24-Aug	Benevia			24-Aug	Talius		
15-Aug	Fast Boron			24-Aug	Fast copper			24-Aug	Benevia		
23-Aug	Talius			31-Aug	Kindred			24-Aug	Fast copper		
23-Aug	Benevia			31-Aug	Switch			29-Aug	Kindred		
23-Aug	Fast Copper			31-Aug	Fast Manganese			29-Aug	Signum		
31-Aug	Kindred			07-Sep	Signum			06-Sep	Nimrod		
31-Aug	Switch			14-Sep	Kindred			06-Sep	Teldor		
31-Aug	Fast Copper			14-Sep	Switch			12-Sep	Kindred		
06-Sep	Signum			20-Sep	Topas			12-Sep	Switch		
13-Sep	Kindred			20-Sep	Teldor			20-Sep	Nimrod		
13-Sep	Switch			04-Oct	Kindred			20-Sep	Teldor		
21-Sep	Nimrod			04-Oct	Scala			05-Oct	Kindred		
21-Sep	Teldor			24-Oct	Hallmark			05-Oct	Prolectus		
05-Oct	Kindred							19-Oct	Hallmark		
19-Oct	Hallmark										

Predator introductions											
Rates/m											
Plot A	Ulves 1			Plot B	12 acres			Plot C,D	Ulves 2		
Date	*n.cucumeris*	*o.laevigatus*	*p.persimilis*	Date	*n.cucumeris*	*o.laevigatus*	*p.persimilis*	Date	*n.cucumeris*	*o.laevigatus*	*p.persimilis*
15-May			10	15-May			10	15-May			10
16-May	200			16-May	200			16-May	200		
31-May			10	31-May			10	31-May			10
20-Jun	200		10	20-Jun	200		10	20-Jun	200		10
								26-Jun		2	
05-Jul		3		05-Jul		3		05-Jul		3	
11-Jul		3		11-Jul		3		11-Jul		3	
12-Jul	200			12-Jul	200			12-Jul	200		
18-Jul	200			18-Jul	200			18-Jul	200		
								20-Jul			10
24-Jul		2		24-Jul		2		24-Jul		2	
25-Jul	200			25-Jul	200			25-Jul	200		

APPENDIX 2.1

Spray programme for trial in Task 2.1.:

Field name / planting	Product	Application Date	Application Time	Harvest Interval	First available harvest Date	First available harvest Time	Actual harvest Date	Actual harvest Time	Picking authorised by
SHEEP SHED									
	BRAVO	31/1	09:20	3	3/2	09:20			
	[illegible]	7/3	17:45	14	21/3	17:45			
	[illegible] Revus WG	28/3	13:30	3	31/3	13:30			
	[illegible]	4/4	14:30	3	8/4				
	[illegible]	14/4	22:45	3	17/4				

Field name / planting	Product	Application Date	Application Time	Harvest Interval	First available harvest Date	First available harvest Time	Actual harvest Date	Actual harvest Time	Picking authorised by
SHEEP SHED									
	Talius [illegible]	19/4	09:45	3	22/4	09:45			
	[illegible]	2/5	15:45	3	5/5	15:45			
	[illegible] Calypso [illegible]	9/5	04:20	3	12/5	04:20			
	[illegible]	12/5	13:30	3	15/5	13:30			
	[illegible]	6/6	20:00	0	6/6	20:00			

Field name / planting	Product	Application Date	Application Time	Harvest Interval	First available harvest Date	First available harvest Time	Actual harvest Date	Actual harvest Time	Picking authorised by
SHARTSDELL EAST									
	BRAVO	7/2	10:15	3	10/2	10:15			
	[illegible]	9/3	12:00	14	23/3	10:00			
	[illegible] Revus WG	27/3	13:30	3	30/3	13:30			
	[illegible] Calypso [illegible]	4/4	14:30	3	11/4	14:30			
	[illegible] Calypso	14/4	11:30	3	17/4	11:30			

Field name / planting	Product	Application Date	Application Time	Harvest Interval	First available harvest Date	First available harvest Time	Actual harvest Date	Actual harvest Time	Picking authorised by
SHARTSDELL EAST									
	Talius [illegible]	19/4	09:00	3	22/4	09:00			
	[illegible]	2/5	12:30	3	5/5	12:30			
	[illegible] Calypso	9/5	19:15	3					

Field name / planting	Product	Application Date	Application Time	Harvest Interval	First available harvest Date	First available harvest Time	Actual harvest Date	Actual harvest Time	Picking authorised by
PARKGATE 1	Parade	16.2.18	15:00	35					CAH
PARKGATE 1	Fortress Switch Dynamec	19.3.18	16:50	14					CAH
PARKGATE 1	Pendhar Scala	29.3.18	19:30	3					CAH
PARKGATE 1	Signum	5.4.18	16:45	3					CAH
PARKGATE 1	Talius	14.4.18	19:00	3					CAH
PARKGATE 1	Scala	20.4.18	3:45	3					CAH
PARKGATE 1	Switch Topas	28.4.18	12:00	3					CAH

Field name / planting	Product	Application Date	Application Time	Harvest Interval	First available harvest Date	First available harvest Time	Actual harvest Date	Actual harvest Time	Picking authorised by
PARKGATE 2	Tarmi	20.4.18	00:00	3					CAH
PARKGATE 2	Switch Topas	28.4.18	16:30	3					CAH
PARKGATE 2	2 Sweetcorn Calypso	4.5.18	23:45	3					CAH
PARKGATE 2	Teldor Silimach	13.5.18	11:00	1					CAH
PARKGATE 2	Signum Topas	20.5.18	8:35	3	23.5.18	8.35	23.5.18	6:30	CAH

Field name / planting	Product	Application Date	Application Time	Harvest Interval	First available harvest Date	First available harvest Time	Actual harvest Date	Actual harvest Time	Picking authorised by
PARKGATE 2	Cerbel Revus Hallmark	22.1.18		14					CAH
PARKGATE 2	Bravo Hallmark	5.2.18	14:00	14					CAH
PARKGATE 2	Parade	16.2.18	11:00	35					CAH
PARKGATE 2	Fortress Switch Dynamec	30.3.18	16:30	14					CAH
PARKGATE 2	Signum Calypso	6.4.18	14:45	3					CAH
PARKGATE 2	Talius	13.4.18	15:00	3					CAH

Field name / planting	Product	Application Date	Application Time	Harvest Interval	First available harvest Date	First available harvest Time	Actual harvest Date	Actual harvest Time	Picking authorised by
PARKGATE 2	Sna Sencorzan	28.5.18	12:00	1	29.5.18	12:00	29.5.18	11:00	CAH

Field name / planting	Product	Application Date	Application Time	Harvest Interval	First available harvest Date	First available harvest Time	Actual harvest Date	Actual harvest Time	Picking authorised by
PG 1	2 Sweetcorn Calypso	3.5.18	20:30	3			7.5.18	6:15	CAH

APPENDIX 3.2.2. Spray records provided for each site.

Spray programme for trial in Task 3.2:

Site 1.

Field name / planting	Product	Application		Harvest Interval	First available harvest	
		Date	Time		Date	Time
CHERRY GROUND	Corbel	12/3	11:30	14	26/3	11:30
	Fontess Difenamec	10/4	17:45	14	24/4	17:45
	Tracer	13/4	12:30	3	16/4	12:30
	Difenamec	17/4	08:00	35	15/5	08:00
	Talius Hortiplufe	24/4	13:00	3	27/4	13:00
	TALIUS	28/4	12:00	3	2/5	12:00
	Maxicrop	13/5	05:00	3	16/5	05:00
	Hortiplufe Signum	16/5	05:00	3	18/5	05:00

Field name / planting	Product	Application		Harvest Interval	First available harvest	
		Date	Time		Date	Time
CHERRY GROUND						
	Hortiplufe	21/5	13:10	3	24/5	13:10
	Amistar Hortiplufe	28/5	17:30	3	4/6	17:30
	Fungura Hortiplufe	5/6	13:00	3	8/6	13:00
	KSO SPOSB Maxicrop	13/6	23:00	0	13/6	23:00
	KSO SPOSB Maxicrop	21/6	21:00	0	21/6	21:00

Field name / planting	Product	Application		Harvest Interval	First available harvest	
		Date	Time		Date	Time
CHERRY GROUND						
	LUNA Cerinum	26/6	23:00	1	27/6	23:00
	LUNARIO	11/7	23:50	1	12/7	23:50
	KSO SPOSB Maxicrop	17/7	23:00	0	17/7	23:00
	Hortiplufe CHARM	1/8	22:30	1	2/8	22:30
	LUNA Benario	19/8	18:30	1	20/8	18:30

Field name / planting	Product	Application		Harvest Interval	First available harvest	
		Date	Time		Date	Time
CHERRY GROUND	SPOSB	1/9	22:50	0	1/9	22:50

Site 2.

To: 11/10/2018
Headings: Pesticides, Nutrition
Area: ha

Topfield B.Sweet eve 2 — Working ha: 2.8640
Variety: Sweet eve 2 — Map sheet:
Crop: Strawberry (Protected) — NG number:

7 Reference: Plan 04229 Slugs Jan/Feb 2018 Job 1 — Issued by: John Longley (05/02/2018)
Implement: Vicon
Derrex — 2.8640 ha — 7.000 kg/ha
MAPP:15351, Active Ingredients:Ferric phosphate, Manufacturer:Certis, Expires:30/06/2033

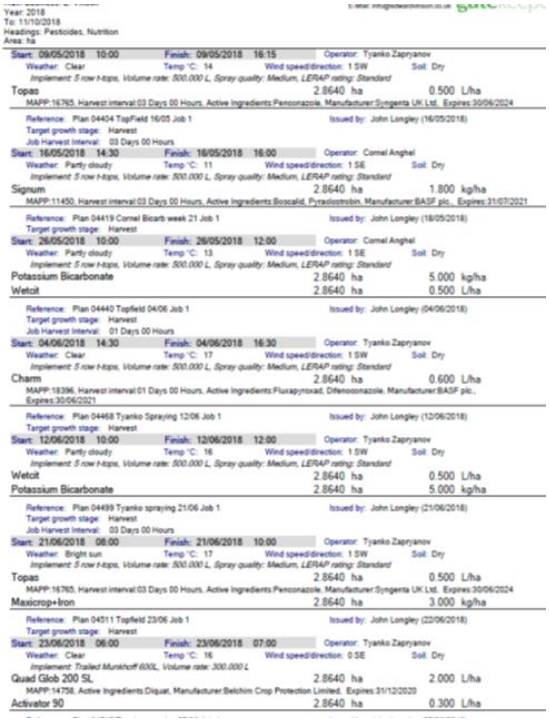
Reference: Plan 04244 Tinbridge D/Topfield 09/03 Job 1 — Issued by: John Longley (09/03/2018)
Start: 09/03/2018 12:30 — Finish: 09/03/2018 15:00 — Operator: Tyanko Zapryanov
Weather: Partly cloudy — Temp °C: 7 — Wind speed/direction: 0 SW — Soil: Moist
Implement: Trailed Munkhoff 600L, Volume rate: 300.000 L
Quit — 2.8640 ha — 2.000 L/ha
MAPP:14874, Active Ingredients:Diquat, Manufacturer:Belchim Crop Protection Limited, Expires:31/12/2020
Activator 90 — 2.8640 ha — 0.300 L/ha

Reference: Plan 04271 Topfield 29/03 Job 1 — Issued by: John Longley (29/03/2018)
Target growth stage: Planting
Job Harvest Interval: 03 Days 00 Hours
Start: 29/03/2018 13:00 — Finish: 29/03/2018 16:00 — Operator: Tyanko Zapryanov
Weather: Partly cloudy — Temp °C: 8 — Wind speed/direction: 1 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 1000.000 L, Spray quality: Medium, LERAP rating: Standard
Topas — 2.8640 ha — 0.500 L/ha
MAPP:16765, Harvest interval:03 Days 00 Hours, Active Ingredients:Penconazole, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024
Borneo — 2.8640 ha — 0.350 L/ha
MAPP:13919, Active Ingredients:Etoxazole, Manufacturer:Interfarm (U.K.) Ltd
Dynamec — 2.8640 ha — 0.500 L/ha
MAPP:18316, Active Ingredients:Abamectin, Manufacturer:Syngenta UK Ltd
Wetcit — 2.8640 ha — 1.000 L/ha

Reference: Plan 04293 Topfield/Tin D 10/04 Job 1 — Issued by: John Longley (10/04/2018)
Target growth stage: 45: First daughter plant with roots
Start: 10/04/2018 13:00 — Finish: 10/04/2018 15:30 — Operator: Tyanko Zapryanov
Weather: Partly cloudy — Temp °C: 9 — Wind speed/direction: 1 SW — Soil: Moist
Implement: Trailed Munkhoff 600L, Volume rate: 300.000 L
Activator 90 — 2.8640 ha — 0.300 L/ha
Quit — 2.8640 ha — 2.000 L/ha
MAPP:14874, Active Ingredients:Diquat, Manufacturer:Belchim Crop Protection Limited, Expires:31/12/2020

Reference: Plan 04305 Tyanko Spraying 13/04 Job 2 — Issued by: John Longley (13/04/2018)
Target growth stage: 61: Early Flower, 10% flowers open
Job Harvest Interval: 14 Days 00 Hours
Start: 13/04/2018 15:30 — Finish: 13/04/2018 17:00 — Operator: Tyanko Zapryanov
Weather: Partly cloudy — Temp °C: 8 — Wind speed/direction: 1 SW — Soil: Moist
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Scala — 2.8640 ha — 2.000 L/ha
MAPP:15222, Harvest interval:03 Days 00 Hours, Active Ingredients:Pyrimethanil, Manufacturer:BASF plc., Expires:31/10/2020
Fortress — 2.8640 ha — 0.250 L/ha
MAPP:08279, Harvest interval:14 Days 00 Hours, Active Ingredients:Quinoxyfen, Manufacturer:Dow AgroSciences Ltd., EAMU:1923/04, Expires:31/10/2020

Reference: Plan 04338 Topfield 25/04 Job 1 — Issued by: John Longley (25/04/2018)
Target growth stage: 61: Early Flower, 10% flowers open
Job Harvest Interval: 07 Days 00 Hours
Start: 28/04/2018 07:00 — Finish: 28/04/2018 09:00 — Operator: Tyanko Zapryanov
Weather: Clear — Temp °C: 10 — Wind speed/direction: 1 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Stroby WG — 2.8640 ha — 0.300 kg/ha
MAPP:17316, Harvest interval:07 Days 00 Hours, Active Ingredients:Kresoxim-methyl, Manufacturer:BASF plc., Expires:30/06/2024



Year: 2018
To: 11/10/2018
Headings: Pesticides, Nutrition
Area: ha

Start: 09/05/2018 10:00 — Finish: 09/05/2018 16:15 — Operator: Tyanko Zapryanov
Weather: Clear — Temp °C: 14 — Wind speed/direction: 1 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Topas — 2.8640 ha — 0.500 L/ha
MAPP:16765, Harvest interval:03 Days 00 Hours, Active Ingredients:Penconazole, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024

Reference: Plan 04404 Topfield 16/05 Job 1 — Issued by: John Longley (16/05/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 16/05/2018 14:30 — Finish: 16/05/2018 16:00 — Operator: Cornel Anghel
Weather: Partly cloudy — Temp °C: 11 — Wind speed/direction: 1 SE — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Signum — 2.8640 ha — 1.800 kg/ha
MAPP:11450, Harvest interval:03 Days 00 Hours, Active Ingredients:Boscalid, Pyraclostrobin, Manufacturer:BASF plc., Expires:31/07/2021

Reference: Plan 04419 Cornel Bicarb week 21 Job 1 — Issued by: John Longley (18/05/2018)
Target growth stage: Harvest
Start: 26/05/2018 10:00 — Finish: 26/05/2018 12:00 — Operator: Cornel Anghel
Weather: Partly cloudy — Temp °C: 13 — Wind speed/direction: 1 SE — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Potassium Bicarbonate — 2.8640 ha — 5.000 kg/ha
Wetcit — 2.8640 ha — 0.500 L/ha

Reference: Plan 04440 Topfield 04/06 Job 1 — Issued by: John Longley (04/06/2018)
Target growth stage: Harvest
Job Harvest Interval: 01 Days 00 Hours
Start: 04/06/2018 14:30 — Finish: 04/06/2018 16:30 — Operator: Tyanko Zapryanov
Weather: Clear — Temp °C: 17 — Wind speed/direction: 1 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Charm — 2.8640 ha — 0.600 L/ha
MAPP:18396, Harvest interval:01 Days 00 Hours, Active Ingredients:Fluxapyroxad, Difenoconazole, Manufacturer:BASF plc., Expires:30/06/2021

Reference: Plan 04468 Tyanko Spraying 12/06 Job 1 — Issued by: John Longley (12/06/2018)
Target growth stage: Harvest
Start: 12/06/2018 10:00 — Finish: 12/06/2018 12:00 — Operator: Tyanko Zapryanov
Weather: Partly cloudy — Temp °C: 16 — Wind speed/direction: 1 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Wetcit — 2.8640 ha — 0.500 L/ha
Potassium Bicarbonate — 2.8640 ha — 5.000 kg/ha

Reference: Plan 04499 Tyanko spraying 21/06 Job 1 — Issued by: John Longley (21/06/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 21/06/2018 08:00 — Finish: 21/06/2018 10:00 — Operator: Tyanko Zapryanov
Weather: Bright sun — Temp °C: 17 — Wind speed/direction: 1 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Topas — 2.8640 ha — 0.500 L/ha
MAPP:16765, Harvest interval:03 Days 00 Hours, Active Ingredients:Penconazole, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024
Maxicrop+Iron — 2.8640 ha — 3.000 kg/ha

Reference: Plan 04511 Topfield 23/06 Job 1 — Issued by: John Longley (22/06/2018)
Target growth stage: Harvest
Start: 23/06/2018 06:00 — Finish: 23/06/2018 07:00 — Operator: Tyanko Zapryanov
Weather: Clear — Temp °C: 16 — Wind speed/direction: 0 SE — Soil: Dry
Implement: Trailed Munkhoff 600L, Volume rate: 300.000 L
Quad Glob 200 SL — 2.8640 ha — 2.000 L/ha
MAPP:14758, Active Ingredients:Diquat, Manufacturer:Belchim Crop Protection Limited, Expires:31/12/2020
Activator 90 — 2.8640 ha — 0.300 L/ha

Year: 2018
To: 11/10/2018
Headings: Pesticides, Nutrition
Area: ha

Start: 25/06/2018 17:00 — Finish: 25/06/2018 19:00 — Operator: Tyanko Zapryanov
Weather: Bright sun — Temp °C: 20 — Wind speed/direction: 1 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Amistar — 2.8640 ha — 1.000 L/ha
MAPP:18039, Harvest interval:03 Days 00 Hours, Active Ingredients:Azoxystrobin, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024

Reference: Plan 04554 Topfield 05/07 Job 1 — Issued by: John Longley (05/07/2018)
Target growth stage: Harvest
Start: 05/07/2018 08:30 — Finish: 05/07/2018 12:30 — Operator: Flavio Di Giovanni
Weather: Clear — Temp °C: 18 — Wind speed/direction: 3 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Wetcit — 2.8640 ha — 0.500 L/ha
Potassium Bicarbonate — 2.8640 ha — 5.000 kg/ha

Reference: Plan 04253 Topfield Under t-tops 17/07 Job 1 — Issued by: John Longley (17/07/2018)
Target growth stage: Harvest
Start: 18/07/2018 08:30 — Finish: 18/07/2018 19:30 — Operator: Cornel Anghel
Weather: Partly cloudy — Temp °C: 19 — Wind speed/direction: 1 SW — Soil: Dry
Implement: Trailed Munkhoff 600L, Volume rate: 300.000 L
Quad Glob 200 SL — 2.8640 ha — 2.000 L/ha
MAPP:14758, Active Ingredients:Diquat, Manufacturer:Belchim Crop Protection Limited, Expires:31/12/2020
Activator 90 — 2.8640 ha — 0.300 L/ha

Reference: Plan 04609 Topfield 17/07 Job 1 — Issued by: John Longley (17/07/2018)
Target growth stage: Harvest
Start: 18/07/2018 16:30 — Finish: 18/07/2018 19:30 — Operator: Flavio Di Giovanni
Weather: Clear — Temp °C: 20 — Wind speed/direction: 2 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Luna Sensation — 2.8640 ha — 0.800 L/ha
MAPP:15793, Active Ingredients:Fluopyram, Trifloxystrobin, Manufacturer:Bayer CropScience Limited

Reference: Plan 04574 Topfield 11/07 Job 1 — Issued by: John Longley (10/07/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 25/07/2018 16:45 — Finish: 25/07/2018 18:45 — Operator: Flavio Di Giovanni
Weather: Clear — Temp °C: 22 — Wind speed/direction: 2 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Takumi SC — 2.8640 ha — 0.150 L/ha
MAPP:16000, Harvest interval:03 Days 00 Hours, Active Ingredients:Cyflufenamid, Manufacturer:Certis, EAMU:2055/16, Expires:30/09/2022

Reference: Plan 04660 Topfield 04/08 Job 1 — Issued by: John Longley (03/08/2018)
Target growth stage: Harvest
Start: 04/08/2018 07:30 — Finish: 04/08/2018 10:00 — Operator: Flavio Di Giovanni
Weather: Clear — Temp °C: 18 — Wind speed/direction: 2 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Potassium Bicarbonate — 2.8640 ha — 5.000 kg/ha
Wetcit — 2.8640 ha — 0.500 L/ha

Reference: Plan 04665 Top field 07/08 Job 1 — Issued by: John Longley (07/08/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 08/08/2018 12:30 — Finish: 08/08/2018 16:30 — Operator: Cornel Anghel
Weather: Partly cloudy — Temp °C: 19 — Wind speed/direction: 3 S — Soil: Dry
Implement: 5 row t-tops, Volume rate: 1000.000 L, Spray quality: Medium, LERAP rating: Standard
Topas — 2.8640 ha — 0.500 L/ha
MAPP:16765, Harvest interval:03 Days 00 Hours, Active Ingredients:Penconazole, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024
Hallmark With Zeon Technology — 2.8640 ha — 0.075 L/ha
MAPP:12629, Harvest interval:03 Days 00 Hours, Active Ingredients:Lambda-cyhalothrin, Manufacturer:Syngenta UK Ltd, EAMU:1705/11

Reference: Plan 04714 Cornel spraying 23/08 Job 2 — Issued by: John Longley (23/08/2018)
Start: 24/08/2018 15:00 — Finish: 24/08/2018 17:00 — Operator: Cornel Anghel
Weather: Partly cloudy — Temp °C: 19 — Wind speed/direction: 1 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard

To: 11/10/2018
Headings: Pesticides, Nutrition
Area: ha

Pyrethrum 5 EC — 2.8640 ha — 1.100 L/ha
MAPP:18532, Active Ingredients:Pyrethrins, Manufacturer:Pelgar International Ltd

Reference: Plan 04728 Topfield 27-28/08 Job 1 — Issued by: John Longley (24/08/2018)
Target growth stage: Harvest
Job Harvest Interval: 07 Days 00 Hours
Start: 28/08/2018 14:00 — Finish: 28/08/2018 16:00 — Operator: Flavio Di Giovanni
Weather: Clear — Temp °C: 15 — Wind speed/direction: 2 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Stroby WG — 2.8640 ha — 0.300 kg/ha
MAPP:17316, Harvest interval:07 Days 00 Hours, Active Ingredients:Kresoxim-methyl, Manufacturer:BASF plc., Expires:30/06/2024
Decis — 2.8640 ha — 0.100 L/ha
MAPP:16124, Harvest interval:03 Days 00 Hours, Active Ingredients:Deltamethrin, Manufacturer:Bayer CropScience Limited, EAMU:1643/13, Expires:30/04/2021

7 Reference: Plan 04739 Topfield T-jet 1/09 Job 1 — Issued by: John Longley (31/08/2018)
Implement: Trailed Munkhoff 600L, Volume rate: 300.000 L
Quad Glob 200 SL — 2.8640 ha — 2.000 L/ha
MAPP:14758, Active Ingredients:Diquat, Manufacturer:Belchim Crop Protection Limited, Expires:31/12/2020
Activator 90 — 2.8640 ha — 0.300 L/ha

7 Reference: Plan 04744 Topfield 03/09 Job 1 — Issued by: John Longley (03/09/2018)
Implement: Trailed Munkhoff 600L, Volume rate: 300.000 L
Quad Glob 200 SL — 2.8640 ha — 2.000 L/ha
MAPP:14758, Active Ingredients:Diquat, Manufacturer:Belchim Crop Protection Limited, Expires:31/12/2020
Activator 90 — 2.8640 ha — 0.300 L/ha

Reference: Plan 04752 Topfield 04-05/09 Job 1 — Issued by: John Longley (04/09/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 05/09/2018 13:15 — Finish: 05/09/2018 15:15 — Operator: Flavio Di Giovanni
Weather: Cloudy — Temp °C: 16 — Wind speed/direction: 2 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Amistar — 2.8640 ha — 1.000 L/ha
MAPP:18039, Harvest interval:03 Days 00 Hours, Active Ingredients:Azoxystrobin, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024
Hallmark With Zeon Technology — 2.8640 ha — 0.075 L/ha
MAPP:12629, Harvest interval:03 Days 00 Hours, Active Ingredients:Lambda-cyhalothrin, Manufacturer:Syngenta UK Ltd, EAMU:1705/11

Reference: Plan 04769 Topfield B 07/09 Job 1 — Issued by: John Longley (07/09/2018)
Target growth stage: Harvest
Start: 07/09/2018 13:15 — Finish: 07/09/2018 15:15 — Operator: Flavio Di Giovanni
Weather: Clear — Temp °C: 16 — Wind speed/direction: 2 SW — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Potassium Bicarbonate — 2.8640 ha — 5.000 kg/ha
Wetcit — 2.8640 ha — 0.500 L/ha

Reference: Plan 04781 Cornel spraying 11/09 Job 2 — Issued by: John Longley (11/09/2018)
Target growth stage: Harvest
Start: 11/09/2018 14:30 — Finish: 11/09/2018 16:30 — Operator: Cornel Anghel
Weather: Partly cloudy — Temp °C: 18 — Wind speed/direction: 1 SE — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Kumulus DF — 2.8640 ha — 1.000 kg/ha
MAPP:04707, Active Ingredients:Sulphur, Manufacturer:BASF plc., Expires:31/12/2021
Potassium Bicarbonate — 2.8640 ha — 5.000 kg/ha

Reference: Plan 04812 Top field 20/09 Job 1 — Issued by: John Longley (19/09/2018)
Job Harvest Interval: 01 Days 00 Hours
Start: 20/09/2018 14:00 — Finish: 20/09/2018 16:00 — Operator: Cornel Anghel
Weather: Partly cloudy — Temp °C: 17 — Wind speed/direction: 1 N — Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard
Benevia 100D — 2.8640 ha — 0.750 L/ha
MAPP:99992, Harvest interval:01 Days 00 Hours, Active Ingredients:Cyantraniliprole, Manufacturer:Headland Agrochemicals Ltd.,

Year: 2018
To: 11/10/2018
Headings: Pesticides, Nutrition
Area: ha

EAMU:1382/18, Expires:30/09/2018

Kindred 2.8640 ha 0.600 L/ha

MAPP:13891, Active Ingredients:Meptyldinocap, Manufacturer:Landseer Ltd.

Reference: Plan 04830 Topfield 26/09 Job 1 Issued by: John Longley (25/09/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 26/09/2018 12:30 Finish: 26/09/2018 14:30 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 17 Wind speed/direction: 1 SE Soil: Dry
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard

Amistar 2.8640 ha 1.000 L/ha

MAPP:18039, Harvest interval:03 Days 00 Hours, Active Ingredients:Azoxystrobin, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024

Tracer 2.8640 ha 0.150 L/ha

MAPP:12438, Harvest interval:01 Days 00 Hours, Active Ingredients:Spinosad, Manufacturer:Landseer Ltd., EAMU:1395/18, Expires:15/10/2018

? Reference: Plan 04852 Cornel spraying 03/10 Job 2 Issued by: John Longley (02/10/2018)
Target growth stage: Harvest
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard

Kumulus DF 2.8640 ha 1.000 kg/ha

MAPP:04707, Active Ingredients:Sulphur, Manufacturer:BASF plc., Expires:31/12/2021

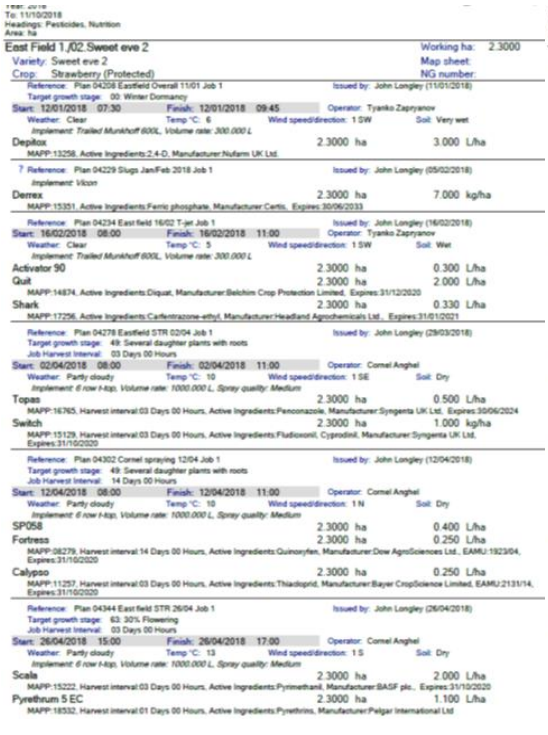
Potassium Bicarbonate 2.8640 ha 5.000 kg/ha

? Reference: Plan 04866 Top field 10/10 Job 1 Issued by: John Longley (10/10/2018)
Job Harvest Interval: 03 Days 00 Hours
Implement: 5 row t-tops, Volume rate: 500.000 L, Spray quality: Medium, LERAP rating: Standard

Scala 2.8640 ha 2.000 L/ha

MAPP:15222, Harvest interval:03 Days 00 Hours, Active Ingredients:Pyrimethanil, Manufacturer:BASF plc., Expires:31/10/2020

Site 3.



Year: 2018
To: 11/10/2018
Headings: Pesticides, Nutrition
Area: ha

East Field 1,/02.Sweet eve 2 Working ha: 2.3000
Variety: Sweet eve 2 Map sheet:
Crop: Strawberry (Protected) NG number:

Reference: Plan 04208 Eastfield Overall 11/01 Job 1 Issued by: John Longley (11/01/2018)
Target growth stage: 00: Winter Dormancy
Start: 12/01/2018 07:30 Finish: 12/01/2018 09:45 Operator: Tyanko Zapryanov
Weather: Clear Temp °C: 6 Wind speed/direction: 1 SW Soil: Very wet
Implement: Trailed Munkhoff 600L, Volume rate: 300.000 L

Depitox	2.3000 ha	3.000 L/ha

MAPP:13258, Active Ingredients:2,4-D, Manufacturer:Nufarm UK Ltd.

? Reference: Plan 04229 Slugs Jan/Feb 2018 Job 1 Issued by: John Longley (05/02/2018)
Implement: Vicon

Derrex	2.3000 ha	7.000 kg/ha

MAPP:15351, Active Ingredients:Ferric phosphate, Manufacturer:Certis, Expires:30/06/2033

Reference: Plan 04234 East field 16/02 T-jet Job 1 Issued by: John Longley (16/02/2018)
Start: 16/02/2018 08:00 Finish: 16/02/2018 11:00 Operator: Tyanko Zapryanov
Weather: Clear Temp °C: 5 Wind speed/direction: 1 SW Soil: Wet
Implement: Trailed Munkhoff 600L, Volume rate: 300.000 L

Activator 90	2.3000 ha	0.300 L/ha
Quit	2.3000 ha	2.000 L/ha

MAPP:14874, Active Ingredients:Diquat, Manufacturer:Belchim Crop Protection Limited, Expires:31/12/2020

Shark	2.3000 ha	0.330 L/ha

MAPP:17256, Active Ingredients:Carfentrazone-ethyl, Manufacturer:Headland Agrochemicals Ltd., Expires:31/01/2021

Reference: Plan 04278 Eastfield STR 02/04 Job 1 Issued by: John Longley (29/03/2018)
Target growth stage: 49: Several daughter plants with roots
Job Harvest Interval: 03 Days 00 Hours
Start: 02/04/2018 08:00 Finish: 02/04/2018 11:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 10 Wind speed/direction: 1 SE Soil: Dry
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

Topas	2.3000 ha	0.500 L/ha

MAPP:16765, Harvest interval:03 Days 00 Hours, Active Ingredients:Penconazole, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024

Switch	2.3000 ha	1.000 kg/ha

MAPP:15129, Harvest interval:03 Days 00 Hours, Active Ingredients:Fludioxonil, Cyprodinil, Manufacturer:Syngenta UK Ltd, Expires:31/10/2020

Reference: Plan 04302 Cornel spraying 12/04 Job 1 Issued by: John Longley (12/04/2018)
Target growth stage: 49: Several daughter plants with roots
Job Harvest Interval: 14 Days 00 Hours
Start: 12/04/2018 08:00 Finish: 12/04/2018 11:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 10 Wind speed/direction: 1 N Soil: Dry
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

SP058	2.3000 ha	0.400 L/ha
Fortress	2.3000 ha	0.250 L/ha

MAPP:08279, Harvest interval:14 Days 00 Hours, Active Ingredients:Quinoxyfen, Manufacturer:Dow AgroSciences Ltd., EAMU:1923/04, Expires:31/10/2020

Calypso	2.3000 ha	0.250 L/ha

MAPP:11257, Harvest interval:03 Days 00 Hours, Active Ingredients:Thiacloprid, Manufacturer:Bayer CropScience Limited, EAMU:2131/14, Expires:31/10/2020

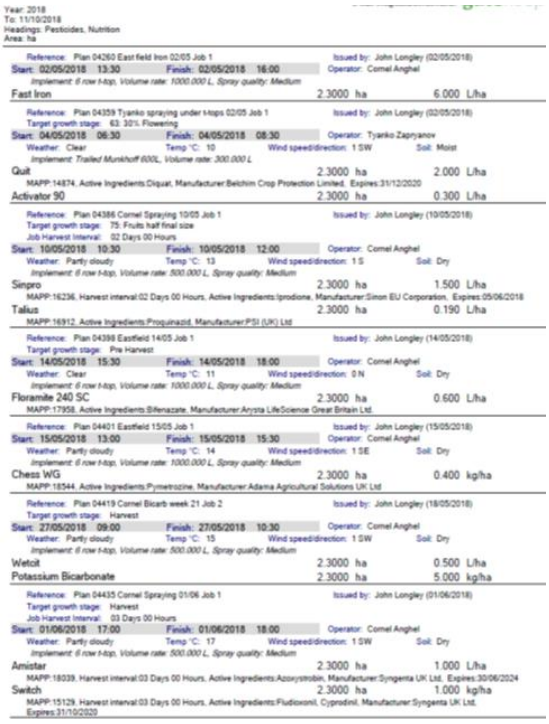
Reference: Plan 04344 East field STR 26/04 Job 1 Issued by: John Longley (26/04/2018)
Target growth stage: 63: 30% Flowering
Job Harvest Interval: 03 Days 00 Hours
Start: 26/04/2018 15:00 Finish: 26/04/2018 17:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 13 Wind speed/direction: 1 S Soil: Dry
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

Scala	2.3000 ha	2.000 L/ha

MAPP:15222, Harvest interval:03 Days 00 Hours, Active Ingredients:Pyrimethanil, Manufacturer:BASF plc., Expires:31/10/2020

Pyrethrum 5 EC	2.3000 ha	1.100 L/ha

MAPP:18532, Harvest interval:01 Days 00 Hours, Active Ingredients:Pyrethrins, Manufacturer:Pelgar International Ltd



Year: 2018
To: 11/10/2018
Headings: Pesticides, Nutrition
Area: ha

Reference: Plan 04260 East field Iron 02/05 Job 1 Issued by: John Longley (02/05/2018)
Start: 02/05/2018 13:30 Finish: 02/05/2018 16:00 Operator: Cornel Anghel
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

Fast Iron	2.3000 ha	6.000 L/ha

Reference: Plan 04359 Tyanko spraying under t-tops 02/05 Job 1 Issued by: John Longley (02/05/2018)
Target growth stage: 63: 30% Flowering
Start: 04/05/2018 06:30 Finish: 04/05/2018 08:30 Operator: Tyanko Zapryanov
Weather: Clear Temp °C: 10 Wind speed/direction: 1 SW Soil: Moist
Implement: Trailed Munkhoff 600L, Volume rate: 300.000 L

Quit	2.3000 ha	2.000 L/ha

MAPP:14874, Active Ingredients:Diquat, Manufacturer:Belchim Crop Protection Limited, Expires:31/12/2020

Activator 90	2.3000 ha	0.300 L/ha

Reference: Plan 04386 Cornel Spraying 10/05 Job 1 Issued by: John Longley (10/05/2018)
Target growth stage: 75: Fruits half final size
Job Harvest Interval: 02 Days 00 Hours
Start: 10/05/2018 10:30 Finish: 10/05/2018 12:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 13 Wind speed/direction: 1 S Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Singro	2.3000 ha	1.500 L/ha

MAPP:16236, Harvest interval:02 Days 00 Hours, Active Ingredients:Iprodione, Manufacturer:Sinon EU Corporation, Expires:05/06/2018

Talius	2.3000 ha	0.190 L/ha

MAPP:16912, Active Ingredients:Proquinazid, Manufacturer:FSI (UK) Ltd

Reference: Plan 04399 Eastfield 14/05 Job 1 Issued by: John Longley (14/05/2018)
Target growth stage: Pre Harvest
Start: 14/05/2018 15:30 Finish: 14/05/2018 18:00 Operator: Cornel Anghel
Weather: Clear Temp °C: 11 Wind speed/direction: 0 N Soil: Dry
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

Floramite 240 SC	2.3000 ha	0.600 L/ha

MAPP:17958, Active Ingredients:Bifenazate, Manufacturer:Arysta LifeScience Great Britain Ltd.

Reference: Plan 04401 Eastfield 15/05 Job 1 Issued by: John Longley (15/05/2018)
Start: 15/05/2018 13:00 Finish: 15/05/2018 15:30 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 14 Wind speed/direction: 1 SE Soil: Dry
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

Chess WG	2.3000 ha	0.400 kg/ha

MAPP:18544, Active Ingredients:Pymetrozine, Manufacturer:Adama Agricultural Solutions UK Ltd

Reference: Plan 04419 Cornel Bicarb week 21 Job 2 Issued by: John Longley (18/05/2018)
Target growth stage: Harvest
Start: 27/05/2018 09:00 Finish: 27/05/2018 10:30 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 15 Wind speed/direction: 1 SW Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Wetcit	2.3000 ha	0.500 L/ha
Potassium Bicarbonate	2.3000 ha	5.000 kg/ha

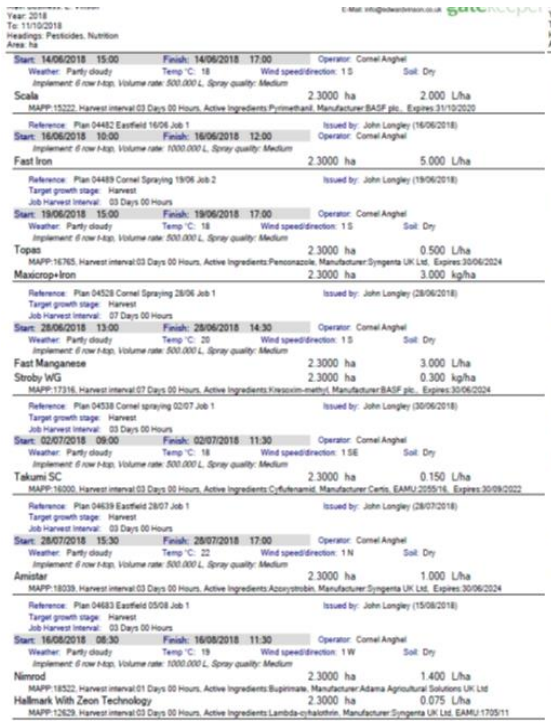
Reference: Plan 04435 Cornel Spraying 01/06 Job 1 Issued by: John Longley (01/06/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 01/06/2018 17:00 Finish: 01/06/2018 18:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 17 Wind speed/direction: 1 SW Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Amistar	2.3000 ha	1.000 L/ha

MAPP:18039, Harvest interval:03 Days 00 Hours, Active Ingredients:Azoxystrobin, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024

Switch	2.3000 ha	1.000 kg/ha

MAPP:15129, Harvest interval:03 Days 00 Hours, Active Ingredients:Fludioxonil, Cyprodinil, Manufacturer:Syngenta UK Ltd, Expires:31/10/2020



Year: 2018
To: 11/10/2018
Headings: Pesticides, Nutrition
Area: ha

Start: 14/06/2018 15:00 Finish: 14/06/2018 17:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 18 Wind speed/direction: 1 S Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Scala	2.3000 ha	2.000 L/ha

MAPP:15222, Harvest interval:03 Days 00 Hours, Active Ingredients:Pyrimethanil, Manufacturer:BASF plc., Expires:31/10/2020

Reference: Plan 04482 Eastfield 16/06 Job 1 Issued by: John Longley (16/06/2018)
Start: 16/06/2018 10:00 Finish: 16/06/2018 12:00 Operator: Cornel Anghel
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

Fast Iron	2.3000 ha	5.000 L/ha

Reference: Plan 04489 Cornel Spraying 19/06 Job 2 Issued by: John Longley (19/06/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 19/06/2018 15:00 Finish: 19/06/2018 17:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 18 Wind speed/direction: 1 S Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Topas	2.3000 ha	0.500 L/ha

MAPP:16765, Harvest interval:03 Days 00 Hours, Active Ingredients:Penconazole, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024

Maxicrop+Iron	2.3000 ha	3.000 kg/ha

Reference: Plan 04528 Cornel Spraying 28/06 Job 1 Issued by: John Longley (28/06/2018)
Target growth stage: Harvest
Job Harvest Interval: 07 Days 00 Hours
Start: 28/06/2018 13:00 Finish: 28/06/2018 14:30 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 20 Wind speed/direction: 1 S Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Fast Manganese	2.3000 ha	3.000 L/ha
Stroby WG	2.3000 ha	0.300 kg/ha

MAPP:17316, Harvest interval:07 Days 00 Hours, Active Ingredients:Kresoxim-methyl, Manufacturer:BASF plc., Expires:30/06/2024

Reference: Plan 04538 Cornel spraying 02/07 Job 1 Issued by: John Longley (30/06/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 02/07/2018 09:00 Finish: 02/07/2018 11:30 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 18 Wind speed/direction: 1 SE Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Takumi SC	2.3000 ha	0.150 L/ha

MAPP:16000, Harvest interval:03 Days 00 Hours, Active Ingredients:Cyflufenamid, Manufacturer:Certis, EAMU:2059/16, Expires:30/09/2022

Reference: Plan 04639 Eastfield 28/07 Job 1 Issued by: John Longley (28/07/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 28/07/2018 15:30 Finish: 28/07/2018 17:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 22 Wind speed/direction: 1 N Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Amistar	2.3000 ha	1.000 L/ha

MAPP:18039, Harvest interval:03 Days 00 Hours, Active Ingredients:Azoxystrobin, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024

Reference: Plan 04683 Eastfield 05/08 Job 1 Issued by: John Longley (15/08/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 16/08/2018 08:30 Finish: 16/08/2018 11:30 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 19 Wind speed/direction: 1 W Soil: Dry
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

Nimrod	2.3000 ha	1.400 L/ha

MAPP:18522, Harvest interval:01 Days 00 Hours, Active Ingredients:Bupirimate, Manufacturer:Adama Agricultural Solutions UK Ltd

Hallmark With Zeon Technology	2.3000 ha	0.075 L/ha

MAPP:12629, Harvest interval:03 Days 00 Hours, Active Ingredients:Lambda-cyhalothrin, Manufacturer:Syngenta UK Ltd, EAMU:1705/11

Year: 2018
To: 11/10/2018
Headings: Pesticides, Nutrition
Area: ha

Start: 01/09/2018 09:00 Finish: 01/09/2018 11:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 19 Wind speed/direction: 1 S Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Pyrethrum 5 EC (18210)	2.3000 ha	1.100 L/ha

MAPP:18210, Harvest interval:01 Days 00 Hours, Active Ingredients:Pyrethrins, Manufacturer:Pelgar International Ltd, Expires:31/05/2020

Reference: Plan 04772 Cornel spraying 07/09 Job 1 Issued by: John Longley (07/09/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 07/09/2018 10:30 Finish: 07/09/2018 13:30 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 18 Wind speed/direction: 1 SW Soil: Dry
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

Amistar	2.3000 ha	1.000 L/ha

MAPP:18039, Harvest interval:03 Days 00 Hours, Active Ingredients:Azoxystrobin, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024

Hallmark With Zeon Technology	2.3000 ha	0.075 L/ha

MAPP:12629, Harvest interval:03 Days 00 Hours, Active Ingredients:Lambda-cyhalothrin, Manufacturer:Syngenta UK Ltd, EAMU:1705/11

Reference: Plan 04774 Cornel Spraying 10/09 Job 1 Issued by: John Longley (10/09/2018)
Target growth stage: Harvest
Start: 10/09/2018 15:00 Finish: 10/09/2018 16:00 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 18 Wind speed/direction: 1 SW Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Potassium Bicarbonate	2.3000 ha	5.000 kg/ha
Microthiol Special	2.3000 ha	1.000 kg/ha

MAPP:16989, Active Ingredients:Sulphur, Manufacturer:UPL Europe Limited, Expires:31/12/2021

Reference: Plan 04804 Cornel Spraying 18/09 Job 1 Issued by: John Longley (17/09/2018)
Target growth stage: Harvest
Job Harvest Interval: 01 Days 00 Hours
Start: 18/09/2018 12:00 Finish: 18/09/2018 13:30 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 17 Wind speed/direction: 1 SW Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Kindred	2.3000 ha	0.600 L/ha

MAPP:13891, Active Ingredients:Meptyldinocap, Manufacturer:Landseer Ltd.

Benevia 100D	2.3000 ha	0.750 L/ha

MAPP:39992, Harvest interval:01 Days 00 Hours, Active Ingredients:Cyantraniliprole, Manufacturer:Headland Agrochemicals Ltd., EAMU:1382/18, Expires:30/09/2018

Reference: Plan 04839 Bungalow/Eastfield 28-9/09 Job 1 Issued by: John Longley (25/09/2018)
Target growth stage: Harvest
Job Harvest Interval: 03 Days 00 Hours
Start: 28/09/2018 15:00 Finish: 28/09/2018 16:30 Operator: Cornel Anghel
Weather: Partly cloudy Temp °C: 18 Wind speed/direction: 1 NE Soil: Dry
Implement: 6 row t-top, Volume rate: 500.000 L, Spray quality: Medium

Amistar	2.3000 ha	1.000 L/ha

MAPP:18039, Harvest interval:03 Days 00 Hours, Active Ingredients:Azoxystrobin, Manufacturer:Syngenta UK Ltd, Expires:30/06/2024

Tracer	2.3000 ha	0.150 L/ha

MAPP:12438, Harvest interval:01 Days 00 Hours, Active Ingredients:Spinosad, Manufacturer:Landseer Ltd., EAMU:1395/18, Expires:15/10/2018

? Reference: Plan 04845 Cornel spraying 01/09 Job 1 Issued by: John Longley (01/10/2018)
Target growth stage: Harvest
Implement: 6 row t-top, Volume rate: 1000.000 L, Spray quality: Medium

Potassium Bicarbonate	2.3000 ha	10.000 kg/ha
Kumulus DF	2.3000 ha	2.000 kg/ha

MAPP:04707, Active Ingredients:Sulphur, Manufacturer:BASF plc., Expires:31/12/2021

Site 4.

CROP MANAGEMENT SYSTEM

Tunnelled Strawberry

DATE: 31/7/18

LOCATION	FIELD NAME	VARIETY	Ha.
Quarries	Rh7	Latonia	2.0

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
600L	Takumi	Cyflufenamid	900ml

PEST LEVEL & JUSTIFICATION: Mildew
HARVEST INTERVAL: 3d EARLIEST PICK DATE: 3/8
SPECIAL INSTRUCTIONS:
ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED
OPERATOR: E. Banks WEATHER & WIND SPEED: 2 Sunny
DATE: 31-7-18 START TIME: 5:00am END TIME: 7am

ACTUAL QUANTITY/OF CHEMICAL APPLIED UNITS	FERTILISER	
	Takumi	1.35L

CROP MANAGEMENT SYSTEM

Tunnelled Strawberry

DATE: 25/8/18

LOCATION	FIELD NAME	VARIETY	Ha.
Quarries	Rh7	Latonia	2.0

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
1000L	Frupica	Mepanipyrim	800ml

PEST LEVEL & JUSTIFICATION: Mildew, Scab
HARVEST INTERVAL: 3d. EARLIEST PICK DATE: 28/8/18
SPECIAL INSTRUCTIONS:
ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED
OPERATOR: E. Banks WEATHER & WIND SPEED: 2 cool
DATE: 25-8-18 START TIME: 5:00am END TIME: 6:30am

ACTUAL QUANTITY/OF CHEMICAL APPLIED UNITS	FERTILISER	
	Frupica	1.6L

CROP MANAGEMENT SYSTEM

Tunnelled Strawberry

DATE: 4/7/18

LOCATION	FIELD NAME	VARIETY	Ha.
Quarries	K1	Amesbury	1.5
"	K2	Amesbury	2.5
"	Rh7	Latonia	2.0

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
1000	Nautral-C	Beauveria Bassiana	3oL

PEST LEVEL & JUSTIFICATION: Red Spider Mite
HARVEST INTERVAL: 0 EARLIEST PICK DATE: 5/7/18
SPECIAL INSTRUCTIONS:
ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED
OPERATOR: E. Banks WEATHER & WIND SPEED: 2 cool
DATE: 4-7-18 START TIME: 5:00am END TIME: 9:30am

ACTUAL QUANTITY/OF CHEMICAL APPLIED UNITS	FERTILISER	
	Nautral-C	18L

CROP MANAGEMENT SYSTEM

Tunnelled Strawberry

DATE: 2/7/18

LOCATION	FIELD NAME	VARIETY	Ha.
Quarries	Rh7	Latonia	2.0

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
1000	Calypso Amister	Thiacloprid & Arogsterobin	

PEST LEVEL & JUSTIFICATION: Mildew, Aphid
HARVEST INTERVAL: 3d EARLIEST PICK DATE: 5/7
SPECIAL INSTRUCTIONS: Pollen pickers into field 5:45
ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED
OPERATOR: E. Banks WEATHER & WIND SPEED: 2 Sunny
DATE: 2-7-18 START TIME: 5:45 END TIME: 7:15am

ACTUAL QUANTITY/OF CHEMICAL APPLIED UNITS	FERTILISER	
	Calypso	500ml
	Amister	2L

CROP MANAGEMENT SYSTEM

DATE: 17/6/18 — Tunnelled Strawberry

LOCATION	FIELD NAME	VARIETY	Ha.
Quarries	R17	Katrina	2.0
"	K1	Amesti	1.5
"	K2	"	2.5

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
1000	Luna Sensation	Fluopyram + Trifloxystrobin	500ml

PEST LEVEL & JUSTIFICATION: Mulden
HARVEST INTERVAL: 1d. EARLIEST PICK DATE: 19/6/18
SPECIAL INSTRUCTIONS: Do R17 before 5:00 then K1, K2
ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED
OPERATOR: G. Barnes WEATHER & WIND SPEED: Cool
DATE: 17-6-18 START TIME: 3:30am END TIME: 7:30am

ACTUAL QUANTITY/OF CHEMICAL APPLIED
UNITS / FERTILISER
Luna Sensation 4.0Ltr

CROP MANAGEMENT SYSTEM

DATE: 9/6/18 — Tunnelled Strawberry

LOCATION	FIELD NAME	VARIETY	Ha.
Quarries	R17	Katrina	2.0L

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
1000L	Tracer	Spinosad	750ml

PEST LEVEL & JUSTIFICATION: Thrip
HARVEST INTERVAL: 1d EARLIEST PICK DATE: 10/6/18
SPECIAL INSTRUCTIONS:
ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED
OPERATOR: G. Barnes WEATHER & WIND SPEED: Sunny
DATE: 9-6-18 START TIME: 10:30 END TIME: 12:00pm

ACTUAL QUANTITY/OF CHEMICAL APPLIED
UNITS / FERTILISER
Tracer 150ml

CROP MANAGEMENT SYSTEM

DATE: 5/6/18 — Tunnelled Strawberry

LOCATION	FIELD NAME	VARIETY	Ha.
K1	Quarries	Amesti	1.5
R17	"	Katrina	2.0

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
1000	Topas	Penconazole	500ml

PEST LEVEL & JUSTIFICATION: Mulden
HARVEST INTERVAL: 3D EARLIEST PICK DATE: 8/6/18
SPECIAL INSTRUCTIONS: Do K1 Today before 6am Do R17 tomorrow before 6a
ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED
OPERATOR: G. Barnes WEATHER & WIND SPEED: Cool
DATE: 5-6-18 START TIME: 4:30am END TIME: 6:00am
6-6-18 4:00am 5:45am

ACTUAL QUANTITY/OF CHEMICAL APPLIED
UNITS / FERTILISER
Topas 1.75Ltr

CROP MANAGEMENT SYSTEM

DATE: 14/5/18 — Tunnelled Strawberry

LOCATION	FIELD NAME	VARIETY	Ha.
Quarries	K1	Amesti	1.5
"	K2	"	2.5
"	R17	Katrina	2.0

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
1000L	Pyrethrum EC	Pyrethrum	2.4L

PEST LEVEL & JUSTIFICATION: ROM
HARVEST INTERVAL: 0 EARLIEST PICK DATE: 14/5/18
SPECIAL INSTRUCTIONS:
ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED
OPERATOR: G. Barnes WEATHER & WIND SPEED: Cool Sunny
DATE: 14-5-18 START TIME: 5:00am END TIME: 9:30am

ACTUAL QUANTITY/OF CHEMICAL APPLIED
UNITS / FERTILISER
Pyrethrum EC 14.4Ltr

CROP MANAGEMENT SYSTEM

Tunnelled Strawberry

DATE: 11/5/18

LOCATION	FIELD NAME	VARIETY	Ha.
Queven	K1	Amesti	1.5
"	K2	"	2.5
"	RH7	katrina	2.0

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
1000L	Dynamec	Abamectin	500ml
	Maxicrop	Seaweed	2.0L

Red Spider mite — Steve Lenton

PEST LEVEL & JUSTIFICATION: Red Spider

HARVEST INTERVAL: 3d EARLIEST PICK DATE: 14/5/18

SPECIAL INSTRUCTIONS:

ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED

OPERATOR: G. Davies WEATHER & WIND SPEED: Cloudy

DATE: 11-5-18 START TIME: 5:00am END TIME: 9:00am

ACTUAL QUANTITY/UNITS	OF CHEMICAL APPLIED FERTILISER	
	Dynamec	30ml
	Maxicrop	12L

CROP MANAGEMENT SYSTEM

Tunnelled Strawberry

DATE: 9/5/18

LOCATION	FIELD NAME	VARIETY	Ha.
Queven	K1	Amesti	1.5
"	K2	Amesti	2.5
"	RH7	katrina	2.0

WATER VOLUME	CHEMICAL OR FERTILISER	ACTIVE INGREDIENTS	RATE HA
1000L	Fortress	Quinoxyfen	250ml
	Maxicrop	Seaweed	2.0L

plum 93 — Steve Lenton

PEST LEVEL & JUSTIFICATION: Mildew

HARVEST INTERVAL: 14d EARLIEST PICK DATE: 23/5/18

SPECIAL INSTRUCTIONS:

ALWAYS READ THE LABEL AND CHECK PROTECTIVE CLOTHING REQUIRED

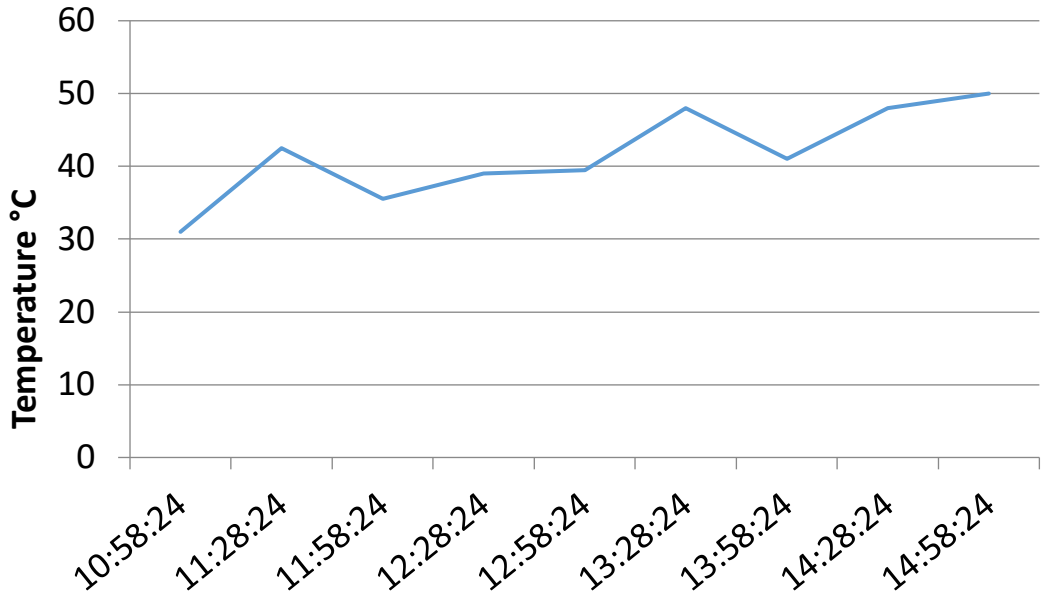
OPERATOR: G. Scard WEATHER & WIND SPEED: Cool

DATE: 9-5-18 START TIME: 6:00am END TIME: 10:30am

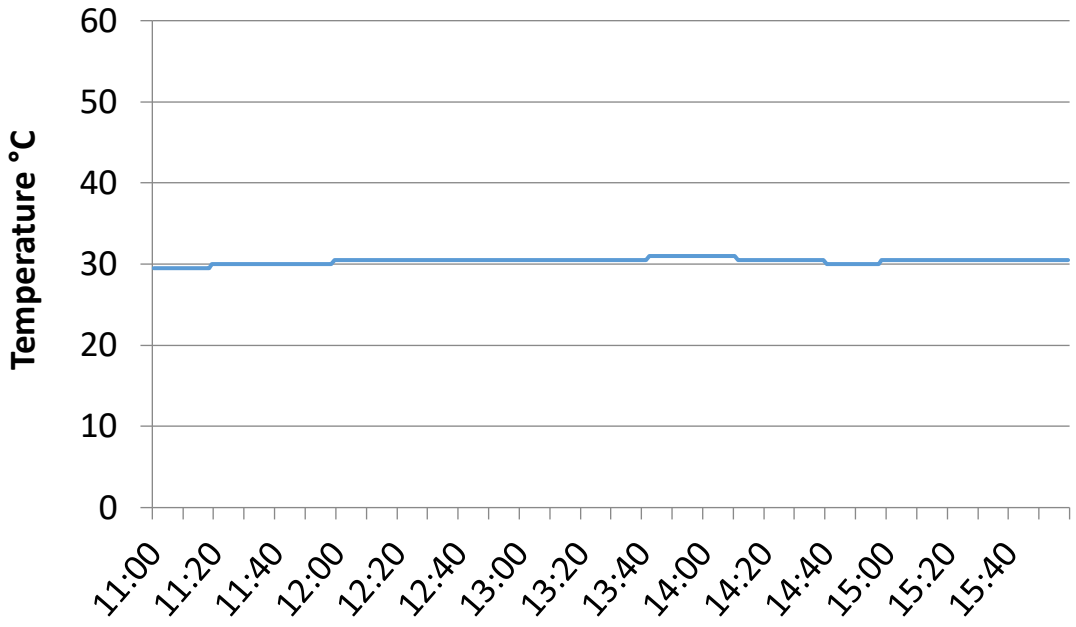
ACTUAL QUANTITY/UNITS	OF CHEMICAL APPLIED FERTILISER	
	Fortress	1.5L
	Maxicrop	12L

APPENDIX 3.2.3. Air temperature and humidity records within the polytunnels at the *N. cucumeris* extraction device trial sites

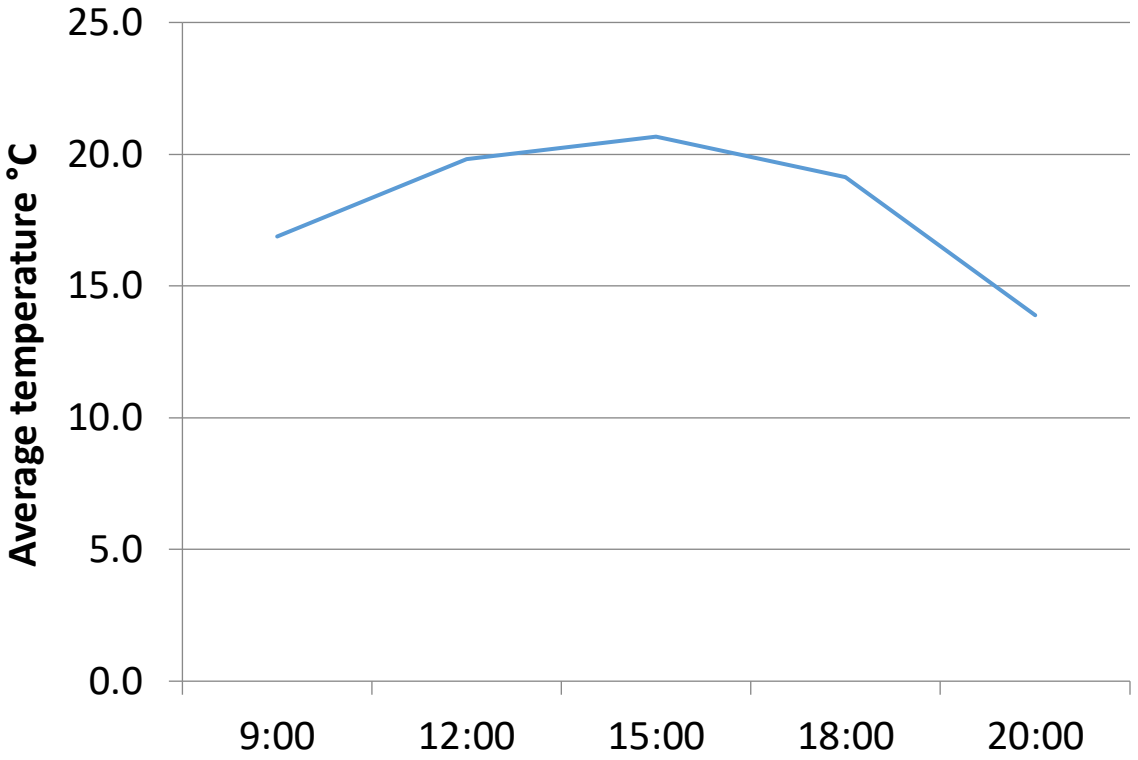
a) Temperature records during Trial 2, 16 July 2018



b) Temperature records during Trial 3, 6 August 2018

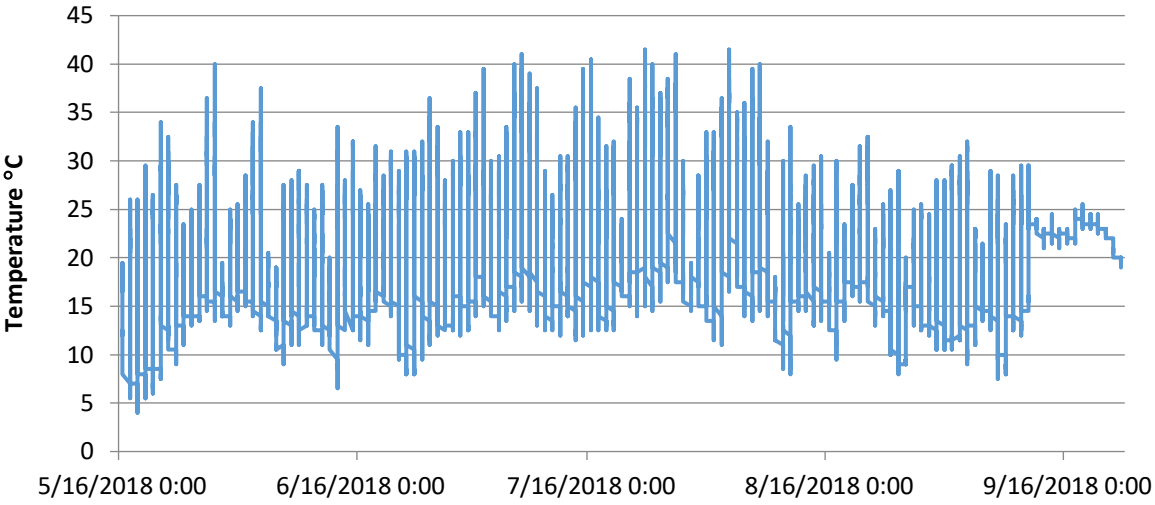


c) Temperature records during Trial 4, 7 to 12 September 2018

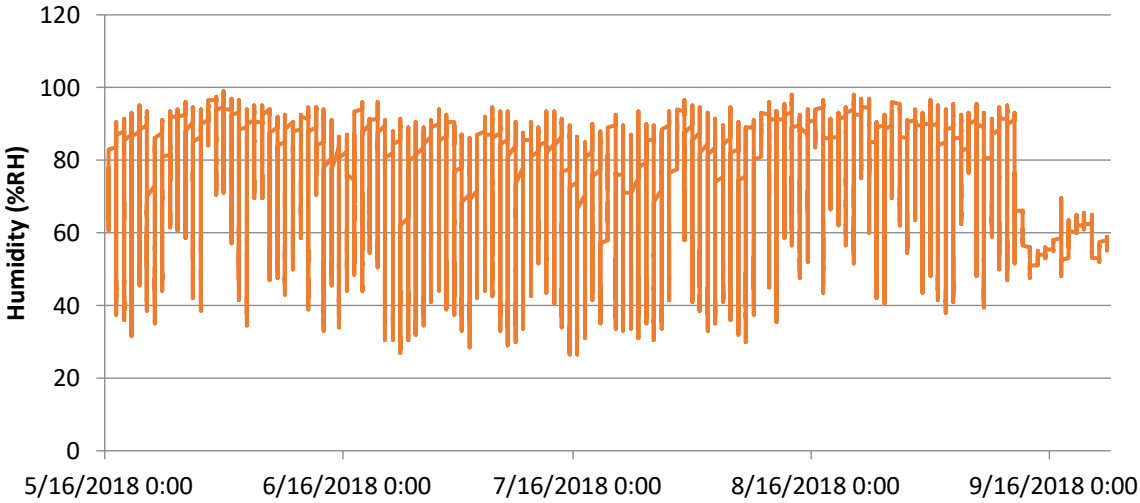


APPENDIX 3.2.4. Air temperature and humidity records within the polytunnels at the garlic trial experimental sites

a) Temperature records at trial site between 16 May and 23 Aug 2018

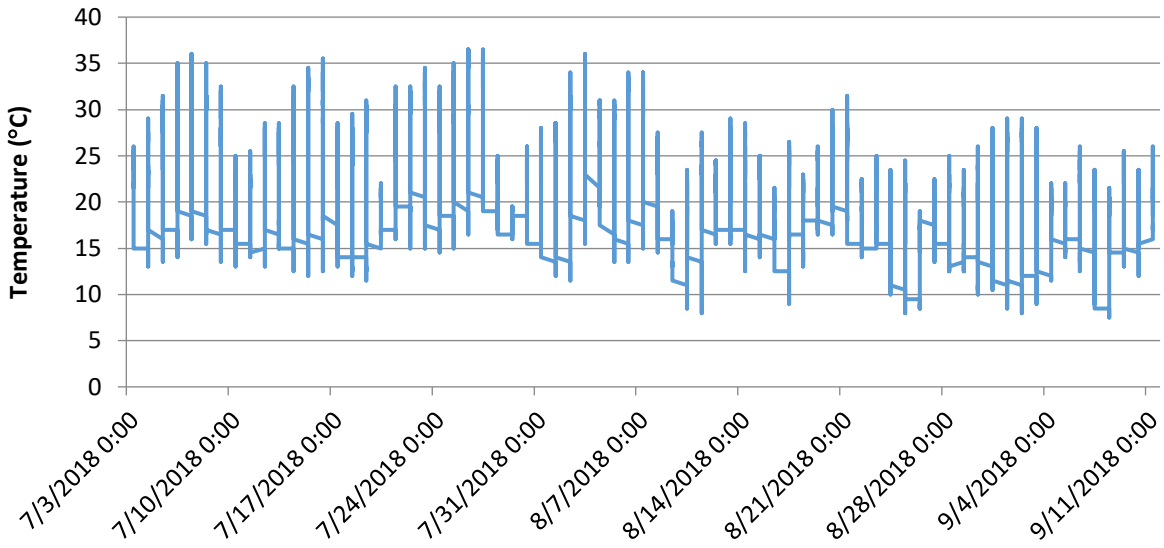


b) Humidity records at trial site between 16 May and 23 Aug 2018

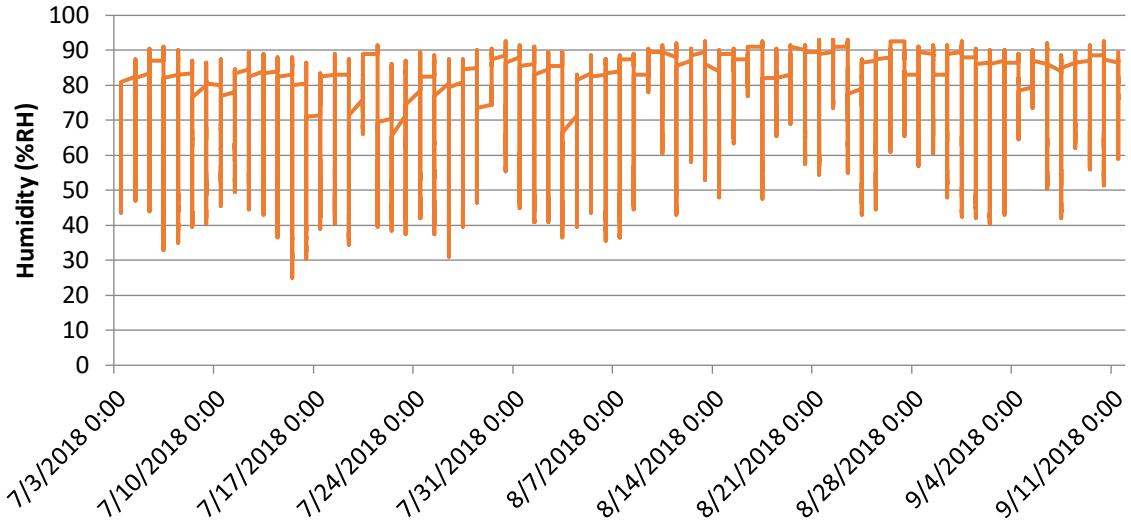


APPENDIX 3.2.5. Air temperature and humidity records within the polytunnels at the push-pull experimental sites

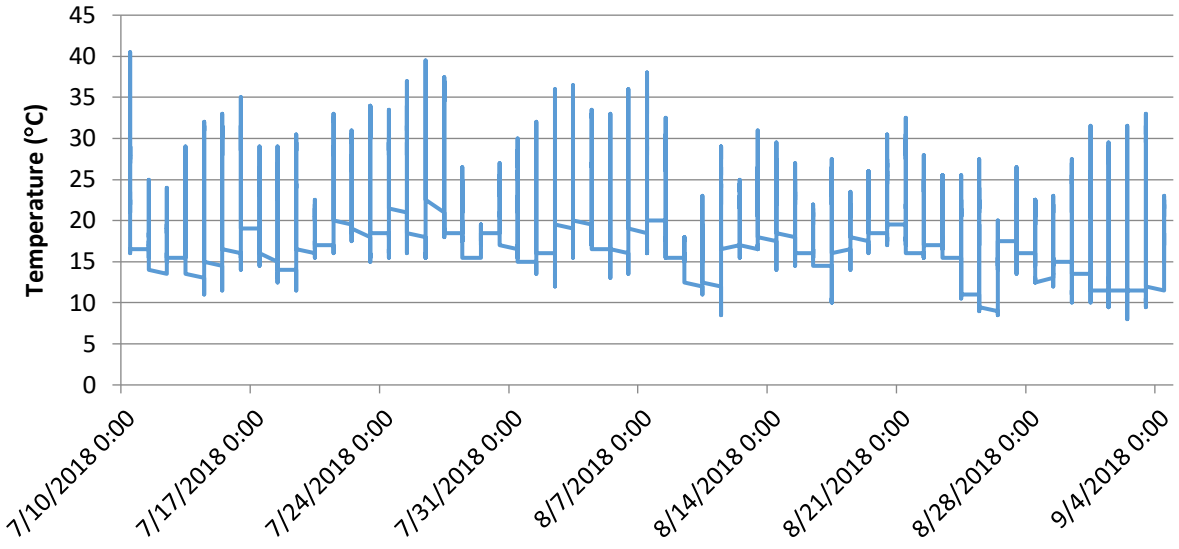
a) Temperature records at Site 1 between 3 Jul and 11 Sep 2018



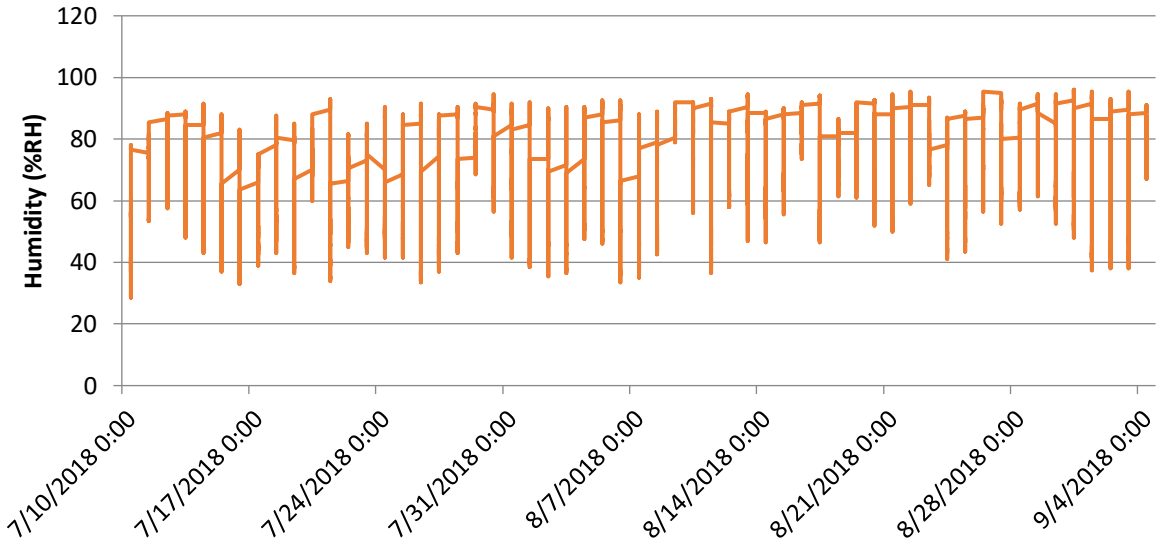
b) Humidity records at Site 1 between 3 Jul and 11 Sep 2018



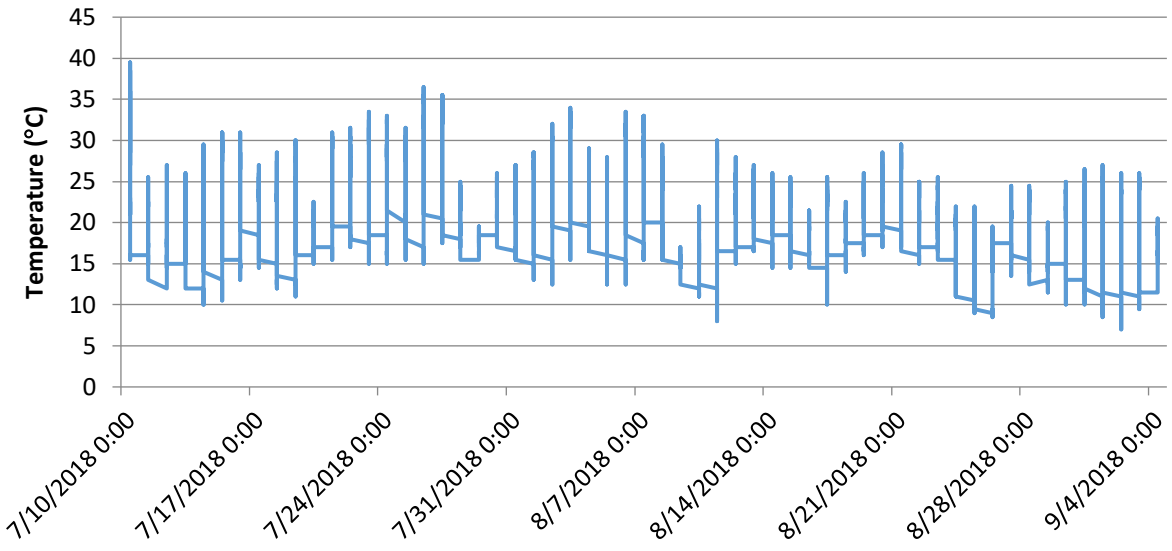
c) Temperature records at Site 2 between 10 Jul and 4 Sep 2018



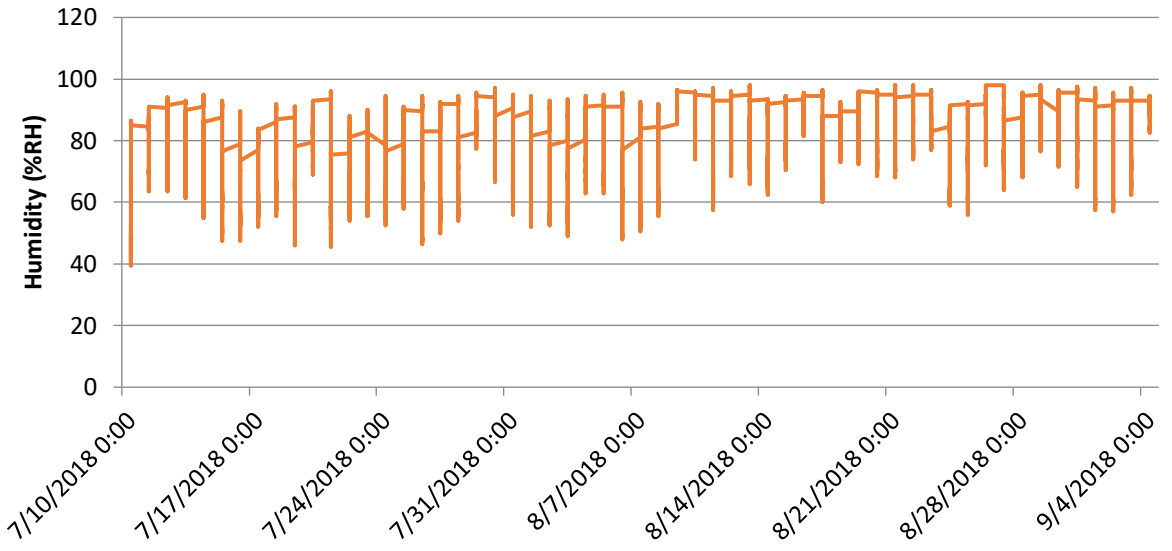
d) Humidity records at Site 2 between 10 Jul and 4 Sep 2018



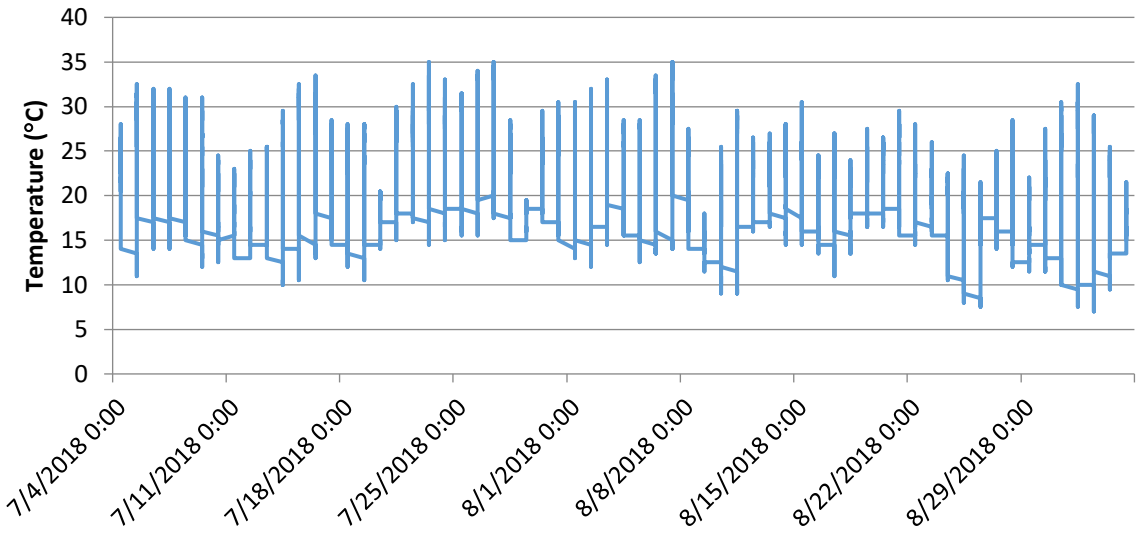
e) Temperature records from Site 3 between 10 Jul and 4 Sep 2018



f) Humidity records from Site 3 between 10 Jul and 4 Sep 2018



g) Temperature records from Site 4 between 4 Jul and 4 Sep 2018



h) Humidity records from Site 4 between 4 Jul and 4 Sep 2018